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AFHRL-TR-74-108(VI)

AIR FORCE HUMAN RESOURCES LABORATORY

COMBAT-READY CREW PERFORMANCE MEASUREMENT SYSTEM: PHASE IIIC DESIGN STUDIES

By
Richard W. Obermayer
Donald Vreuls
Ernest J. Conway

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

FLYING TRAINING DIVISION
Williams Air Force Base, Arizona 85224

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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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This report is the sixth of 7 volumes.

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supporting analyses
design trade offs

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

The current Phase IIIC report deals with design studies to determine desirable system features to meet the research needs documented in the earlier reports of this sequence. Chapter II presents analyses of factors to be considered in training measurement system design. Chapter III indicates the nature of tradeoffs for each system criterion established in the Phase II report. Recommendations based on these analyses are discussed in Chapter IV.

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PREFACE

This interim report was produced as a result of the Phase IIIC 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 current Phase IIIC report deals with design studies to determine desirable system features to meet the research needs documented in the earlier reports of this sequence. Chapter II presents analyses of factors to be considered in training measurement system design. Chapter III indicates the nature of tradeoffs for each system criterion established in the Phase II report. Recommendations based on these analyses are discussed in Chapter IV.

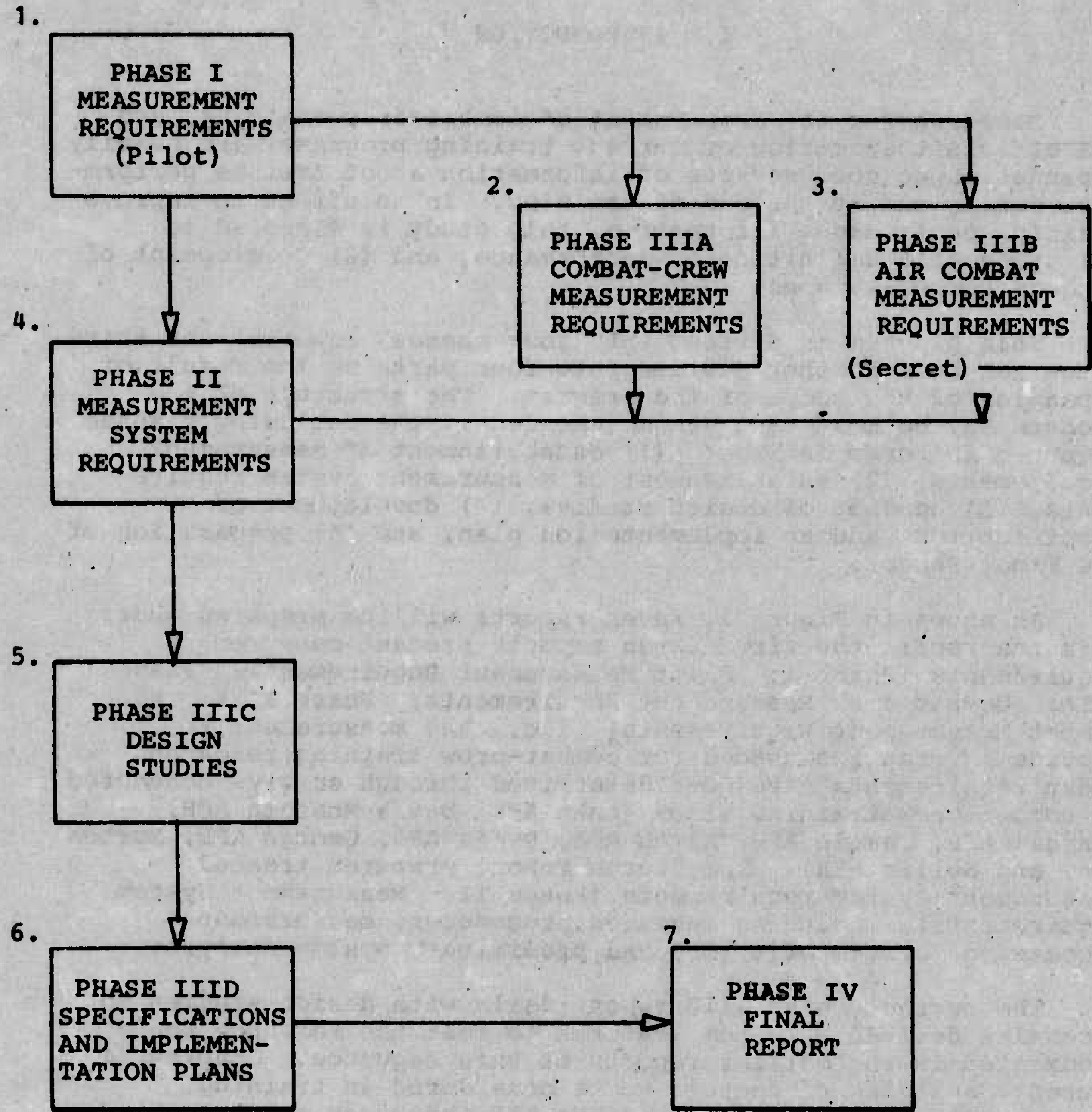


Figure 1. Program Reports.

II. SUPPORTING ANALYSES

A number of analyses have been performed in this program to guide design decisions. Eight primary analytic steps are presented in this chapter; these steps are listed in Table 1, along with comments indicating the specific sources of information used in each analysis and the principal products.

Example measurement (1)* was produced as a product of visits to combat-crew training units to attempt to express the main items of information relevant to training. Using this as a stimulus, preliminary measurement definitions were made along with assumed techniques for computation, leading to identification of a required set of parameters (2) for measurement generation. These analyses were begun in earlier program phases, and subsequently were revised and extended.

Continuing from the basic analyses, specific computational algorithms were chosen for both automatic (3) and manual (4) modes of measurement, forming an initial software specification. The next steps in the sequence attempt to determine best methods for sensing the needed information (5), and the nature of appropriate data processing equipment (6). As video or photographic means of sensing information must be considered, it follows that a minimum resolution for such devices must be specified to ensure that the desired data are sufficiently legible (7). Lastly, data are collected relating to cost and personnel requirements (8) to permit tradeoff analyses between alternative measurement system candidates.

Prototype Measurement

The genesis of measurement development in this program is the definition of training information requirements obtained through visits to combat-crew training units. The principal representation of these information requirements has been termed prototype measurement; an example is presented in Table 2. The information needs have been prepared for each flight phase in a tabular form, with blanks indicating specific measurement which should be developed. In a number of cases the measurement to fill the blank is obvious; in other cases much thought must be given to the proper measurement and to the feasibility of indicated measurement.

Measurement Parameters

When measures are defined to answer to informational needs, the parameters which must be sensed to permit measurement are not immediately evident, since the measure specifies the output of a

*Parenthetical numbers relate to the numbered analyses in Table 1.

TABLE 1

DESIGN ANALYSES

	PURPOSE	SOURCE	RESULT
1.	Determine Measurement Needs	CCTS Visits	Prototype Measurement
2.	Identify Physical Parameters for Measurement	Prototype Meas. and Preliminary Measure Algorithms	Measurement Parameters
3.	Develop Automated Measure Descriptions	#1 & #2; Assume Instrumented Aircraft	Measure Functions & Conditions (Implies Software)
4	Develop Manual Measure Descriptions	#1 & #2; Assume Video Cameras Installed in Aircraft	Measure Functions & Conditions (Implies Procedures)
5.	Determine where to Obtain Information	Analysis of Parameter x Data Source x Training Phase	Alternative Feasible Sources of Information
6.	Determine Data Processing Needs	#3 & #4	Alternative Data Processing Equipment
7.	Determine if Visual Information is Sufficiently Accurate	Avail. Literature Field Studies	Video/Photo Specifications
8.	Determine Cost Tradeoff Data	Industrial Visits	Cost and Personnel Estimates

TABLE 2

EXAMPLE OF PROTOTYPE MEASUREMENT

TAKEOFF & CLIMB*

CONDITIONS:

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

TAKEOFF ROLL: (TO power until rotation)

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

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

Rot. Speed: _____________ Stab. Trim: _____________
Pitch: Rate: ___________ Bank: ___________________
Final: __________ Centerline Dev.: ________
Overshoot: ______ Heading: _______________

LIFTOFF: (Pos. Vert. Vel.)

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

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

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

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

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

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

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

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

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

computation, and the computation itself must be known before the inputs to the computation (the parameters) can be determined.

Figure 2 depicts the relationship between the specified measures, the computation, and measurement parameters. In Figure 2, the output measures (O) correspond to the information requirements dictated by the blanks in the prototype measurement forms. In addition to basic test parameters (M), the following types of parameters may be needed for computation: (1) parameters for implementing logic to start and stop measurement computations (S), (2) information related to desired performance (D), (3) and error information derived from the difference between actual and desired performance (E). In short, given output measures (O), to determine other parameters which must be sensed (M,S,D,E), it is necessary to determine logic and computations to be used in measurement data processing (i.e., the measurement algorithms).

Automated Measurement Descriptions

Assuming automated measurement, i.e., parameters are automatically recorded for subsequent computer analysis, the primary details of measurement computation (Figure 3 shows a representative flow diagram) are presented in Table 3 for each maneuver and maneuver segment of combat-crew training phases. The table indicates the name of each measure, the specific function to be computed, and the start/stop conditions for controlling computation. For example, centerline deviation during the takeoff roll is desired output information, the average, minimum and maximum deviation are the specific computations which should be performed between brake release and rotation. Comments are also provided as considered appropriate by the analyst to point up alternatives, or where problems may be encountered during design.

