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COMBAT-READY CREW PERFORMANCE MEASUREMENT SYSTEM: PHASE IIID SPECIFICATIONS AND IMPLEMENTATION PLAN

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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

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The current and seventh report presents specifications and an implementation plan for the performance measurement system recommended as a result of this program. The following chapters relate to each of the major subsystems (I. Data Acquisition, II. Data Processing, III. Personnel, and IV. Facilities) and to the steps recommended for implementation (V. Implementation Plan). The Appendix presents example equipment of the types included in this specification.

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PREFACE

This interim report was produced as a result of the Phase IIID activities 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 AFB, Arizona. Major J. Fitzgerald, Chief, Combat-Crew Training Branch, was the contract monitor.

This report is one of a series of seven reports constituting the Final Report of Contract F41609-71-C-0008. These reports are listed below:

Combat-Ready Crew Performance Measurement System:

AFHRL-TR-74-108(I): Final Report

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

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I. INTRODUCTION

Research for the improvement of combat-crew training, and the efficient execution of current training programs, are heavily dependent upon good sources of information about trainee performance during and at the end of training. In an effort to improve training performance information, this study is directed to (1) systematic definition of performance, and (2) development of methods for measurement.

This program is divided into four phases, however, the third phase has been further divided into four parts as the result of expansion of the scope of the program. The structure of the program may be most easily comprehended if the following planned sequence is borne in mind: (1) establishment of measurement requirements, (2) establishment of measurement system requirements, (3) conduct of design studies, (4) development of specifications and an implementation plan, and (5) preparation of the Final Report.

As shown in Figure 1, seven reports will be prepared under this contract; the first three reports present measurement requirements (Phase I: Pilot Measurement Requirements; Phase IIIA: Combat-Crew Measurement Requirements; Phase IIIB: Air Combat Measurement Requirements), i.e., the measurement to provide information needed for combat-crew training research. These requirements have been determined through surveys conducted at combat-crew training sites (Luke AFB, Davis-Monthan AFB, Tyndall AFB, Castle AFB, Altus AFB, Dyess AFB, George AFB, Norton AFB, and Nellis AFB). The fourth report prepared treated measurement system requirements (Phase II: Measurement System Requirements), including research procedures, measurement processing, system criteria, and preliminary system analyses. The fifth (Phase IIIC: Design Studies) report dealt with design studies to determine desirable system features to meet the research needs documented in the earlier reports of this sequence.

The current and sixth report presents specifications and an implementation plan for the performance measurement system recommended as a result of this program. The following chapters relate to each of the major subsystems (I. Data Acquisition, II. Data Processing, III Personnel, and IV. Facilities) and to the steps recommended for implementation (V. Implementation Plan). The Appendix presents example equipment of the types included in this specification.

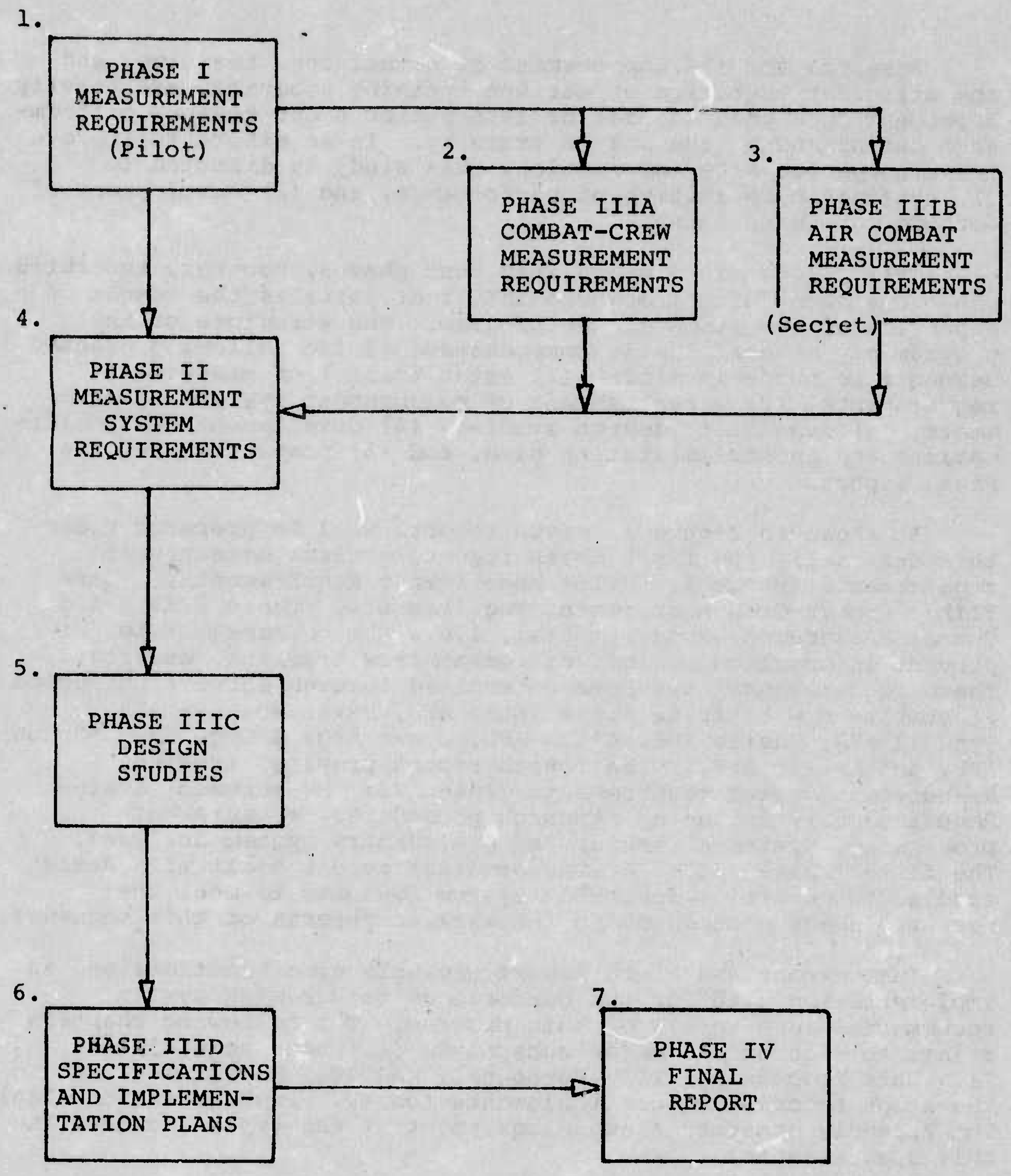

Figure 1. Program Reports.

II. DATA ACQUISITION SUBSYSTEM

Data Acquisition Categories

Combat-crew training performance information may come from a number of sources and through a variety of media. The data acquisition subsystem must provide the capability for acquiring all information needed for measurement and the interface with manual and automatic means for compiling an integrated, correlated, common raw data base.

Data sources are divided into five categories for the current treatment: (1) aircraft or simulator data collection, (2) field data collection, (3) briefing or debriefing data collection, (4) documentary data collection, and (5) external data sources. Each information source poses different conditions for data acquisition, although a form of recording is used in each case, requiring some means for data playback.

The Data Acquisition Subsystem, therefore, consists of the major components of the block diagram shown in Figure 2. This chapter will be devoted to specification of the data collection devices for each source of information (as listed in Table 1), and devices for data playback.

Aircraft/Simulator Data Collection Station (ASDCS)

It was found through design tradeoff studies, that training performance measurement inflight or in simulator solely by means of (1) video or photo recording or (2) digital recording, was not entirely satisfactory for either technique. If a decision must be made to go one way or the other, assuming that video legibility requirements can be met, then a video recording system would be chosen for comprehensive measurement, simplicity and flexibility for the pursuit of research goals, and lower overall costs. However, a hybrid system combining the advantages of video/photo and digital recording is preferable to an unmixed system. A hybrid system is assumed in the current specification, but 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.

The distribution of measurement parameters for recording by video or digital techniques is portrayed in Figure 3. Audio information must be collected by both video/photo and digital recording to provide a stand-alone data collection capability with either technique; consequently, these data acquisition devices will be termed Audio/Video Recording (AVR) and Audio/Digital Recording (ADR) in correspondence with previous usage. Most pictorial information can be easily obtained only with

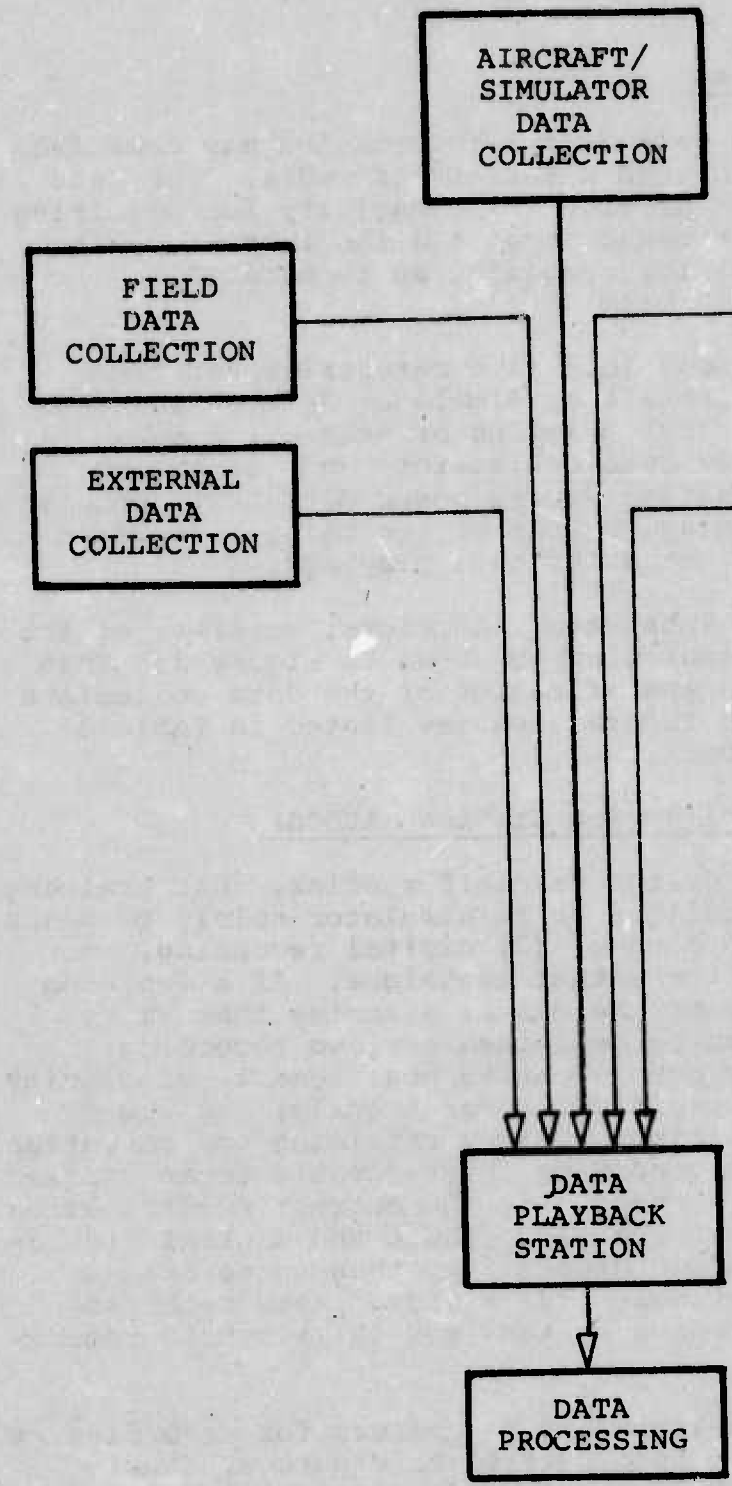

Figure 2. Data Acquisition Block Diagram.

TABLE 1

CATEGORIES OF INFORMATION SOURCES AND CORRESPONDING DATA COLLECTION DEVICES

SOURCE OF INFORMATION	DATA COLLECTION DEVICES
1. Aircraft/Simulator	Audio/Video Recorder + Aux. Camera + Audio/Digital Recorder
2. Field (e.g., Runway, GCA Radar, Range)	Camera + Transceivers + Audio Recorder
3. Briefing/Debriefing	Audio Recorder + Slide Camera
4. Documents	Manual Conversion from Documents to Paper Tape Necessary (e.g., Dash-One, Phase Manuals)
5. External Data (e.g., Ground Tracking Radar, Related-Experiment Results)	Data Received in Computer-Compatible Form (Cards, Magnetic Tape, Paper Tape)

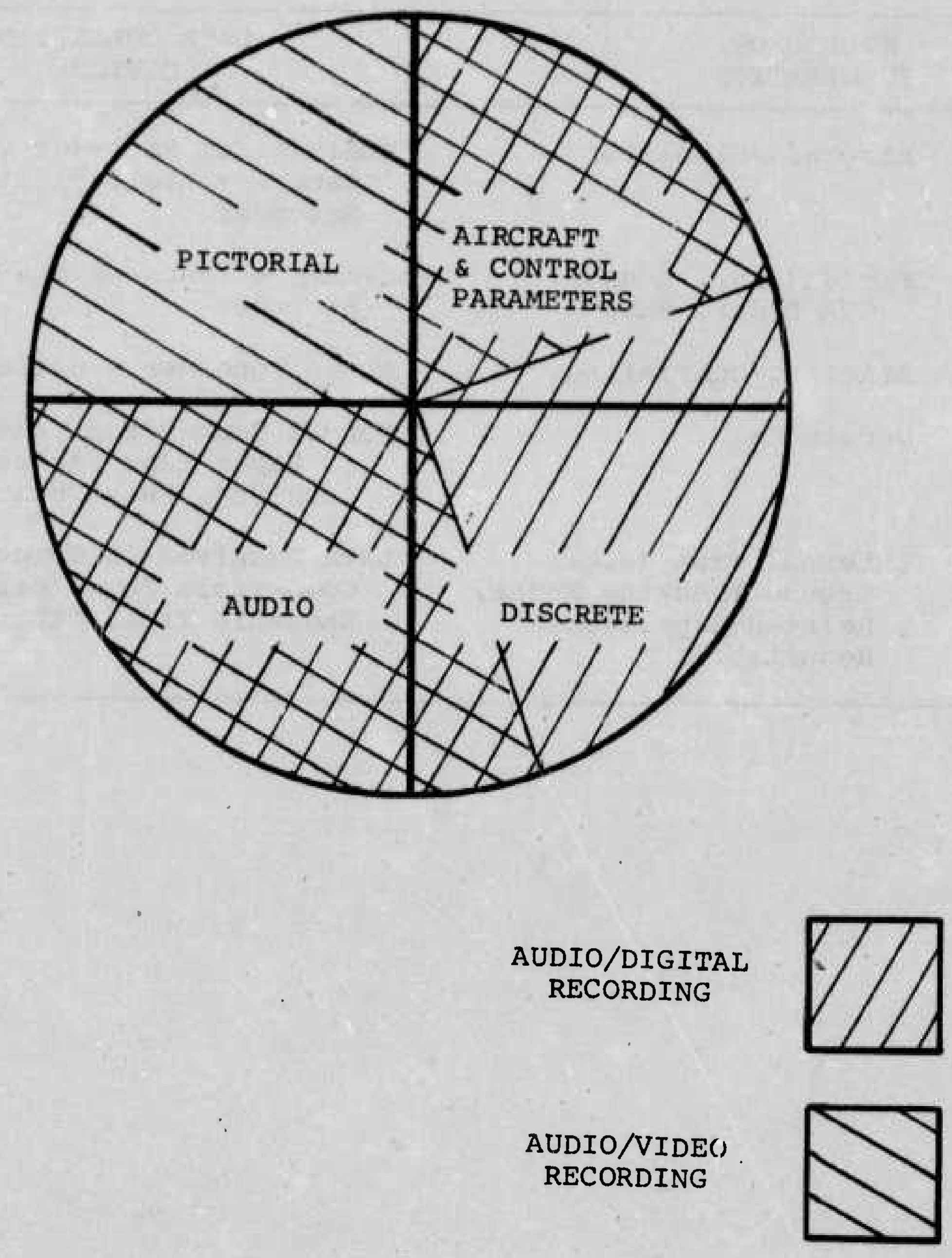

Figure 3. Distribution of Data Acquisition Between Audio/Digital Recording and Audio/Video Recording.

video/photo techniques, therefore, other avionics display information, such as radar, navigation and weapon control, will be excluded from the ADR to reduce the complexity and associated costs of attempting to record large numbers of parameters through digital methods. Aircraft and control parameters (e.g., airspeed, altitude) will be collected on the ADR, and as many as possible within the field-of-view of the AVR, In a similar manner, discrete signals (e.g., wheels up, speed brakes out) will be recorded on the ADR, and means will be developed to allow recording a small number of critical discrete parameters (e.g., weapons release) on the AVR to permit an AVR stand-alone capability and to enhance manual measurement processing.

A block diagram of the Aircraft/Simulator Data Collection Station is shown in Figure 4. An Auxiliary Camera (AC) is necessary to provide information where neither the AVR nor ADR is applicable; such a camera is specifically needed to document position over recognizable terrain and the drop zone (Combat Airlift Training), but is likely to have general usefulness for providing data recording for items outside the view of the video cameras. Recording controls and displays (RCD) are needed to provide manual and simple programming of recording events, for display of information for equipment set-up and for the use of an onboard experimenter. Interface with the interphone system for audio recording completes the aircraft/simulator data collection station.

It is recommended that the same data acqusition system be used in both aircraft and simulator environments, although in some simulator applications re-programming of the simulation computer may provide the equivalent of the specified digital recording.

Audio/Video Recording (AVR). Figure 5 presents a block diagram of the audio/video recording capability desired. Two video cameras will be provided, with the option for connecting a special-purpose camera instead of either of the two standard cameras. It is desired to record complete images from both video cameras, however, in lieu of this, image control is necessary to allow combining the outputs of the two cameras into a single composite picture. Audio recording of crew communications is required, but the upper frequencies of the available bandwidth is needed for recording discrete parameters as audio-encoded signals. The audio/video recorder must permit remote control in synchronization with other recording devices.

The video and photo information to be recorded in each training application is listed in Table 2 for the F-4 and C-141 aircraft; other aircraft are expected to require similar application of video and photo recording. In addition to the use of video/photo recording shown in Table 2 for combat-crew training performance measurement, the use of a helmet-mounted camera, instead of one of the standard video cameras, is

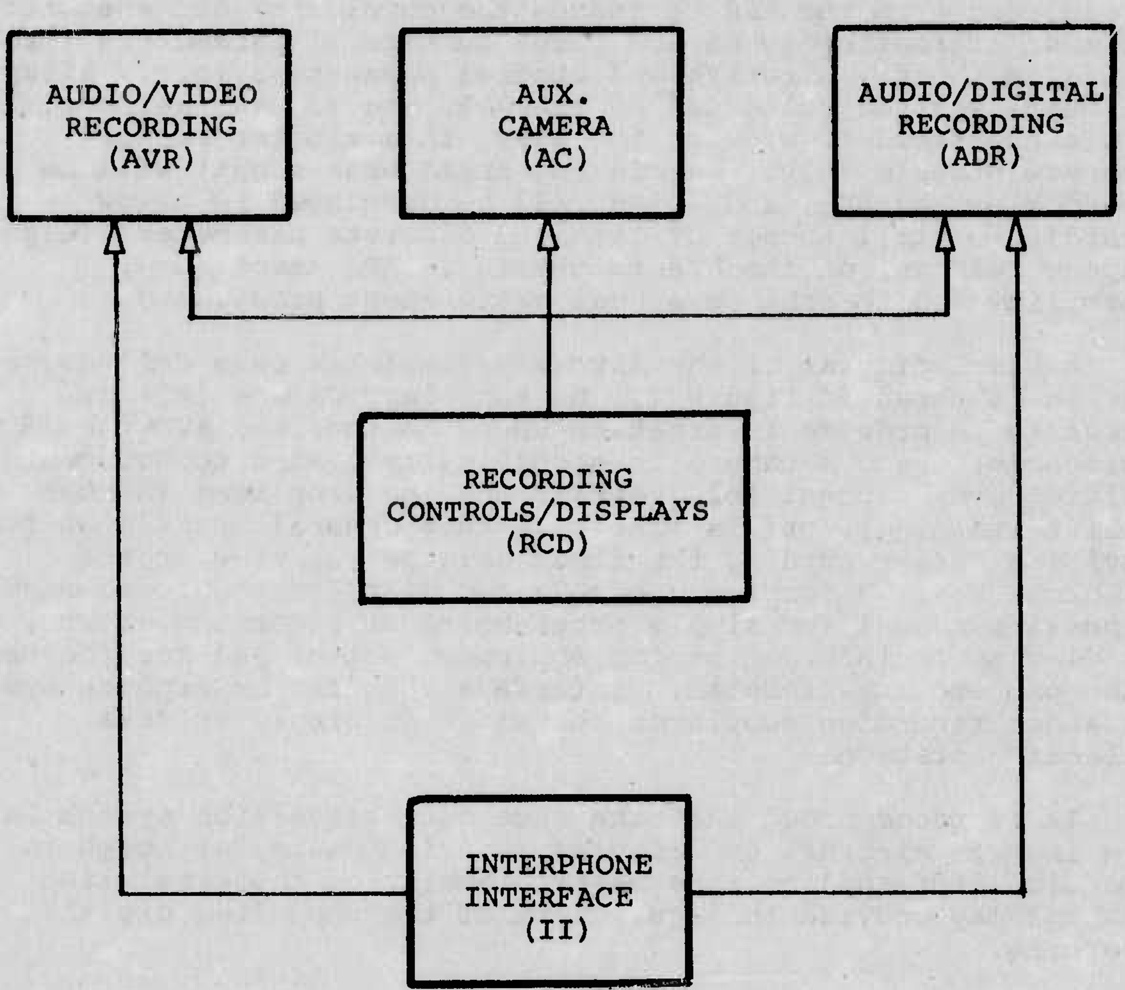

Figure 4. Aircraft/Simulator Data Collection Station.

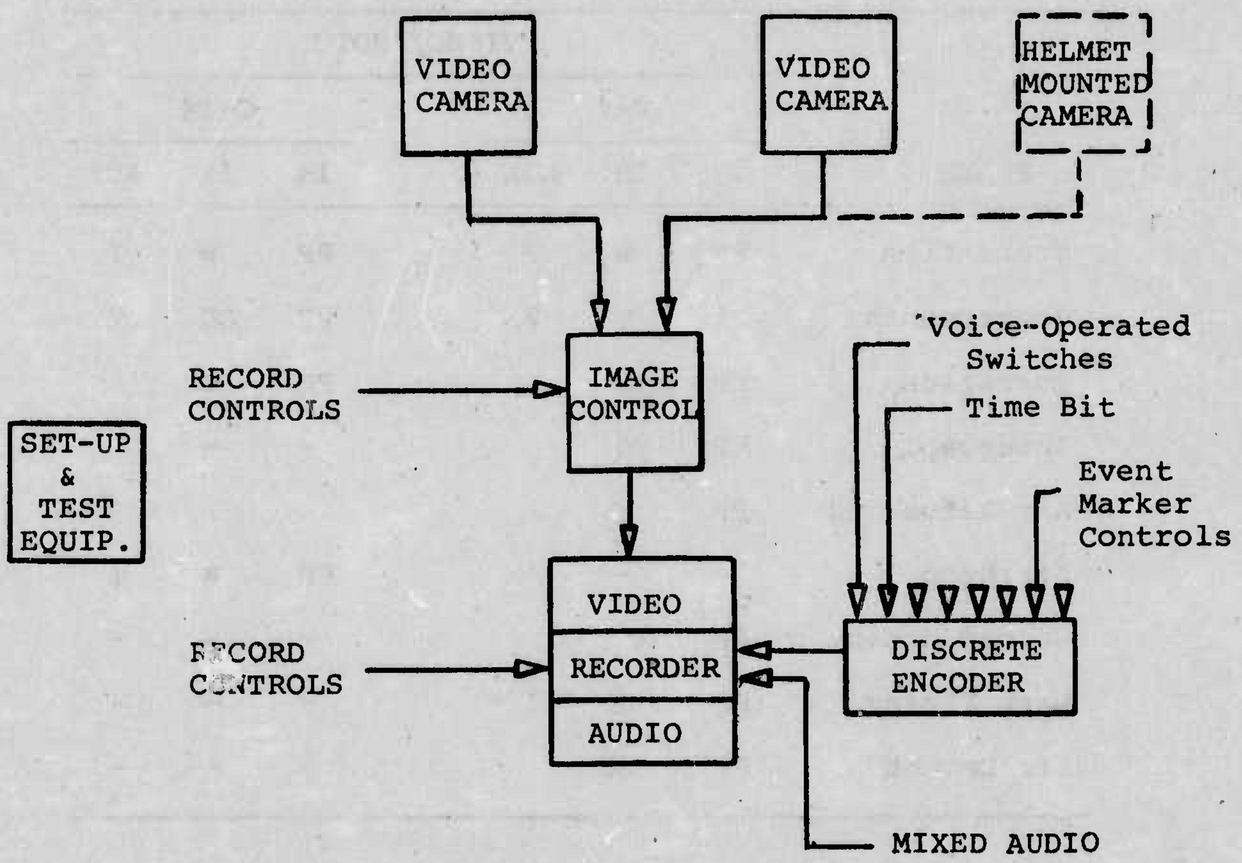

Figure 5. Audio-Video Recording (AVR).

TABLE 2

VIDEO/PHOTO DATA FIELDS BY TRAINING PHASE

PHASE	VIDEO/PHOTO F-4 1A	F-4 1B	F-4 AUX	C-141 1A	C-141 1B	C-141 AUX
Transition	PP	W	?	PP	W	?
Instruments	PP	W	?	PP	CC	?
Formation	PP	W		PP	W	
Intercept	PP	SC		-	-	
Air Refueling	PP	W				
Air Drop	-	-		PP	W	T
Ground Attack	PP	GC		-	-	-
Dart Firing	PP	GC		-	-	-
Air Combat	PP	GC		-	-	-

LEGEND:
PP: Pilot's Panel
W: Windscreen
SC: Scope Camera
GC: Gun Camera
CC: Center Console
T: Terrain Directly Below
?: Possible Use

contemplated to acquire information on targets the crew should keep under surveillance, and behavioral measurement of the crewmember's eye fixation patterns.*

1. Audio/video recorder. Specifications for an audio/video recorder and playback system are listed in Table 3 as they apply to the entire system as evident upon playback for data processing (rather than the characteristics of individual system components). It is vital that the system permit high-quality video reproduction of external airborne and ground targets as well as cockpit displays; if these images do not permit the extraction of needed information, then use of such a system for performance measurement is questionable. The audio communications must also be unquestionably intelligible. Excellent recording quality must be available in spite of the severe environments encountered during combat-crew training. Further, the system must be easy to use and maintain. The design and installation of the system must consider the limitations imposed by cockpit operations and flight crew, and must not impose any dangers to personnel safety.

Off-the-shelf video recording systems have been previously tested in combat-crew training environments. The results of specific tests of interest are available in the following documents.

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

Department of the Air Force, Headquarters, USAF Tactical Fighter Weapons Center. A-7D Airborne Video Recording System (AVRS). TAC-TR-70A-113F, Nellis AFB, Nevada, 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(FT)-TRM-17, Air Force Systems Command, Brooks Air Force Base, Texas, October 1971.

A number of unsatisfactory incidents are reported in these documents, including loss of information due to glare, electromagnetic interference, vibration, maneuvering g's, and a number of operating problems. The design and installation of the audio/video recording system must eliminate these problems so that data collection is not impaired during system test and operation.

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*Devices are also available for this purpose which allow direct digital recording of eye movements.

TABLE 3

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 syste, 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.

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*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.

2. Image control. Simultaneous synchronized recording of two complete pictures from two video cameras is desired. If two-channel video recording is not possible, then extensive image controls are necessary to attempt to approximate the desired information and resolution by allowing the available image area to present the most important information from each camera. Methods desired for image control are listed in Table 4; the design should include as many of these features as possible, as well as others which may become apparent to enhance data collection ability.

3. Discrete encoder. Recording of discrete events is necessary to measure quantities which infrequently change, and quantities which are important to measurement control (i.e., start-stop logic). Unfortunately, many of these (e.g., weight off the wheels, flap settings) are either invisible or out of the field-of-view of video/photo cameras. Incorporation of these quantities can greatly increase the value of video recording; consequently, a method for discrete recording should be developed if practical. A method is suggested here for encoding discrete information as audio tones within the available audio recording bandwidth, however, other approaches may be available for consideration. As depicted in Figure 6, communication recording should occupy the frequency spectrum 300-3000 Hertz, leaving the higher frequencies available for recording a tone for each binary parameter. The number of parameters which may be recorded in this manner depends on the audio bandwidth actually available, the bandpass of audio filters during playback, and the stability of tone oscillators for recording. A minimum of 10 discrete recording channels should be provided, but 24 or more channels could be useful.

A selectable time bit (at 1, 2 or 4 second intervals), derived from the time code generator, must be recorded as one of the discrete channels to aid processing during playback.

4. Set-up and test equipment. The audio/video recording system will also include equipment for check-out and test of the video system (other than standard test equipment), and for set-up of the specific images required for recording.

Audio/digital recorder (ADR). The parameters allocated to audio/digital recording are listed in Table 5 for key training phases. These parameters can be divided into the following categories: (1) aircraft parameters, (2) control parameters, (3) binary discrete parameters, (4) time, and (5) communications. 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 a portion of these channels must be sampled more often to allow spectral analyses and precise training as shown in Table 6.

TABLE 4

IMAGE CONTROL METHODS

1.	Horizontal Split	X% Camera A, Y% Camera B.
2.	Vertical Split	X% Camera A, Y% Camera B.
3.	Inset Camera A picture within Camera B picture.	
4.	Alternate Camera A, Camera B at .1, .5, 1, 2, 3, 5, 10 second and 1, 2, 5 minute intervals (or continuous adjustment of interval).	
5.	Sequence: (1) split screen, (2) full image of Camera A on Event A, (3) return to split screen on Event B. (Event A & B are aircraft discrete parameters designated for digital recording.)	
6.	Pan camera back and forth within the cockpit at selectable rate.	