Since this table indicates the functions to be computed, the conditions under which computation should occur, and indirectly the source information upon which to base computation, the basic information is provided to allow preparation of computer programs for automatic measurement.

Manual Measurement Descriptions

Automated measurement analysis assumes automatic recording of relevant parameters to permit automatic computation; that is, each parameter must be recorded at a sufficiently high sampling rate to allow computation on an instant-by-instant basis. In the case of computing average centerline deviation, recording would occur probably from the release of brakes, all centerline deviations would be summed, when a change in pitch angle was noted the summation would cease and the total divided by the number of samples summated.

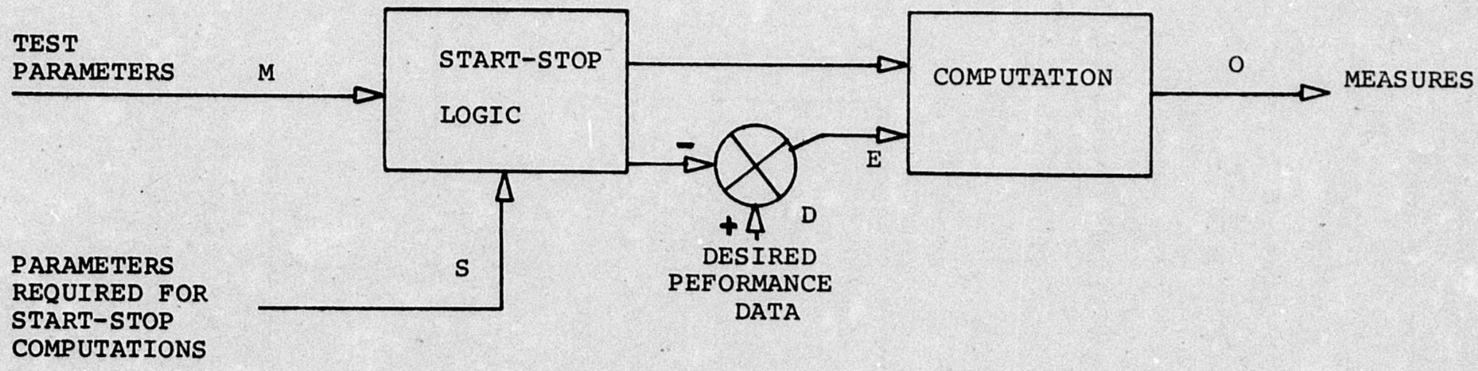


Figure 2. Identification of Measurement Parameters.

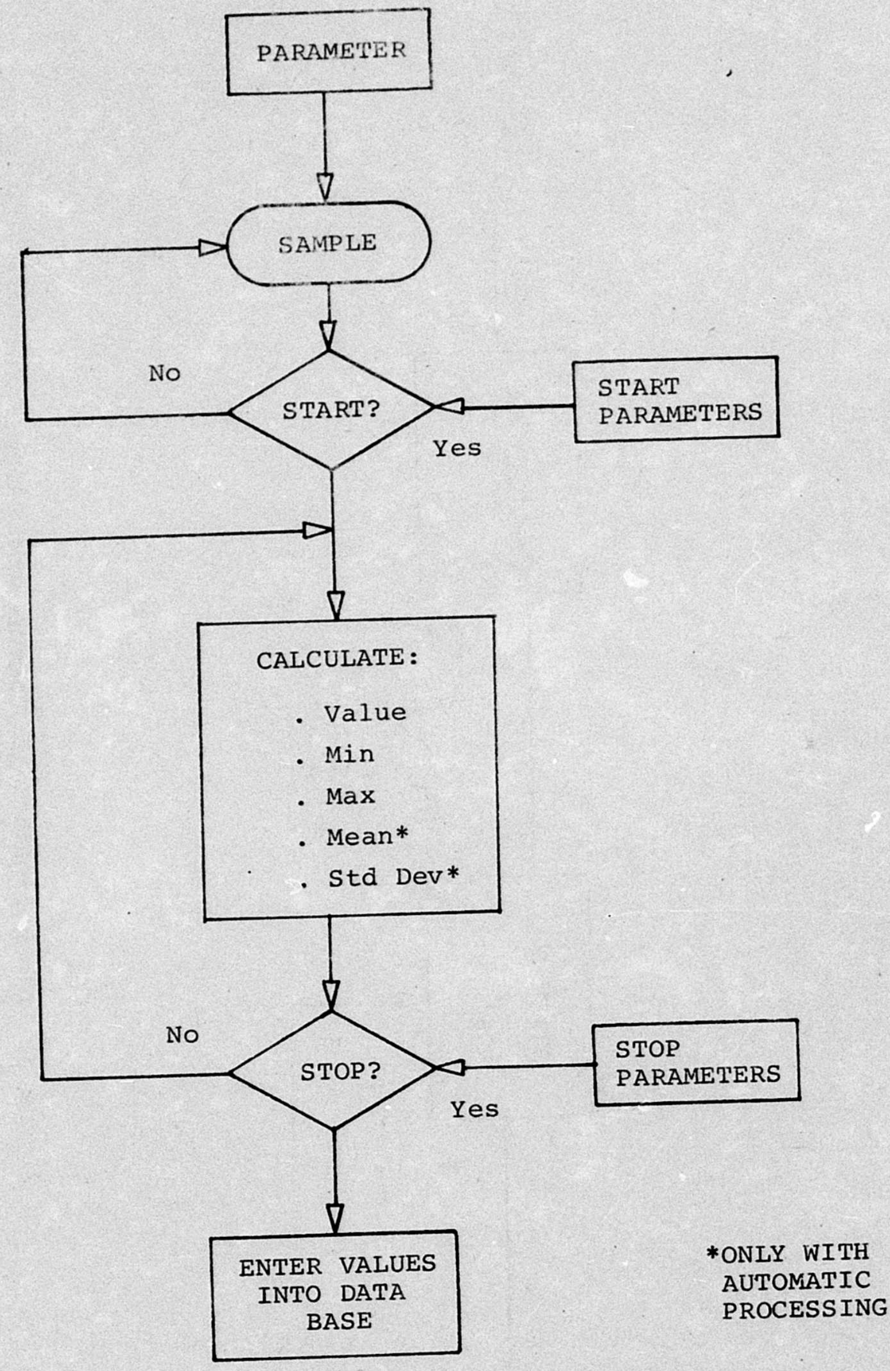


Figure 3. Example Raw Data Processing.

TABLE 3. AUTOMATED MEASURE DESCRIPTIONS

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
TAKEOFF Roll	GMT	Value	At brake release.	
	Gross WT	Value	At brake release.	
	Wind Direction	Value	At brake release.	
	Wind Velocity	Value	At brake release.	
	Temperature	Value	At brake release.	
	Field Elevation	Value	At brake release.	
	Altimeter Setting	Value	At brake release.	
	Formation Posn.	Value	At brake release.	
	Power	Average	From brake release to rotation.	Power, aircraft dependent; use fuel flow, TIT or N_2.
	Centerline Deviation	Average Minimum Maximum	From brake release to rotation.	Complex instrumentation . On ILS runways, use localizer deviation corrected for range. Range either ILS/DME or approximation using the integral of airspeed. . TACAN accuracy probably not sufficient. . Windscreen, HUD photography possible source with rotation. . Good inertial (commercial quality) also possible source.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
	Heading	Average Minimum Maximum	Error from rnwy heading from brake release to rotation.	Insertion of rnwy heading required in processing.
	Roll	Minimum Maximum	From brake release to rotation.	Looking for maximum left and maximum right roll attitude.
	Distance down runway (DDR)	Value	At rotation.	Complex instrumentation . On ILS/DME rnwys, DDR can be computed from DME. . TACAN accuracy may be sufficient depending on location/geometry relative to rnwy. . $\frac{1}{T}\int(\text{airspeed})dt$ may be reasonable approximation. . Commercial quality INS may suffice. Takeoff conditions need not be recorded on board, but may be manual entries into system based on flight records, etc.