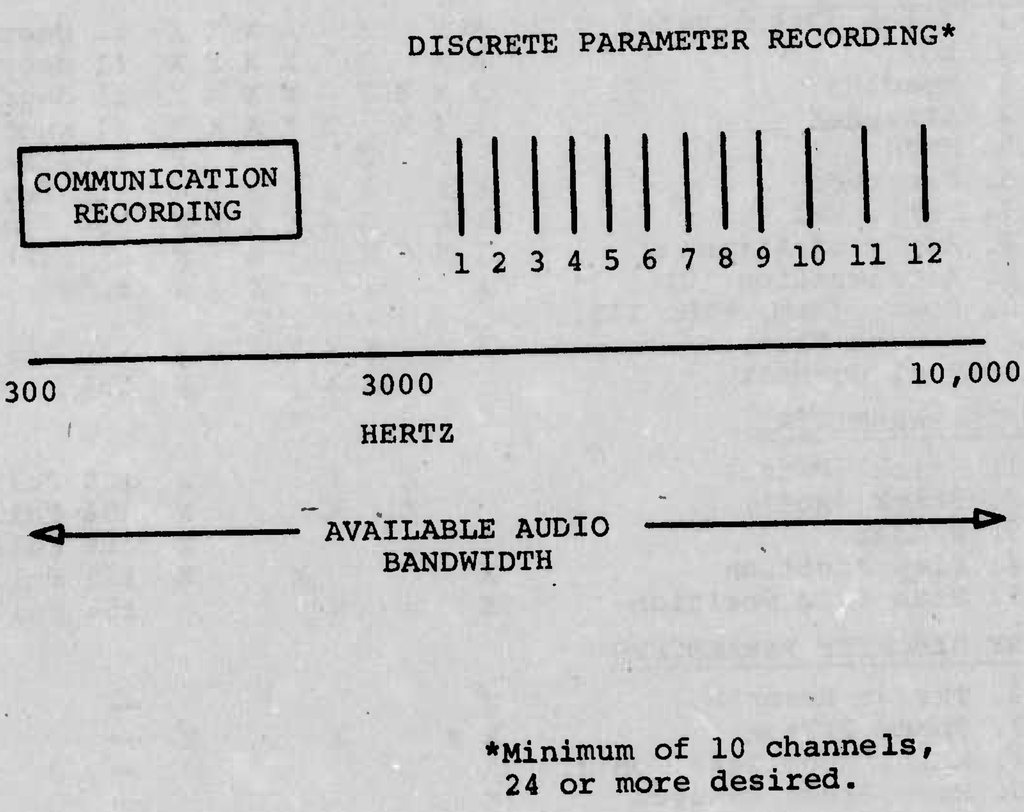


Figure 6. Discrete Audio Recording.

TABLE 5

AUDIO/DIGITAL RECORDER PARAMETERS

	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				--
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.
COMMUNICATIONS	X	X	X	X	X	X	X	X	X	

TABLE 6

DIGITAL RECORDING CHANNELS AND SAMPLING RATE*

No. of Channels (Minimum)	Sampling Rate (Times each channel is sampled each second)
16	2
10	10
5	20

*In addition to Discrete Parameters and Time.

Digital recording accuracy is also indicated in Table 5 specifying the deviation allowed between the recorded information indicated to the pilot by cockpit displays. It is important that recorded information compare closely to cockpit displayed information since data collection anomalies will be attributed to pilot performance; for example, if the pilot is expected to maintain an airspeed of 135±5 knots, and there is a 5 knot discrepancy in the recorded information, the pilot may be scored as exceeding permissible tolerances when actually performing excellently. Consequently, the accuracies listed in Table 5 are designated to allow an error of no more than approximately 5%-10% the tolerance band permitted the pilot (e.g., if the pilot is permitted a tolerance band of ±10 knots, then ±1 knot error is permitted).

A gross block diagram of the Audio/Digital Recorder is presented in Figure 7; the principal parts are (1) the recorder electronics, (2) the recorder, and (3) the test stand. As there are alternative designs which may achieve the desired result, further definition will not be attempted here, however, the specifications given in Table 7 are intended for design guidance.

The test stand must include all equipment, other than standard test equipment (e.g., voltmeters and oscilloscopes), to permit digital recorder checkout and calibration of all channels prior to each data collection flight; the same equipment should facilitate diagnosis and repair. Maintenance ease with minimal personnel, and high reliability so that data collection takes place as needed (probably on an intense schedule), is extremely important to the intended applications.

Auxiliary Camera (AC). An auxiliary camera is needed as a supplement to audio/video/digital recording to record either displays in the cockpit or external views (such as the terrain below during airdrop); consequently, a variety of lenses and mounts are expected to be necessary. External controls will

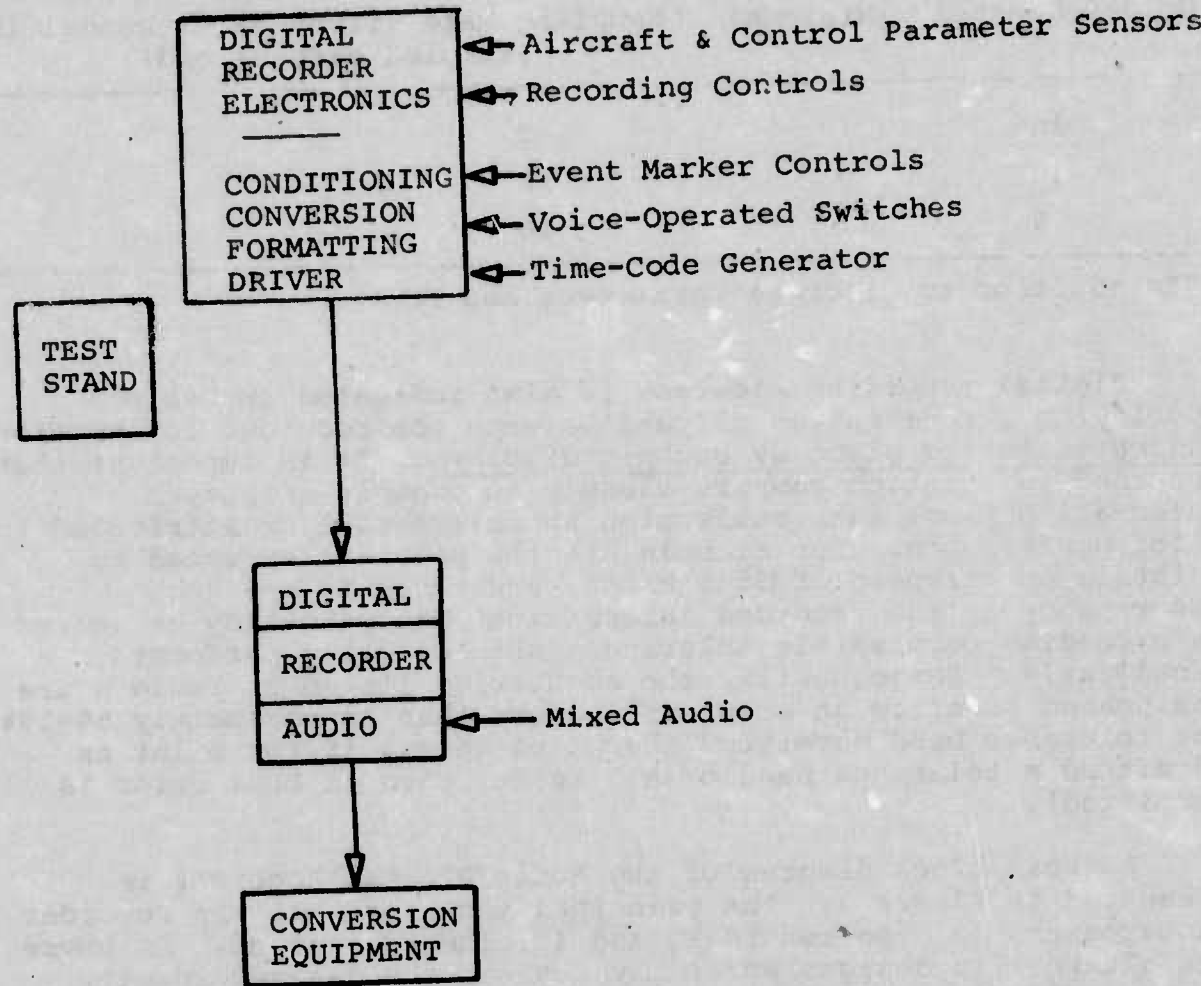


Figure 7. Audio-Digital Recording (ADR).

TABLE 7

AUDIO/DIGITAL RECORDER SPECIFICATIONS

PARAMETERS/ACCURACY: As indicated in Table 5 (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.

expose the film in either a motion picture sequence, or as individual frames (from 0.1- to 10-second intervals).

Interphone Interface (II). The interphone interface (see Figure 8) is to permit selection of the communications from any crewmember, and to 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 specified 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.

Recording Controls/Displays (RCD). Recording controls and displays provide manual and programmed control of recorder functions, and information for the human operators using the system during set-up and data collection. A block diagram of the RCD is presented in Figure 9a.

A time-code generator and event-mark controls are included in the RCD to be recorded on discrete recording channels. These discrete signals are also used to turn the recording system on and off, or initiate timers which will switch the system on or off after a specified interval. As indicated in Figure 9b, the following sequence is desired: (1) recording is initiated by either event A (one of the discrete signals recorded) 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. For current purposes an event for recording control may be a manual input (an event mark), an aircraft discrete parameter, or a specified time bit from the time-code generator.

It is recommended that the RCD be divided into two units with controls and displays as shown in Table 8. Unit 1 provides information and control useful to a member of the flight crew during training; while it should be small and non-obtrusive, operation must be possible in a cockpit environment with full flight dress. Unit 2 permits set-up of recording programming prior to a planned mission; it may be normally utilized by a ground technician. However, some aircraft and circumstances may dictate the presence of an airborne experimenter; in this case, both units must be co-located at his station.

Personnel tasks during recording. Gross personnel tasks for recording of aircraft/simulator data are listed in Table 9. Further task definition will be possible when detailed equipment designs are selected.

Field Data Collection Station (FDCS)

The Field Data Collection Station (FDCS) will provide data collection at remote places such as at the runway, the bombing range, or ground surveillance radar. For these purposes,

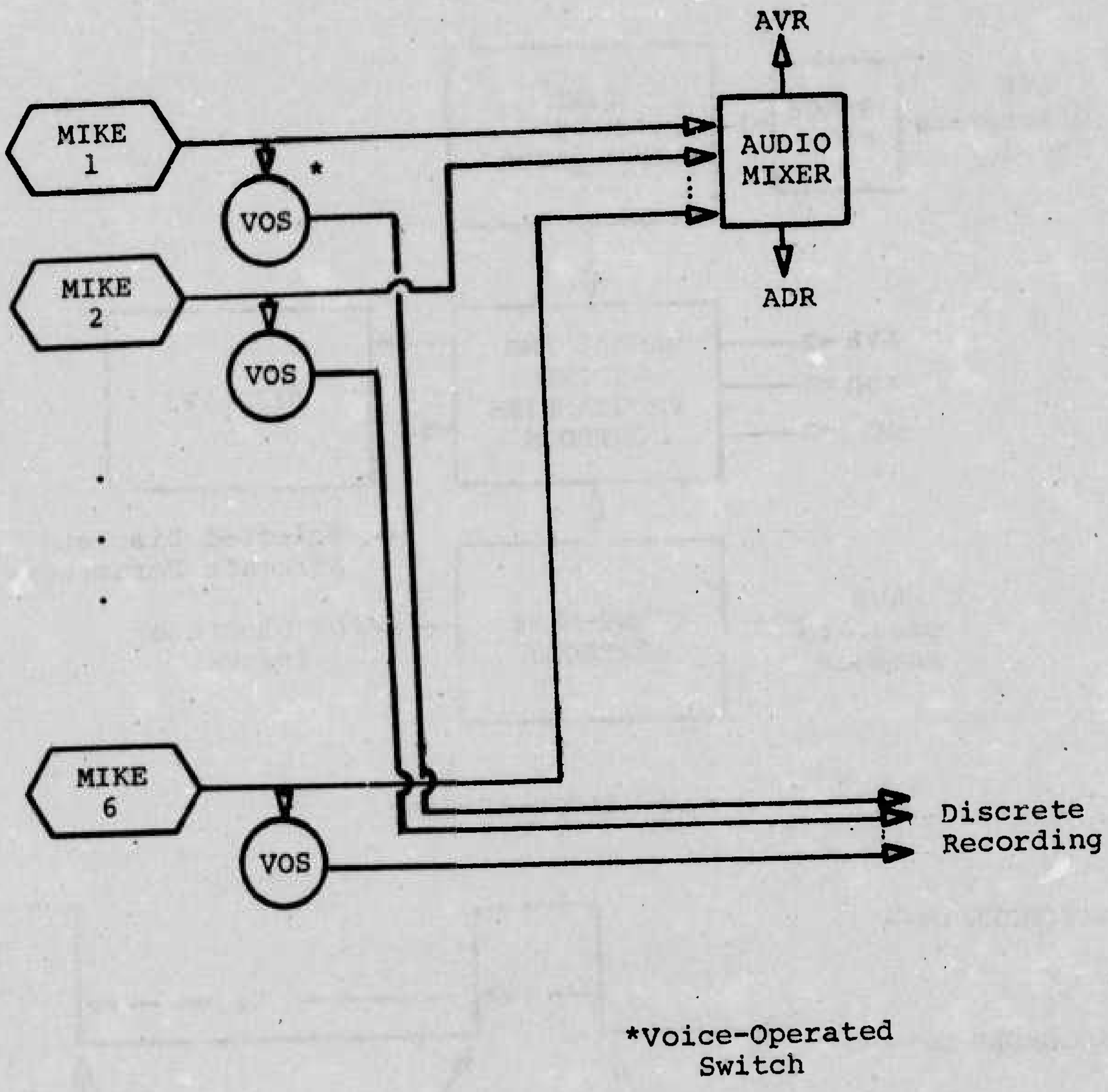
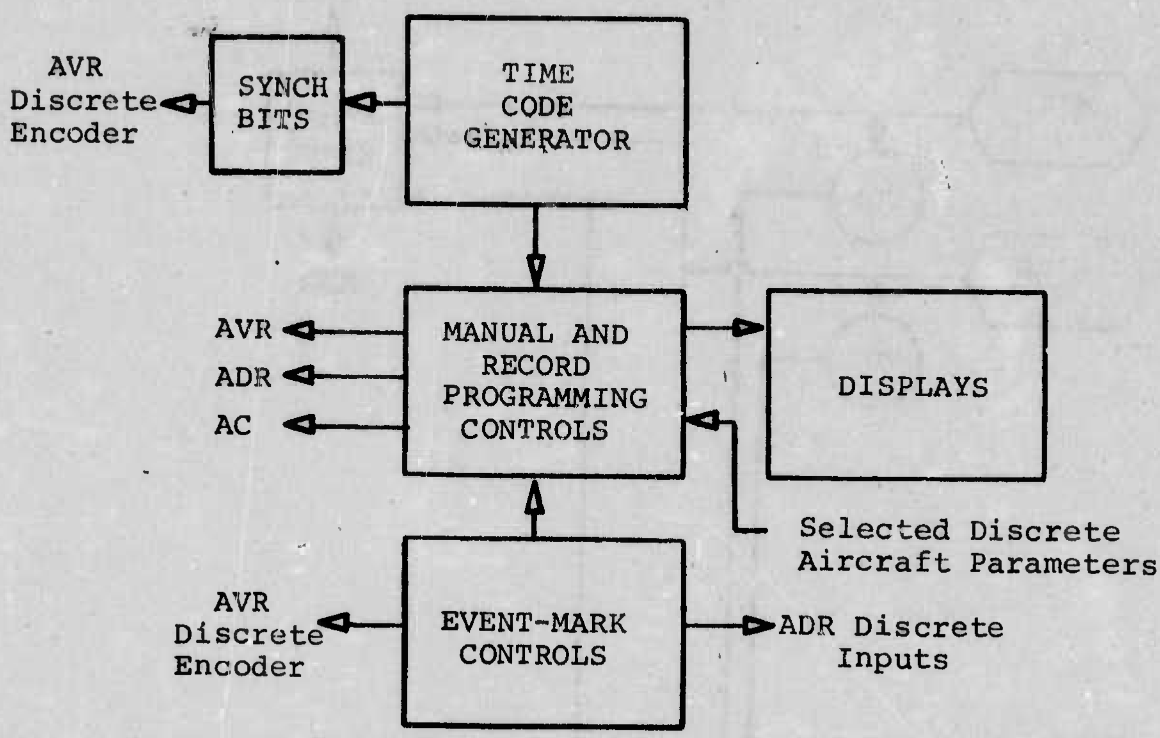
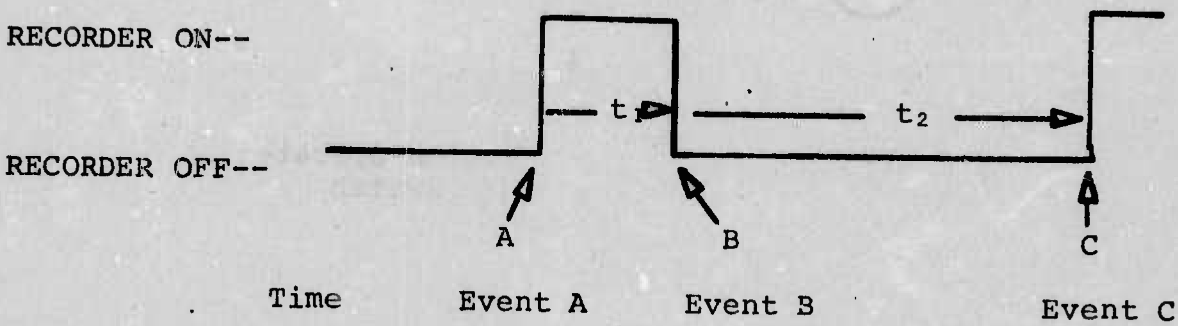


Figure 8. Interphone Interface.



a. BLOCK DIAGRAM



Note 1: t_1, t_2
Programmable

Note 2: Events (A,B,C)
Can be: (1) Manual Input
(2) Acrft Discretes
(3) Specified Time

b. PROGRAMMED RECORDING SEQUENCES

Figure 9. Recording Controls and Displays

TABLE 8

RECORDING CONTROLS/DISPLAYS

<u>UNIT 1</u> (For Flight Crewmember or Airborne Experimenter)

On-Off, Start-Stop Controls for Aux. Camera, AVR and ADR
Event Marker Controls
Digital Time Display
Time Setting Controls
Tape Remaining Display for AVR and ADR

<u>UNIT 2</u> (For Ground Technician or Airborne Experimenter)

Record Programming:

- On-Event/Manual Start/Interval A
- Interval B/Off-Event
- Interval C/On-Event
- Interval D/Off-Event

Video Framing:

- Horiz. Split - % Camera A/B
- Vertical Split - % Camera A/B
- Inset - % Camera A/B
- Time Split - 0.1, .5, 1, 2, 3, 5, 10 seconds
- Event A Full Camera A, Return to Split on Event B

Aux. Camera:

- Exposure Rate: Motion, .1, .5, 1, 2, 3, 5, 10 seconds

TABLE 9

PERSONNEL TASKS FOR RECORDING

SYSTEM CHECKOUT
Test, Replace/Repair, Preventative Maintenance, Adjust
LOAD TAPES
PERFORM CALIBRATION AND PRE-FLIGHT RECORDING
SET-UP FOR DATA COLLECTION
Record Programming: On/Off Events in Time Intervals
Video Framing: Split, Inset, Time, Sequence
Aux. Camera Exposure
INFLIGHT/SIMULATOR
System On
Manual Start/Stop as Required
Manual Event Mark as Appropriate
System Off
PERFORM POST-FLIGHT RECORDING
UNLOAD TAPES

portable equipment with self-contained power sources is needed. A simple data collection station is desired; Figure 10 depicts the major equipment items, a camera with timing control, an audio tape recorder, and transceivers.

Camera. Camera specifications for the FDCS are much the same as for the Auxiliary Camera for aircraft/simulator data collection. Therefore it would be desirable for these camera systems to be compatible. An accurate clock is needed in the corner of each frame of the FDCS camera to allow correlation with data collected elsewhere. The exposure-timing mechanism requirements are the same as for the auxiliary camera (motion, .1, .5, 1, 2, 3, 5, 10 seconds).

Audio tape recorder. A small hand-carried cassette-type tape recorder is required for recording of ground station communications and other verbal information.

Transceivers. Transceivers will be used for data collection team communications between the FDCS crew and the remainder of the data collection team at the data playback and processing facility, and to monitor flight crew transmissions during training missions. The frequency and power of these units is, of course, governed by Air Force regulations, but maximum communication capability within these constraints is desired (these units may be provided from the Air Force Inventory).

Briefing/Debriefing Data Collection Station.

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 provide a source of subjective measurement for correlation with measured performance indicators. Many of these briefings are so rich in information that a small hand-carried cassette-type recorder may be necessary for recording for later transcription. A small camera may also be useful, if detailed briefing displays are used and copies of briefing slides are unobtainable.

Documentary Data Collection Station (DDCS)

Desired performance and measurement control parameters will also be obtained from documents such as the Dash-One Technical Order, Phase Manuals, and operational publications. No special equipment is believed necessary for this form of data collection, although digital encoding equipment for computer processing (e.g., teletype) is necessary but will be discussed in regard to the Data Playback Station.

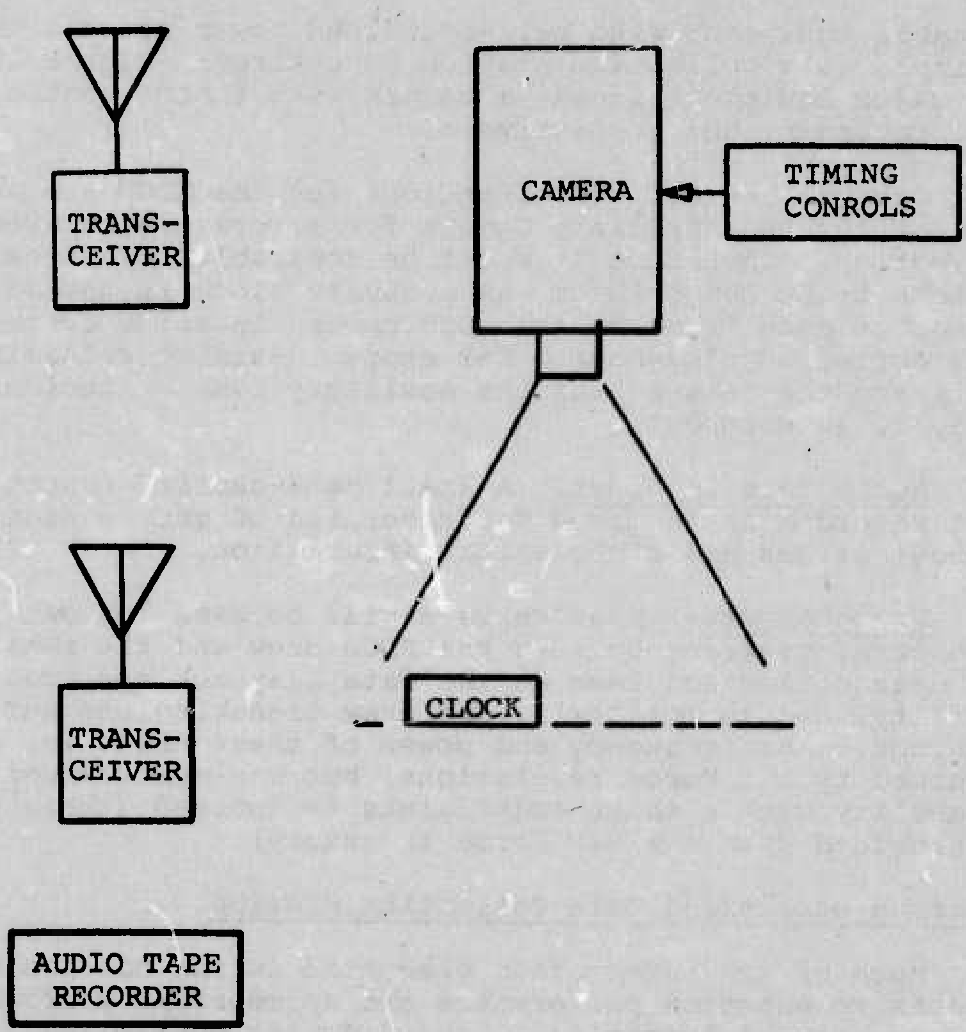


Figure 10. Field Data Collection Station.

External Data Collection Station (EDCS)

Data will also be produced on occasion by an external source which must be correlated with data collected during combat-crew training. For example, external data may be produced by another experimental investigation performed elsewhere, or the output of a ground multiple-target tracking radar on an instrumented test range. These data must be provided to the current facility in a form permitting processing with the available general purpose digital computer. Under this assumption, no special data acquisition need be provided for externally produced data.

Data Playback Station (DPS)

The Data Playback Station (DPS), as shown in Figure 11, must permit the transformation of data collected through the five avenues shown in Figure 2 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.

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 provides 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

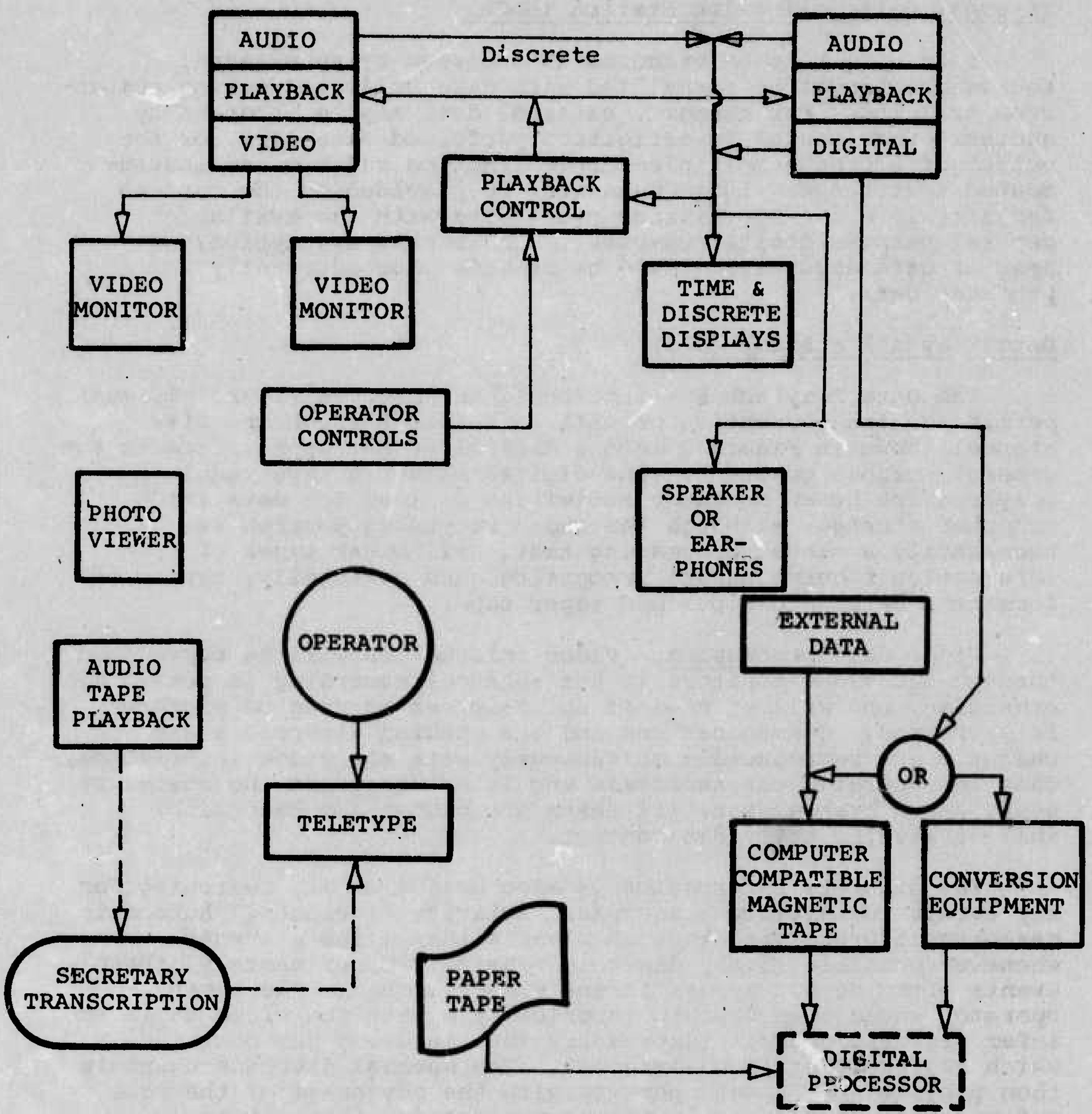


Figure 11. Data Playback Station.

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).

A TELETYPE[1], or similar device, will be used to punch paper tape to enter video data into computer storage.

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.

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.

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, and photo analysis must proceed without benefit of the special discrete channels used with video. Information may be located by (1) searching for conditions on the cockpit instruments or outside view, and (2) finding specific frames or indications on the panel clock as directed by information from the audio or digital information. The resulting information must be coded onto punched paper tape, normally including time values to allow correlation with data from other sources.

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*Trademark of the Teletype Corporation.

Manual data processing workstation. Manual processing tasks identified in the previous paragraphs are summarized in Table 10. The design of the data processing workstation is important to the efficiency and accuracy of the entire training measurement system; its design should carefully consider human operator requirements and limitations. It should be noted that this workstation may be used for training feedback and critique by training personnel, as well as used for data processing tasks. A minimum list of manual processing equipment, controls and displays is presented in Table 11; other controls and displays may be added to enhance the dual purpose of this workstation.

TABLE 10

PERSONNEL TASKS DURING DATA PLAYBACK

VIDEO

Load tape, play
Read calibration values
as dictated by measurement script:

1. Use automatic control to (1) stop at event on specific discrete channel, and/or (2) advance N seconds -- i.e., count time bits on discrete channel (Example: Advance to "gear-up").

2. Use fast/slow/single-frame forward/reverse controls to search in the neighborhood of measurement interest (Example: Search for out-of-tolerance condition).

3. Use teletype to punch paper tape for computer entry (Example: Parameter code number, parameter value, time).

DIGITAL

Load tape
Play into conversion equipment to (1) transmit data directly to disc storage, or, (2) produce compatible magnetic tape to play on computer magnetic tape units.

AUDIO

Load tape, play, stop at auditory information desired
Video: Note parameter values
Digital: Note time from digital recorder discrete display
Punch paper tape (Example: Code number, time).

PHOTO

Load film, wind film through viewer
as dictated by measurement script:

1. Search for conditions indicated by instruments, and read specified valued, and/or,

2. Find specific time indications on clock (as derived from digital time readout) or a specific frame number and read specified values.