For all maneuvers, communications should be recorded for accuracy, brevity, phraseology and as a key for measurement (start/stop) of other parameters.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Rotation	Airspeed	Value	Weight off nosegear.	
	Stab Trim	Value	Weight off nosegear.	
	Roll	Minimum Maximum	Weight off nosegear until weight off main gear, or positive V/V.	
	Pitch Rate	Minimum Maximum	"	
	Centerline Deviation	Minimum Maximum Average	"	See takeoff roll for instrumentation notes.
	Heading	Minimum Maximum Average	"	
	Pitch	Maximum	"	
Liftoff	Pitch	Value	Weight off main gear or positive V/V.	
	Airspeed	Value	"	
	Roll	Value	"	
	Heading	Value	"	
	V/V	Value	N-seconds after liftoff.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Gear Up	Airspeed	Value	When gear up selected.	
	V/V	Value	"	
	Pitch	Min, Max	From gear up select until gear up & locked.	
	Roll	Min, Max	"	
	Heading	Min, Max	"	
	V/V	Value	When gear up and locked.	
Flap Schedule (Except B-52 and F-106)	Stab Trim	Min, Max	From handle up to full up flaps.	F-106 has no flaps.
	Pitch	Min, Max	"	
	Roll	Min, Max	"	
	Heading	Min, Max	"	
	Airspeed	Value	When handle up <u>and</u> again when flaps full up.	
	V/V	Value	"	
	Altitude	Value	"	Require field elevation for HAT computation or measure radar altitude directly.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Flap Schedule (B-52 Only)	Airspeed	Value	Measure four times	
	Pitch	Value	(1) Start of retraction	
	Altitude	Value	(2) First position	
	V/V	Value	(3) Second position	
	Stab Trim	Value	(4) When full up.	
Climb & Leveloff (Accelerate)	Power	Value	When climb A/S achieved.	Depends on flight (vertical Axis only).
	Airspeed	MC		
	Pitch	Value		
	Altitude	Value		
	GMT	Value		
(A/S Climb)	Power	Avg.	From airspeed climb until DSRD MACH achieved	Assume constant A/S MACH climb.
	Airspeed	Min, Max, MC		
	Pitch	Min, Max		
	V/V	Min, Max		
	MACH	MC		
	Altitude	Max		
(MACH Climb)	Power	Value (initial)	From MACH=DSRD until ALT=ALT-10% V/V.	
	MACH	Min, Max		
	Pitch	Min, Max		
	V/V	Min, Max, MC		
(Leveloff)	GMT	Value	AT ALT=DSRD ALT	
	V/V	Value		
	Pitch	Value		
	MACH	Value		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
PATTERN, Landing	Gross WT		Before Initial	
	Wind Direction			
	Wind Velocity			
	Runway Used			
	Field Elevation			
	Temperature			
	Altimeter Setting			
	Formation Posn.			
Initial	Power	Value	At initial point (when established) and radio call)	Determination of A/C established on initial can be made after the fact fy plotting posn. Position measure undefined can be lat/long, brg and distance from known TACAN or an x-y coordinate system relative to the base.
	Airspeed	Value		
	Altitude	Value		
	Heading	Value		
	Position	Value		
	Time	Value (GMT)		
Pitchout	Power	Value	At pitchout point (radio call)	
	Airspeed	Value		
	Altitude	Value	"	
	Position	Value	"	Position measure undefined <spacing for #2, #3, #4 a/c.
	Spacing	Value	"	
	Bank	Value	After 30^{o} of turn	
	AOA	Value	"	Not C-130
	G	Value	"	Not C-130
	Airspeed	Value	When: Speed brakes out; Speed brakes in; Gear down; Each Flap actuation	
	Flap Position	Value(amount)	Each Flap actuation.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Downwind	Power	Value	When established on downwind (radio call).	
	Airspeed	Value		
	Altitude	Value		
	Heading	Value		
	Stab Trim	Value		
	Spacing	Value		<Spacing = distance, #2, #3, #4.
	Airspeed	Value	Each Flap actuation.	
	Flap Position	Value	Each Flap actuation.	
	Rnwy Lateral Displacement	Value	When established on downwind.	
Base, Dogleg, Final	Power	Value	Each 100' of altitude from 900' to 100' AGL.	
	Airspeed	Value		
	Altitude	Value		
	Heading	Value		
	Roll	Value		
	V/V	Value		
	Trim	Value		
	Flap Posn	Value		
	Rnwy Centerline displacement	Value		Plot of ground track vs Alt also desired.
Landing (Threshold)	Altitude	Value	At rnwy threshold	
	Airspeed	Value	"	
	Heading	Value	"	
	Roll	Value	"	
	Rnwy Centerline displacement	Value	"	Position measure undefined.
	Lateral Drift	Value	"	Position rate (drift) undefined.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
(Touchdown)	Airspeed	Value	At Touchdown	Touchdown determination (1) weight on main gear (best), or (2) main gear rotation, or (3) $vv \leq \phi$.
	Heading	Value	"	
	Roll	Value	"	
	Pitch	Value	"	
	V/V	Value	"	
	Rnwy Centerline Displacement	Value	"	
	Distance Down Runway	Value	"	
	GMT	Value	"	
(Rollout)	Heading	Min, Max, Avg	From Touchdown until A/S< K knots.	K knots should be low enough to assure ability to stop, but higher than turn-off speed or measures will include deviations due to turn-off. Position measures undefined.
	Rnwy Center-Displacement	Min, Max, Avg		
	Brakes	Measure control	"	
	Airspeed	Value	At nose gear down; At thrust reversal; At nose steering engaged; At drag chute deployment; At first brake application.	
	Power	Value	At thrust reversal.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Go-Around	Power	Value	At go-around point.	Determination of go-around point undefined.
	Speed Brakes	In or out?	At max power.	
	Airspeed	Value	Each flap activation.	
	Flap Position	Value	Each flap activation.	
	Airspeed	Value	At gear retraction.	
	Pitch	Value	(1) Initial value (2) At go-around point.	
	Pitch	Maximum	From go-around point until N seconds after positive v/v.	Termination of go-around (N-seconds after vv=+) to be determined.
	Roll	Min, Max		
	Altitude	Value	At go-around point.	
		Minimum	From go-around point until N seconds after positive V/V.	
		Value	At go-around termination.	
	GMT	Value	At go-around point.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
INSTRUMENTS: GENERAL CASE	Pitch Roll Heading Thrust Airspeed MACH Altitude V/V AOA	(a) Value, or absolute value. (b) Min, Max, Avg, absolute average. (c) Error from desired value. (d) Min, Max, Avg, absolute average, or RMS error.	(a) At specific times, events or positions in profile. (b) For specific intervals or events. (c) At specific times or positions in profile. (d) Error between desired and actual over specific intervals.	Completion of error data requires setting desired data into measurement logic.
	Time	(e) Count (number) cumulative.	(e) Count each time tol. exceeded time length of each out of tol. condition.	
	Nav Radio Freq VOR/TACAN	Value error (See above for distinction).	At specific times, events or positions in profile.	
	Datum	Value or error		
	DME Range	Value		
	VOR/TACAN Course Error	Value, min, max, avg, $\lvert avg \rvert$, or RMS error.	At specific times, events or positions in profile, or during specific intervals.	
	ILS Local, error	Value		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
	G/S Error	Number of out of tolerance events. Time out of tolerance.	Count each time tol. exceeded time length of each out of tol. condition.	
	Cross-Track Deviation	Course error in radians X DME range.		

MANEUVER	MEASURE	FUNCTION	SFQUENCE	COMMENTS
INSTRUMENTS: EXAMPLE MEAS.				
SID				Example is Vulture One SID, Luke AFB, AZ.
(Takeoff)				See takeoff measurement.
(Segment I)	Airspeed	Min, Max, Avg.		
	V/V	Min, Max, Avg.	From climb established until the 4 n.m DME Fix (on runway heading).	
	Heading	Min, Max, Avg. error from rnwy heading.		
	Roll	Min, Max, Avg.		Min, Max ≈ Left, may Right.
	Altitude	Max,		For measurement control.
	DME	Value		
	VOR/TACAN Channel	Value		Should be Chan. 77.
	VOR/TACAN Course Set	Value		Should be set to 294° radar for proper CDI presentation.
	Heading	TOT*	When heading error from rnwy >5°.	
	Roll	TOT	When |roll|>10°	
(Segment 2)	Airspeed	Min, Max, Avg.	From 4 n.m. DME Fix to LUF TACAN	LUF station passage defined as<DME 1 n.m. and>bearing 90°
	Pitch	Min, Max, Avg.		
	DME	Max		
	Altitude	Min, Max, Avg.		
	"	Value		For measurement control.
	DME	Value		
	DME	TOT	From 4 n.m. DME Fix to LUF TACAN and when DME>8 n.m.	
	Airspeed	Min, Max, Avg.		
	Roll	Max		
	Thrust	Min, Max, Avg.		
	Altitude	TOT	From 4 n.m. DME Fix to LUF, and when Alt>4000 ft.	

*Time out of tolerance

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Station Crossing*	Time	GMT Value	When DME <1 n.m. and TACAN Bearing >90°.	(SID Vulture I, Example, cont'd.) Station passage measures; typical of enroute except that station crossing DME range criteria must be a function of altitude.
	Altitude	Value		
	Heading	"		
	Airspeed	"		
	Roll	"		
	Thrust	"		
	DME Range	"		
	TACAN Bearing			
Navigator Leg*	Airspeed	Min, Max, Avg.	From LUF Station crossing to Vulture (DME>, 31 n.m.).	SID Vulture One example continued, although typical of enroute Nav. Leg. Computation of course error can be derived by subtracting desired course from computation of actual radial based on Heading & Relative Bearing. Meas. control.
	Heading	"		
	Roll	"		
	Pitch	"		
	V/V	"		
	TACAN/VOR Course	"		
	Error or Bearing	"		
	Altitude	Min, Max		
	DME	Value	(continuous)	
	Cross-Track Dev.	Course Error (Radians) X	From LUF to Vulture	
	A computation	DME Range; Min Max, Avg, RMS		
	Cross Track	TOT	When cross track >4 n.m.	
				*Measure sets overlay takeoff, flap schedule, climb schedule and level-off measurement. To fit current altitude, heading & speed criteria, error scores from desired values should be computed.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
PENETRATION & TACAN APPROACH				Example = Tacan 2, rnwy 21 L & R, Luke AFB example.
(IAF: Morris-town Inter-section)	Nav Freq	Value	Prior to IAF ETA When DME < 22 n.m. <u>and</u> within ± 10° of LUF R314.	CH 77 desired.
	Heading	Value		
	Airspeed	Value		
	Altitude	Value		
	Time	GMT Value		
	Roll	Value		
	Thrust	Value		
	V/V	Value		
	Tacan Bearing	Value		
	DME Range	Value		Meas. control
	Tacan Radial Computation	Compute radial from heading & relative bearing.	Prior to IAF	
(Holding)	Altitude	Min, Max, Avg	From IAF crossing to IAF crossing (each revolution)	
	Airspeed	Min, Max, Avg		
	DME Range	Min, Max		
	Heading			
	Tacan Bearing	For computations		
	Dme Range			
	Cross-track Deviation-Computation	Max L, Max R of inbound course. Compute actual radial from heading & bearing, compute error from desired radial (314), then compute x-track from course error and DME range.	"	Max L & Max R, together with Min, Max DME defines airspace used to hold. Further measurement can be based on excursions beyond criterion airspace (number of times out, length of time out, heading, A/S, roll when airspace exceeded).