3. Punch paper tape.

TABLE 11

MANUAL PROCESSING EQUIPMENT, CONTROLS AND DISPLAYS

Video Monitor and Associated Controls (two needed if dual-video recording is possible).

Audio/Video Playback Unit and Associated Controls (fast/slow slew forward/reverse, single-frame forward/reverse precision tape footage indicator).

Audio Playback Unit and Associated Controls, Speaker, Headset, precision tape footage indicator.

Audio/Video Discrete Display (10-24 Indicators).

Audio/Digital Conversion Unit with Associated Controls and displays for operation.

Audio/Digital Discrete Display (24 Minimum).

Digital Time Code Display (Hrs, Min, Sec, 1/100 Sec.)

Programmed Playback Control

Advance audio/video tape to an Event on discrete channel <u>N</u> N=1,2,...

Advance audio/video tape <u>X</u> Events on discrete channel <u>N</u> N=1,2,... (normally the time-bit channel).

TELETYPE, Tape Reeler and Hand Tape Winder.

Film Viewers (16 mm and 35 mm).

III. DATA PROCESSING SUBSYSTEM

The system to process training research measurement as it has been developed in this study is described in terms of the characteristics of (1) desired hardware and (2) associated software.

Data Processing Hardware

It is desirable to have all measurement processing tools in a central location ready for use when they are needed; therefore, a dedicated processing facility is assumed as shown in Figure 12. Most measurement processing can be performed on general-purpose computing equipment; however, if data are to be extracted from airborne instrumentation, special conversion equipment is needed.

Data Processor. The heart of the measurement data processing facility is a general purpose digital computer. Based on experience with many inflight and simulator expermients (see Table 12), the computer should have about 16,000 to 32,000 words of memory, a word size of at least 16-bits but preferrable 24-bits, and a basic operation time of no more than one-to-three microseconds. Much of the tuility of the system for measurement and data analysis depends on the presence of the following peripheral equipment:

(1) Magnetic Tape Units. At least two magnetic tape units with 7 or 9 track and variable density capability should be provided as a means to store program and data files, a vehicle for entry of externally collected data (possible from airborne instrumentation recordings), as as an intermediate output medium. Of course, a magnetic tape controller should accompany the units.

(2) Disk Units. Although it is possible to operate without disk storage for many small experimental efforts, the use of disk storage can speed operations, increase capacity, provide efficient program and data file storage and retrieval, and permits the use of powerful software structures and operating routines. A minimum of two logical disk units are required; four logical units are preferred.

(3) Line Printer/Plotter. The line printer permits high-volume output in a timely fashion, which is necessary for data listings and multiple statistical analyses. A minimum speed of 300 lines per minute is desired. Since almost all performance measurement output requires plotting for interpretation, a plotting capability is quite desirable. Recent hardware development suggest that a combination printer/plotter may provide both capabilities at a reasonable cost.

(4) Teletype. A teletype or a console typewriter is required for program control, system monitoring and manual data entry.

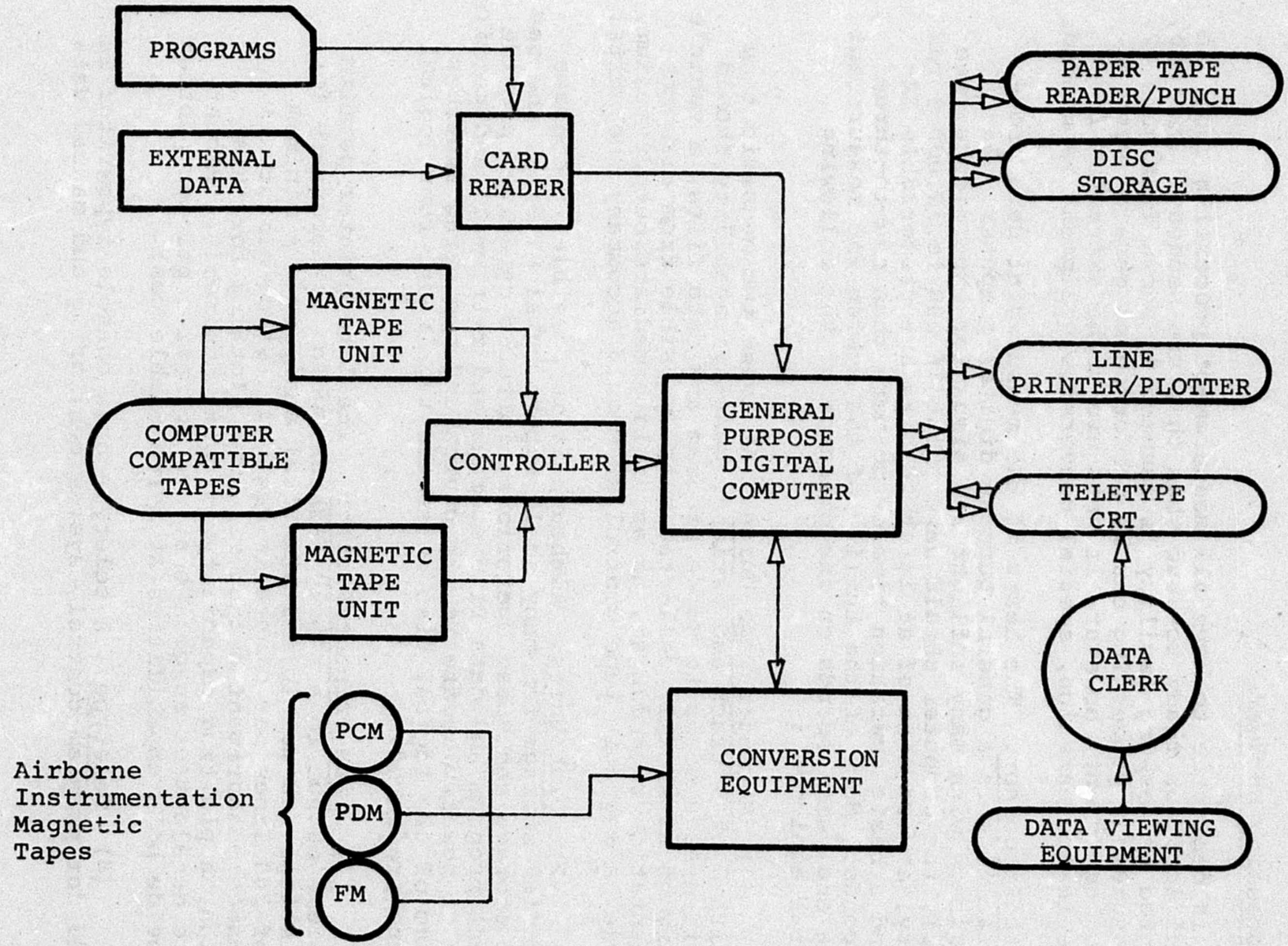

Figure 12. Dedicated Measurement Processing Facility.

TABLE 12.

DATA PROCESSING SYSTEM HARDWARE

Processor
Memory (16-32K words)
Word Size (18-24 bit)
Cycle Time (1-3 microseconds)
Floating Point Hardware
Card Reader
Magnetic Tape Units (2) + Controller
Disk (204 logical units)
Plotter/Printer (at least 300 lines/ min)
Teletype or Input Typewriter
Paper Tape Reader/Punch
CRT Display
Airborne Magnetic Tape Conversion

(5) CRT. Since infromation must be provided for training feedback, manual data entry, software and data editing, an electronic display (cathode ray tube) is recommended.

(6) Paper Tape Reader and Punch. Paper tape provides a low-cost input/output capability, compatibility with other computers, and is the primary input medium for manually reduced data in the processing system. It is a standard feature with most computers and Teletypes.

(7) Card Reader. A card reader permits convenient entry of data collected from external sources such as subjective data, paper-and-pencil measurement forms and data from other experiments. Computer programs can be manipulated in card form.

Airborne Tape Conversion. 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, this is not likely to be the case; conversion equipment that will read the airborne magnetic tape and produce computer compatible tapes will then be required. The exact nature of such equipment will be a function of the configuration and format of the airborne instrumentation system.

(1) Configuration. Although the tape width may be computer compatible, the reel size may be different requiring that the tape be rewound onto another reel. If a tape cassette is used (such that the tape cannot be physically removed), then the tape must be electronically copied; a playback unit will be required.

(2) Format. Current airborne recording technology dictates a recording format which is different than that used in a general purpose digital computer to maintain accuracy in spite of noise and recorder irregularities. Pulse code modulation (PCM), pulse duration modulation (PDM) and frequency modulation (FM) techniques are used. Conversion equipment may be needed for several types of recording if compatibility with currently instrumented aircraft is desired.

Software

Data processing system software requirements fall into two major categories, (1) the executive monitor, and (2) measurement processing. The monitor, together with its utility programs and operating system provide the fundamental software tools which are used to construct and execute user programs and to manipulate data files. Measurement processingprograms form the logic for generation, control and analysis of performance measurement data.

Executive Monitor. The monitor supervises all input/output (I/O) operations and traps errors. All programs are initiated from the monitor. Manual return to the monitor should be possible from any user program at any time during processing. All programs should return to the monitor upon normal completion.

The monitor should be able to operate in a manual or batch processing mode. In the batch processing mode it receives its commands from the batch input device, usually a card reader or paper tape reader. Batch processing reduces operator intervention and allows rapid, semi-automatic processing of sequential programs. Manual mode monitor communications with the operator should operate through the console keyboard, a typewriter or teletype.

The monitor should provide a device independent operating system, wherein the assignment of program logical I/O devices to the actual physical devices are handled by the monitor and can be changed at runtime by a monitor command. Typically, I/O device handlers and buffers are brought-into memory by such monitor assignments. I/O handlers should allow asynchronous operation so that processing can continue while I/O is taking place.

The handlers should provide the capability to operate in a named file or non-file priented mode. In the file oriented mode several names files may be contained on a particular tape or disk. During file oriented operations, a specific names file is opened (initiated) for reading or writing. In the non-file mode, the whole logical device is treated like a magnetic tape in terms of read, write, rewind and backspace operations. It is desireable to be able to open a names file for <u>both</u> reading <u>and</u> writing, but this feature is not possible to open a names file for reading and writing, then it is important that the handlers provide both file oriented and non-file oriented service.

In addition to its own operating system and housekeeping routines, the monitor should call at least seven utility programs through a simple keyboard command in the manual mode, or paper tape commands (or cards) in the batch processing mode. These routines are shown in Figure 13, and are briefly described in the following text since they are common in modern software structures.

(1) Text Editor. The editor is intended for on-line use with Teletype alone, or with a combination keyboard and CRT display. The purpose of the editor is to create or change (correct) a file of (a) text, (b) user program instructions (such as FORTRAN or Machine Language source programs, or (c) numbers while the operator is on-line.

The editor should allow the operator to open and close files by name, and to change the names of existing files. To assist with data input, provisions for tabulating (i.e.: moving the "carriage" to pre-defined positions) and adjusting the tab

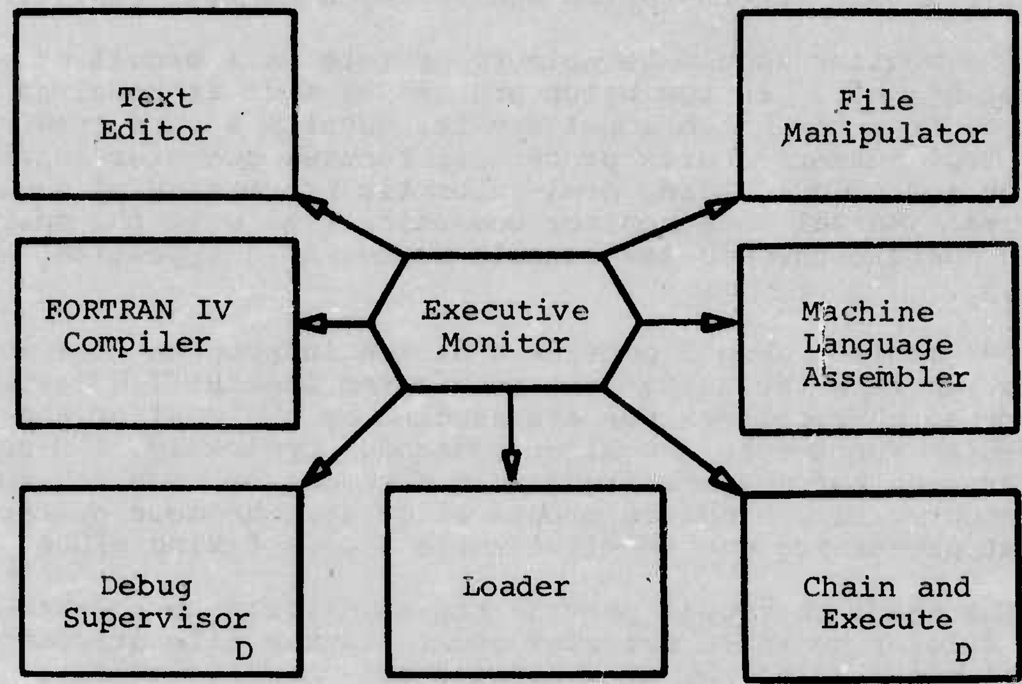

Figure 13. Executive Monitor and Utility Programs.

positions should be incorporated. There should be provision for fetching n-lines of input data from another peripheral device, such as a paper tape reader. Once a file is opened, the operator either inputs text or data in the input mode, or changes the content of the file in the edit mode. A convenient method of switching between modes at any time in the file should be provided.

In the input mode, the operator types text, instructions or data into the file, one line at a time. If the input mode is being used to insert several lines into an existing file, the remaining portion of the file should be undisturbed by the newly inserted text.

In the editing mode, must text editors start at the first (or top) line of a file, and bring successive or requested lines to the working area on command. Typically, a line is brought to the working area by (1) specifying a line number, (2) asking for the next line or n-lines, (3) searching the file for a statement number that may be contained at the beginning of the line, or (4) searching the file for a character string that may be contained on the desired line. Once in the working area, the line can be re-typed, added onto, deleted, or any defined character string within the line can be changed. A summary of these desired editor control functions is shown in Table 13.

Good human engineering of the text editor control functions is essential to keep the operator error rates and subsequent machine time utilization to an acceptable level. Editor commands should be in natural language where possible, and abbreviated. For example, to locate the variable ISUM in a FORTRAN source file, a simple locate command, "L ISUM" should be sufficient to search the file for ISUM, and to bring the first line containing ISUM to the working area fir operation. Whether or not the line containing ISUM is echoed on the output device when it is found should be a function of a "verify" switch, which is normally on, but can be turned-off with a simple command such as "V OFF."

It is frequently necessary to make the same changes to repetative character strings throughout a file. One command string should be sufficient to do so. For example, a command such as, "L C /ISUM/SUM" (where slashes are field delimiters for example purposes only) should cause the editor to search the entire file, and to change earch ISUM it finds to SUM.

A requirement for the operator to completely spell commands (such as "LOCATE") is an example of an undesireable design feature. Similarily. some text editors allow movement through the file in a forward direction only, which can lead to error and consume excessive machine time; a simple backup command should be provided. Some editors tend to make the use of line numbers mandatory in the edit mode; although it may be convenient at certain times to use line number references, it should not be <u>mandatory</u> for the operator to do so.

TABLE 13

TEXT EDITOR CONTROL FUNCTIONS

OPEN, CLOSE and RENAME a file.

TAB change.

GET n-input lines from peripheral device.

FIND a statement number.

LOCATE a character string.

CHANGE a character string within a line.

LOCATE AND CHANGE repetative character strings throughout the file.

RETYPE a line.

ADD to the end of a current line.

OVERLAY n-lines with an equal number of lines to be input.

DELETE the current line or n-lines.

PRINT (output) the existing line or following n-lines.

Bring NEXT line or n-lines to the working area.

BACKUP one or n-lines.

NOTE: Text editor should be called from monitor with single command.

(2) File Manipulator. The file manipulator is a utility program which can be called from the monitor by a simple command in order to perform the file operations shown in Table 14. Through natural language input to the keyboard, the operator should be able to transfer, rename, segment, combine, delete, verify, and copy files from device to device (or within the same device to create a new file with a different name but using the contents of the old file). Although file manipulation is primarily intended for named file oriented devices, it is desirable to permit a binary block transfer or copy of non-file oriented data. This would provide capability to dump the contents of any tape (that can be read) onto the line printer for examination, or to copy any tape that can be read.

(3) FORTRAN IV Compiler. FORTRAN IV should provide a compiler-level language with sufficient power for the generation of most performance measurement user programs, with several specific additions. The computer should allow (a) a minimum of six-dimensional array manipulation, (b) negative DO loop indexing, (c) format-free input with character fields separated by commas, (d) all ASC II printing characters allowed in Hollerith fields, (e) any arithmetic expression as a legal array subscript, and (f) any array element as a legal subscript. A single command to the monitor should load the FORTRAN compiler.

When the compiler is loaded, a single command string should be sufficient to identify the source program to compile and the requested output options. Output options should include the "standard" set, such as (a) binary object program, (b) object listing, (c) source listing, (d) error only listing and (e) symbol map. Although not available in some systems, it would be desirable for source listings from the compiler to show the relative starting address of the binary (object) instruction set that corresponds to each source program instruction line. The FORTRAN characteristics desired are summarized in Table 15.

(4) Machine Language Assembler. A machine language programming capability should be provided for the generation of user programs and FORTRAN callable subroutines for processing and special purpose I/O operations that are more efficiently handled in machine language. As with the FORTRAN compiler, the machine language assembler should be callable from the monitor with a single command. Once loaded, a single command string to the assembler should be sufficient to identify the source file and standard output options such as error diagnotics, symbol maps and cross-references.

(5) Loader. Most software structures require a loader, which loads binary object programs into memory, and starts their execution. Two versions of the loader are required, a load-and-go version which loads the programs and initiates execution, and a load and wait version which requires an operator command to

TABLE 14

FILE MANIPULATOR CONTROL FUNCTIONS

TRANSFER named file from one device or media to another.

RENAME a file on any device or media.

SEGMENT a file into several new files.

BRING-TOGETHER (combine) several files into one file.

DELETE a file.

VERIFY the existence of a file on any device or media.

COPY the entire contents of one device (such as disk) onto another (such as tape).

CONVERT TABS to multiple spaces (and converse).

DELETE trailing blanks and card sequence numbers, and replace with carriage return, line feed, rubout (for converting card images to paper tape).

LIST the contents of any file oriented device (i.e.: the names of files contained on that device).

Call from monitor with single command.

TABLE 15

FORTRAN CHARACTERISTICS

At least 6-dimensional array capability.
Negative DO LOOP Indexing.
Format-free input (Character fields separated by commas).
All Printing ASC II Characters legal in Hollerith Fields.
Any arithmetic expression as a legal subscript.
Any array element as a legal subscript.

execute. The loader should be called from the monitor with a single instruction. One command string should identify the object programs to load and any desired options such as load maps.

Many loaders demand that the main program and all required external subroutines be identified by name in the load command. The loader should require only the name of the main program, and should search the files and load subroutines and external subfunctions which have been identified in the main program. Although this highly desirable feature is not possible in some software structures, its incorporation will significantly reduce operator error and machine time during manual monitor operation.

If the loader is used by the monitor to load the aforementioned utility routines, its operation should be completely automatic. Thus, one monitor command to bring-in the text editor should locate the text editor program, load it into core, and initiate its execution.

(6) Debug Supervisor. A program to supervise the execution of machine language or FORTRAN user programs for debuggine purposes is highly desirable. The debug program should be called directly from the monitor, and should automatically call the loader. Once the user program is loaded, debug command/control should be through the keyboard in an abbreviated natural language format where possible. Keyboard control options should permit the operator to perform the functions shown in Table 16.

A minimum of four breakpoints should be definable prior to program start and during any program halt. The breakpoints are assumed to be the address of a specific instruction in the program. It would be desirable if the addressed could be specified relative to the first program instruction address.

Capability to examine the contents of memory words should be by reference to the symbol name or address. A variable name, or its location should be a sufficient command to cause the memory word to be found, and its contents typed out. Typically, the binary contents of memory words can be interpreted in several ways (i.e.: as an octal or hexidecimal number, an alphanumeric string, a symbolic instruction, or in (raw) binary). It is highly desirable that the memory word be interpreted on output, and that interpretation modes be under operator control.

Control functions which permit changing the contents of a memory location are editing functions which should be considered desirable, but not mandatory. The size of the Debug Supervisor is important since it must reside in core with the user program(s). Editing functions should be omitted if they cause a significant increase in the size of the program.

TABLE 16

DEBUG SUPERVISOR CONTROL FUNCTIONS

Start program.
Halt at pre-defined breakpoints (minimum of four).
Examine contents of registers and memory words by symbolic reference.
Make additions and corrections to machine language instructions using symbolic code (edit function).
Change the contents of registers and memory words (edit function).
Step to the next instruction.
Continue program execution to the next breakpoint.
Restart program from a specified address.
Transfer control to Debug on Keyboard control input.

Finally, it is possible that a program will enter a continuous loop prior to reaching the first breakpoint. A keyboard control input should be provided to transfer control to the Debug Supervisor at any time during user program execution. Such manual transfers to Debug should be treated as a breakpoint halt, if possible. This would make all breakpoint halt control functions legal from a manual transfer.

(7) Chain and Execute. Chain and execute is a desired supervisory program that permits segmentation and execution of user programs which may otherwise be too large to reside in memory. Performance measurement processing frequently requires lengthy editing and analysis programs whcih operate on large data arrays. Data arrays as large as 8,000 words are often required. Floating-point word formats may double or triple data array sizes in some computers. A modest amount of memory can be exceeded quite easily by operating system and user program requirements. Program chaining software is a cost-effecitve way to provide the needed capability with a modest amount of memory.

Chain and execute systems usually consist or a resident main program, other resident programs, a resident COMMON storage area, and a set of subroutines which can overlay each other as directed by the operator. These subroutines are grouped into Units which can overlay each other. One or more subroutines can ben contained in a Unit. When overlay Units are loaded, they are written on top of the core image area allocated to overlays and to not distrub the rest of core. Of course, the overlaying Unit will "wipe-out" the core image of the resident Unit; however, any of the overlay Units can be restored to resident core in their original form. Several Unites may overlay a larger Unit without overlaying each other. Cascading of sub-overlays should not be limited.

An overlay Unit is loaded into core when a subroutine contained therein is called. It remains in core until it is overlayed by another Unit. Any routine in a resident Unit can call a subroutine in a non-resident Unit; however, the calling program will be overlayed and will not reside in core. In this case, the called subroutine can only terminate by calling another subroutine since it cannot return to the calling program. Resident subroutines can exist outside of the overlay structure, and can be called by subroutines within the overlay structure when they are in core.

If the performance measurement hardware facility contains more than 32,000 words of memory, the incorporation of program chaining software is not critical.

Measurement Processing. The goal in defining a candidate measurement processing software system was to achieve a balance between two extreme system philosophies, (a) a highly generalizable, automated system and (b) a very manual system. The average researcher dreams of a generalizable measurement processing system which is automated and provides him with interactive command and control. An example of such a system would be one in which the operator would (a) sit at a keyboard/CRT, (b) command the computer through all stages of processing, online, (c) specify analysis options by keyboard overlays or by lightgunning computer generated lists of alternatives and (d) would be provided with desired hard copy at his request. Building a system to provide such operator-computer conversation would take a large programming effort and a substantial amount of hardware.

On the other hand, the usual experimental situation consists of measurement processing which is specifically programmed for only one study, or narrow range of studies. As each new programmer, researcher or study problem enter the environment, most of the programming has to be re-done. There is no reason to expect otherwise because each member of the research team will bring into the environment his unique background, skill and creativity. Each will have a preference for doing a given job in a unique way. This leads to substantial programming for each study, however, and it can decrease the timeliness of the result and increase the cost of the product.

Some compromise between semi-automatic, generalized software and unique programming for each study is necessary. Extensive experience with several hardware/software systems and many simulator and inflight research studies have guided us in the selection of processing alternatives which we believe to be the best general approach. Certainly, as knowledge of a specific computer, a specific operating system, specific hardware, and a specific set of research test plans become available, some of the alternatives should be reconsidered. Software, like Disneyland, should never be complete as long as there is creative imagination.

Historically, there are five stages of performance measurement processing, (1) acquire data, (2) input data to processing media, (3) edit data, (4) create measures from raw data--measure transformation, and (5) analysis. These five stages form the structure of measurement processing software as shown in Figure 14.

Each stage requires specific input control information and data, and produces specific output. ACQUIRE data reads paper tape into computer-controlled files (such as a text, auditory and video/photographic (V/P) data) and allows preliminary editing. A label file containing control information is created through the keyboard. 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 tape into a file. Raw data files are tested for error in EDIT, where final corrections are made and data are placed into the data bank. Following operator directions, measure sets for each event are created by MEASURE TRANSFORM and placed into a temporary analysis file. Analysis routines read the measure sets and perform operated directed analyses. Hard copy is available at each stage of processing.

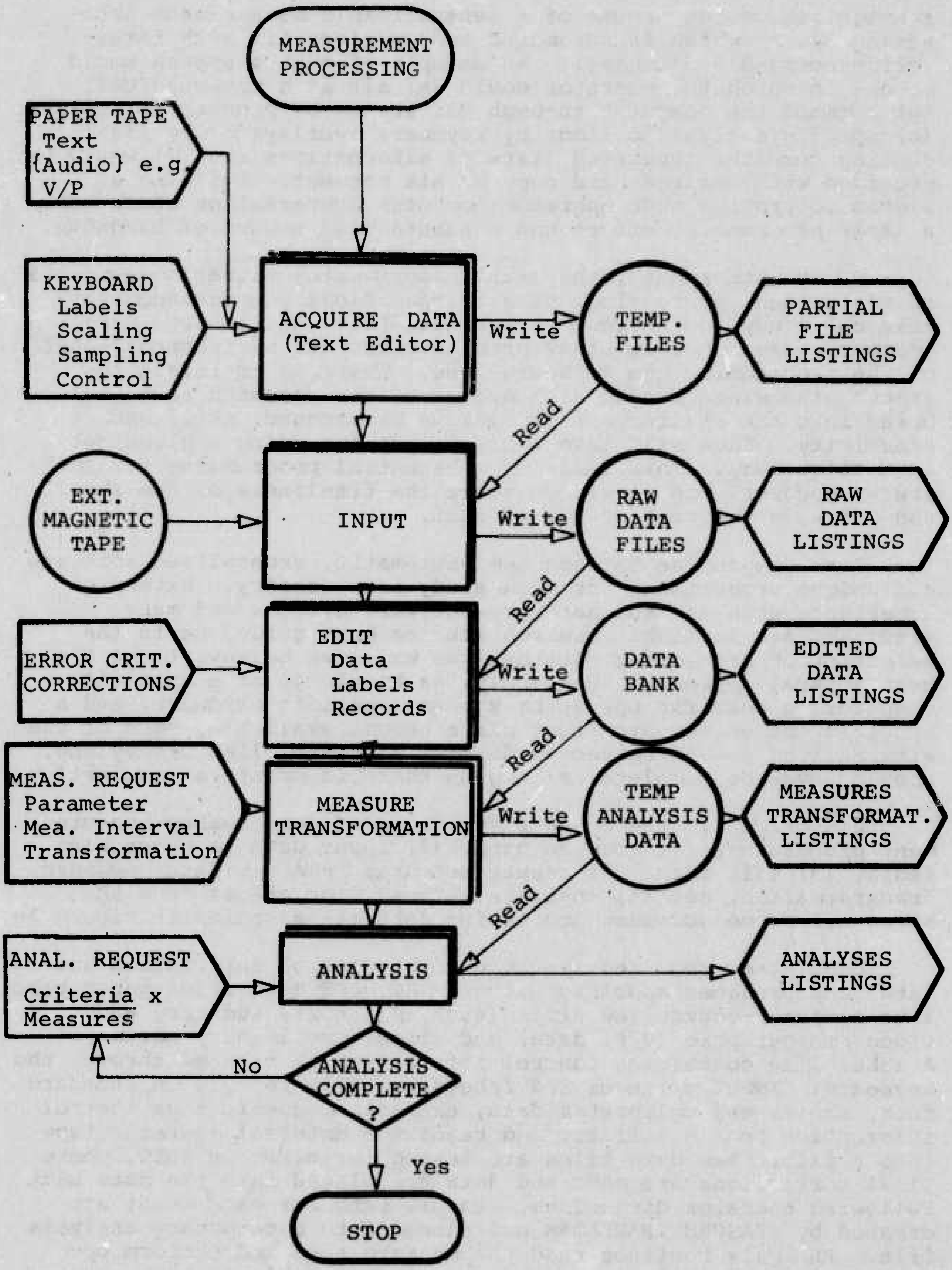

Figure 14. Measurement Processing Functions.

(1) <u>ACQUIRE Data</u>. The purpose of this first processing stage is to create computer files of data which can be input from paper tape or keyed directly into the computer. As shown in Figure 15, the system text editor is used. It is assumed that a named file will be created for each kind of data used by the system. For example, photographic data may be contained in the PHOTO file, auditory commands may be contained in the CMD file, etc. Once the data are in files, they should be edited for error, file structure and format. Editor or File Manipulator commands can be used to list the file contents as they are (one line at a time); no special formatting will be possible with the text editor or file manipulator systems programs.

In addition to files for paper tape data, a label file should be created at this time. The label file contains data identification, scaling and control information that will be used to format all data files in the next program, input.

The data acquisition structure using the system text editor is straight-forward; however, it requires the generation of input paper tapes off-line, without the benefit of software to lead the data reduction operator through the process, and to check errors. The initial plan was to specify interactive (man-computer) software for on-line, computer guided collection of non-magnetic tape data (such as video, auditory, or photographic). Such a system would increase the amount of data that could be collected. More importantly, interactive software could increase the accuracy of the manually reduced data by several orders of magnitiude by leading the operator through the data reduction process and by performing reasonability checks of the incoming data.

Unfortunately, an examination of the amount of data to be processed reveals that such a system would require far more computer time than could be made available without a background/foreground (B/F) or time-shared operating system with several terminal stations. A larger processing facility than has been defined would be required to fully tuilize B/F or time-shared operations. Even with a B/F operating system, the programming of man-computer interactive software would require a lot of memory and a substantical programming effort.

A non-interactive, initial data reduction system was chosen in order to keep the facility small, and to retain as much procedural flexibility (ability to do many kinds of studies) with a minimim hardware and software inverstment. Therefore, the data would be punched on paper tape, offline, then brought to the computer for editing, errors and all.

The arrangement of parameters on paper tape is likely to be quite varied from file to file and across all training phases. The data must be punched onto paper tape in an order

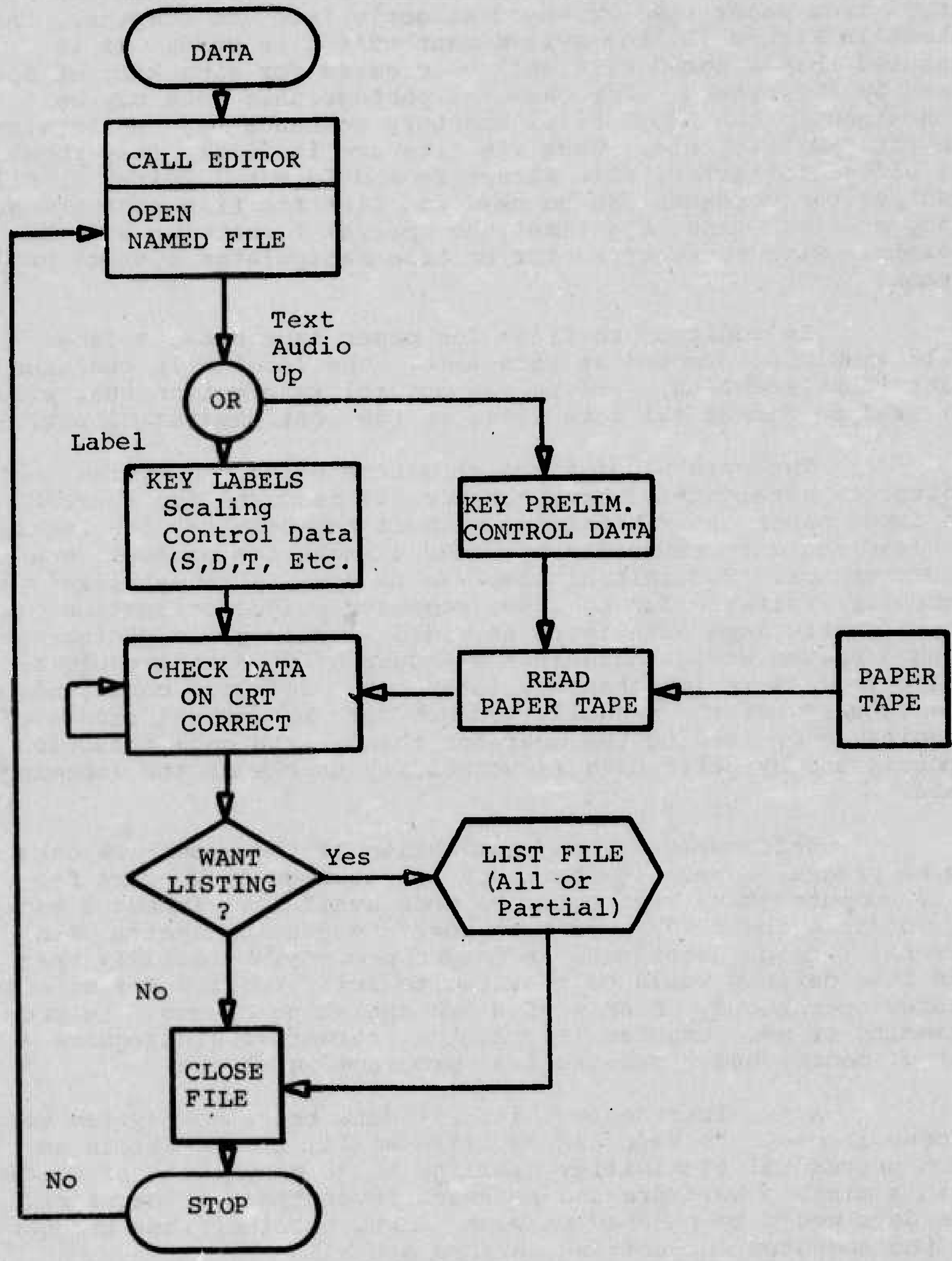

Figure 15. Acquire Data Processing Functions.

that is convenient for the operator and will produce the fewest errors. As a consequence of the large number of parameters that can be derived from many different sources, it will be necessary to attach a parameter indentification number (tag) onto each measure. More is said about this data formatting issue in the next section.

(2) INPUT Data. INPUT arranges and labels the file records in standard form, scales and calibrates data, extract magnetic tape control information from other files and reads the external magnetic into a file. The processing functions are indicated in Figure 16.

Starting with the temporary files from ACQUIRE, INPUT performs any necessary data computation, and scaling. For data reduction ease, and to reduce errors, it is possible that data which have been manually reduced may not be scaled in units that will be consistent with the rest of the data bank. Altitude, for example, need be input only to the number of digits that are significant for the particular maneuver being flown. Units of time may be relative to a previous time hack; units may require adjustment to mission time. Mils might be converted to degrees. Additionally, calibration frames might provide data which are used to adjust all data of a particular parameter to account for to day, or aircraft to aircraft differences. Once the data are properly adjusted, they are written into the temporary files in a standard format.

Some of the data contained in the temporary files and the label control file will be used to control initial scaling and sampling of digital magnetic tape data. Such data will have to be identifies, extracted, and placed in a file of magnetic tape control information prior to reading the referenced magnetic tape.

The external magnetic tape, whether it was generated in an aircraft, in a simulator, from some other source, or comes from special tape conversion equipment will be dumped entirely onto disk before processing. A machine language program for this purpose may be required unless the file manipulator monitor program provides such dumping capability. It is likely that the data contained therein will not be in standard engineering units, and will require unpacking, scaling and calibration. Next, the data will be sampled, and broken into logical events as dictated by the information in the magnetic tape control (MT Control) and label files. Records will be formatted and written in the MT data file.

All data files which will be subject to numeric analysis should be formatted in a standard way to minimize programming of EDIT, MEASURE, TRANSFORM, and ANALYSIS routines. Files will contain much more data than can be fit in memory; generally, programs will read down a file and select only the data desired. The largest record, of course, has to fit in memory.

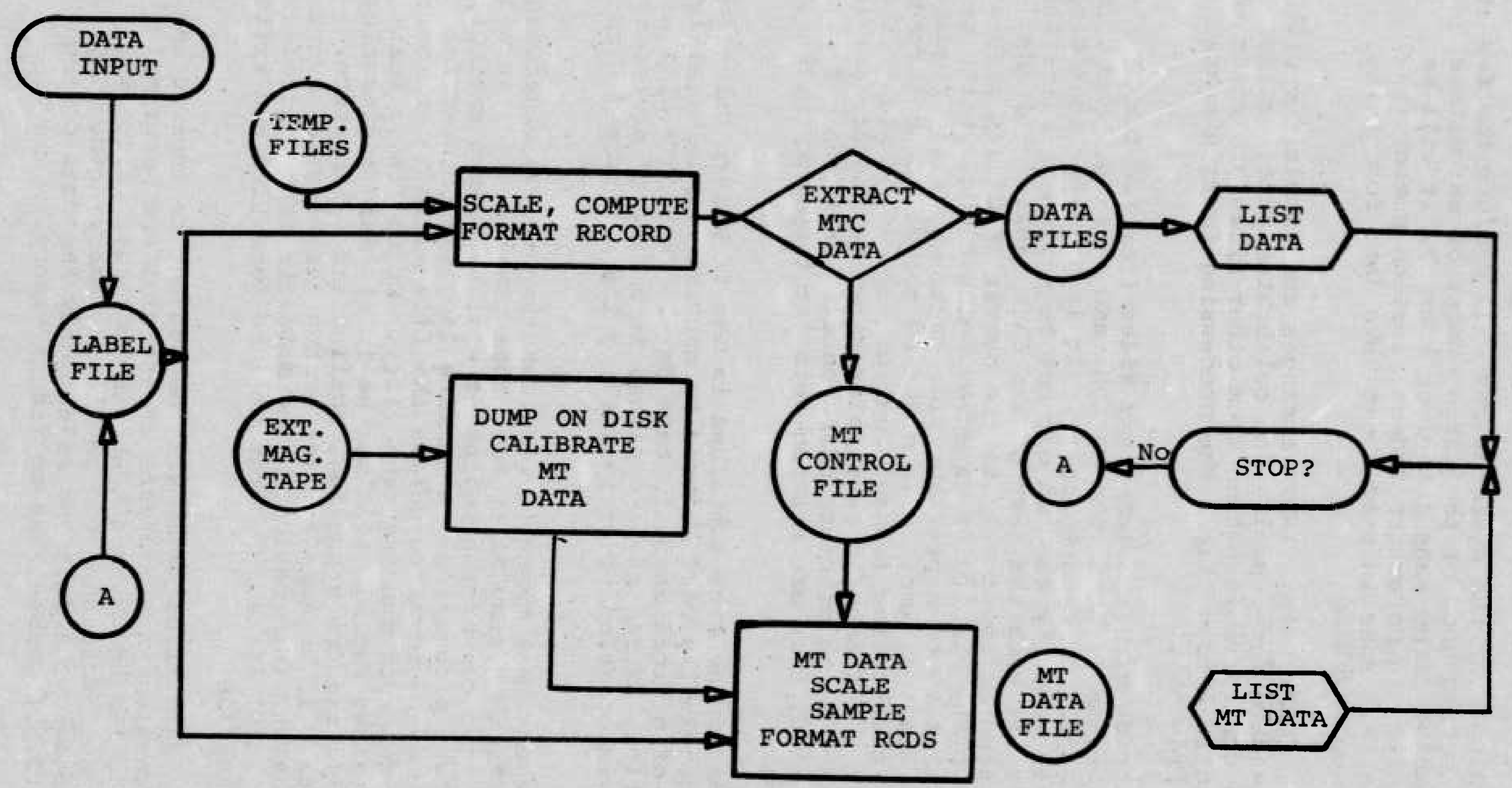

Figure 16. Data Input Processing Functions.

Each data record should be identified by experiment, subject, day, trial, event, group and any other experimental condition(s) that will serve as a unique identification of that record. A formatting system that has been most successful in measurement processing is suggested. It serves to minimize search programming; it permits records to be placed in any order in the files, and it provides automatic placement (indexing) of data into multidimensional arrays for factorial analyses. The format is shown in Figure 17.

The data format requires a fixed size label record that uniquely identifies the following data. The label record usually contains only numbers, but there is no reason why it could not contain both alphabetic and numeric characters. The record is relatively small; typically, 20 data words will be more than sufficient for training experiments. The last word in the data array contains the number of words in the following data record.

The size of the data record is variable because the last element of the label array indexes the read command for the data array. Thus, in FORTRAN, the following sequence,

```
DIMENSION LABEL (20), IDATA (8000)
EQUIVALENCE (LABEL (20), NW)
.
.
READ (IUNIT) LABEL
READ (IUNIT) (IDATA(I), I=1, NW)
.
```

would cause a binary (unformatted) read of the label record with its unique identifiers and the number of words in the data array, followed by a read of that data array. The data array must be dimensioned, however, to the largest anticipated size. Typically, the data array has been treated as a one-dimensional array for input/output (I/O) purposes. It can be equivalenced to any combination of smaller single or multi-dimensional arrays, and/or scalar variables.

The problem of identifying the parameters within the data array requires special attention. Any one data source for a given phase of training will produce a relatively small number (10-20) of parameters. Across all training phases and all sources of data, however, the parameter list might be quite large (100-200). Not only is the parameter list large, but the order in which parameters will be contained in any file is likely to be varied. The method of identifying parameters must be carefully selected to minimize the programming and processing of housekeeping functions throughout the measurement processing system.

There are at least two good methods to uniquely identify parameters in the data array. First, all parameter organization subsets can be specified in a look-up table that is contained in

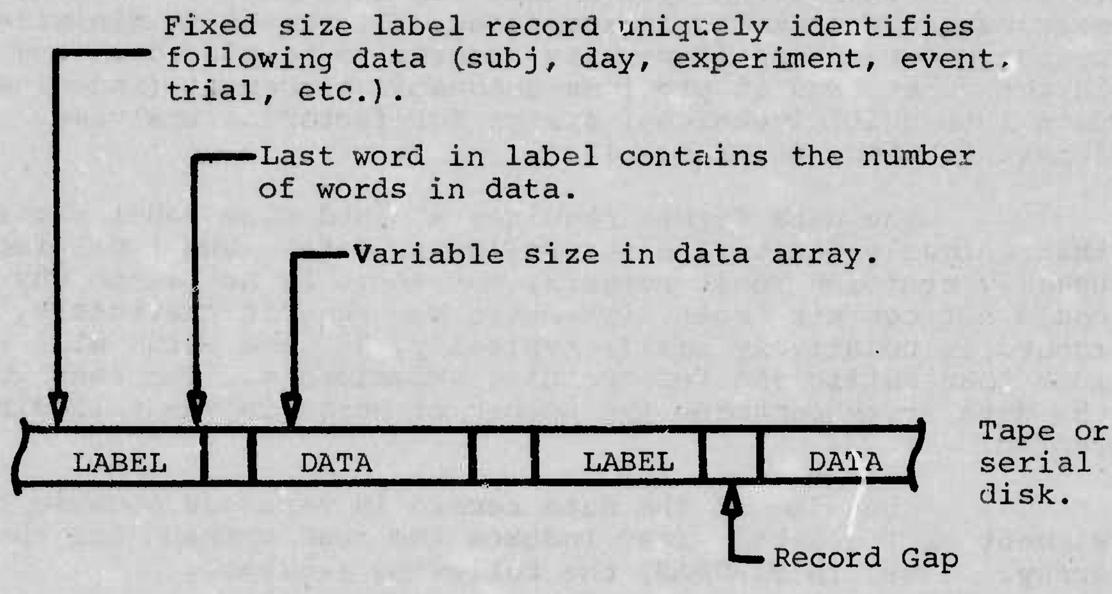

Figure 17. Data File Record Format.

all subsequent programs. One element of the record label can contain a pointer to the portion of the table that defines the parameter ordering in the following data array. A second method would be to pack the data value with the parameter number. Each reference to data in subsequent programs would require unpacking to determine the parameter number and its value.

The choice of method cannot be made until the hardware is selected because it will be dependent on (1) the number of binary digits in a computer word, (2) subroutine access time, (3) fixed and floating point arithmetic processing time, and (4) whether the data are stored in fixed or floating point.

The number of binary digits dictate how large a number can be prepresented in fixed point format; if it is sufficiently large (24 bits), then a parameter identification tag can be packed with the data in the same word and still retain four to five digit accuracy. Unpacking of data will be a highly repetative operation which can be performed with a machine language subroutine or integer mode arithmetic. The amount of time consumed by each operation will be an important factor. If the data must be stored in floating point to achieve accuracy (because of an insufficient word size), parameter tag packing with the data word will probably not be desirable.

Processing would be most straight-forward if the data were stored in a binary, 24-bit word. This would permit integer mode manipulations (often faster than floating point) and would probably eliminate the necessity of a table look-up.

(3) <u>EDIT</u>. Raw data files are tested for error in EDIT, where final corrections are made and data are placed into named files in the data bank. It is assumed that all textual data will be edited using the monitor text editor and will not be edited in this program.

Editing capability should include ability to correct (a) numeric data within a record, (b) labeling data within the label record, and (c) record manipulations such as combining, splitting and deleting records from the file. It is possible, also, for the wrong labels to be associated with the wrong data records. Typically, when this happens all labels are misplaced by one record or several records and need to be "rippled up or back." Such editing will take place during record editing (as opposed to data editing).

EDIT is a man-computer interactive program which will require the operator or experimenter to make data corrections while on-line. The operator will lead the computer through all corrections and computations, although the actual manipulation and housekeeping will be performed by the computer (a substantial chore). All operator input has to be error checked and the software at every operator input point must provide instructions on entry options, formats, and diagnostic error messages. The processing functions are shown in Figure 18. The operator control functions associated with each processing function are shown in Table 17.

The first processing function in EDIT is to open the file to be edited (by name) and to find the first record to be edited. (The first record of the file will be the first record to be edited only at the beginning of data editing). Operator specification of the desired record should be by subject, date trial and event rather than record number. The record control module will perform the necessary housekeeping and manipulation functions to search for the new data records and set-up the correct data bank file. In pre-positioning the data bank file it would be desirable to read up to the requested record and be able to write corrected records from that point on.

In the file-oriented mode of the handlers it may or may not be possible to open a file for both reading and writing. The data bank file may have to be copied onto a scratch disk, then written from the scratch disk onto the data bank disk up to the indicated record in order to have the data bank file opened for writing and properly positioned. Since the files are likely to be quite large, inability to open a file for both reading and writing tends to dictate a strong desirability for at least three logical disk units (possibly four logical units).

Next, the data are checked for errors against criteria that are contained in the error criteria file and preliminary statistics (mean, standard deviation, min and max) are computed for repetitive parameters. If error criteria are to be changed (as they will during initial data collection for each study), a switch option to key in such criteria should be included.

Historically, two kinds of error criteria have been quite useful. First, data should be checked against the maximum and minimum values expected for any parameter in the event being measured. It can be seen that error criteria tables will have to be constructed for each reasonable class of events, and that the event number in the label record can indicate which set of criteria to use. Secondly, where successive samples of the same parameter are contained in the data record, each parameter should be checked against criteria for the maximum absolute magnitude change that is anticipated from sample to sample. These two checks have caught most data errors in past experience when the criteria were empirically set to false alarm (error flag a good number) about 1% of the time. Preliminary statistics or repetitively sampled data within one record will provide a good indicator of where the error criterion chould be set.

The highest source of error is expected to be the manually reduced data. Transposition errors are expected to account for about 40% of these errors. Transposition errors in the most significant digit stand a good chance of being caught

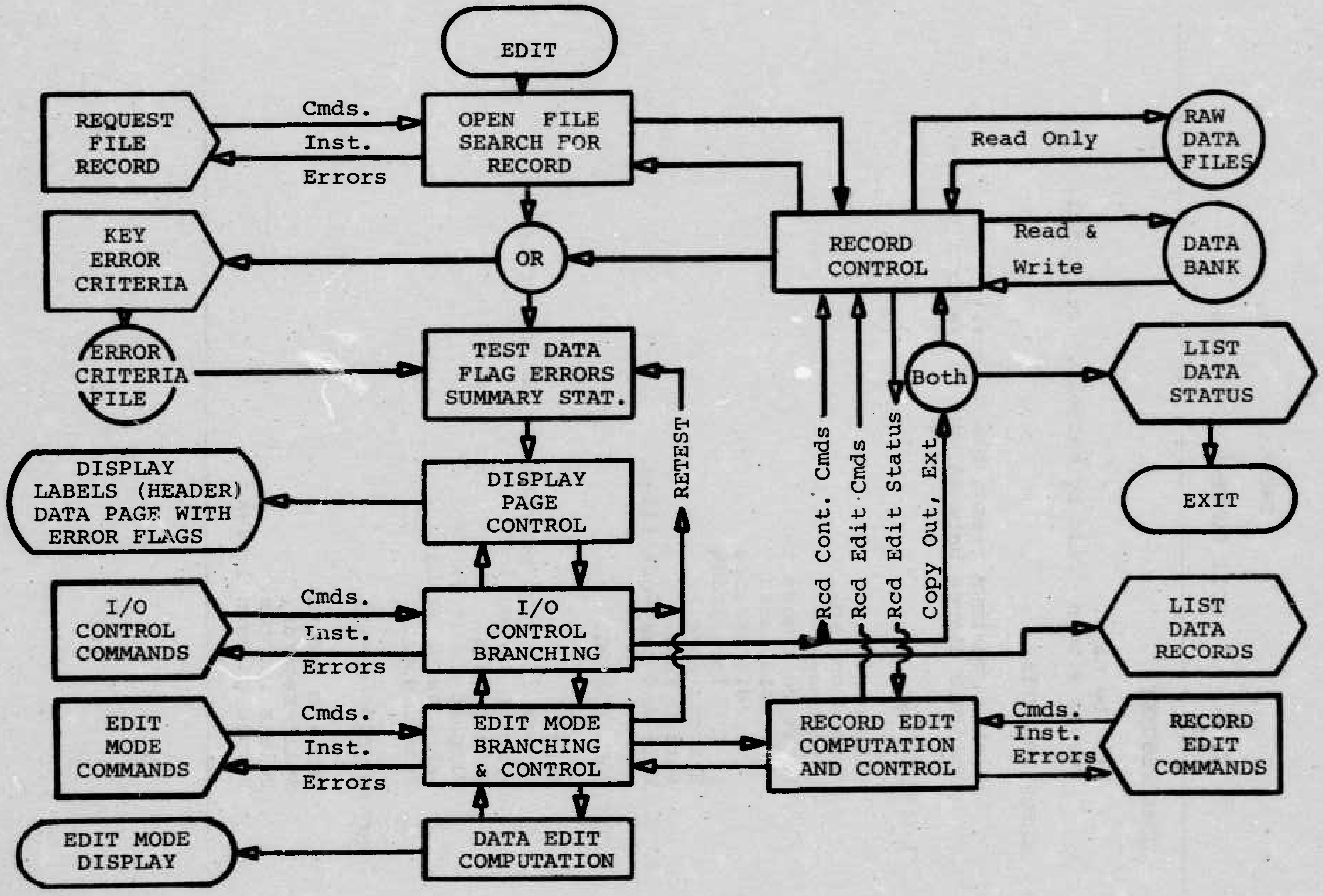

Figure 18. Edit Processing Functions.

TABLE 17

EDIT CONTROL FUNCTIONS

DATA REQUEST

File by name.
Record within file by subject, day, trial.

ERROR CRITERIA

Minimum/maximum reasonable values.
Absolute change between successive data points.

I/O CONTROL

Page control.
Record control.
Hard copy.
Enter edit mode to:
- edit data
- edit records
- delete scans

Refresh page.
Retest data.
Exit and copy-out files.

EDIT MODE CONTROL

Mean.
Linear fit from previous or following data.
Type in correction.
Delete data.
Flagged datum is good.
Label value change.
Retest data.

RECORD EDIT CONTROL

Combine records.
Split records.
Delete records.
Ripple up/down lables.

by the absolute magnitude of change criterion. However, transposition errors in the least significant digits will be very difficult to detect without substantial knowledge of the statistical properties of the particular parameter and its past history. The number of data digits in any one number that is keyed-in by an operator during ACQUIRE should be kept to a minimum to decrease the probability of an initial error and to increase the probability that the error checking routine will detect one.

Next, the data are displayed to the operator on a CRT. Each record is likely to produce many pages of data. Each page should contain the data labels in a header that is adequately decoded. The header for subject 1, day 2, trial 5, event 22 should at least show "S 1 DY 2 TR 5 EV 22" (instead of just "12522") in addition to the page number and the total number of pages. All data parameters shown within the page should be labeled with parameter name abbreviations, where possible. The last page should include summary statistics of each repetative sample. Figure 19 shows an example of such a page format for a data editor which is under development.

The I/O control brancing module permits the operator to control the functions shown in Table 17 through abbreviated natural language commands to the keyboard. The operator should be able to page foreward or backward, one page or n-number of pages within a record. He should be able to advance or back-up n-number of records with the file. He should be able to request hard copy of any page. Ability to refresh the page on command, and retest the data for errors should also be provided. The software, however, should automatically recompute the statistics prior to displaying them on the last page if a change has been made in a preceeding page. The operator should also be able to exit the EDIT program at this point, causing the data files to be properly altered by any changes and closed. The status of the file editing should also be printed by such a command, indicating the first and last record edited. In addition to I/O control, this module should provide access to the data edit module; the command to enter edit should imply the purpose for entering the edit module (such as edit data, edit records or delete scans) to conserve input requests.

Entry into the edit mode should cause the software to automatically search for flagged errors and request a keyboard command to perform one of the following options: (a) replace the number with the average of the preceeding and following numbers, (b) replace the number with a linear fit of the preceeding two numbers or following two numbers, (c) type in a number, (d) delete the datum or (e) delete the error flag, indicating that the datum is good. In addition to changing flagged errors, the operator should be able to exercize the edit options on any manually designated datum. Editing of label values should also be possible. It should also be possible to delete whole lines, or scans of

PAGE 5 OF 5 EXPERIMENT 1ØØ1 RAW DATA BASE SAMPR= 5
SUBJ= 1 DAY= 1 TRIAL= 3 TON= Ø TOFF= Ø ERR= 1 NW= 711

SCN	BOOM	PTCH	ROLL	YAW	COLL	PED	HEAD	W/D	ALT	CYRL	TORQ	RRPM
97	1Ø	2Ø	-3Ø	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	11Ø	12Ø	13Ø
98	1Ø	2Ø	-3Ø									13Ø
99	1Ø	2Ø	-3Ø	4Ø	5Ø						12Ø	13Ø
1ØØ	1Ø	2Ø	-3Ø			6Ø	7Ø			11Ø		13Ø
1Ø1	1Ø	2Ø	-3Ø	4Ø	5Ø			8Ø	9Ø		12Ø	13Ø
----	----	----	----	----	----	----	----	----	----	----	----	----
AVG	1Ø	2Ø	-29	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	1Ø3	12Ø	13Ø
VAR	Ø	Ø	35	Ø	Ø	Ø	Ø	Ø	Ø	1423	Ø	Ø
MIN	1Ø	2Ø	-3Ø	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	-11Ø	12Ø	13Ø
MAX	1Ø	2Ø	3Ø	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	11Ø	12Ø	13Ø
N	1Ø1	1Ø1	1Ø1	51	51	34	34	26	26	34	51	1Ø1

Figure 19. Sample Display Page Format.

(Previous pages contained data lists up to Scan 97.
The software from which the table was derived
permitted variable sample rates for each parameter.)

data (a scan is one sample of all parameters taken at the same time). Exit from the edit mode to the I/O branching module should be a manually commanded function except where scans are deleted. Deleting scans should automatically branch to re-computation of record statistics and re-display of the page.

A specially formatted edit mode display page should be constructed to show only a sample of the parameter being edited and an indication of the datum being operatied on. The edit mode page should provide feedback of each correction.

The remaining editing operation is record edit. Here the operator should have the capability of (a) combining records, (b) splitting records, (c) deleting records, and (d) rippling labels up or down the records. Record combining should cause two adjacent records to be brought together into the first record, and the label for the second record should be either deleted, or all labels should be rippled-up. If the INPUT program has mistakenly placed data into two records instead of one, it probably also has mis-registered the labels. The command string de-fault assumption should be that the labels are out of order and should be rippled-up (record #2 label goes to record #3, etc.). The converse error can also occur: INPUT could have placed data into two records instead of one. In this case, records should be split, and the command string de-fault assumption should be that the labels should be rippled-back unless otherwise directed. The same applies to deleting records. However, when labels are rippled up or back, there will either be one more or one less label set than data records. The next action for the operator will be to add the missing label, or delete the extra label from the file.

Although it is not shown on the flowchart, there should be a switch capability to provide automatic error checking and listing of data. Automatic sequencing through record read, test data, and list data records (with error flags) should continue until the record file is exhausted or the switch is turned-off.

The design and programming of the edit routine will require careful planning and thought. However, the utility of such a program cannot be overstated since the formatting and correcting of data files historically consumes the most time in measurement processing.

(4) MEASURE TRANSFORM. Having formatted and corrected data on file, the next stage is to create performance measures from the raw data, and to output these measures in a temporary file that will be used for analysis. MEASURE TRANSFORM processing functions are shown in Figure 20. Fundamentally, the processing involves reading a raw data record from the data bank, and converting the raw data into specifically designated measures. Instructions for creating each measure are contained in a measurement request file.

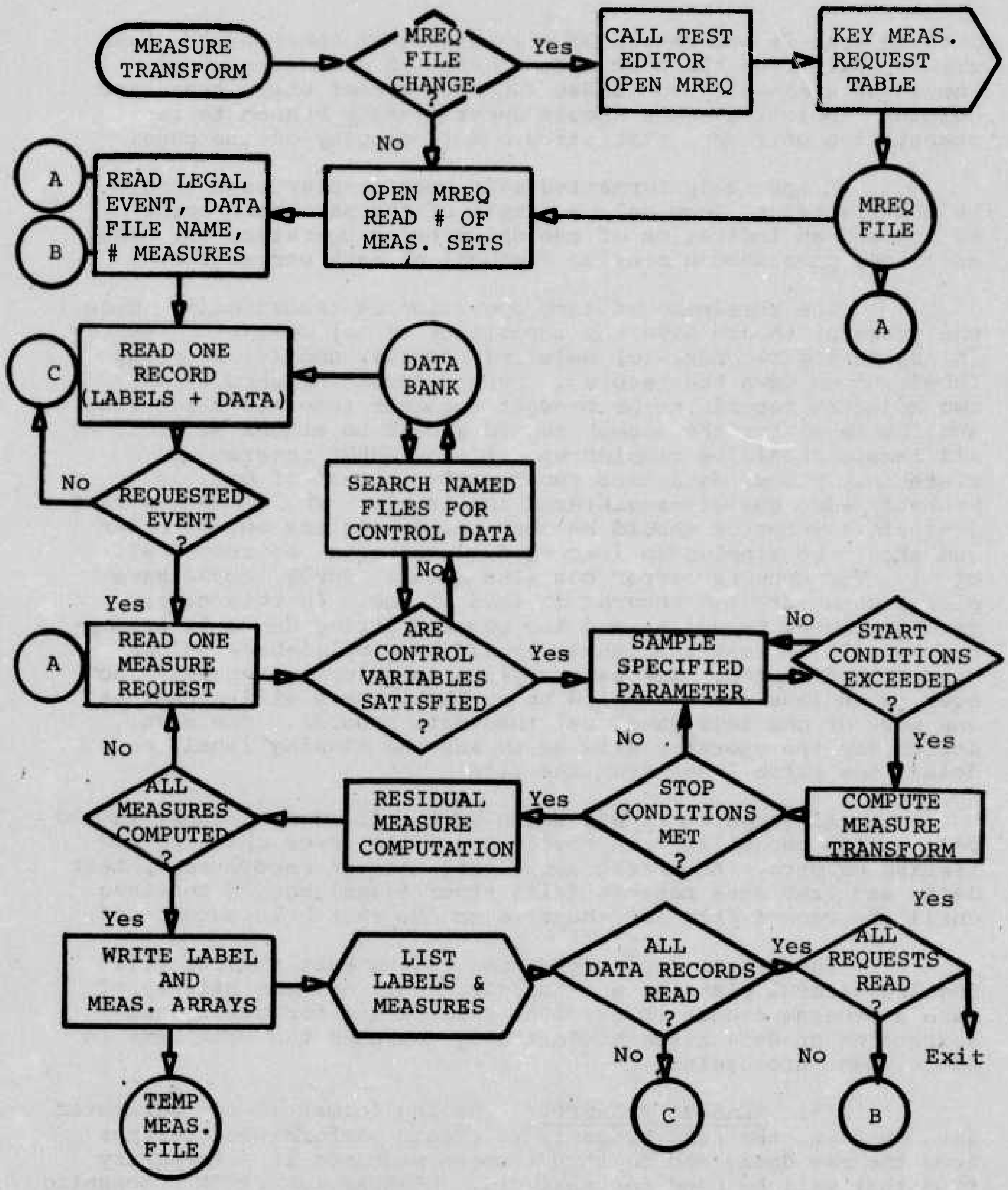

Figure 20. Measure Transform Processing Functions.