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
(Penetration on R314 to 16 DME Arc)	Airspeed	Min, Max, Avg	From V V <-2000 FPM to arc interception level point.	Arc interception lead point based on DME = (Mach X 10)- 2 + desired fix(16).
	Thrust	Min, Max, Avg		
	Heading	Min, Max, Avg		
	Roll	Min, Max		
	Pitch	Min, Max, Avg	"	
	V/V	Min, Max, Avg MC	"	
	Altitude	Min, Max	"	
	Speed Brakes	Value	"	
	Time	GMT Value	When V V <-2000 FPM and again at arc intcp. lead pt.	
	Tacan Bearing	Values for computations		
	DME Rng			
	Cross Track Computations	Min, Max, Avg error from desired radial.	From IAF crossing to arc interception lead pt.	See holding for computation.
(Arc to R260) and (Arc to R195)	Airspeed	Value, Min, Max, Avg	Values at arc intercept (DME < 17 n.m. and BRG > 70°); min, max and avg from arc intcpt to crossing R260. Repeat value meas at R260 and min, max and avg meas to R195 interception lead point.	
	Thrust	Value, Min, Max, Avg		
	Heading	Value		
	Roll	Min, Max		
	Pitch	Min, Max		
	Altitude	Value, Min, Max		Termination of arc measurement at lead point for turn to R195: Turn rate — Lead Pt (n.m.) 1.5°/sec — 1% X ground speed 3.0°/sec — .5% X g.s. 6 S < 150 knots — ½ n.m. lead.
	V/V	Value, Min, Max, Avg		
	Speed Brakes	Value		
	Tacan Bearing	Value, Min Max, Avg, MC		
	DME Rng	Value, Min, Max, Avg, MC		
	Time	Value (EMT)		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
(R195 to FAF to Map)	Airspeed	Value, Min, Max, Avg	All "values" when heading within 15^{o} of final course (015^{o}); min, max & avg from above until 6 nm DME fix. At 6 nm DME fix, measure "values." Then repeat measures of min, max, avg until map (DME =2nm). Measure values again at map.	Pattern, land and go-around measures overlay these measures (in part).
	Thrust	Value, Min Max, Avg		
	Heading	MC, Value, Min, Max, Avg, Std		
	Roll	Min, Max, Avg, RMS		
	Pitch	Min, Max, Avg, Std		
	Altitude	Value, Min, Max		
	V/V	Value, Min, Max, Avg, Std		
	AOA	Value, Min, Max, Avg, Std		
	Speed Brakes	Value		
	DME Rng	MC, also Value for		
	Tacan Bearing	Value comp.		
	Time	Value, GMT		
	X-track Dev. Computation	Max_L, Max_R, Avg, RMS		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
ILS, EXAMPLE (IAF)	Heading	Value (also for computation)	When VOR $\geq 90^{o}$	ILS rnwy 31, March AFB
	Speed	Value		
	Altitude	Value		
	Time	Value, GMT		
	VOR Freq	Value		
	VOR Bearing	Value (for computation)		
(Turn to 134^{o}) (Turn to 314^{o})	Heading	Value	When: $131^{o} <$ heading $< 139^{o}$ and when: $311^{o} <$ heading < 319 until alt <4400.	Repeat measures until descent below 4500'. Holding pattern airspace determination cannot be made without DME from RIV Vortac and calibration of VOR holding pattern from Vortac.
	Speed	Value		
	Altitude	Value		
	Time	Value (GMT)		
	VOR Bearing	Value		
(Descent from 4500)	Heading	Value, Min, Max, Avg, Std	Values when alt < 4400.	
	Roll		Min, max, avg, RMS until glide scope = ϕ or VOR bearing $> 90^{o}$, whichever occurs first.	
	Pitch			
	Speed	Value, Min, Max, Avg		Alternate stat. crossing when TO/FM goes from to → from.
	Thrust	"		
	Altitude	Value, Min, Max		
	Time	Value (GMT)		
	VOR Bearing	Value, Min, Max, Avg		
	ILS Freq	Value		
	ILS Localizer	Value, Min, Max, Avg, RMS		
	ILS Glide Scope	Value (for computation)		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
	Gear Flaps Speedbrakes			As required in pattern, land measurement.
(G/S Int to mm)	Pitch	Value, Min Max, Avg, Std	Values at middle marker.	
	Roll	Value, Min, Max, Avg, RMS		Also desireable to have unused radios set for missed approach. (Freq and course)
	Heading	Value, Min, Max, Avg, Std	Min, max, avg, std, RMS from G/S int to mm.	
	V/V	Value, Min, Max, Avg, Std		
	Airspeed	Value, Min, Max, Avg, Std		
	Thrust	Value, Min, Max, Avg		
	AOA	Value, Min, Max, Avg, Std		For localizer only, disregard glide scope, use MDA as altitude criteria, score min, max altitude from VOR inbound.
	Localizer	Value, Min, Max, Avg, RMS (TOT)		
	Glide Scope	Value, Min, Max, Avg, RMS, (TOT)		
	Marker Beacon	Value for meas. control.		
	Altitude	Value		
	Time	Value (GMT)		
	(Localizer)	TOT (TOL A), % total	When loc > TOL A	TOT = DME out of tolerance; TOL values to be established. Also, possible to set sucessive TOL bands A, B, C, etc. % total= % of total TOT for each TOL band excursion.
		TOT (TOL B), % total	When loc > TOL B	
	(Glide Scope)	TOT (TOL A), % total	When G/S > TOL A	
		TOT (TOL B), % total	When G/S > TOL B	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
GCA, GENERAL EXAMPLE (Initial Vectoring)	Pitch Roll Altitude Heading V/V A/S AOA Thrust	Min, Max, Avg error from last command.	From command to command.	
	Posn: Tacan Brg DME	Value	Each cmd.	
(Final vectoring)	Gear	Value (in landing configuration	Per commands.	
	Flaps Pitch Alt V/V AOA Thrust Roll Heading	Min, Max, Avg, error from last command. Also Std Heading, VV Pitch & RMS roll.	From command to command and at gate.	Determination of gate (100' 1/2 mi) is required.
	Pitch Cmds Roll Cmds	Count Count	Slightly: above(below) above(below) well above (below) commands Heading cmd changes.	
	Posn: Tacan Brg DME	Value, Min, Max, Avg, Std, Error	Value, each command and at gate. Min, max, avg, std from G/S interception to gate.	Min, max, avg, std vertical & horizontal path error to be recontructed from calibrated Tacan on ideal profile.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
FORMATION				
Join-up Lead:	Thrust	Min, Max, Avg	From start of join-up until joined.	1. Conditions which define start of joinup & "joined" to be empirically determined.
	Airspeed	Min, Max, Avg		2. Closing rate available from ground tracker or airborne radar if: a. Radar installed and b. Lockon is possible.
Element(s)	Closing Rate	Min, Max, Avg		
	Time	Cumulative		
Close Form Lead:	Turn Rate	Min, Max, Avg	For each steady-state maneuver segment.	
	G's	"		
	Thrust Rate	"		
Element(s)	Stab Trim	"		
	Stick Pitch	" + reversals		
	Stick Roll	"		
	Range	Min, Max, Avg		1. Rng, bearing & altitude difference from #1-#2; #2-#3; #3-#4.
	Bearing	Min, Max, Avg		
	Altitude	Min, Max, Avg Difference		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Trail Elements	Range	Min, Max, Avg	Each steady-state maneuver segment.	Measures from following aircraft to lead.
	Bearing	Min, Max, Avg		
	Altitude	Min, Max, Avg Diference		
	X-Track Deviation or	Min, Max, Avg	"	Deviation of follower from ground track of previous aircraft.
	Airspeed	Values		
	Heading	"	Plotted or listed per unit time from radar lock until trail formation terminated.	Sampling rate to be empirically determined.
	Altitude	"		
	Bearing	"		
	Range	"		
	Elevation Angle Radar	"		
	Time			

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
INTERCEPT Initial Conditions Target	Heading	Value		
	Altitude	"		
	MACH	"		
	ECM	Type used		
	Evasive Maneuvers	Definition		
Interceptor	Heading	Value, Compute HCA		Heading crossing angle computed from TGT & INT. data.
	Altitude	"		
	MACH	"		
	Closing Velocity	"		
	Range	"		
	Attack Type	Definition		Define attack type such as SNAP, co-altitude, datalink, close control, MCC.
Search	IF Gain			Scope adjustment may be replaced by high quality scope camera or TV info.
	Video Gain	Value	At start of initial vectoring.	
	Erase Gain			
	Heading	Min, Max	Each 5 n.m. segment (see below).	
	MACH	Min, Max		
	Altitude	Min, Max		
	Fuel Quantity	Value (monitor for meas control)	Each 5 n.m.	(5 n.m. sample subject to verification)
	Target Azmuth		From time interceptor within effective radar range until lockon, <u>or</u> fire, <u>or</u> 1 n.m. range.	
	Target Elevation			
	Target Range			
	Target Closing Velocity			

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Search (Continued)	Target Aspect Radar Elevation Scan Width Time (GMT)	Value		Target aspect computed from TGT-INT Δheading and TGT bearing or from ground tracks.
	Lockon Pulse Firing Pulse	(Monitor for meas. control)		
Lockon	Target Azmuth Target Elevation Target Range Antenna Azmuth Antenna Elevation Range Gate	Value	Sample each second from ½action switch depressed until lockon, or firing, or switch released. If no lock, return to search measures.	
	½ Action Switch	Monitor fcr meas. control.		
	Lockon Pulse	"		
	Firing Pulse	"		
	Heading	Min, Max, Avg		Aircraft control during lockon.
	Altitude	Min, Max, Avg		
	MACH	Min, Max, Avg		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Attack	Lockon Pulse Pitch Roll Heading Thrust MACH	Monitor for meas control.		Aircraft control
	AOA G TGT Heading TGT Elevation TGT MACH TGT Aspect ANT. Elevation ANT. Azmuth TGT Range Closing Velocity Steering DOT Error	Value	Each one n.m. of range from lockon to fire, or Rmin, and at fire, or until TGT aspect $<90^{\circ}$, then each 5 seconds until fire, or Rmin and at fire.	One n. m. sample to be empirically verified.
	Firing Circle Radius Time	Meas. control		
	Missile ΔElev	Value	At firing only	Δ's are between fire compu system & missile seekers insure that missile looking at same target as fire compu.
	Missile Δ Azmuth	Value	"	
	Missile Δ Range	Value	"	
	Missle ΔVC	Value	"	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Reattack	Attack Measures Search Measures Lockon Measures		Each 5 seconds	For re-attack, return to attack meas. set, sampling each 5 seconds unless lock broken. If break lock, return to search & lockon & attack measures, but sample each 5 sec.
Breakaway, Escape	Pitch Roll Heading Altitude MACH Time (GMT & Seconds)	Value	At max G during breakaway turn.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
GROUND ATTACK Initial Conditions	GWT Air Temp Air Press Wind Dir/ Veloc. Formation Posn	Values	Initial conditions at start of runs.	Also define: type of weapon delivery, target type, range pattern.
Downwind/ Base	Spacing Heading Altitude Airspeed Time	 Value (Meas. control) Value Value Value	When established on downwind/base	Spacing = gross position behind prior aircraft. Established on downwind subject to develop. test; however heading & altitude within tolerance assumed.
Turn to Final	Altitude Airspeed V/V Pitch Power Heading Roll	Value Value Value Value Value Value (Meas. control) Value	When heading within 70° of final <u>and</u> roll > 30°.	Values to trigger meas. subject to test.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Final	Heading			
	Pitch			
	Roll			
	Airspeed			Also, interphone reading of air-speed, alitiude, dive angle for accuracy and brevity.
	Altitude	Value	At start and stop of firing, or at bomb release.	
	G			
	AOA			
	Slip			
	Slant Range			
	Target Position on Sight			
	Time			
	Aim Point Error			On HUD equipped a/c.
	Bomb Fall Line Error			
	Flight Path Error			
	Impact Pt	Values		
	# Hits	Values	Each pass	
	Foul	Yes-No		
	Dry Pass	Yes-No		
Recovery	Altitude	Min	From V/V >500 FPM until roll > 30^{o}.	
	G	Max		Meas. control constants subject to test.
	AOA	Max		
	Pitch	Value	When roll >30^{o}.	
	Time	Value		
	Roll	Meas. control		
	V/V			

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
AIR REFUELING				Based on B-52 refueling.
Descent	V/V Time in Tol A	(TOT) Cumulative, % total.	When V/V in Tol A.	Tolerances to be established.
	V/V Time in Tol B	Cumulative, % total.	When V/V in Tol B.	
	V/V Time in Tol C	Cumulative, % total.	When V/V in Tol C.	
	V/V Time out Tol C	Cumulative, % total.	When V/V out of Tol C.	
	Time Total	Cumulative	From start to finish of descent.	
	Altitude	For meas. control.		
	V/V	"		
	A/S	"		
	Repeat Time Measures for Ns			
Rendezvous	Altitude	Value	At 2 nm, 1 nm, and 1/2 nm of range.	Range can be derived from onboard radar or estimated from tanker image size on film or T.V. (forward looking).
	Airspeed	Value		
	Range	For meas. control.		
Precontact	Closing Velocity	Meas. control		
	Range	Avg, STDEV	When range <A and B< closing velocity <C.	
	Altitude Error	Avg, STDEV		
	*Stick, Pitch	STDEV, Reversals		
	Stick, Roll	STDEV, Reversals		
	Thrust	Avg, STDEV, Reversals		
	Spoiler or Speed Brakes	Value		
	Stab Trim	Value		

*Stick used synonomously with control wheel.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Contact	Time	Value (GMT & seconds)	At contact start.	
	Time	Value (GMT & seconds)	At disconnect.	
	Time	Cumulative	Between start & disconnect.	
	Time	Per Cent	All lights green.	
	Up Lights Down Lights Fore Lights Aft Lights	Count	Count each illumination and value at disconnect.	
	Centerline Deviation	Min, Max, STDEV, Reversals, and values at disconnect.		For each contact.
	Thrust	Min, Max, STDEV, Reversals.		
	Probe Engaged	Meas. control		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
ACM				
	Altitude Airspeed Mach AOA G V/V Heading Pitch Roll Rudder Stick Pitch Stick Roll Thrust Flaps			
	Speed Brakes Position (X,Y) Slant Range Range Rate (Closing Velocity)	Values	Sampled from the begining of each maneuver segment until the end.	Maneuver segment start/stop to be based on replay of data.
	Target Aspect			Bearing off tail of tgt.
	Heading Crossing Angle			Angle off or angle between flight paths of 2 air-craft.
	Armament Sw. Positions Fire Pulse Fuel State Ordnance Load Event Timing			

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Dart Firing	Time	Value (GMT)	At start of pass.	
	# Hits	Value		
	Airspeed	Value	At start of pass. Initial and final values.	Start/stop logic to be determined.
	Range	Value		
	Azmuth	Value		
	Elevation	Value		
	Pass #	Count	At start of pass.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
AIRDROP EXAMPLE				
Pretaxi	Time	GMT	Checklists complete: Before Engine Start, After Engine Start, Before Taxi	
	Command Markers	Value	At Taxi	
	Communication Freq	Values	At Taxi	
Taxi	Time	Value, GMT	At brake release.	Joinup is first time a/c within one length of a/c ahead. End of taxi undefined.
	Nose/Tail Separ.	Min, Max, Avg	From joinup to end of taxi.	
	Brake Applications	(Count) number, duration.		
	Thrust	Min, Max		
	Time	GMT	Taxi checklist complete.	
Takeoff	Time	GMT	Before t.o. and lineup checklists complete.	
	Time	Value, Behind leader.	At t.o. break release.	
	Centerline Deviation	Min, Max, Avg	From break release to liftoff.	
	Thrust	Avg		
	Airspeed	Value	At rotation.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Join-Up	Time	GMT	After t.o. and climb checklist complete.	
(Lead)	Heading	Min, Max, Avg	From start of joinup profile until accel.	Joinup profile start undefined.
	Airspeed	Min, Max, Avg		
	Altitude	Min, Max, Avg		
	Time	For Meas. control.	Time hack.	
(Wingmen)	Time to Join	Cumulative	From t.o. to established in formation posn.	
Acceleration	Time	GMT	When airspeed >A, and time >acceleration hack.	
	Thrust			
	Range	Min, Max, Avg	From accel. start until stabilized at enroute speed.	Spacing measures range, bearing, Δ alt from flight leader.
	Bearing	Min, Max, Avg		
	Δ Altitude	Min, Max, Avg		
	Airspeed	Value		
IFR Formation	Range	Min, Max, Avg	Between checkpoints.	Lead aircraft referenced.
	Bearing	Min, Max, Avg		
	Altitude	Min, Max, Avg		
	Time	Value		
Orbit Fix	Time	Value, GMT	Arrive at fix.	
	Time	Value, GMT	Depart fix.	
	Time	Value, GMT	Descent checklist comp.	
	IFR Form. Spacing			See IFR formation.
	UFR Form. Spacing			