It is assumed that the measurement request file will be created and changed with the monitor text editor. Although the specific construction of the file will depend on the design of the program, one way of computing the required functions is implied by the file contents shown in Table 18. The first file entry should indicate to the program the number of measure sets that are to be processed. For each measure set the first set of entries should include the event number that is to be processed, the name of the data file, and the number of measures requested.

Each measure request should define the parameter or parameters, the measurement interval, the type of transformation, and the location of control variables or their values. Although most processing will involve only one parameter at a time, multi-dimensional algorithms such as correclations or bode plots will require simultaneous processing of more than one parameter. Note that the measurement request file will be a direct translation of the measurement specifications for each training phase contained in the Phase III-C report.

The measurement interval is defined by indicating the conditions under which measurement is to start and stop. Measurement can simultaneously start and stop if only one value is desired. For example, pitch attitude at liftoff can be defined by starting and stopping measurement when the weight-off-wheels discrete changes from zero to one, or when the rate of climb is greater than 100 feet-per-minute.

The type of transformation to be computed within the measurement interval (between start and stop) can be value (such as pitch attitude at takeoff), an error score (such as the difference between the assigned altitude and the actual altitude), or any one of several time, amplitude, or frequency domain transformations shown in Table 19.

Algorithm control variables, such as start and stop conditions, tolerance band values, and error history overlays can reside in the record being processed (such as weight-off-wheels), other data files (such as auditory command values), or they may not be contained in the data base at all. Each measure request must indicate where to find each algorithm controlvariable This is done by indicating the name of the file and the name or number of the parameter to look for. Since all data are formatted by subject, day, event, etc., the software knows the record being processed and can find the corresponding record in another file. Special cases may arise, however, where control data are not contained in the files, and the measure request set will have to provide the control data.

TABLE 18

MEASURE REQUEST FILE CONTENTS

---

1. Number of requested measure sets.

2. For each request set:*

    a. Legal event (event which is to be processed).

    b. Name of data file.

    c. Number of measures requested:

        (1) Parameter (or parameter for multi-dimensional algorithms).

        (2) Measurement interval (start/stop).

        (3) Type of transform.

            i.e.: Value, Error score, and each Time/ Amplitude/Frequency domain treatment.

        (4) File location of algorithm control variables.

            i.e.: Where to find desired values, tolerance bands, start/stop conditions.

        (5) Values of algorithm control variables not in files.

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*Information contained in Phase III-C report.

TABLE 19

CANDIDATE MEASURE TRANSFORMS

VALUE (At specific times, points, -functionals).
-Counts-

TIME HISTORY (From specific times, points, [functions] to specific times, etc.).

[Three ways of describing time history:]

1. Time Domain

   TOT, I, in/out TOL
   T to DO

2. Amplitude Domain

   Central tendency
   Avg, AA, Med, Mode
   Variability
   Rng, Min, Max, RMS, SDEV

3. Frequency Domain

   Reversals
   Auto Correlation (periodocity)
   Harmonic analysis (power spectra)
   I/O analysis and models (multi-dimensional algorithm)
   Bode plot (amplitude & phase plots)
   Root locus
   Transient response

ERROR HISTORY OVERLAYS

ΔTime history (and various treatment and desired values).

MULTI-DIMENSIONAL ALGORITHMS

Correlations between measures at a fixed points. (x vs y)
Lagged cross-correlations (crude phase meas.). (x vs y at later time).
Multiple regressions (aX + bY + cZ vs W).
Canonical correlation (aX + bY + cZ vs dU + eV + fW).
Multi-dimensional system models (multi-parameter, dynamic rep.).

Measure transformation program functions start with a reading of the measure request file (Figure 20). The first instruction read from the file is the number of measure sets (events)[1] to be processed. Next, the legal event number, data file name and the number of measures in the set are read. The data file can then be opened and searched for the first record of the requested event. When it is found, all measures pertaining to that data record are generated by processing each measure request sequentially until all measures in the set have been computed and placed in the measures data array.

The measure processing loop starts with a definition of control variables from the measure request file. Named files are searched for unsatifsied (undefined) algorithm control variables. Next, the specified parameter is sampled until the start conditions are met. Sampling and computation continues until stop conditions are met. At this time any residual computations are made and the computed measure is placed in a measures data array. When all measures are computed, the label of the data bank record is used to uniquely identify the measure data (except for the number of words counter), which are written into a temporary measurement file.

The above process, starting with C in Figure 20, is repeated until all data records have been read.

If there is more than one measurement set requested (more than one event), the entire process, starting with B in Figure 20, is repeated until all measurement sets have been processed and listed in the line printer.

In operation, it is envisioned that the experimenter will formulate the measurement request file for trial data, receive preliminary output, and iteratively change the file until the measurement output appears reasonable. Then he will call in the analysis programs.

(5) <u>ANALYSIS</u>. The last stage in measurement processing is to perform statistical analyses on the measures which have been placed in temporary files by the measure transform program. The analysis program (Figure 21) will receive its instructions from an analysis control file, and will read all records of the temporary measures file, one measure at a time, and perform the desired analyses by calling them up as subroutines. The analysis control file should contain the information shown in Table 20.

---

[1]One measure set is assumed per event. An event is assumed to be the basic unit of analysis which may or may not correspone to a training phase. It is desirable to retain flexibility for each experimenter to define an event.

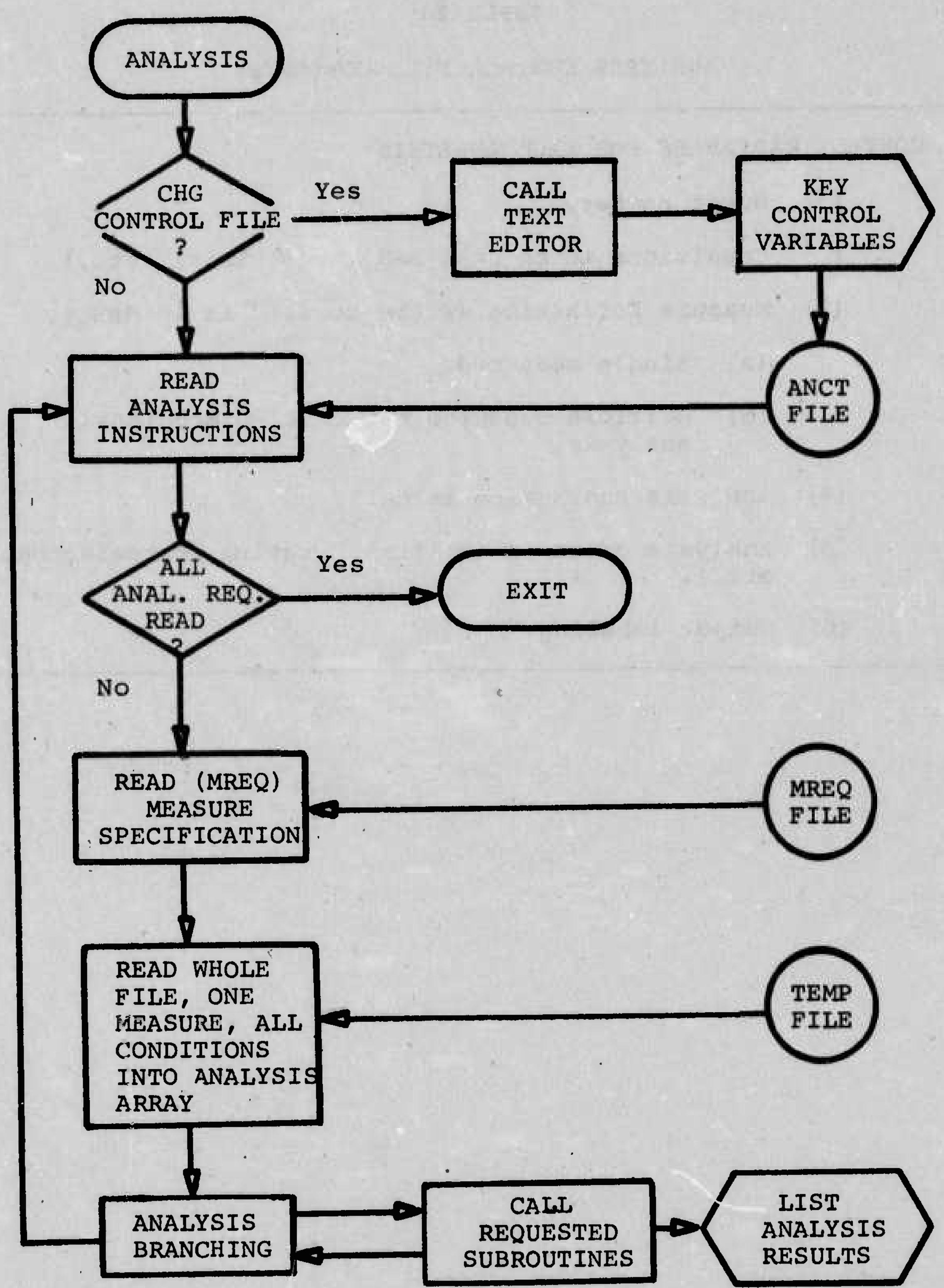

Figure 21. Analysis Processing Functions.

TABLE 20

ANALYSIS CONTROL FILE CONTENTS

CONTROL VARIABLES FOR EACH ANALYSIS:

(1) Event number.

(2) Conditions to be analyzed (S, D, Trial, etc.).

(3) Measure Definition (where to find it in MREQ).

(a) Single measured.

(b) Multiple measures for multi-dimensional analysis.

(4) Analysis subroutine to call.

(5) Analysis criteria (critial F-ratios, correlations etc.).

(6) Output labeling.

The first control variable is the event number which is needed because more than one event may be contained in the MREQ and TEMP files. Event number will be used also to control output labeling.

The conditions to be analyzed should be specified next in a way that permits the analysis of all factorial conditions or separate analyses of special conditions. Often, research problems demand capability to perform sub-analyses of data which have been collapsed or broken-out in special ways.

Complete measure definitions are contained in the MREQ file; the analysis control file need only reference where in MREQ the desired measure is defined. Multi-dimensional analyses, however, relate two or more measures. Measure definition must have the capability to specify more than one measure for one analysis.

Analysis subroutines should be indicated. Analysis criteria, such as critical F-ratios and significant correlation values should be entered. This is especially important for efficient processing where successive sub-analyses are predicted on the results of a previous analysis (as in tests for simple effects or in multiple discrimination analysis).

Finally, output labeling should be implied by the aforementioned control variables; however, if they are not completely defined, there should be a table entry for them.

The last record of the analysis control file should contain a coded entry to indicate that all analysis requests have been satisfied.

Having set-up the analysis control file, one set of instructions will be read (Figure 21). Unless the exit code is encountered, the needed definition of the measures (such as where the measures are in the temporary file) will be read from the MREQ file.

Next, the temporary file is processed. Notice that a data transposition occurs; one measure (datum) will be taken from each record to fill the smallest cell in an n-dimensional analysis array. (For analyses which required two measures, two measures will be taken). The position of the datum in the analysis array will be indexed by the contents of the label array for that record. The analysis array should be filled when the last record of the temporary file is read. The file will be closed and read again to process the next measure at the conclusion of the analysis of the first measure. Using the label array to index the analysis array in this fashion eleminates the requirement for temporary file records to be written in any special order. The data are extracted and properly disposed as they are encountered.

Finally, the data are ready for the candidate analysis routines listed in Table 21. The analysis programs are envisioned as subroutines that will reside in a re-locatable overlay structure (discussed under the topic of the executive monitor, chain and execute supervisor). Using such re-locatable overlays, call statements for logical groupings of analysis subroutines can be contained in the main program, with control branching to the requested analysis. As the analysis routine is called, it will be brought into memory for processing. It is not realistic to expect all analysis routines to be called from one analysis program. However, the use of overlays permits grouping of the subroutines that require similar data structures, and will reduce the number of special purpose programs that have been written.

Analysis subroutines should perform as much bookkeeping as possible. For example, many canned analysis of variance subroutines output f-ratios, but do not test the f-ratios against the critical ratio because they are built as general purpose subroutines. This requires the experimenter to search for significant results, and requires an additional analysis pass to perform multiple range tests, etc. Analysis of variance subroutines should contain an option to test the f-ratios against an experimenter supplied (in ANCT) critical ratio, and output the significant level of each main effect and interaction. Having done so, the multiple range tests (tests of simple effects) can be processed automatically on the basis of a significant result, and tables of means and standard deviations can be broken-out as a function of all significant effects. Such "automatic" processing should serve to provide for the experimenter the output he needs with the fewest possible passes on the computer. However, automatic processing should not prevent the experimenter from specifying the output he wants.

General purpose analysis routines frequently do not perform the exact computation that the experimenter wants. Since the experimenter is the one responsible for the results (not the computer program) there is no alternative: either the experimenter or a programmer available to him must re-program or write a new routine that suits the study requirements. Often, a few hours of programming can provide the necessary capability. It can be expected that variations in the analysis routines will be programmed from study to study. As studies are conducted, a substantial library will be built. As the library is built, the probability that an existing routine will fit the experiment will increase.

Analysis routines should label their output with alphabetic characters that are related to the experiment being conducted. General purpose routines often label data with arbitrary notation, such as I, J, K, L, M, etc. The experimenter and others who are interested in the results of the experiment must go to another source to find out what each of these labels

TABLE 21

CANDIDATE ANALYSIS SUBROUTINES

FACTORIAL BREAKOUTS

Average, Absolute average, Median, Mode, Standard deviation.

CORRELATION

MULTIPLE REGRESSION

Linear
Non-linear

CANONICAL CORRELATION

FACTOR ANALYSIS

ANALYSIS OF VARIANCE (At least 4-factor).

Randomized blocks.
Treatment X subjects.
Within and between.
Partially heirarchal.

TESTS OF SIMPLE EFFECTS

Duncans test
Newman-Keuls

ANALYSIS OF CO-VARIANCE

T-TEST

F-TEST

NON-PARAMETRIC TESTS

CURVE-FITTING (Least squares fit).

PLOTTING SUBROUTINES

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means for that experiment. While this is not a big issue, it is simple enough to set-up a file of experimental condition labels that imply the conditions (such as S for Subject, D for Day, T for Trial, R for Replication, etc.) and to use these labels throughout the processing and analysis. It is a simple matter, for example, to program an analysis of variance subroutine to expect such labels to be in common storage, or in the call statement. A default label assumption could be made within the program if the labels were not set-up.

Alpha-labeling applies to other output as well. For example, measure number 22 would be more meaningful if it were output as "ALT SDEV," (for altitude standard deviation) instead of measure 22. Similarily, event 14 might be better labeled, "TAKE-OFF ROLL."

Data output should be formatted so that it can be transfered onto a photo-ready page for a report. Much report preparation time is spent re-formatting and/or retyping data. Proper attention to the output format can sace considerable work later on.

As a concluding comment, all programs except EDIT provide operator process control through control files. All control files contents could be set-up offline with card decks rather than online with the text editor. The first instruction in all processing stages would be to read the control cards into the file. Although quite acceptable (even preferred) in a large, batch processing computer facility, the use of cards for control files would extend the overall processing time because of the time required to get on a keypunch machine, re-order the deck and re-submit the program between each run. Although there are times when the experimenter will need time to study results, during initial measurement development, days will be saved if the experimenter can quickly move from trial output to changes in the request files, and back into the programs. The turn-around time is a critical factor in the time required to develop the measure set, and analysis routines.

IV. THE PERSONNEL SUBSYSTEM

Phase IIIC Design Studies

In the previous phase report (Phase IIIC: Design Studies), an analysis was made of personnel requirements for the performance measurement system. In that analysis, estimates were given of (1) the types of skills needed in the system and (2) the number of individuals required for system staffing.

As was pointed out in the previous report, system personnel requirements stem from required manual tasks and the quantity of required manual data processing. In the two preceding chapters of the present report, additional clarification has been given of task requirements within the data acquisition and data processing subsystems. It is reasonable, therefore, to re-assess the total personnel requirements of the performance measurement system.

Qualitative Personnel Requirements

Consistent with the previous personnel requirements analysis, 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.

1. System director. One individual must be responsible for management and supervision of the operating system. The success of a system of this type depends to a very large extent upon careful planning and continuous control. Maximum system effectiveness can only be achieved by a detailed program technical plan and considerable adaptability in program execution when the unexpected occurs (as it frequently does in complex applied experimentation). 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.

2. Research personnel. Trained scientific personnel are necessary to support all phases of the performance measurement process 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 (see page 25). In some cases, he will be expected to serve an an inflight experimenter (see page 20), and will be responsible for the operation of the RCD units. 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.

3. Computer programmer. As has been pointed out in Chapter III (pages 46-47), a compromise approach has been taken in the design of the data processing subsystem to provide generalized software with the assumption that some unique programming for each individual study will be required. It has been our consistent experience that this approach offers the greatest flexibility and overall effectiveness for performance measurement systems. 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.

4. Data clerks. The data acquisition subsystem provides a heterogeneous set of input data which must be processed by data clerks. Table 10 (page 31) has listed the major personnel tasks required for manual data processing of video, digital, audio, and photo raw data. As noted, video and photo data present very similar manual data transcription problems. With video, photo or audio data, the end product from the data clerks is a punched tape. Very detailed information has been given in Chapter III as to the interfaces of the manual data clerks with the data processing subsystem. 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.

5. 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. Tasks associated with the airborne (or simulator) audio/video/photo/digital recording equipment have been described in Chapter II (cf., Table 9, page 24). Within the ground facility, data processing hardware (cf., Table 12, page 35) is sufficiently extensive to suggest the necessity for a computer technician. Finally, the ground contains a variety of video, audio, and photographic equipment (see Appendix A, pages A-17 through A-21) which must be maintained and continuously operated.

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

Quantitative Personnel Requirements

The number of personnel required for the performance measurement system will depend upon at least three major parameters: (1) the number of aircraft (or simulators), flights, and maneuvers flown for recording purposes within each flight per day, (2) the specific configuration of the data collection devices, and (3) the required turn-around time for data processing, analysis, and interpretation. To provide ranges of quantitative personnel requirements, variations were considered within and across each of the first two categories.

1. It is, of course, very difficult to predict precisely how many aircraft might be expected to be flown per day in future research experimentation. For purposes of estimation, a range of from one to four aircraft per day has been estimated. Past experience strongly suggests that a maximum of two research flights per day per aircraft is as much as can be reasonably expected, particularly with complex aircraft and recording systems. It is, perhaps, better to estimate that each aircraft will give one valid and usable recording flight per day. Within that one flight, the question of the content of the flight in so far as measurement is concerned must consider the specific maneuvers, recording techniques, and storage capability of the recording devices. Examination of these variables from the previous and present phase studies suggest a range of 30-60 minutes of recorded data per flight may be expected. In the present phase report, detailed attention has been given to inflight timing including off and on sequencing (cf., page 20; Figure 9, page 22). Efficient recording time is very much influenced by the presence of an onboard inflight experimenter and/or automatic start-stop switching.

For the estimation of personnel requirements, therefore, it has been estimated that the performance measurement system will have to accommodate data collected from one to four aircraft per day, each of which will generate one recording flight per day (or the equivalent of one aircraft with two flights per day or two aircraft with two flights per day). Range of data recording times are estimated to vary from 30-60 minutes.

2. Chapter II of this phase report describes in considerable detail a hybrid performance measurement system incorporating audio/video recorders, audio/digital recorders, and auxiliary cameras (cf., Table 1, page 5). This system will collect and store data in a specific manner, some of which will require subsequent manual data processing. This hybrid system has been assumed here as one case, and is termed the "complete system" in the quantitative personnel requirements estimates.

For the purposes of comparison, a "minimal system" has also been defined. The minimal system would consist of a single audio/video recording system in the aircraft or a single cockpit camera plus some form of audio recording. The minimal system would, of course, generate much less data than the complete system, and, in addition, would require far simpler airborne installations. The "cost" obviously is in the completeness and accuracy of the raw data bank. In some cases, however, aircraft restrictions may be such that only the minimal system may be feasible.

3. For any performance measurement system, a key determinant of processing methods and processing personnel is the required turn-around time for data processing, analysis, interpretation, and use. Most such installations continue to employ standard batch-processing approaches which essentially involve collecting all data and then subsequently processing it. This method invokes two costs: there is a considerable time delay before data are available, and, very often, much of the raw data never are processed. The training research environment is such that processed data should be made available as soon as possible, particularly if the data are to be used for knowledge of results to instructor and student pilots. If this were not so, data could be processed at leisure with a minimum data processing personnel complement.

The present personnel performance measurement system assumes that relatively immediate data processing will be required. Due to the manual processing steps required by the hybrid system, real-time data processing is not feasible. However, it is assumed that the data will be transformed into computer-compatible form (e.g., the necessary punched tape) on the same day that they are collected. Usable processed data, therefore, will be available on the same day of the flight or at the latest within 24 hours (the nature of the available outputs are shown as listings in Figure 14, page 48).

Table 22 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) either the complete or minimal data acquisition subsystem. Further, these estimates apply to the inflight experimentation case only.

A different pattern for personnel requirements develops if one looks at the flight simulator performance measurement requirement only. Some assumptions are necessary about the flight simulator configuration. First, it is assumed that only one simulator is available. Thus, simultaneous flights are not available as was the case with the aircraft. In this case, two simulator "flights" per day is probably a reasonable average for most installations although past experience indicates that well-maintained and well-staffed flight simulators can accommodate up to four "flights" per day. Second, it is assumed that the audio/video recorder component of the data acquisition subsystem is not available as part of the simulator; obviously, this is not

TABLE 22

ESTIMATED PERSONNEL REQUIREMENTS:

INFLIGHT EXPERIMENTATION

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	3
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	2	3	4	0	0	0	0
A/B Techincian	1	2	3	4	1	1	2	2
(2) Comp. Technician	1	1	1	1	1	1	1	1
(3) Equip. Technician	0	0	1	1	0	0	1	1
Secretary	1	1	2	2	1	1	1	1
Sum	7	9	15	19	5	6	10	12

always the case. Third, the audio/digital recorder component may or may not be available or the simulator computer may be used to perform as the digital recorder. Fourth, with regard to the data processing subsystem, data received from the inflight experiment and the simulator experiment present essentially the same entry context.

Table 23 presents a summary of estimated personnel requirements for the performance measurement system as used in flight simulator experimentation. The two data acquisition subsystem configurations are assumed: complete and minimal. A range of from one to four "flights" per day is assumed. With respect to skill category, no requirement exists, obviously, for airborne installation engineers and technicians; instead, audio/video technicians are assumed.

It is reasonable at this point to make a number of statements about the tasks of each skill category and the interrelationships between skill categories from which the estimates in Tables 22 and 23 were primarily evolved:

System director. In addition to his management and supervisory responsibilities, the system director is the only research specialist for the lower system load cases. In the inflight experimentation case, he serves as lead scientist for the single flight per day either with complete or minimal data acquisition system. For the flight simulator case (Table 23), he is the lead scientist for both one and two simulator "flights" per day. In all conditions, he must serve as lead scientist for one flight per day whether airborne and simulation.

Research personnel. Quantities of research personnel vary between the inflight and simulator situations. For inflight research, it is standard practice for each flight to have a lead scientist assigned specifically. Sharing across simultaneous and/or overlapping flights is not possible. In the simulator, however, actual simulator "flights" must be sequential. With three or four simulator flights, only two lead scientists are required (one being the system director) with the only overlap being in briefing and debriefing of subject pilots.

Computer programmer. In the Phase IIIC design studies it was estimated a system programmer might be desirable during the first year of operation, but after that a system load of at least four flights per day would be necessary to justify a full-time computer programmer.

Data clerks. Whether or not the data come from inflight or simulator experiments makes little difference to the functions and tasks of the data clerks. Data types and loads are essentially equivalent given the data acquisition configurations. By its nature, however, the complete system requires more data processing, and the increasing loads are represented in Tables 22

TABLE 23

ESTIMATED PERSONNEL REQUIREMENTS:

FLIGHT SIMULATOR EXPERIMENTATION

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	0	1	1	0	0	1	1
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) Audio/Video	1	1	1	1	1	1	1	1
(2) Computer Tech.	1	1	1	1	1	1	1	1
(3) Equip. Tech.	0	0	1	1	0	0	1	1
Secretary	1	1	2	2	1	1	1	1
Sum	6	6	10	12	5	5	8	9

and 23. With the minimal system, load and processing time estimates suggest that for one or two flights per day, the data transcription clerk can also generate the subsequent paper tapes.*

Engineer/technicians. There are sharp differences in the kinds and numbers of engineers and technicians between the inflight and simulator experimental cases. For the inflight case (Table 22), the complete system in the aircraft is assumed to require one engineer for each set of two aircraft plus one technician per aircraft; these estimates are based on actual experience with inflight aircraft instrumentation situations.** In the simulator (Table 23), a technician is required to calibrate, operate and maintain the audio/video recorder. The computer technician is responsible for the data processing subsystem in both cases (plus the interface to the audio/digital simulator recorder). With low flight loads, an equipment technician is not required with his duties being shared either with the airborne engineers and technicians for the inflight case and the audio/video technician for the simulator situation. As flights per day increase, however, an equipment technician must be added to insure that all peripheral equipment are properly calibrated and operable.

Secretary. It has been noted that one of the tasks of the secretary is to assist in audio tape transcription (see Figure 11, page 28). With the minimal system, it is probable that one secretary can perform this subfunction. With higher system loads for the complete system, it is probable, however, that an additional secretary may be required to insure that audio transcription does not lag behind other data input scheduling.

Turn-around time. It must be noted again that the system requirement for data processing turn-around time dictates, to a large degree, the number of system personnel. If data processing can be relegated completely to an off-line status (i.e., at some time other than those days when flights are actually run) a single data clerk is sufficient for all situations, and even this position can be eliminated if research and engineering personnel are willing to perform the necessary manual data processing tasks. It should be understood, however, that this technique inevitably

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*It would appear that with the minimal system sampling techniques can reduce manual data processing requirements significantly while still maintaining satisfactory accuracy levels. See: Isley, R.N., and Caro, P.W., Jr. Use of time-lapse photography in flight performance evaluation. Journal of Applied Psychology, 1970, 54(1), 72-76.

**Although it should be noted that practice varies widely; Table 22 probably represents the minimal case.

means a very considerable time delay between data collection and data in a usable format. It is difficult to see how the training research context can afford this particular kind of delay if modern training concepts such as adaptive training and knowledge of results for learner-centered training systems are to be implemented.

V. IMPLEMENTATION PLAN

System Acquisition Methods

The analysis to this point has described all of the elements necessary for a potential performance measurement system. The next step is an implementation plan for system requisition. Many approaches are possible, but the most effective method appears to be one based on Air Force Systems Command Manual AFSCM 375-5: System Engineering Management Procedures. Figure 22 diagrams the proposed measurement system implementation plan. Figure 23 presents a coordinated schedule for system implementation.

As shown in both figures, five major steps are required:

1. Selection of a system integration contractor;
2. Completion of preliminary detail system and subsystem design;
3. Selection of the final system design with appropriate Category I testing;
4. Procurement of system hardware and system integration; and
5. Completion of final system tests resulting in system turnover to the Air Force.

System Integration Contractor

The final performance measurement system will be a collection of a variety of hardware and software components. With respect to hardware subsystems, very extensive use is expected of off-the-shelf components (see Appendix A). At this stage in any system acquisition, prior experience strongly suggests the desirability of a system integration contractor working under the direction of the Air Force.

To use the AFSCM 375-5 methodology, it is assumed that sufficient technical inputs are available to establish a satisfactory Statement of Work for the development contract (Figure 22; Step 1.1). The results of the present study are considered to be the basic and necessary technical data to execute this step.

Design Review

However, with the normal time span that will occur before a development contract is initiated, technological advances may be expected. Therefore, preliminary detail design for the final system is necessary (Figure 22; Step 2.1) to update the input data. In Figure 23, a two-month period has been allocated for this step, a time period which is very brief and which may have to be extended.

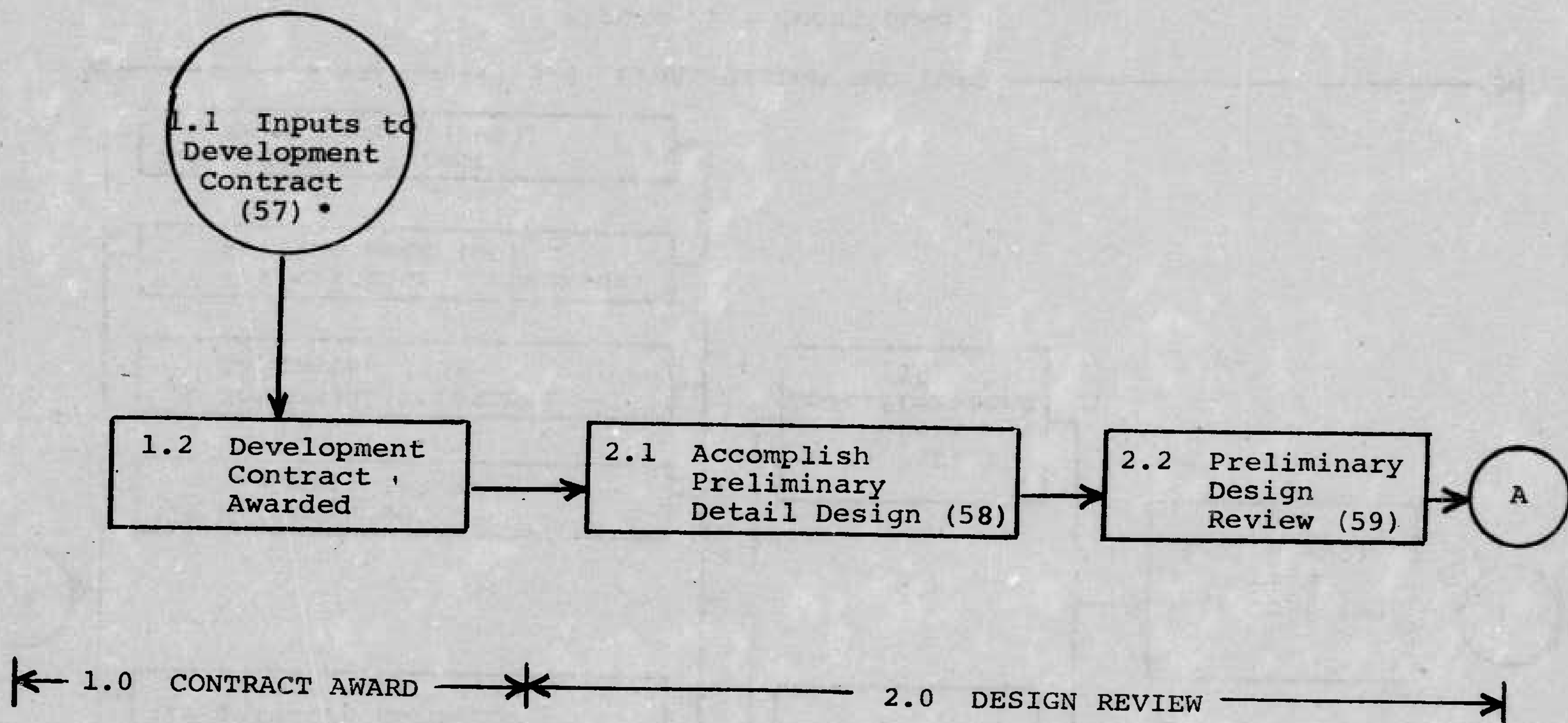

Figure 22. Measurement System Implementation Plan.