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Low Level Leg	Time	GMT Value	"Over" each fix.	
	Position Error	Value		
	Bearing			
	Range	Min, Max, Avg	From fix to fix.	Relative to lead aircraft.
	Altitude			
	Roll	Max		
	X-Track Error	Min, Max, Avg		
	Terrain Clearance	Min, Max, Avg		
	X-Track Error	Value	Each commanded heading change.	Also include navigator heading, speed cmds.
	Heading	For meas. control.		
Slowdown	Time	GMT Value	Throttles to idle.	
	Position Error	Value		Pos. error to be defined.
	Airspeed	Value	Each flap setting.	Flap schedule will vary from C-130 to C-141.
	Altitude	Value	At level off.	Level off at drop altitude also.
	Time	GMT Value	At drop airspeed.	P/CP/N communications.
Drop Countdown	Time	GMT Value	When each (P,N,LM) completes checklist at 20-min, 10-min, 6-min, 3-min, 1-min.	
	Time	GMT Value	Call for DZ winds surface, drop alt, & mean effective.	
	Alt A/S Hdg Command markers	Values	Measure set-up at N-minute warning.	Time to measure to be defined.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Drop	Interphone			Record nav. instructions.
	Aircraft Track	Values	Across drop zone.	
	Time	GMT Value	At green light.	
	Position Error	Value		Position relative to CARP of lead aircraft, <u>or</u> track of lead vs. track of wingman.
	Bearing	"		
	Range	"		
	Altitude Airspeed Heading Groundspeed	Value, Min, Max, Avg	Value at green, red light, min, max, avg between.	
	Drift Roll	Value, Min, Max, Avg	Value at green, red light, min, max, avg between.	
	Range Score	Values, Range, Clock Code		
	Interphone			Note difficulties reported, deployment lag, etc.
Post-Drop	Time	Value GMT	Each item and total checklist complete.	
	Time	Value GMT	Start of turn-out.	
	Time	Value GMT	Start of acceleration.	(N. countdown & call from lead)
	Thrust	Value		
	Airspeed	Min, Max	From start of accel until enroute speed.	
	Heading	Min, Max, Avg		Also-other vertical and horizontal navigation items as dictated by flight plan.
	Range	Min, Max, Avg		
	Bearing	Min, Max, Avg	From red light to completion of acceleration.	
	Δ Altitude	Min, Max, Avg		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
Return	Time	Value GMT	Clearance requested.	
	Time	Value GMT	Climb checklist complete.	
	Time	Value GMT	Turn to ascent pt.	
	Thrust		Value at each check-	
	Airspeed		point; min, max, avg	
	V/V	Min, Max, Avg,	between checkpoints or	
	Range	Value	maneuver segments.	Other items as
	Bearing			dictated by flight
	Δ Altitude			plan.
	Time	Value GMT	Cruise checklist	
Land Ovhd Pattern	Time	Value GMT	Descent checklist, before land check-list, after land checklist.	
	Interphone			P/CP communications.
	Airspeed	Min, Max, Avg		
	Altitude	"	From established	
	Heading	"	on initial until	
	Bearing	"	break.	From flt. leader.
	Range	"		
	Roll	Values		
	Thrust	"	At break turn.	
	Altitude	"		
	Airspeed	"		
	Airspeed		When establish on	
	Altitude	Value	downwind.	
	Range			From previous air-craft.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
	Roll	Min, Max	From established on final until ½ mile.	
	Airspeed	Min, Max		
	Range	Min, Max		
	Flaps	Value	At ½ mile.	
	Altitude	Value		
	Time	Value	Behind lead aircraft.	
Land	Centerline Deviation	Value		
	Runway Distance	"	At touchdown.	
	V/V	"		
	Airspeed	"		
	Time	Value	Behind lead.	
	Time	Cumulative	Reverse thrust application.	
	Thrust	Max		
Post Mission	Nav Logs CARP Computations Told Cards	Values		As needed to complete meas. sets.

If manual data reduction were to proceed in the same fashion as automated measurement, then Table 3 would also provide the appropriate measurement descriptions; however, manual entry of a number of parameters at a high rate is very slow, prone to error, and exceedingly tedious. Nevertheless, the human operator must perform essentially the same functions as the automated system, as shown in Figure 3, to produce the required measures. The human operator may, however, perform measurement computations himself, and directly enter the measure into a data base for further processing. Since measurement calculations such as the mean and standard deviation require high-rate sampling by the human operator in order to achieve the computation, these are discarded, and only functions such as a specific value, the minimum value, or the maximum value, are retained as allowable human operator functions.

Manual measurement, then, requires that the human operator search for starting conditions (a specific time or value, or out-of-tolerance condition) and then enter a specific parameter value or search for the maximum or minimum value. It is believed that the human operator can reasonably perform these tasks, while performing the equivalent of the automated measurement is unlikely to provide an attractive alternative. It should be noted that the manual measurement processing philosophy to be used does not provide all the information obtainable with an automatic system; subsequent tradeoff analyses must take this into account.

Manual measurement descriptions, within the restrictions noted, are presented in Table 4. In the same manner that automated measurement descriptions are believed to be appropriate for the initiation of software development, the manual measurement descriptions should provide information needed to develop manual techniques and operator instructions.

The number and type of manual operations required for each training phase have been noted, and assuming approximately 30-minutes of film or video recording, it is estimated that any flight in any of the training phases analyzed should produce data which can be manually analyzed within approximately 1½ hours. This estimate is based on estimates of a number of manual operations which cannot be accurately timed without direct empirical test; more accurate estimates will be possible only when manual data processing tests are conducted.

Alternative Data Sources

Tradeoff analyses are to be especially concerned with the information provided by a given system compared to the total information needs. Additionally, design information is needed to point the way to a composite system (or systems) capable of answering to all information requirements. To meet these needs, an analysis has been performed indicating the alternative sources from which measurement parameters can be obtained (see Tables 5-13). For each parameter indicated by the measurement

TABLE 4. MANUAL MEASURE DESCRIPTIONS

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
TAKEOFF				
Conditions		Value/Log*	Gross wt	Manual enter from
		Value/Audio	Wind D/V	*Flt log or *Audio
		Value/Log	Temp	
		Value/Log	Field elev	
		Value/Audio	Altimeter setting	
		Value/Log	Formation posn	
		Value/Audio	Rnwy assignment	
T/O Roll & Rotation	GMT	Value/PC*	When A/S	*PC = Panel Camera
	Stab Trim*	"	register and	*Stab Trim may not
	Power	" /PC/MC	T/O power set.	be in field of view.
	Heading	"	Again when	*W/I = within
	Roll	"	pitch ≅ rotation	tolerance, tol. to
	DDR	" /WC	angle.	be established.
	Cl W/I Tol.	Binary/WC*		*W/C = windscreen
	Pitch	Value/PC/MC*		camera
	A/S	" " "		*MC = measurement
				control
Liftoff	Pitch	Value/PC	When V/V	
	Roll	"	positive.	
	Airspeed	"		
	Heading	"		
	V/V	MC/PC		
	V/V < 0	Binary/PC	For N-sec.	
			after liftoff.	
Gearup	Airspeed	Value/PC	When gear up	
	V/V	"	selected and	
	Pitch	"	when up & locked.	
	Roll	"		
	Heading	"		
	Gear Indicator	MC/PC		

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
Flap Schedule	Stab Trim	Value/PC	At start of flap retraction, at any "inter-mediate" positions, and at flaps full up.	Stab Trim may not be in view.
	Pitch	"		
	Roll	"		
	Heading	"		
	Airspeed	"		
	V/V	"		
	Altitude	"		
	Flap Indicators	MC/PC		Assumes in view.
Accelerate, Climb, & Level-off	Power	Value/PC	At mach/ A/S / and altitude climb schedule points, at assigned altitude-10% of V/V, and at assigned alt. (Assn. alt FM audio or log)	
	Pitch	"		
	Airspeed	" /MC		
	Mach	" /MC		
	Altitude	Value/PC/MC /Audio		
	V/V	Value/PC/MC		

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
PATTERN, LANDING				
Conditions	Gross Wt	Value/Log		
	Wind D/V	Value/Audio		
	Runway	Value/Audio		
	Field Elev.	Value/Log		
	Temperature	Value/Log or Audio		
	Altimeter Set	Value/Audio		
	Form Posn	Value/Audio or Log		
Initial	Power	Value/PC	When pilot calls initial.	
	Airspeed	"		
	Altitude	"		
	Heading	"		Position from calibrated Tacan, or from W/C view of apch. environm.
	GMT	"		
	Position	Value/WC		
	UHF Comm	"Initial"/ Audio/MC		
Pitchout	Power	Value/PC	At pitchout point (at radio call or roll $\approx 60^{\circ}$)	
	Airspeed	"		
	Altitude	"		
	Position	Value/WC	"	Approximate posn
	Roll	Value/PC/MC	After n-degrees of turn (stabilized)	
	AOA	Value/PC		
	G	Value/PC		
	UHF Comm	"Pitchout/ Break"/MC		Note elapsed time from prev. aircraft pitchout.
	Spacing	Time from prev. A/C.		

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
	Airspeed	Value/PC	When:	
	Speedbrakes	PC/MC	Speedbrakes in-out	
	Gear	PC/MC	Gear Down	
	Flaps	PC/MC	Each flap activation	
	Flaps	Value/PC	Each flap activation	
Downwind	Power	Value/PC	When established on downwind per Radio call or hdg ≅ Rnwy-180° following pitchout.	
	Airspeed	"		
	Altitude	"		
	Heading	"		
	Stab Trim	"		
	UHF Comm	"Downwind"/ MC		
	Spacing	Value/WC		Distance from prior A/C.
	Airspeed	Value/PC	Each flap/gear activation	
	Flap Posn	Value/PC	Each flap activation	
	Flaps	PC/MC		
	Gear	PC/MC		
	Rnway Lat. Displacement	WC	When established on downwind.	Proper positioning A/P environment thru W/C to be developed.
Base, Dogleg, Final	Power	Value/PC	Each 100' of alt. from 900 to 100	
	Airspeed	"		
	Altitude	" /PC/MC		
	Heading	" /PC		
	Roll	"		
	V/V	"		
	Stab Trim	"		
	Flap Posn	"		
	C_L Displacement	Value/WC		Plot, ground track vs. altitude de-sireable.