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

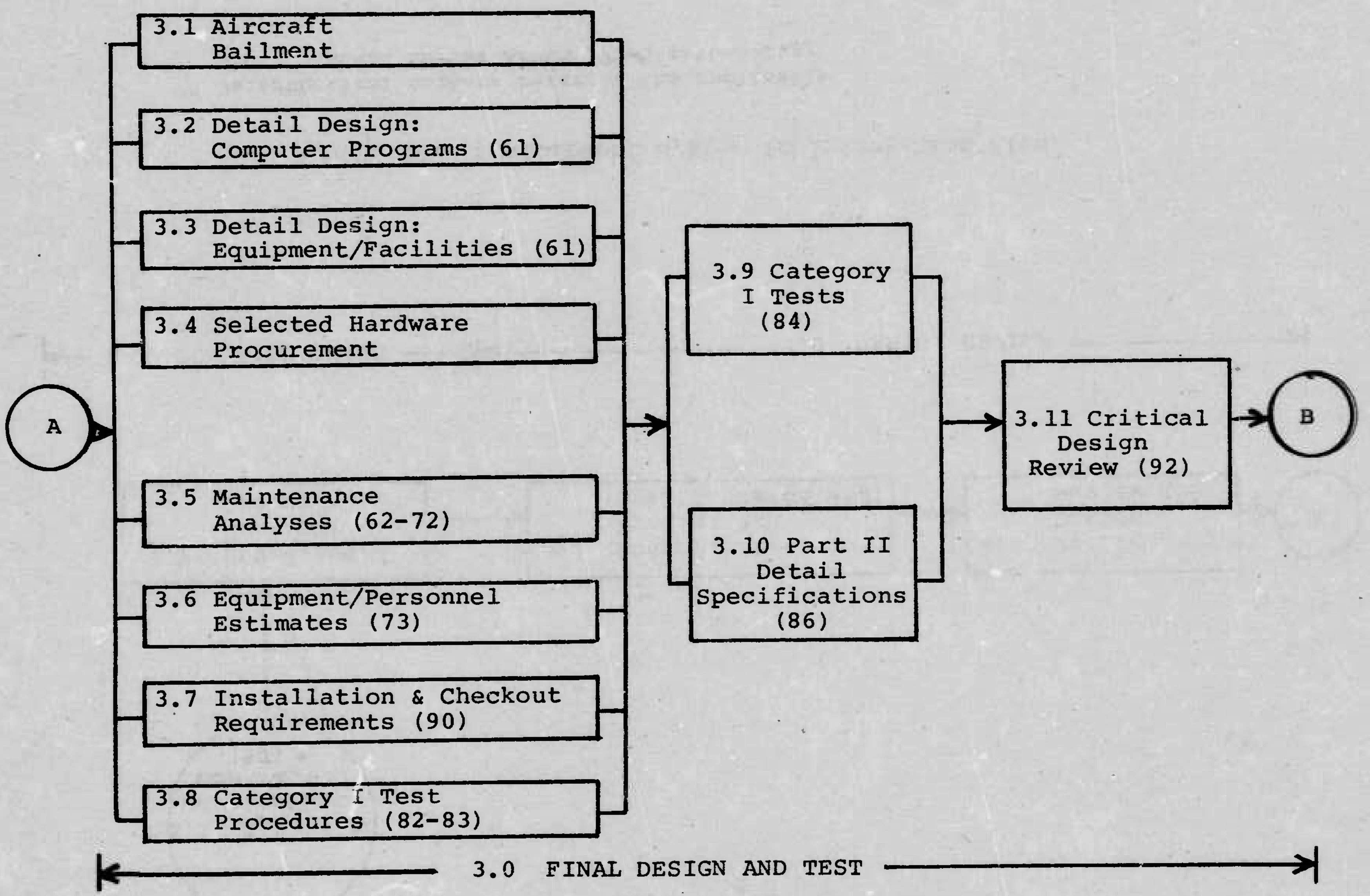

Figure 22 - (continued).

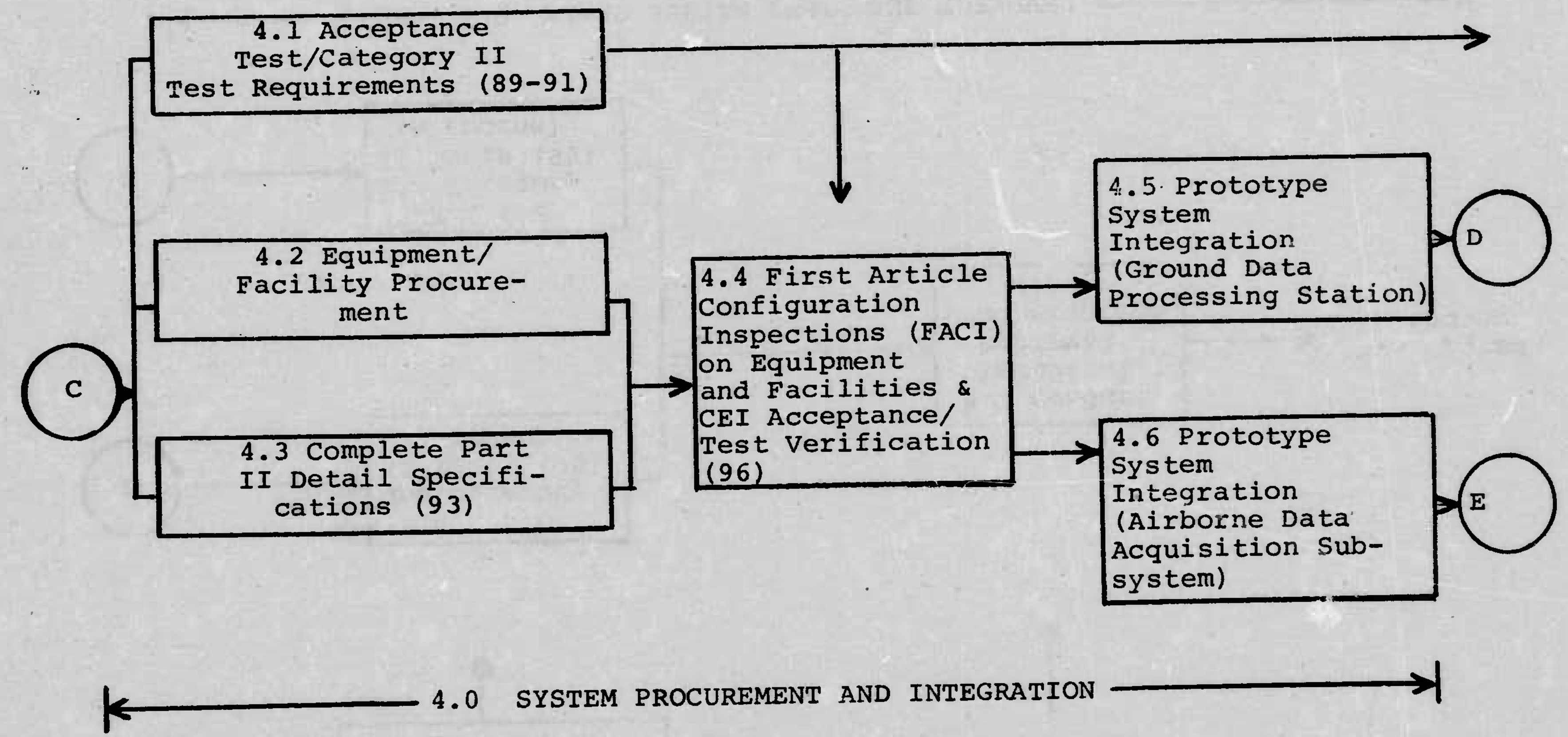

Figure 22 - (continued).

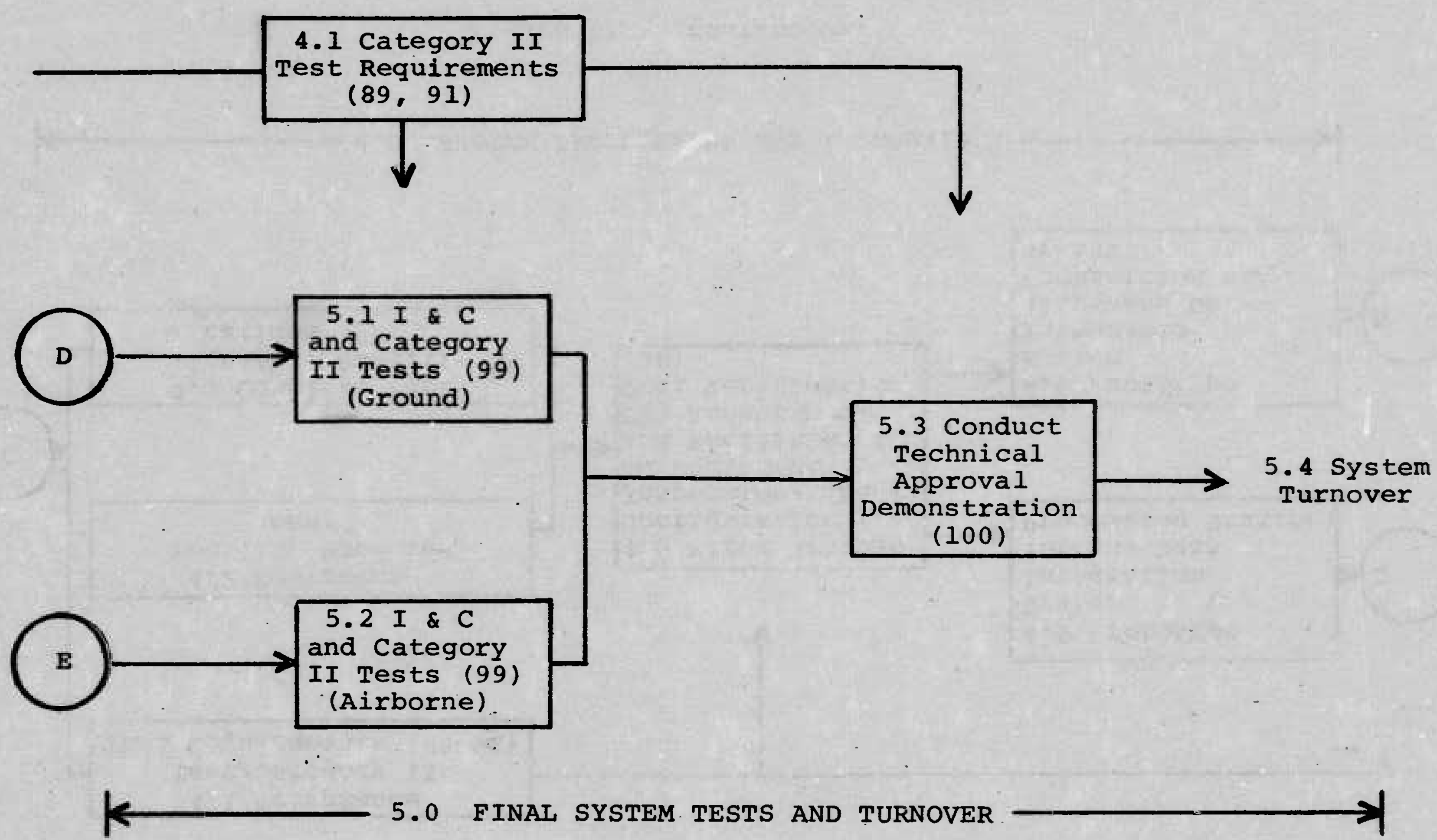

Figure 22 - (continued).

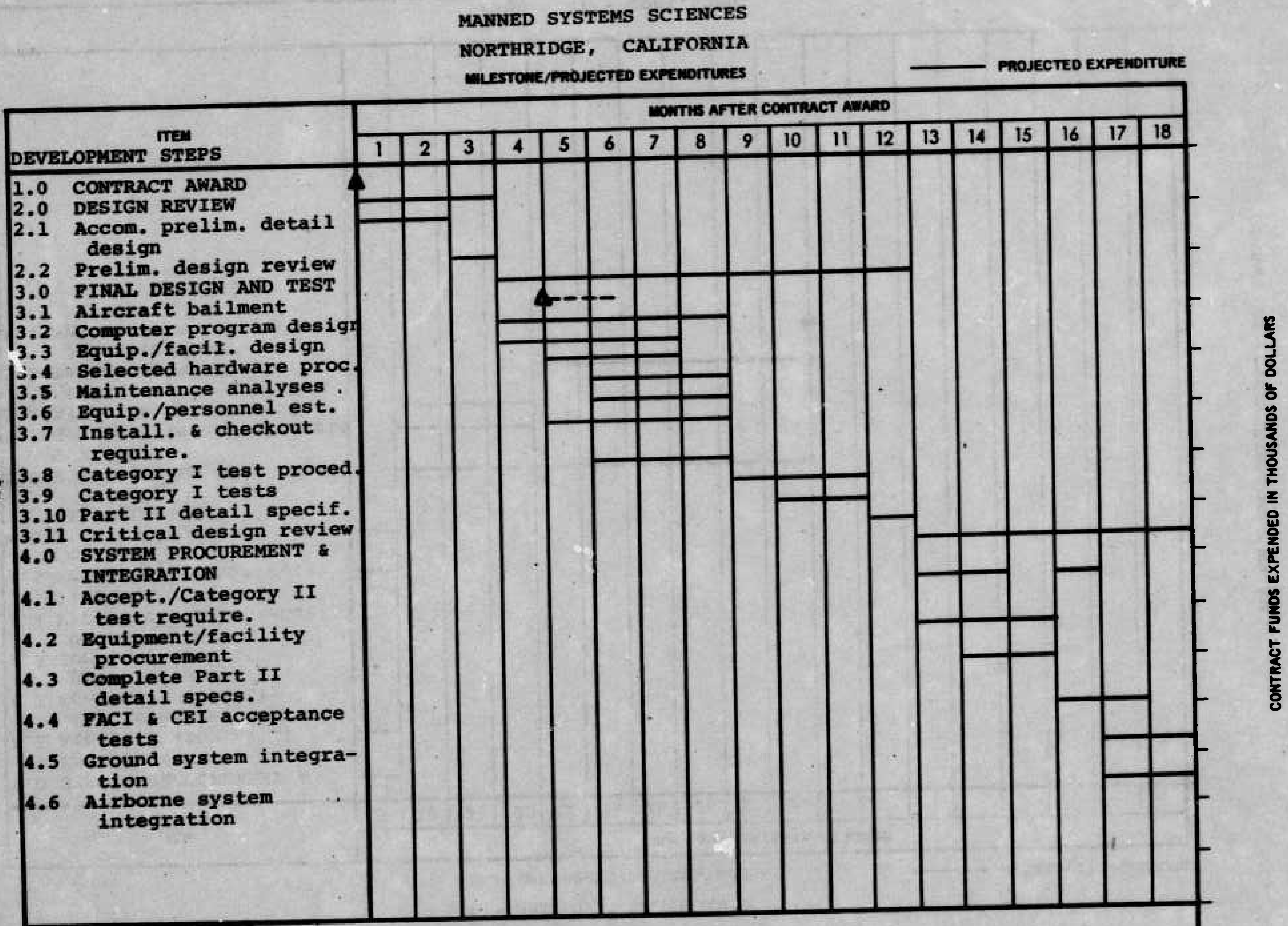

Figure 23. Measurement System Implementation Plan Schedule.

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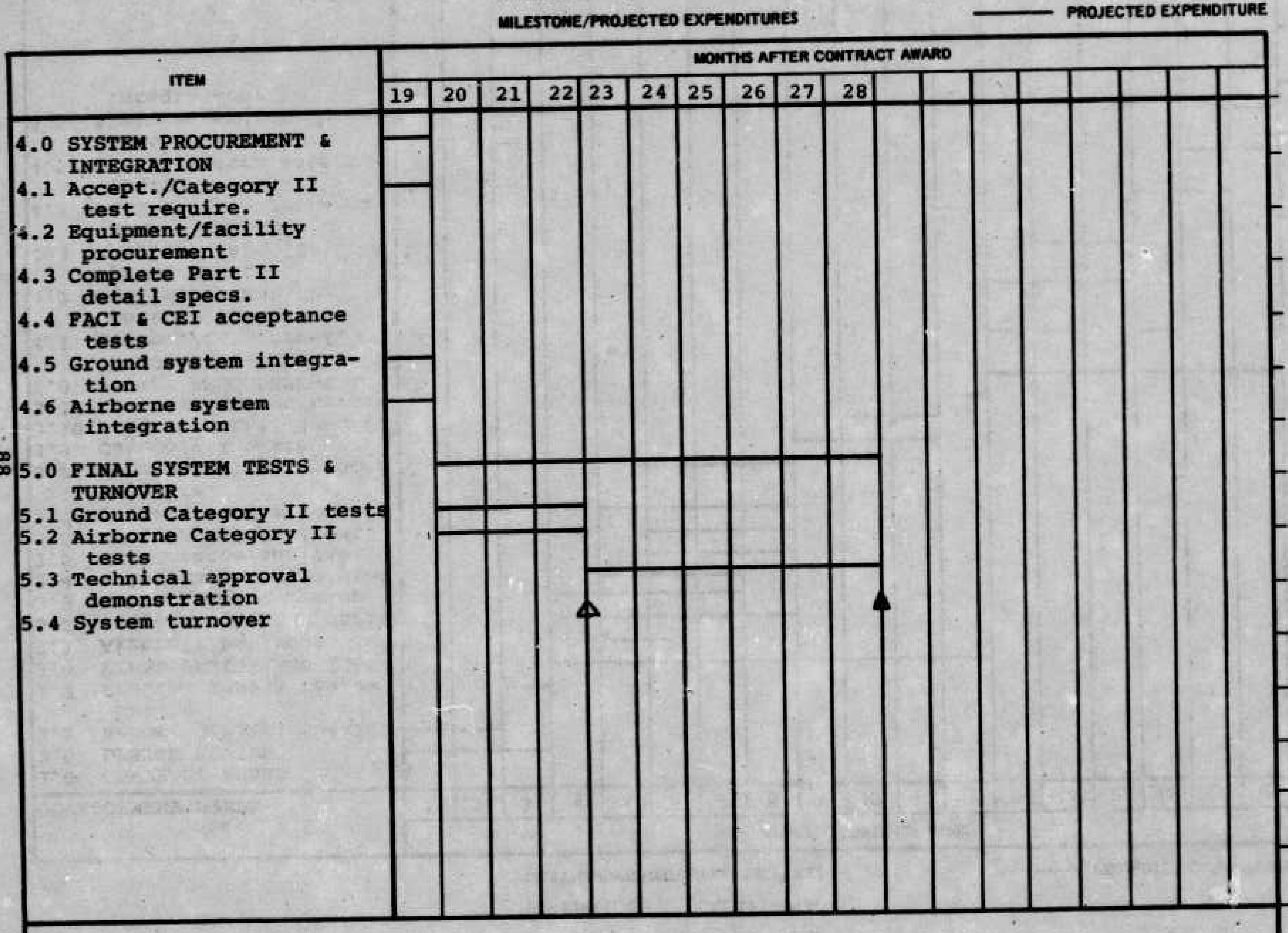


Figure 23 - continued.

To insure that development is proceeding properly, a preliminary design review is scheduled (Figure 22; Step 2.2). This review is a control step to provide direction to the system integration contractor by the Air Force.

Final Design and Test

Eight critical items have been selected for emphasis in final system design (Figure 22; Steps 3.1 through 3.8). Three of these items may be pointed out for particular emphasis:

1. The earliest possible aircraft bailment (Step 3.1) is recommended. The necessary modifications for in-flight performance measurement equipment appear to be extremely time-consuming, based on the data collected in the study survey.

2. Detailed design of the final computer software programs (Step 3.2) is the longest single item (see Figure 23). It is very difficult to predict how long will be required for program development, de-bugging, checkout, and test. Past experience suggests that this step may be the critical path in the acquisition network.

3. Some selected hardware procurement (Step 3.4) may be required, primarily for test and analysis purposes. A specific case in point is the video recorders where basic questions exist as to their capability in the in-flight environment. If possible, selection of the computer would be desirable at this point although it is not essential for development.

At the end of this phase, final detailed specifications (Step 3.10) should be available for the critical design review (Step 3.11) after which the final performance measurement system is frozen.

System Procurement and Integration

All subsystems are now procured, and system integration is accomplished. As shown in Figure 22, the airborne (Step 4.6) and ground (Step 4.5) subsystems have been kept seperate under the possibility that one and not both might be acquired. This separation is not recommended, but practical considerations may intervene.

Final System Tests and Turnover

Category II tests are shown for the ground data processing subsystem (Step 5.1) and the in-flight data acquisition subsystem (Step 5.2). It is anticipated that the technical approval demonstration (Step 5.3) will, in fact, be the execution of a complete research experiment conducted jointly by the system integration contractor and Air Force technical personnel. With this techniques, total system testing can be achieved; usable research data will be collected; and Air Force technical personnel will be provided training on the system under the most realistic of research environments.

Implementation Schedule

As noted, Figure 23 presents a time schedule covering all the steps in the implementation plan. As may be seen in that Figure, a 28-month program is anticipated. Based on past experience and the information collected during this study, it is believed that this is a realistic system acquisition schedule for the performance measurement system.

APPENDIX A. EQUIPMENT SURVEY

Introduction

This section presents a tentative survey and specification of equipment and instrumentation required for implementation of CCTS performance measurement program. The data are derived from manufacturer's published specifications and an in-depth evaluation of the equipment presented (and other alternative equipment) is required prior to any procurement decision. Because of the numerous number of manufacturers in several equipment areas (video equipment, data processing equipment), it was necessary to restrict the survey of equipment to "representative" samples of the various areas.

Appendix A has three major sections. Section One addresses the monitoring and data collection equipment anticipated for installation in the test aircraft(s). Each major piece of equipment in this section is addressed separately. Section Two discussed the post-flight ground debriefing facilities and associated equipment. Section Three addressed the data processing facilities and equipment requirements anticipated for detailed analysis and evaluation of the collected data.

Section One: Airborne Equipment Requirements

Figure 1 presents an overview of the required airborne data collection and monitoring equipment. The airborne equipment consists of two (possibly three) audio/visual cameras, one audio/visual recorder, one gunsight and one instrument camera, a standby cockpit voice recorder, a digital data recorder, and supporting timing and initiating devices as appropriate.

Audio/Video Recorders. Previous attempts to use relatively inexpensive off-the-shelf video recording equipment for airborne applications have not been entirely successful. One apparent reason for this lack of success was the use of video recording equipment with insufficient resolution (200 to 250 lines) and illumination control devices for visually enriched airborne environments. This resulted in unacceptable video resolution under conditions of high ambient illumination. The studies did demonstrate, however, that commercially available equipment could operate in an acceptable manner in airborne applications.

A review of inexpensive commercially available video recorders (Table 1) and cameras (Tables 2 and 3) suggests that it is possible to obtain recording equipment with roughly twice the resolution (350-500 lines) of the equipment used in the above mentioned studies. Increased resolution is achieved, however, at a cost of increased equipment size and weight. Very high resolution equipment results in sharp increases in the cost and temperamentality of both cameras and recorders. For this reason, the

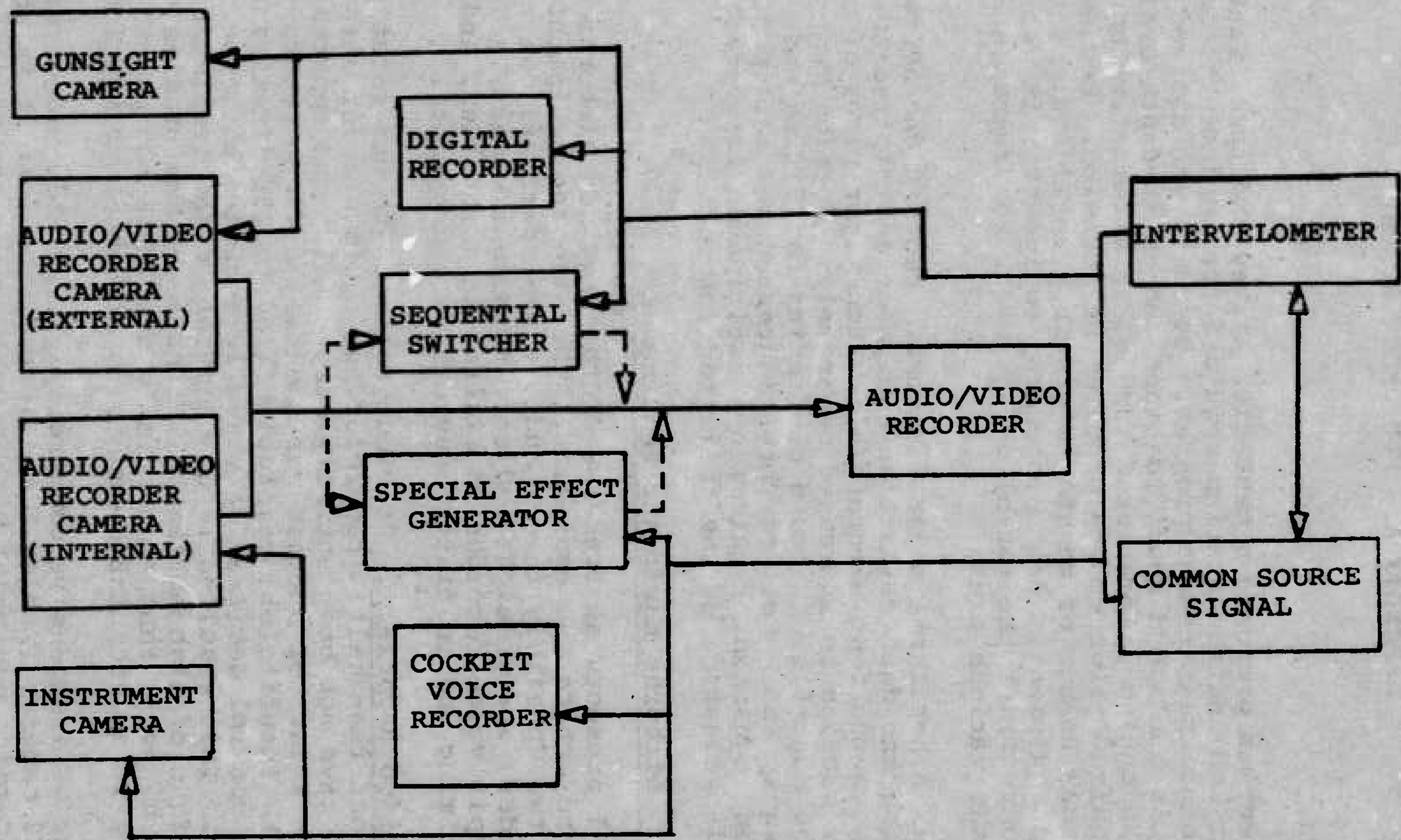


Figure 1. Typical Airborne Instrumentation Configuration.

TABLE 1. VIDEO RECORDER SURVEY

COMPANY	MODEL NO. *PORTABLE	TAPE SIZE & TYPE	HORIZONTAL RESOLUTION LINES	RECORD TIME	RECORD HEADS	POWER	AUDIO BANDWIDTH	S-T-N RATIO	DIMENSIONS W/D/H (IN INCHES)	WT. IN LBS	PRICE *INCLUDES CAMERA
Ampex	VTR-5800C	1"	350	60 min	2-HS	110V 60 Hz	75-12KHz	40dB+	28¼ x 18¼ x 12½	85	$ 5,500.00(b/w) $ 6,250.00(C)
Concord	VTR-800	½"	300+	60 min	2-HS	110VAC 60 Hz	80-10KHz	40dB+	157/8x85/8x153/8	33	$ 695.00
	VTR-820	½"	300+	60 min	2-HS	110VAC 60 Hz	80-10KHz	40dB+	157/8x85/8x153/8	33	$ 950.00
	VTR-450T	½"	300	30 min	2-HS	12VDC	80-10KHz	40dB+	143/8x91/4x45/8	15	$ 1,350.00*
	VTR-4800	½"	300-350	30 min	2-HS	12VDC	80-10KHz	40dB+			$ 2,400.00
	VTR-3000	1"	450+	1 hr	2-HS	N/A	80-10KHz	43dB+	26 x 16 x 12	97	$ 5,000.00
	VTR-2300	1"	400+	1 hr	2-HS	N/A	80-10KHz	40dB	22 x 16 x 11	80	$ 3,900.00
Craig	6404	½"	250+	63 min	2-HS	117V 60 Hz	70-10KHz	40dB	18½ x 10¼ x 17½	59	$ 800.00
	6406	½"	250+	22 min	2-HS	12VDC	100-8KHz	40dB	5 x 13 x 10½	15	$ 1,500.00*
	6403	1"	400+	96 min	2-HS	117V 60 Hz	60-10KHz	42dB	25 x 21 x 18.5	185	$ 4,200.00
Echo Science (Airborne Systems)	WRR-302-01*	1"	500+	96 min	2-OS	105V 60/400 Hz	60-10KHz	40dB	70 x 22 x 24	400	$35,000.00
	WRR-411	1"	500+	90 min	2-OS	105V 60/400 Hz	60-12KHz	40bD+	28 x 19 x 11	85	$45,000.00
	WRR-211	1"	500+	60 min	2-OS	23VDC 115VAC/400	60-12KHz	40bD+	18x117/8x67/8	45	$15,995.00
	WRR-202	1"	500+	30 min	2-OS	115V 400Hz	60-12KHz	39dB	15 x 11.4 x 6.4	38	$14,995.00
	WRR-201-01*	1"	500+	30 min	2-OS	28VDC 115AC/400	60-12KHz	40dB	15 x 11.5 x 6.5	37	$14,995.00
Javalin	X-400 VTR	½"	300+	1-7 hrs	4-HS	117VAC 60Hz	80-10KHz	40dB+	18½ x 17 x 10	58	$ 2,000.00
Panasonic	NV-3020*	½"	300+	60 min	2-HS	12VDC 110/60 Hz	80-10KHz	40dB+	155/8x83/8x153/8	33	$ 700.00
RCA	N/A										
Shibaden	SVC-520 color	½"	350+	60 min	2-HS	12VDC	N/A	40dB	16.8 x 14 x 9	29.7	$ 1,300.00(C) $ 748.00(b/w)
Sony	AVC-3400*	½"	300+	30 min	2-HS	12VDC	100-10KHz	40dB	11x63/16x11.5	183/4	$ 1,200.00*
Unitron	VT-100*	½"	200+	20 min	2-HS	12VDC	100-10KHz	40dB	10 x 4.4 x 10.3	10	$ 995.00*
	VT-110	½"	250+	30 min	2-hs	12VDC	80-10KHz	40dB+	10 x 4.4 x 10.6	16	$ 1,595.00*

TABLE 2

VIDEO CAMERA SURVEY

Company	Model	Vidicon	Resolution (Lines)	Lens Type and Mount	Dimensions (Inches)	Weight Lbs.	Price *Includes Recorder
Ampex	CC-400	1" Type 8758	550	25mm, f/1.9	4 1/8 x 6 3/8 x 11	9	$400
	CC-450	2/3 Separate Mesh	600 (Center)		14 3/4 x 10¼ x 6¼	15	995
Concord	MTC-18						
	VTR-450T	2/3" Separate Mesh	450	15-75mm Zoom f/2.1	2 7/8 x 5 1/8 x 8¼	5.5	1350*
	TCM-40	2/3" Separate Mesh	500	15-75mm Zoom f/2.1	2 7/8 x 5 1/8 x 8½	5.5	745
Craig	6406	2/3" Separate Mesh	450	15-45mm Zoom f/1.8	3 x 5 x 8½	6	1500
	6106	1" Type 7262A	500	25mm, f/1.8	4¼ x 6½ x 11½	12	350
	6102	2/3" Separate Mesh	550+	16mm, f/1.6	4 x 5 x 10	10	250
GBC	CTC-2001-2* *2 piece Camera	1" Type 7735A	550	25mm, f/1.4	Head 2 x 3 x 4 Box 5 x 5½ x 8	2.2 10.0	495
	OD-722	1" Type 7735A	500	25mm, f/1.4	N/A	N/A	495
	CTC-3002 (Silicon)	1" Type 7735A	650	25mm, f/1.4			695
	AE-50 ALC (Sound)	1" Type 7735A	550	25mm, f/1.4			495
Javalin	VC-100	2/3" Separate Mesh	650	16mm, f/1.6	8 3/4 x 2 3/4 x 5	4.5	300
Panasonic	WV-200P	2/3" Separate Mesh	550	16mm, f/1.6	3¼ x 5 9/16 x 10	4.4	220
RCA	N/A						
Shibaden	HB-50	2/3" Separate Mesh	500	25mm, f/1.9	5.2 x 6.8 x 9.6	2.7	395
Sony	AVC-3400	2/3" Separate Mesh	400+	16-64mm Zoom f/2	2 13/16 x 5 x 15 1/16	6	1200
Unitron	VT-100	2/3" Separate Mesh	400+	10-40mm Zoom f/1.8	3 x 4.4 x 7.3	4.1	995

TABLE 3

SPECIAL EQUIPMENT

SPECIAL EFFECTS GENERATORS:	
Panasonic Model WJ-540	$325
Craig Model 9823	300
Model 9824	350
Model 9825	350
SEQUENTIAL SWITCHES:	
Craig Model 9826	200

survey was restricted to equipment with moderately high resolution, small packaging and modest initial costs. Within these constraints, a number of alternative cameras and recorders are commercially available and should be examined more closely.

In securing equipment for the present application, two approaches are possible: arbitrary selection of a camera and a video recorder based on the survey data, or selection of several cameras and several recorders and laboratory testing them prior to installation. Since many pieces of this equipment have not been field tested, it is felt that the latter approach is the most reasonable in the long run. A series of simple ground tests of equipments selected should provide evidence of the acceptability and airworthiness of various combinations of cameras and recorders prior to installation in aircraft. This would result in considerable savings in terms of both installation costs and time. These savings in turn should offset the cost incurred in securing several different cameras and recorders.

Video Recorder Testing. A tentative list of cameras, video recorders and other associated equipment to be considered for laboratory testing is presented in Table 4. The equipment is listed as three "systems" only for the purposes of incrumental procurement and should not be construed as meaning three independent systems. The items purchased for the "basic system" would be combined with and tested with items purchased for the "intermediate" and the "high resolution" system.

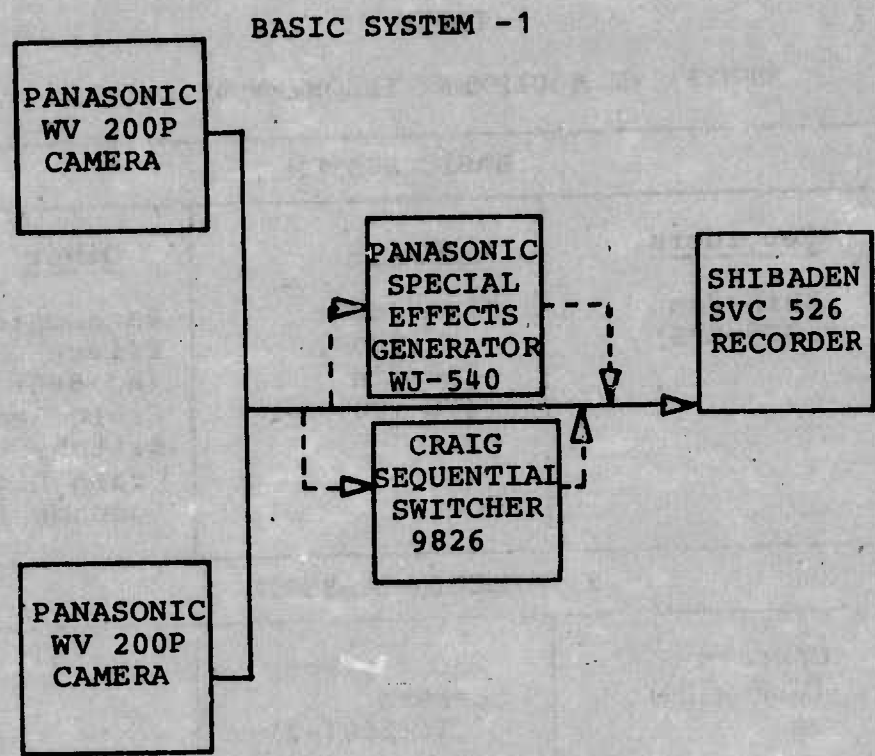
The test paln would be to simply combine each video camera with each video recorder and perform a series of simple tests to obtain samples of video tape from each combination. The tests should include exposures to low, moderate, high and rapidly changing illumination conditions, several scene panning rates, and several target backgrounds. These test samples would be examined and evaluated by the video equipment integration contractor for image quality and equipment serviceability. Projections could then be made as to the optimum combination of components for installation into the test aircraft. Sample testing combinations are presented in Figure 2.

Other Equipment. In addition to evaluating the recording equipment, tests should be conducted to determine the effectiveness and value of using a special effects generators (superimposing two camera views on a single film frame), and sequential switchers (sequentially recording views from different cameras for differing lengths of time on some film). Likewise, the Craig automatic light doucher (which reduces light entering camera if rapidly increaseing illumination exceeds the camera's automatic adjustment capability) should be evaluated.

TABLE 4

TENTATIVE EQUIPMENT RECOMMENDATIONS

Recorders	Cameras	Other
BASIC SYSTEM		
Shibaden (SUC-526)	Panasonic (WV-200P) Javalin (VC-100)	Panasonic Special Effect Generator (WJ-540) Craig Sequential Switcher (9826) Craig Light Activated Doucher (2715)
INTERMEDIATE SYSTEM		
Concord (VTR-2300)	GBC 2-piece Camera (CTC-2001-2)	
HIGH RESOLUTION SYSTEM		
Echo Science (WRR-211)		



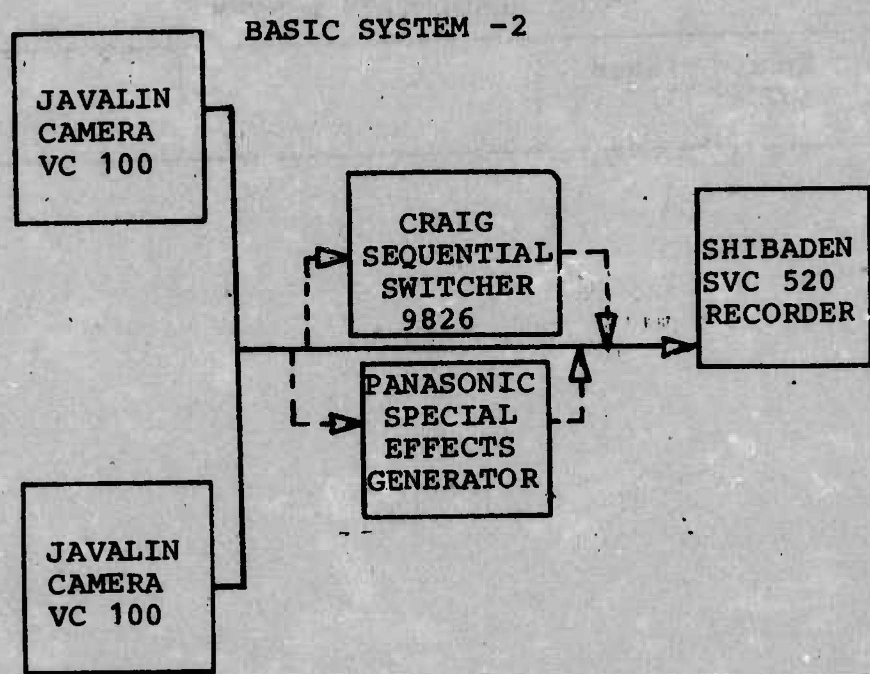
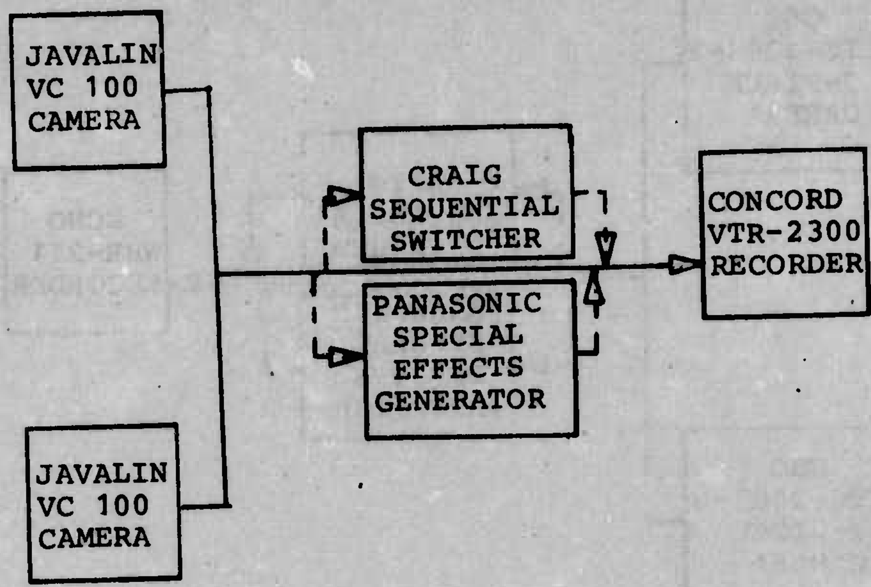


Figure 2. Tentative Test Configurations.

INTERMEDIATE SYSTEM -1



INTERMEDIATE SYSTEM -2

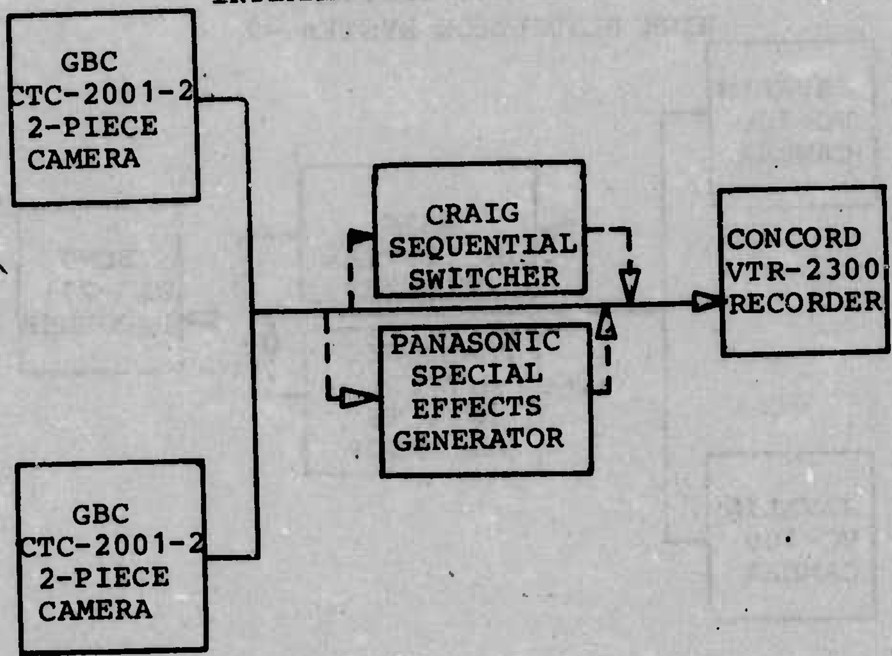
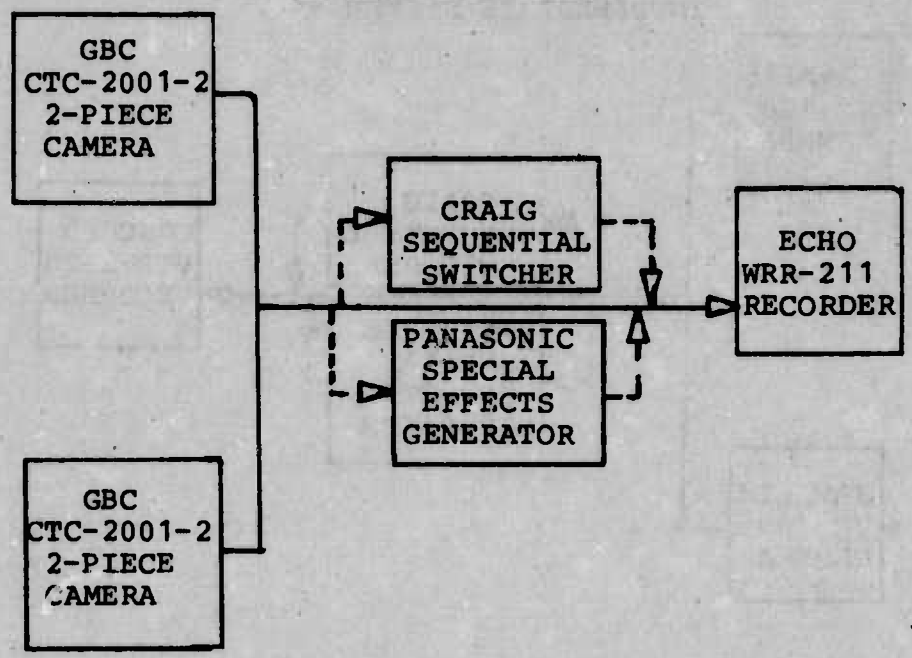


Figure 2. Tentative Test Configurations (Continued).

HIGH RESOLUTION SYSTEM -1



HIGH RESOULTION SYSTEM -2

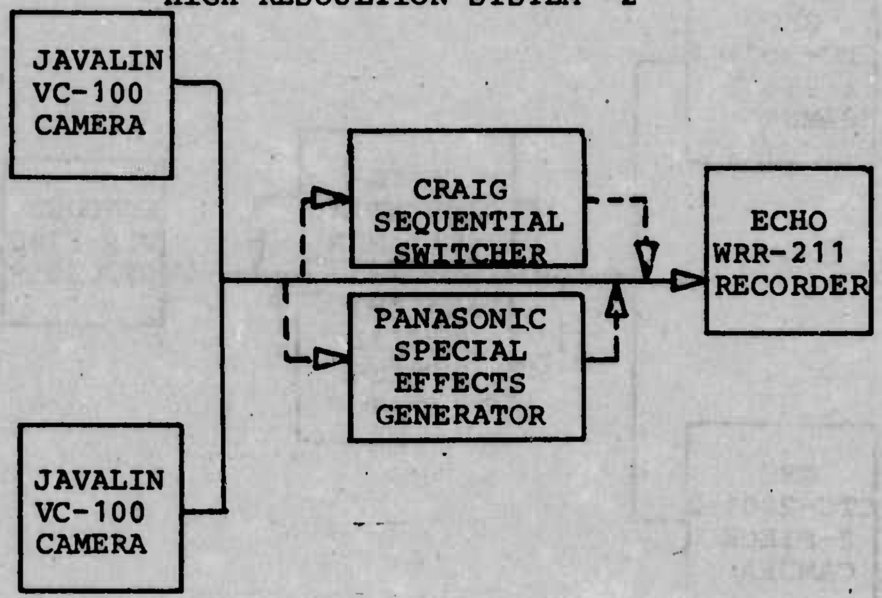


Figure 2. Tentative Test Configurations (Continued).

TABLE 5

PHOTOGRAPHIC CAMERA SURVEY

Company	Model	Type	Film Capacity (Feet)	Frame Rate fps	Dimension (Inches)	Weight (Lbs.)	Price
Bolex	H16-EBM	16mm	100	12-64 fps	9 x 6 x 3	8	$1200
Minolta	Autopak-8-D10	Super 8mm	50	Single or 8-50	3 3/4 x 8 x 9¼	6	800
Kodak	Analyst Intervalometer	Super 8mm	100	1¼ sec to 1/90 sec	3 x 6¼ x 4½	9	500
Perk-Elmer	N-9	16mm	10	10-60 fps	3 7/8x6 1/8x9½	12	1800
Photosonic	KB-19A	16mm	100	24-200	8.8 x 3.5 x 3.7	9	6000
	KB-19B	16mm	100	48 fixed	8.8 x 2.6 x 3.7	9	3500
	KB-21C	16mm	200-600	25-200	7.8 x 5.4 x 3.9	11	2975
	KB-25A	16mm	100	24 or 48	N/A	4.8	N/A
	KB-26A	16mm	100	24 or 48	N/A	4.8	N/A
	1 VN	16mm	100	24 or 48	4.7 x 2.3 x 5.1	6	2000
Teledyne/Milligan	DBM-2A	16mm	100	16-48	10½ x 3 3/4 x 3¼	1½	2500
	DBM-44	16mm	400	2-400	9 2/16x4 1/8x6 3/8	9	2700
	DBM-3C	16mm	100	2-400	8½x4 1/8x6 1/8	7 3/4	2700
	DBM-54	16mm	400	2-400	12½x4 1/16x6½	13	2850
Visual Instrumentation	SP-1	Super 8mm	100	18 to 250	6 3/4x3 7/8x2 7/8	3¼	1200

Installation. After the initial testing and evaluation has been satisfactorialy completed, the video equipment selected would be prepared for installation in the test aircraft(s). The video cameras (two or more) would be installed in the cockpit in a manner which would optimize internal and external visual coverage. Each camera would be securely mounted to maintain the optimum field of coverage. The cameras would then be connected directly to the recording device or to a special effects generator or sequential switching device based on the results of ground evaluation of these devices. Depending upon the aircraft selected, combining glasses or mirrors may be utilized to aid in recording.

Photographic Cameras. It is anticipated that a film-based photographic system will be used as a backup mode (primary mode if the video recording systems prove unacceptable) for data collection. Again, one camera will address the instrument panel while the second camera addresses external targets. The cameras can be tied into a common event signal for simultaneous filming of two or more views and/or into intervolometers for time-lapsed or event specific filming. A camera can be set up with a data chamber which can insert time, day, date, aircraft and pilot name on border of the film. An automatic scanning device can be included so that a single camera can cover a target area larger than its normal field of view.

With the enormous variety of photographic equipment available, it is difficult to specify a given camera for a given application without definitive knowledge of the aircraft in which it will be installed. A number of contractors build cameras for specific application in specific aircraft; several manufacturers build cameras which are easily adaptable to several systems , and a number of manufacturers produce commercially available (and relatively inexpensive) camera systems which are technically capable of airborne application, but which have not been utilized for this purpose. The problem, consequently, it to establish the technical capabilities required of the system and then perform a cost-effectiveness tradeoff. Table 5 summarizes data for a number of currently available photographic systems. In this summary, a number of commercially available, but presently untried, cameras are included for comparison purposes. Table 6 lists summary data for currently available supporting equipment for airbonre photographic applications.

Tentative candidates for the internally oriented and the externally oriented cameras are listed in Table 7.

TABLE 6a

TIME CODE GENERATORS

Company	Model	Dimension	Weight	Sequence Length	Freq. Range	Calibration Accuracy	Cost
HP	HP 3722A	16 3/4x5 7/32x 16 3/8	23	15-∞			$2700
	HP 200AB	7½ x 11½ x 12	15		20-40KHz	±2%	225
	HP 200CD	7 3/8 x 11½ x 14 3/8	22		5-600KHz	±2%	330
	HP 205A6	20 3/4 x 12 3/4 x 15½	56		20-20KHz	±2%	700

TABLE 6b

INTERVALOMETER

Company	Model	Interval Settings	Power Source	Price
Lafayette	5001A	.01 to 100 sec	115VAC	$124
	5001D	.01 to 100 sec	115VAC	210
	5400A	Variable to 500 Sec	28VAC	149
	5431A	0.1 to 111.0 Sec	115VAC	640
	5430	0.1 to 110 Sec	115VAC	475
	5002	0.1 to 100 Sec	115VAC	175
Northrop	INT-172	Variable	28VAC	475
Visual Instrumentation	200	Variable	28VAC	500

TABLE 7. CANDIDATE CAMERAS

EXTERNAL	INTERNAL
Photosonic KB-25A or Milligan DBM-3C	Photosonic 1VN or Visual Instrument SP-1

Cockpit Voice Recorders. It is anticipated that an additional voice recording system will be required for (a) backup in the event of audio-visual recording system failure, and (b) a primary voice recording system in the event the audio-visual system proves unacceptable.

A number of voice recorders are produced specifically for airborne application. A number of commercially available recorders, however, appear to offer sufficient potential for meeting present requirements at a considerable reduction in procurement costs. These recorders are summarized in Table 8.

Based on the manufacturer's published data, the Sony TC-110A is recommended for consideration and further evaluation.

Airborne Digital Recorders. An airborne digital recording system is required for measurement of instrumentation and aircraft outputs during critical periods of the student/pilot's flight. A number of such systems are available. Several of these are summarized in Table 9. For the present application, the Incra-Data Mark II appears to offer the most potential.

Section Two: Post Flight-Debriefing Requirements

This section addresses the facilities required for housing the post-flight debriefing rooms and equipment as well as the data processing equipment (discussed in Section Three). In addition to the ground mobile facilities, the required debriefing equipment will be summarized.

Ground Mobile Facilities. A ground mobile debriefing facility and data processing center are required for this program. These facilities could be mounted in several truck drawn trailers or in one or two large mobile home type of trailer devoid of interior partions and furnishings (with the exception of restroom facilities). It is felt that the latter type of vehicle would be the most flexible in terms of equipment configurations, personnel organization, and functional utilization of available space.

TABLE 8. COCKPIT VOICE RECORDER SURVEY

COMPANY	MODEL	RECORD TIME	S-T-N RATIO	POWER	TAPE SIZE	DIMENSIONS IN INCHES	WT(LBS)	PRICE
Ampex	AR-550	30 min	42dB	115V,400HC	1/4"	5 1/8x11 7/8x7 7/8	20	$2,000.
	MICRO34	30 min	40dB	12VDC	1/4"	6 x 11 1/8 x 2 1/2	5.5	122.
Craig	2605	60 min	40dB	12VDC/110, 60 Hz	1/4"	5 1/2x1 3/8x3 1/2	1.9	100.
Fairchild	A-100	30 min	45dB	115V,400Hz	1/4"	5 x 12 1/2 x 7 1/2	21.4	2,300.
Panasonic	RQ 2365	60 min	42dB	12VDC/110, 60 Hz	1/4"	7 5/8x11 7/8x3 1/4	4.4	110.
Sony	TC-110A	30-120 min	40dB	12VDC	cas-sette	5 3/4x2 1/2x9 1/2	4	125.
	TC-40A	30-120 min	38dB	12VDC	cas-sette	1 15/16x7x4 4/8	1 7/8	100.

TABLE 9. DIGITAL RECORDER

COMPANY	MODEL	CHANNELS	TAPE CAPACITY	DENSITY	DIMENSIONS IN INCHES	WEIGHT IN LBS	PRICE
Ampex	ATM-13	6	1200 ft	800 bpi	4 7/8x11 7/16x8 3/8	26.5	$24,000.
Astro-science	E-116	N/A	N/A	N/A	N/A	N/A	N/A
H-P	2547A	7	1200 ft	200/556	N/A	N/A	9,000.
	2547B	7	2400 ft	200/556	N/A	N/A	11,000.
	2547C	7	2400 ft	800	N/A	N/A	11,000.
	2547D	7	1200 ft	800	N/A	N/A	12,000.
Incra-Data	MARK II	7	1000 ft	800	6 3/4x7 3/4x13 5/8	29	14,750.

Basic Requirements. The facilities are required to house:

(a) Post-flight debriefing rooms.
(b) Data processing equipment area.
(c) Limited office space for technical personnel.
(d) Work area for equipment technicians.
(e) Work area for supporting secretarial personnel.
(f) Storage area for records and data.
(g) Restroom facilities.

Tentative Configurations. These facilities can be housed in either one 12-foot wide by 60-foot long mobile home type of vehicle (somewhat cramped, however) or more comfortable in two such vehicles. Figure 3 suggests a possible configuration using two vehicles. Single-unit configurations permit little room for offices.

Approximate Cost. The mobile vehicles suggested in Figure 3 are commercially available from a number of mobile home manufacturers for between eight and twelve thousand dollars each (depending upon location and options selected). This price includes the heavy duty flooring and frame required to accomodate the data processing equipment.

Equipment Requirements. The basic equipment required for post-flight debriefing consists of:

(a) Dictation/tape recorder equipment.
(b) 16mm (or 8mm) file viewer/printer.
(c) Video tape monitor.
(d) Video tape playback unit.

One of each of the above pieces of equipment would be required for each of the debriefing rooms used. At present, a minimum of two debriefing rooms are anticipated. A tentative configuration is presented in Figure 4.

Video Monitors. Table 10 summarizes technical specifications and prices for a sample of the video monitors commercially available. For the present program, it is felt that a 12-inch monitor should be sufficient for reviewing video tapes. Either the Sony or the Concord 12" monitor should be considered.

Video Playback Equipment. Two (or more) video recorders will be required to playback the video tape filmed in the aircraft. These playback units need not necessarily be identical to the units installed in the test aircraft. (Table 1 summarizes video recorders). For the present application, the Shibaden model SVC-250 or the Javalin model X-400TVR should be considered.