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
Landing (Threshold)	Altitude	Value/PC	At threshold	
	Airspeed	"		
	Heading	"		
	Roll	"		
	CL Disp.	" /WC		
	Threshold	WC/MC		
(Touchdown)	Airspeed	Value/PC	At touchdown- When V/V starts to drive from relative steady state to zero w/out accompanying pitch change.	Also impact "jar" might be cue or radar altimeter, if installed.
	Heading	"		
	Roll	"		
	Pitch	"		
	V/V	"		
	GMT	"		
	CL Disp.	Value/WC		
	DDR	"		
	V/V	MC/PC		
(Rollout)	Heading	W/IV Tol/PC	From touchdown until airspeed<k knots at pitch = $\emptyset^{o}$ at thrust reverse.	K knots value to be defined.
	CL Disp.	" /WC		
	Airspeed	Value		
	Pitch	MC/PC		
	Airspeed	MC/PC		
	Thrust Reversal	MC/PC		
	Power	Value/PC	At thrust reverse.	

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
Go Around	GMT	Value/PC	At go around point, either go-around pitch attitude or max power (or both) whichever occurs first.	
	Pitch	Value/PC/MC		
	Roll	Value/PC		
	Altitude	"		
	V/V	" /PC/MC		
	Power	MC/PC		
	Flaps	MC/PC		
	Flaps	Value/PC	Each flap activation	
	Airspeed	Value/PC	Also at gear retraction.	
	Gear Posn	MC/PC		
	Altitude	Value/PC/MC	Atlowest altitude (V/V >ø)	

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
INSTRUMENTS: GENERAL CASE	GMT Pitch Roll Heading Thrust Airspeed Mach Altitude V/V AOA Tacan Freq CRS Set CRS Error Bearing DME Rng. Vor Freq CRS Set CRS Error Bearing ILS Freq Log Error G/S Error Pitch St. Err Bank St. Err Mker Beacon ADF Freq Bearing	1. Values at events. 2. ErrorFM desired. 3. Time-out-of-tol (TOT). 4. Number-out-of-tol (NOT). 5. Peak deviations (PKD). 6. Measurement control.	1. At specific events, positions. 2. Out of tolerance or peak deviation over specific intervals. 3. At specific time intervals.	

MANEUVER	MEASURE	FUNCTION/SOURCE	SEQUENCE	COMMENTS
SID-VULTURE 1				(Vulture One, LAFB, Ariz.)
Climb Rnwy Heading to 4 nm Dme	Heading	TOT, NOT, PKD	From liftoff (TVU) to 4 nm D	
	Altitude	Max		
	Airspeed	Value	At 4. n.m. DME	
	DME	MC		
	V/V	MC		
Turn to Closs LUF	Airspeed	Max	From 4 nm fix to LUF	
	Altitude	Min, Max, MC TOT, NOT	" and alt >4000	
	DME	Max, MC TOT, NOT	" and DME >8nm	
	Airspeed	Value	" each time alt> 4000, DME >8 nm.	
Station Crossing	GMT	Value	When bearing $\geq 90^o$ and DME $\leq$1 mi + asg. altitude.	
	Heading	Value		
	Airspeed	Value		
	Altitude	Value		
	Tacan Bearing	MC		
	DME	MC		
Navigation Leg	Altitude	Min, Max, MC TOT, NOT	From LUF to Vulture when |alt-asgned| 200'	(31 n.m. DME fix)
	Tacan CRS Error*	Compute XTK, Max, MC, TOT, NOT		
	DME		When XTK >4n.m.	Based on DME X CRS. error.
	V/V	Min, Max	From Lum to Vulture	
	Heading	Min, Max		

*Tacan CRS error from CDI or computation from heading/rel.bearing vs. dsrd radial.

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
PENETRATION + APRCH.				Tacan z, Rnwy 21, LAFB, Ariz.
IAF	GMT	Value	When DME <22nm and LUF R314.	Assume Tacan tuned.
	Heading	Value		
	Airspeed	Value		
	Altitude	Value		
	Tacan Brg	MC		
	DME	MC		
Holding	DME	Min, Max, MC	From IAF to IAF	
	Tacan CRS Err	Compute ITK, Max		
	Alt	Min, Max		
		TOT, NOT	When $\|Alt-Asg\| >$ 200'	
Penetration (R314 to 16 Dme Arc)	Airspeed	Min, Max	From IAF to turn 16 n.m. acc	
	Heading	Min, Max, MC	"	
	V/V	Min, Max		
	DME	MC	"	
	Tacan CRS Err	Compute XTK, Max		
	Roll	MC		
	Altitude	Value	At turn pt. to 16nm arc.	
	Airspeed	Value		
	DME	Value		
(Arc to R260) And R260 to R195	Airspeed	Min, Max	From 16 mi arc intcpt.	
	Altitude	Min, Max		
	V/V	Min, Max		
	Tacan Brg	Min, Max		
	DME Rng	Min, Max		
	Heading	MC & radial comp.		
	Heading	Value	At rad $260^{o}/195^{o}$	
	Altitude	Value		
	Airspeed	Value		
	DME	Value		

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
(R195 to FAF (6 DME) and to Map)	Airspeed	Value, Min, Max	1. Values at R195 intercept, 6 mi dme + map (dme= 2 nm)	
	Heading	Value, Min, Max		
	Altitude	Value, Min, Max TOT, NOT		
	V/V	Value, Min, Max	2. Min, max TOT, NOT, between - alt < minimum for leg.	
	AOA	Value, Min, Max		
	Tacan X Track	Value, Max, TOT NOT	XTK > tolerance.	
	DME	MC, computation		
	GMT	Value		
	Thrust	Value		
For ILS, <u>Add</u> to Above	Localizer	Value, Max TOT, NOT	1. Values at Lom, mm,	
	G/Slope	Value, Max TOT, NOT	2. Max, TOT, NOT in between	
	MKR	MC		
GCA, Initial	Airspeed	Min, Max	From CMD to CMD (audio MSMT)	
	Altitude	Min, Max		
	Heading	Min, Max		
	AOA	Min, Max		
GCA, Final	Airspeed	Min, Max		
	V/V	Min, Max		
	AOA	Min, Max		
	Pitch CMDS	Count	Slight above (below)	
		"	above (below)	G/P AOA
		"	Well above (below)	From Audio
	Heading	TOT, NOT	Error from HDG CMDS.	
		Count	Number HDG comments.	

MANEUVER	MEASURE	FUNCTION	SEQUENCE	COMMENTS
	Posn	Value		
	Altitude	Value		
	Heading	Value	At "gate"	
	Airspeed	Value		
	V/V	Value		
	AOA	Value		

TABLE 5. ALTERNATIVE DATA SOURCES FOR TRANSITION PARAMETERS

PARAMETERS	DATA SOURCE							
	Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proced. -1, etc.	Instr. Pubs. and LCL Proced.	Range Scores
GMT	X		X					
Pitch	X		X			M		
Pitch Rate	X		-					
Roll	X		X			M		
Heading	X		X				M	
Airspeed	X		X			M		
MACH	X		X			M		
Altitude	X		X			M	M	
V/V	X		X			M		
AOA	X		X					
G	X		Q?					
Power	X		X			M		
Thrust Rev	X		Q?					
Speed Brakes	X		Q?					
Position, xy		X	RA					
C_L Deviation, (Also Rnwy Lat.)		X	RA					
Lat. Drift		X	-					
Threshold		X	RA			M		
DDR		X	RA					
Spacing		X	RA					
Main Gear Cntct	X		-					
Nose Gear Cntct	X		-					
Nose Steer Engaged	X		-					
Gear Select	X		Q?					
Flap Select	X		Q?			M		
Stab Trim	X		-					
Drag Chute	X		-					
UHF Comm — Initial, Rnwy Break, Wind Downwind, Alti-meter				X				
GWT					X			
Wind D/V				X				
Temp					X			
Field Elev							M	
Alt Setting				X				
Form. Posn					X			
Rnwy Assign				X				
Wheel Brakes	X		-					
Parameters	22	6		4	3	8	4	

X = Available; Q = Questionable; RA = Reduced Accuracy;
M = Data from Other Sources for Error Comparison.

TABLE 6. ALTERNATIVE DATA SOURCES FOR INSTRUMENT PARAMETERS

PARAMETERS	DATA SOURCE							
	Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proced. -1, etc.	Instr. Pubs. and LCL Proced.	Range Scores
GMT	X		X		M			
Pitch	X		X					
Roll	X		X					
Heading	X		X				M	
Airspeed (or MACH)	X		X					
Altitude	X		X				M	
V/V	X		X					
AOA	X		X					
Power (Thrust)	X		X					
TACAN Freq.	X		Q		M		M	
Course Set	X		X		M		M	
Course Error	X		X					
Bearing	X		X					
DME	X		RA		M		M	
VOR Freq.	X		Q		M		M	
Course Set	X		X		M		M	
Course Error	X		X					
Bearing	X		X					
ILS Freq.	X		Q				M	
Localizer Error	X		X					
Glide Slope Error	X		X					
Marker BCN	X		X				M	
Speed Brakes	X		Q					
Heading Vectors				X				
GCA Glide Path				X				
ADF Bearing	X		X		M		M	
UHF Comm				X				

TABLE 7. ALTERNATIVE DATA SOURCES FOR INTERCEPT PARAMETERS

PARAMETERS	FUNCTION	DATA SOURCE: Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proced. -1, Etc.	Instr. Pubs. and LCL Proced.	Range Scores
TARGET									
Heading		X_T		X_T				M	
Altitude		X_T		X_T				M	
MACH		X_T		X_T				M	
Azimuth			X						
Elevation	Prior		X						
Range	to		X						
Range Rate	Lockon		X						
Aspect Angle			X		D				
NCA		X_T		X_T					
ECM				RA				M	
Maneuvering				RA	D			M	
INTERCEPTOR									
Pitch		X		X	C				
Roll		X		X	C				
Heading		X		X	C				
Altitude		X		X	C				
V/V		X		X	C				
MACH		X		X	C				
AOA		X		X					
G		X		X					
Power		X		X	C				
Fuel Quantity		X		X		X			
Antenna	Azimuth	X		X	D	RA			
	Elevation	X		X	D	RA			
After { (Tgt)	Range	X		X	D	RA			
Lock { (Tgt)	Range Rate	X		X	D	RA			
	Range Gate	X		X					
Steering Dot	Error	X		X		RA			
Firing Circle	Radius	X		X					
$R_{min.}$, $R_{max.}$		X		X					
Lockon Pulse		X		X					
IF Gain		X		RA					
Video Gain		X		RA					
Erase Intensity		X		RA					
GMT		X		X		X			

TABLE 7. ALTERNATIVE DATA SOURCES FOR INTERCEPT PARAMETERS (Cont.)