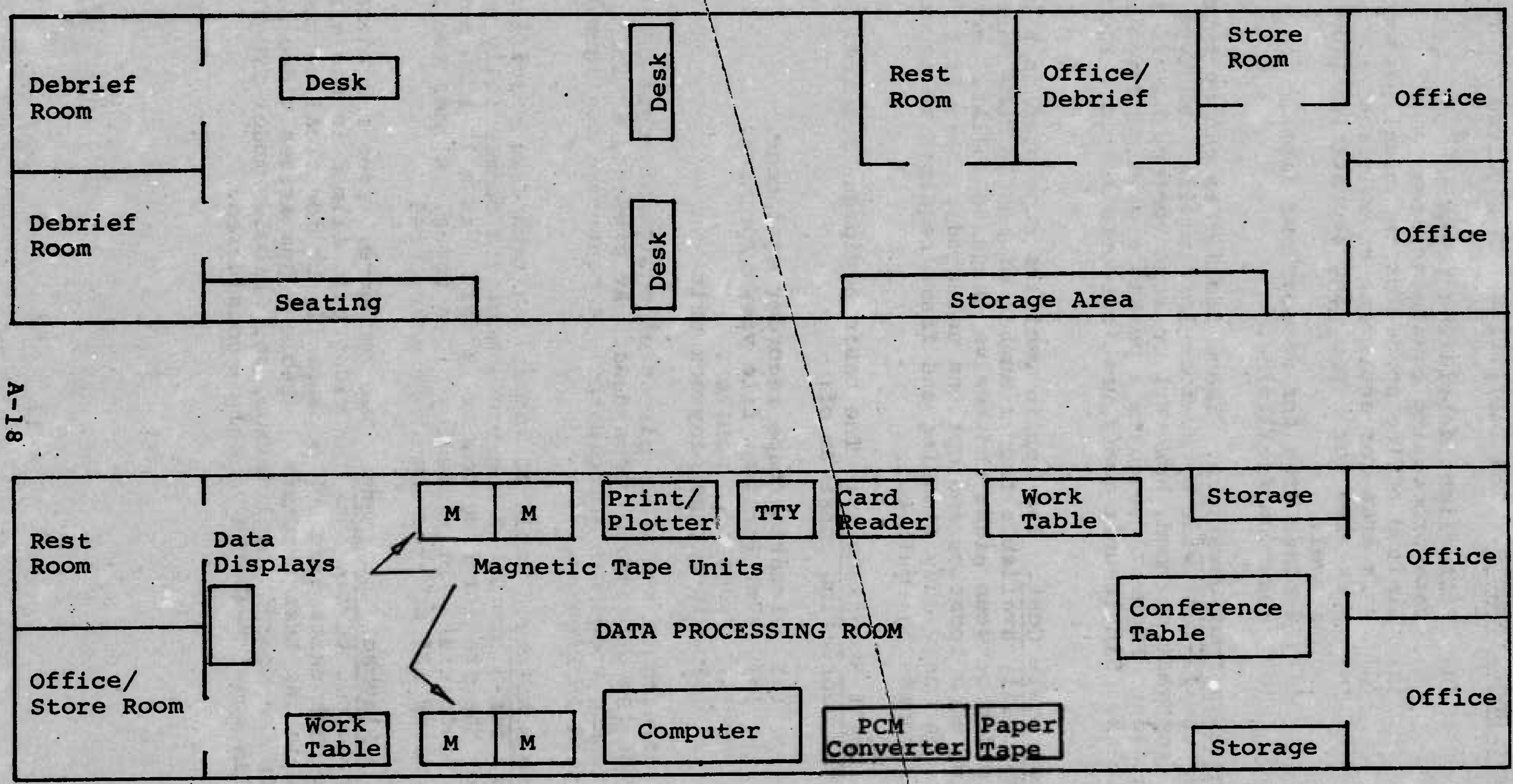
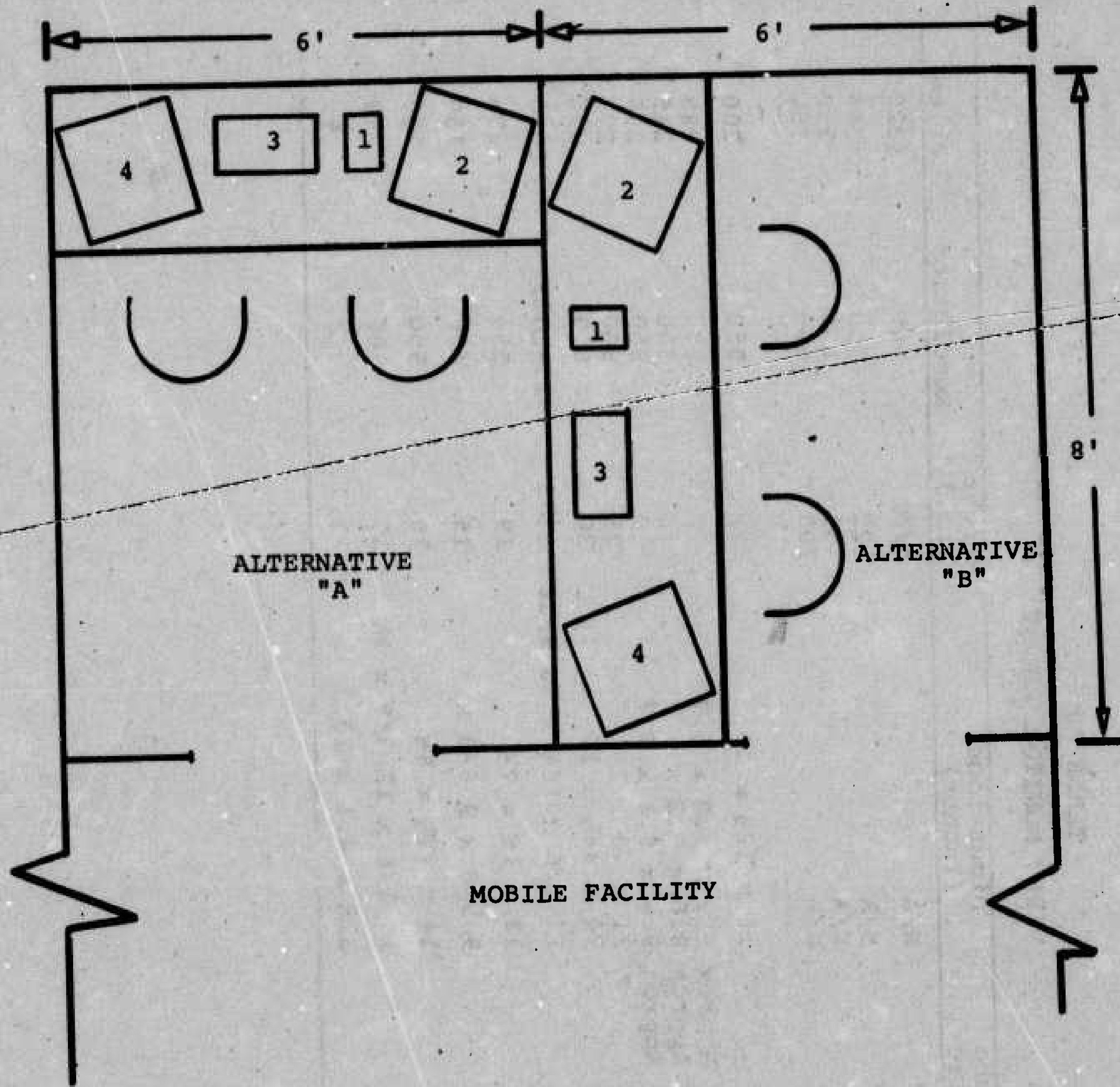


Figure 3. Example Mobile Measurement System Configuration (12' x 60' Trailers).



1 - Dictaphone
2 - 16mm (8mm) Viewer/Printer
3 - Video Monitor
4 - Video Playback

Figure 4. Tentative Debriefing Room.

TABLE 10

VIDEO MONITOR SURVEY

Company	Model	Tube Size	Dimensions (Inches)	Weight (Lbs.)	Resolution	Price
Ampex	TR-823	23"	N/A	N/A	500	$320
Concord	MR-740	12"	N/A	22	500	200
	MR-900	19"	N/A	81	600	250
	MR-2000 (Color)	19"	N/A	105	650	750
Craig	6201	12"	16 x 12½ x 10	21	550	200
GBC	MV-5	5'	Approx 5.9 x 6.3 x 8.9	9	550	289
	MV-9A	6"	Approx 8.6 x 9.2 x 8.7	18	550	245
	MV-9A+Audio	6"	Approx 9.6 x 9.2 x 8.7	19	550	295
	MV-19	19"	21 x 20 x 16	28	600	297
	MV-23	23"	24 x 24½ x 16	30	600	395
H-P	6947A	17"	17 1/6 x 16½ x 20 9/16	43.8	525-1029	1050
Javalin	12VM205	12"	12 x 18 x 7½	19	550	275
Panasonic	TR 910V	6"	9 5/8 x 9 5/8 x 9	15	400	150
Shibaden	TV-120U	12"	14 x 12½ x 8½	16	500	230
Sony	RC-400	12"	14 1/6 x 11 3/8 x 9½	17	500	250
Unitron	VT 100	3"	3.8 x 4.4 x 10.3	3.7	400	95

Film Viewer/Printer. A number of manufacturers produce 8mm, 16mm, or 35mm film viewers and frame printers. The 3-M Company Model "400" reader-printer is a proven product and is recommended for the present application. This model sells for approximately $1,500 for the motorized version and accepts either 16mm or 35mm film.

Dictation Equipment. The dictation or tape recording equipment required for verbal data collection purposes need not be of exceptionally high quality and can, therefore, be selected from among the large number of inexpensive recording systems currently available. Table 11 summarizes the specifications for a number of these recorders. For the present application, the Sony TC-40 tape recorder appears to meet all requirements.

Section Three: Data Processing Equipment

This section briefly outlines some of the commercially available equipment meeting the general requirements established in the Data Processing Subsystem (discussed in Section III of text). Recommendations made in this section are tentative and made for illustrative purposes only. A more exhaustive specification of requirements would be required prior to any final selection of components.

Equipment Required. Figure 5 presents an overview of the data processing and peripheral equipment required for the present program. The equipment consists of:

(a) General purpose digital computer.
(b) Input/output devices including;

Magnetic Tape Units
Card Reader
Paper Tape Punch/Reader
Line Printer/Plotter
Teletype
CRT Data Viewer
Disc Storage
Other Data Viewing Equipment

(c) Appropriate data conversion and control equipment.

Digital Computer. After an initial survey and screening of currently available digital computers, the twenty-five computers listed in Table 12 appear to meet the technical requirement of the present program.. It is observed that the range of capabilities and cost of these remaining systems is great. Even within one computer model, capability and procurement costs are quite variable. The PDP model 15 or the Raytheon Model 704 (or equivalent alternatives), however, represent good potential candidates for the present program.

TABLE 11. TAPE RECORDER SURVEY

COMPANY	MODEL	RECORD TIME	S-T-N RATIO	DIMENSIONS IN INCHES	WEIGHT IN LBS	PRICE
Craig	2603	60 min	40dB+	5 1/4 x 9 x 2 3/4	3.4	$ 44.95
	2605	60 min	35dB+	3 1/2 x 1 3/8 x 5 1/2	1.7	99.99
	2606	60 min	40dB+	9 3/4 x 11 1/2 x 3	7.6	60.00
	2607	60 min	40dB+	9 3/4 x 10 1/4 x 3 1/4	6.5	60.00
	2610	60 min	40dB+	9 3/4 x 10 1/4 x 3 1/4	6.5	40.00
Doro	7QR	30 min	N/A	6 x 2 1/8 x 4 3/8		250.00
Hitachi	TRQ 260	30 min	40dB			70.00
	TRQ 280	30 min	40dB			50.00
	TRQ 290	60 min	40dB			60.00
Sony	TC 40	60 min	40dB	2 1/3 x 3 1/2 x 4 7/8	2.7	109.00
Panasonic	RQ-276S	60 min	40dB	10 3/8 x 10 3/8 x 3 1/4		50.00
	RQ-222AS	60 min	40dB	5 1/8 x 9 1/8 x 1 7/8		80.00
	RQ-236S	60 min	42dB	7 5/8 x 11 7/8 x 3 1/4		90.00
Magnavox	V9020	60 min	40dB	6 3/4 x 2 x 4 1/2	3.1	80.00
MGA	TC-20	60 min	30dB	1 3/4 x 6 x 4	1 lb 10 oz	50.00
Ampex	CR 034			6 x 12 x 2		122.00

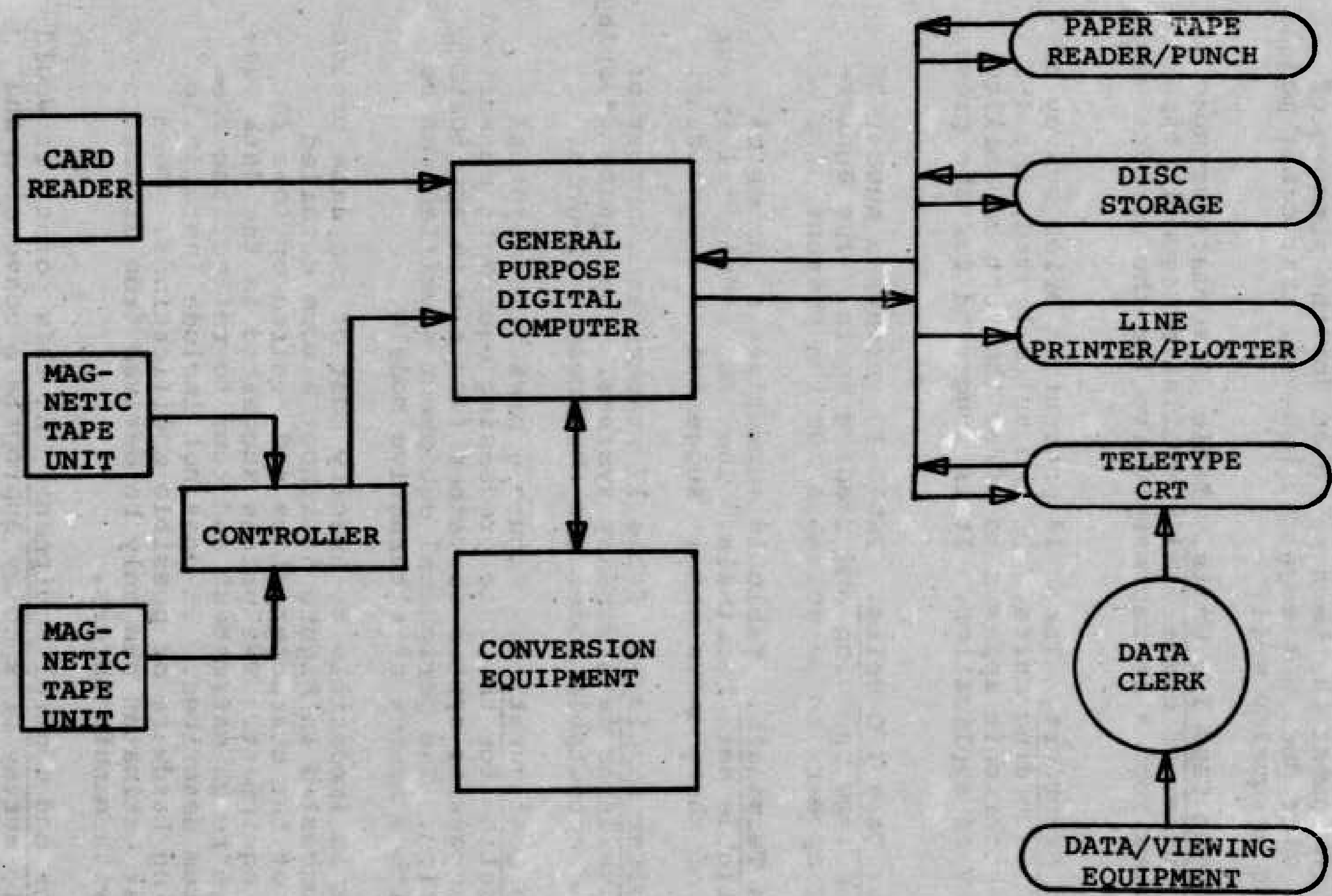


Figure 5. Equipment Requirements.

Input/Output Devices. An infinite variety of peripheral equipment exists for currently available digital computers. The following surveys again suggest representative samples of available equipment. One particular trade name and model for each piece of equipment has been selected for the purpose of illustration. This does not suggest, however, that other models could not perform equally well.

Magnetic Tape I/O Units. Table 13 summarizes specifications for a number of commercially available magnetic tape units. The Ampex series is representative for the present program.

Disc Recorders. Table 14 presents a brief survey of candidate disc recording units. Of the units listed, the ISS moving head recorer unit appears to offer the most capability and flexibility of application. It is suggested for the present program.

Paper Tape I/O Units. Table 15 surveys a number of available paper tape punching and reading units. The Bunker-Ramo model 761 appears to be suitable for the present program.

Data Terminals. Table 16 summarizes a number of currently available data terminals. The ITEL model 1051 is the most flexible of these units and is suggested as a candidate.

Computer Displays. Table 17 summarizes a number of commercially available data display systems. The Infoton display is a proven and acceptable model for the present program.

Tentative Configuration. Figure 6 presents a typical system organization for the data processing equipment summarized above. This suggested system is rather flexible in application and configuration. The peripheral equipment specified can be substituted with a number of alternative models.

Cost. It is impossible to specify cost of the data processing system suggested in Figure 5 without a more detailed specification of the characteristics and desired options for each piece of equipment. The prices suggested in the data summary tables are"rough estimates" and tend to reflect the base cost of the item described. It does not include installation cost, supporting hardware or possible modifications. More definitive cost estimates can only be derived from direct negotiations with manufacturers.

Conversion and Control Equipment. At this point, it would be difficult to survey or specify appropriate conversion and control equipment for the anticipated data processing system. Conversion and control subsystems are system specific and are designed, for the most part, specifically for the peripheral and central equipment selected. At the present time, however, the Astrodata "Translator" appears to offer sufficient flexibility to interface many of the component subsystems discussed above.

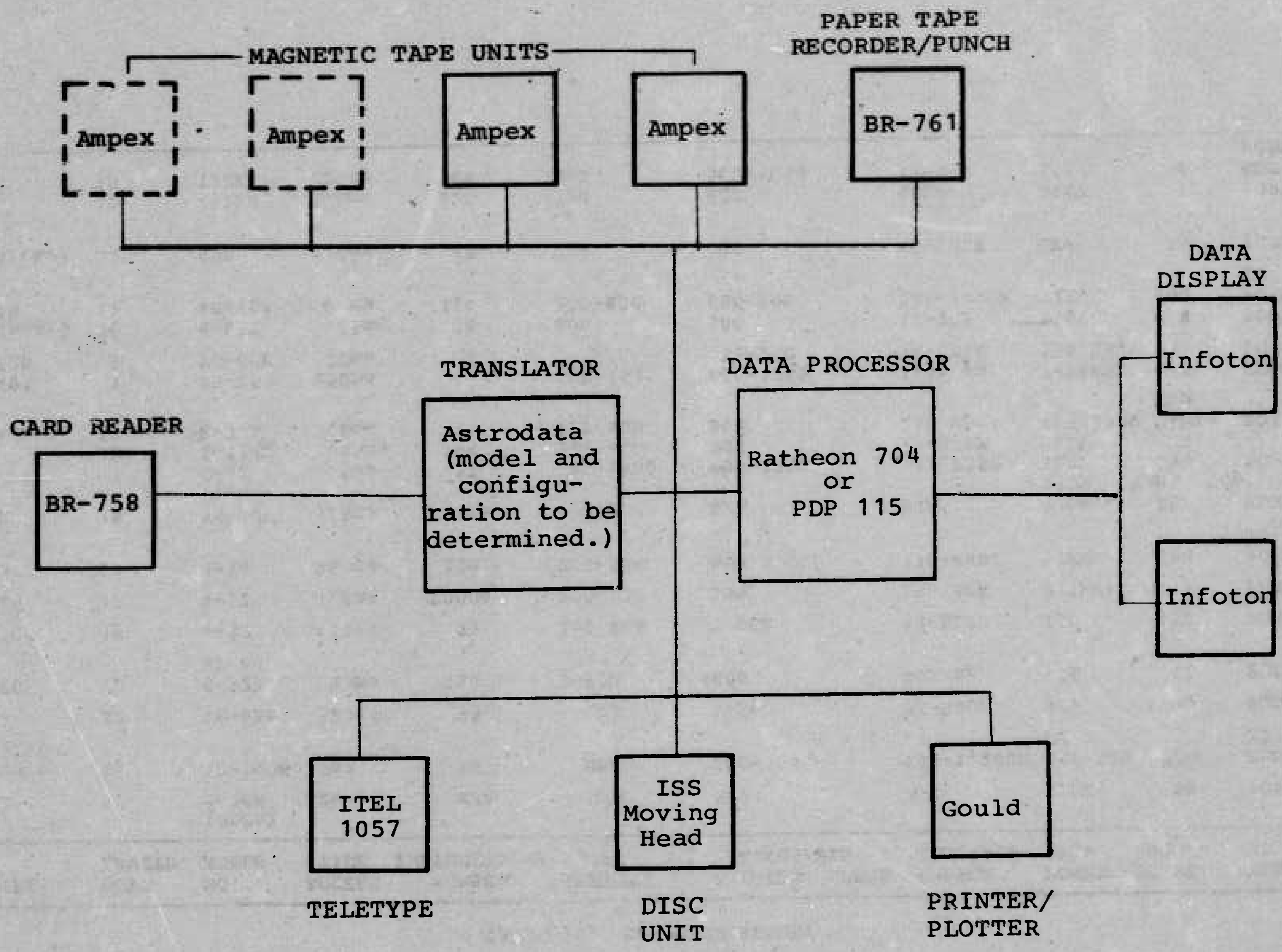


Figure 6. Tentative Data Processing Configuration.

TABLE 12. COMPUTER SURVEY

COMPUTER	WORD LENGTH	NO. WORDS	ACCESS TIME	NUMBER INSTRUCTIONS	DENSITY BPI	PRINTER SPEED LINES/MIN	APPROX. COST ($K)	POWER REQD.	SQ FT REQD.	LANGUAGE
BR-133	15	(core) 8-16K	2ms	N/A	N/A	N/A	N/A	1.5K	10	FORTRAN
Burroughs 2500/3500	16	10-500K	1ms	95	800	700-1040	192-1,200K	208-240 KV	N/A	FORTRAN IV
C-8500	32	16-65K	520ns	93	800	1,000	75-300K	48V	1000	FORTRAN
CDC-160A	12	8-32K 32-64	22.[illegible]s	134	2-500	600	90K up	115	12	FORTRAN
CDC-1700	16	4-32	1.1ms	72	200-800	1,000	43-500K	150	150	FORTRAN
EAI 640	16	4-32	1.6ms	2000+	200-800	300	28-150K	2.1KV	14	FORTRAN
GE-215	20	4-16	36 ms	300+	200-556	450 & 900	110-440K	17KV	680	FORTRAN IV
H-316R	16	16-32K	1.6ms	72+	800	N/A	52K+	475W, 115V	2½ Table Top	FORTRAN
H-120	1	2-32	1.5ms	37	200-1600	450-1300	113-225K	15KV	390	FORTRAN IV
H-632	32	8-131K	.85ms	144	200-800	300	97-375K	220V	22	
HP-2116B	16	8-32K	1.6ms	70	200-800	300	24K up	115/230V	Table Top	FORTRAN
IBM-1401	1	10-20	550ms	43	200-1511	600-1285	125K up	7-16KV	450	FORTRAN
IBM-1620	2	20-60K	20ms	32	N/A	150-240	74-200K	15A, 230V	22	FORTRAN
Interdata-3	16	4-65K	.75ms	75	800	300	11-22K	115V	4	FORTRAN
NCR-315	12	10-80K	6 ms	124	200-800	600-900	204-1440K	17KV	500	FORTRAN IV IV
Okiminitac-7000	24	65K	5.6ms	50	200	525	40-800K	5KV	$15m^2$	FORTRAN IV
PDP-8	12	4-32K	1.5ms	225	750	900	~~10K+~~	24KV	7	FORTRAN IV
PDP-15	18	128K	800ns	64	260	300-1000	17-91K	115V	6	EXT FORTRAN

TABLE 12. COMPUTER SURVEY (CONTINUED)

COMPUTER	WORD LENGTH	NO. WORDS	ACCESS TIME	NUMBER INSTRUCTIONS	DENSITY BPI	PRINTER SPEED LINES/MIN	APPROX. COST ($K)	POWER REQD	SQ FT REQD.	LANGUAGE
Philco 2000-211	8	8-32K	4.0 ms	225	750	900	1500K	24KV	1300	FORTRAN IV
Raytheon 704	16	4-32K	1.75ms	74	800	300	15-290K	110V	5	FORTRAN IV
RCA 3301	6	40-160K	1.5 ms	61	200-800	1000	536K	23.2KV	900	FORTRAN IV
SCC-4700	16	4-65K	.92ms	90-109	200-800	300-1000	17-100K	110V	7.5	FORTRAN IV
SDS-940	24	33K	3.5 ms	94	800	140-2400	250-600K	3KV	22	FORTRAN IV
SDS Sigma 2		16K	2.25ms	37	200-800	1000	26-150K	208V	14	FORTRAN IV
UNIVAC III	6	8-32K	4.0 ms	67	333	700-920	925K	47KV	750	FORTRAN IV

TABLE 13. MAG TAPE I/O SURVEY

COMPANY	MODEL	POWER	DIMENSIONS	WEIGHT IN LIBS	REWIND TIME	CHARACTERS	TAPE SPEED	DENSITY BPI	NO. TRACKS	COST
Honey-well	316 series 516-4150	120VAC, 60Hz	60¼ x 27 x 38	900	4.5 min	28.8K	36 IPS	800	N/A	$18,000.
	516-4155	120VAC, 60Hz	60¼ x 27 x 38	900	2.0 min	64.0K	80 IPS	800	N/A	N/A
B-R	170/192	60Hz, 600W	59 x 20 x 16½	400	2.1 min	N/A	76 IPS	556	N/A	$25,000.
CalcomP	76	208V, 3 phase	30 x 29 x 66	380	2.0 min	60 K	N/A	800	N/A	$22,100.
	770	208V, 3 phase	30 x 29 x 60	380	2.0 min	150 K	N/A	800	N/A	$26,300.
	780	208V, 3 phase	30 x 29 x 60	390	1.0 min	180 K	N/A	800	N/A	$30,500.
	1040	208V, 3 phase	30 x 29.5 x 60	425	1.0 min	320 K	N/A	up to 1600	N/A	$60,000.
H-P	3950/A	N/A	18 x 25 x 60	N/A	130 sec	60 K	3¼-120	800	14	$21,200.
	3950/B	N/A	18 x 25 x 60	N/A	130 sec	60 K	3¼-120	800	7	$14,615.
BR	BR-765A	60V, 600W	N/A	N/A	N/A	56 K	96 IPS	556	N/A	$ 9,700.
	BR-765B	60V, 600W	N/A	N/A	N/A	56 K	96 IPS	556	N/A	$19,950.
H-P	HP-2020A	115V, 60Hz	19 x 24 x 60	428	3.1 min	40 K	30 IPS	200	7	$13,300.
	HP-2020B	115V, 60Hz	19 x 24 x 60	428	3.1 min	55 K	45 IPS	200	7	$13,895.
								556		
	HP-3030G	115V, 60Hz	19½ x 23½ x 60	428	3.1 min	80 K	75 IPS	800	9	$18,500.
Ampex	ATM-13511	115V, 400Hz	24½x16 3/4x16½	149	3.0 min	120 K	75 IPS	up to 800	N/A	N/A
	ATM-13591	115V, 60Hz	24½x16 3/4x18	175	3.0 min	120 K	75 IPS	up to 800	N/A	N/A
Sagu-mund	SABRE IV	115V, 60Hz	18 x 22 x 72	450	1.0 min	N/A	96 IPS	96 IPS	N/A	N/A

TABLE 14. DISC RECORDER SURVEY

COMPANY	MODEL	POWER	DIMENSIONS IN INCHES	WEIGHT IN LBS	WORDS/ DISC	TRACKS/ SURFACE	SURFACES/ DISC	WORDS/ DISC	COST (APPROX.)
Honey-well	516-4650	115V, 60Hz	39x35 3/4x30	300	N/A	200	2	756K	N/A
	516-4651	115V, 60Hz	39x35 3/4x30	300	N/A	200	2	756K	N/A
Calcomp	CD1	208V, 60Hz	30 x 24 x 40	350	N/A	200	10	58 mil	$ 10,000
	CD12	208V, 60Hz	30 x 24 x 40	350	N/A	200	20	29.[illegible] mil	$ 62,000*
	CD225	208V, 3 phase	32 x 33 x 60	510	N/A	200	200	233 mega bits	N/A
									*with controller unit
HP	8620A	115V/60Hz	32 x 28 x 45	N/A	184K	200	N/A	N/A	$ 23,500
	8620B	115V, 60Hz	32 x 28 x 45	N/A	368K	200	N/A	N/A	$128,000
ISS	MOVING HEAD	110V/60Hz	30 x 29 x 60	365	250K	400	28	N/A	$ 75,000

TABLE 15A. PAPER TAPE PUNCH SURVEY

COMPANY	MODEL	DIMENSIONS IN INCHES	WEIGHT IN LBS	CHARACTER DENSITY	TAPE SIZE IN INCHES	TAPE SPEED	COST (APPROX.)
Honeywell	516-52	17½ x 24 x 25 5/8	150	10 CPI	1	110 c/s	$3,800.00
BR	BR-716	33 x 20 1/4 x 20½	310*		1	60/sec	$3,075.00
H-P	HP2753A HP2753A	30 x 28½ x 60	325	10 cpi 10 cpi	½	120c/sec 120c/sec	$4,000.00 $3,825.00

TABLE 15B. PAPER TAPE READER

COMPANY	MODEL	DIMENSIONS IN INCHES	WEIGHT IN LBS	CHARACTER DENSITY	READING TIME	CHANNEL CAPACITY	COST
Honeywell	516-50	17½ x 24 x 25 5/8	150	10 cpi	3000/sec	8 levels	N/A
B-R	BR-762	33 x 24½ x 20½	310*	N/A	300/sec	5-8	$2,425.00
H-P	HP2765B	30 x 24½ x 20	200	N/A	3000/sec	8	$2,100.00

*Includes reader and punch

TABLE 16A. DATA TERMINALS SURVEY

COMPANY	MODEL	DIMENSIONS IN INCHES	WEIGHT IN LBS	TRANSFER RATE	FUNCTIONS	COST
ITEL	1021*(360)	38 x 18 x 9	65	14.8 cps	Typewriter	N/A
	1051*(360)	28 x 16 x 7	70	14.8 cps	Typewriter, Punch tape/card, Reader	N/A
BR	BR-185	11½ x 14 x 16½	75	10 cps	88-C Keyboard	$3,500.
BR	BR-730 Enter/Read Keyboard	N/A	N/A	10 cps	89 Characters, 2 marker controls, Insert/delete by line or page.	$2,475.
	BR-731 (Read-only)	11½ x 11 x 12½	45	10 cps	Read only keyboard	$1,800.
	BR-785A	N/A	N/A	N/A	Teletype/printer 80 chact.	$2,250.
	BR-785B	N/A	N/A	N/A	Teletype/printer 80 chact.	$2,100.

TABLE 16B. TELETYPES

COMPANY	MODEL	DIMENSIONS IN INCHES	WEIGHT IN LBS	TRANSFER RATE	FUNCTIONS	COST
Honeywell	ARS-33		60	12 cps	Teletype	$1.700.
	ARS-35		84	18 cps	Teletype/printer	$4,400.
H-P	HP2752A		65	10 cps	Teletype/printer/ paper tape	$4,600.
	HP2752B		65	10 cps	Teletype/printer/ paper tape	$4,800.

TABLE 17. COMPUTER DISPLAYS

COMPANY	MODEL	DIMENSIONS IN INCHES	WEIGHT IN LBS	DISPLAY SIZE	KEYBOARD/ CONTROL	CHARACTER HEIGHT	CHAR./ DISPLAY	CHAR./ LINE	LINES/ DISPLAY	CHAR. SET	COST
BR	85	48 x 46 x 30	750	23"	20 key	3/8"x1"	N/A	30	18	N/A	$30,000.
Hewlett-Packard	9150A	N/A	38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Computer-Display,	TK340	N/A	45	14"	24 key	N/A	N/A	34	N/A	N/A	N/A
BR	BR-720	34 x 36 x 42	175	12"	16 key	0.13x0.10	960	30	18	N/A	$ 1,425.
	BR-722	39 x 58 x 42	210	27"	16 key	0.10to0.15	960		26	N/A	$ 2,450.
Video Systems	VST 1000	18 x 18 x 18	53	10.5x8"	37 key	0.2x0.1	1296	36	18	64	$ 2,470.
	VST 1200	18 x 18 x 18	58	10.5x8"	37 key	0.2x0.1	1296	72	18	64	$ 2,670.
	VST 2000	18 x 18 x 18	58	10.5x8"	37 key	N/A	2592	64	18	64	$ 2,870.
	VST 3720	18 x 18 x 18	59	10.5x8"	37 key	N/A	2592	96	18	96	$ 2,870.
Info-ton	300	18 x 24 x 16	38	12 x 14	40 key	0.2x0.11	2600	N/A	N/A	N/A	N/A