PARAMETER	FUNCTION	DATA SOURCE							
		Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proced. -1, Etc.	Instr. Pubs and LCL proced.	Range Scores
INTERCEPTOR (Cont'd.)									
Missile	Δ Elevation	X							
	Δ Azimuth	X							
	Δ Range	X							
	Δ V_C	X							
Crew Coordination					X				

X = Parameter Available; RA = Reduced Accuracy; C = Commands;
D = Descriptive Commentary; X_T = Tgt A/C Instrum.;
M = Desired Setup.

TABLE 8. ALTERNATIVE DATA SOURCES FOR AIR REFUELING PARAMETERS

PARAMETER	FUNCTION	DATA SOURCE: Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proced. -1, etc.	Instr. Pubs. and LCL Proced.	Range Scores
GMT		X		X					
Airspeed		X		X					
Altitude		X		X					
V/V		X		X					
Range (To Tanker)		P	X	RA					
Range Rate		P		RA					
Stick (Pitch)		X							
Stick (Roll)		X							
Thrust		X		X					
Spoilers (Speed Brakes)		X		Q					
Stab Trim		X							
Probe Engagement		X		Q					
Centerline Displacement			X	X					
*Lights Up			*	X					
Down			*	X					
Fore			*	X					
Aft			*	X					
Altitude Error			X	RA					
Crew Coordination					X				

*Lights could be attained by instrumenting tanker, unlikely due to logistics problems.

P = Probable from onboard radar, if available.

TABLE 9. ALTERNATIVE DATA SOURCES FOR AIRDROP PARAMETERS

PARAMETERS	DATA SOURCE							
	Instr.	X-Y	Triple V-P	Audio	Flight Log	Aircraft Op. Proced. -1, etc.	Instr. Pubs. and LCL Proced.	Range Scores
Pitch	X		X					
Roll	X		X					
Heading	X		X	C			M	
Altitude	X		X				M	
V/V	X		X				M	
Thrust	X		X				M	
Flap Position	X		Q				M	
GMT	X		X				M	
Cross-Track Error		X						
Position Error		X	X		X			
Groundspeed	X[1]				X			
Drift	X[1]				X			
Terrain Clearance	X		X					
From Lead: Range		X[3]	RA					
Bearing		X[3]	RA					
Δ Altitude	X_L^2		RA					
Drop Lights (Red, Green)	X			X				
CARP					X			
AARP (Actual Air Release)		X	X					
Drop Score				X				X
Wheel Brakes	X							
Airspeed	X		X	C			M	
DZ Temp				X			M	
Pressure				X			M	
Wind D/V				X			M	
Crew Coordination				X				

[1]From Doppler
[2]Assumes lead instrumented.
[3]Some cases can obtain from radar.

TABLE 10. ALTERNATIVE DATA SOURCES FOR FORMATION PARAMETERS

PARAMETERS	DATA SOURCE							
	Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proc. -1, etc.	Instr. Pubs. and LCL Proced.	Range Scores
LEAD AIRCRAFT								
Airspeed	X_L		X_L					
Thrust	X_L		X_L					
Thrust Rate	X_L		X_L					
Turn Rate	X_L		X_L					
G's	X_L		X_L					
ELEMENTS								
Airspeed	X		X					
Heading	X		X					
Stick Pitch	X							
Stick Roll	X							
Stab Trim	X							
Range		X	RA					
Range Rate		X	RA					
Bearing		X	RA					
Δ Altitude[1]	1		X					
GMT	X		X					
Start/Stop				X				
Crew/Formation Coordination				X				

X_L = Instrumented or camera on lead a/c.

[1] Δ Altitude can be obtained with less than required accuracy by instrumenting altimeters in both a/c. However this possibility was rejected.

TABLE 11. ALTERNATIVE DATA SOURCES FOR GROUND ATTACK PARAMETERS

PARAMETERS	DATA SOURCE							
	Instr.	X-Y	Dual V-p	Audio	Flight Log	Aircraft Op. Proc. -1, etc.	Instr. Pubs. and LCL Proc.	Range Scores
GWT				X	X			
Temp				X				
Press (Alt. Setting)				X				
Wind (Direct/Velocity)				X				
Formation Posn					X			
Pitch	X		X			M	M	
Roll	X		X					
Heading	X		X				M	
Airspeed	X		X			M	M	
Altitude	X		X			M	M	
V/V	X		X					
AOA	X		X			M		
G	X		X			M	M	
Slip	Q		X					
Power	X		X			M		
GMT	X		X					
Target Slant Range		X	RA					
Aim Point Er			X					
(HUD) Bomb Fall Line			(X)					
Flight Path Er		X	RA					
Impact Pt				X				X
Number of Hits				X				X
Foul				X				X
Dry Pass				X				
Spacing		X	RA	RA				
Pickle	X			RA				
Weapon Release	X							
Crew Coordination				X				

TABLE 12. ALTERNATIVE DATA SOURCES FOR DART FIRING PARAMETERS

PARAMETERS	DATA SOURCE: Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proc. -1, etc.	Instr. Pubs. and LCL Proc.	Range Scores
GMT	X		X					
Airspeed	X		X					
Range		X	RA					
Azimuth		X	RA					
Elevation		X	X					
Pass Number	X		X					
Hits				X				X
Crew Coordination				X				

TABLE 13. ALTERNATIVE DATA SOURCES FOR AIR COMBAT MANEUVERING PARAMETERS

PARAMETERS	DATA SOURCE							
	Instr.	X-Y	Dual V-P	Audio	Flight Log	Aircraft Op. Proc. -1, etc.	Instr. Pubs. and LCL Proc.	Range Scores
GMT	X		X					
Pitch	X		X					
Roll	X		X					
Heading	X		X					
Airspeed	X		X					
MACH	X		X					
Altitude	X		X					
V/V	X		X					
AOA	X		X					
G's	X		X					
Rudder	X							
Stick Pitch	X							
Stick Roll	X							
Thrust	X							
Flaps	X		Q					
Speed Brakes	X		Q					
Target Range[2]		X	RA[1]					
Range Rate		X	RA					
Aspect Angle		X	RA					
Heading Crossing An.		X						
Elevation (Δ H)		X	RA					
Armament Switch Posns.	X							
Fire Pulse	X							
Fuel Quantity	X		X					
Ordnance Load	X				X			
Event Timing & Marking	X			X				
GWT					X			
Crew Coordintation				X				

[1]Target ranging possible only during terminal tracking or when target in camera range.
[2]Accurate position, X, Y & Z of each aircraft, together with instrumentation of each aircraft can provide these data.

descriptions (Tables 3 and 4), data sources have been identified in the following categories: (Instr) Obtainable with automatic instrumentation recording, (X-Y) spatial coordinates obtainable from such devices as ground radar stations, theodolite, and ground observers, (Dual V-P) obtainable with either two photographic cameras or a video camera recording system, (Audio) obtainable with audio magnetic tape recording, and other data available from verbal reports, flight forms and operational documents.

The analyses of alternative data sources was performed separately for each major training phase. Since performance information needs apparently vary as a function of training phase, different systems may be appropriate for different training phases. The analysis is performed in this way to attempt to define system modules that can collectively meet all information needs.

Note that while alternative sources may permit data for a given parameter, not always the same accuracy is possible. In Tables 5-13 X indicates that high accuracy is available, RA indicates that reduced accuracy is possible, but sufficient for the purposes envisioned, and Q indicates that data are available, but it is questionable whether the accuracy is sufficient except for unusual situations.

Data Processing Facilities

It is, of course, desirable to have all data processing tools ready at hand for use whenever needed, although it is possible to operate under some circumstances with some or all computing facilities remotely located. In addition to general-purpose computing equipment, if data are to be processed from complex airborne instrumentation, special conversion equipment is needed.

Dedicated data processor. The heart of the measurement data processing facility is a general purpose digital computer. Based on experience with extensive inflight and simulator experiments, the computer should have approximately 16,000 to 32,000 words of memory, a word size of at least 16 bits, and a basic operation time of approximately 1 microsecond to 3 microseconds. However, as may be seen from Figure 4, the utility of the system for measurement and data analysis depends on the peripheral equipment.

(1) 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 are also conveniently manipulated in punched-card form.

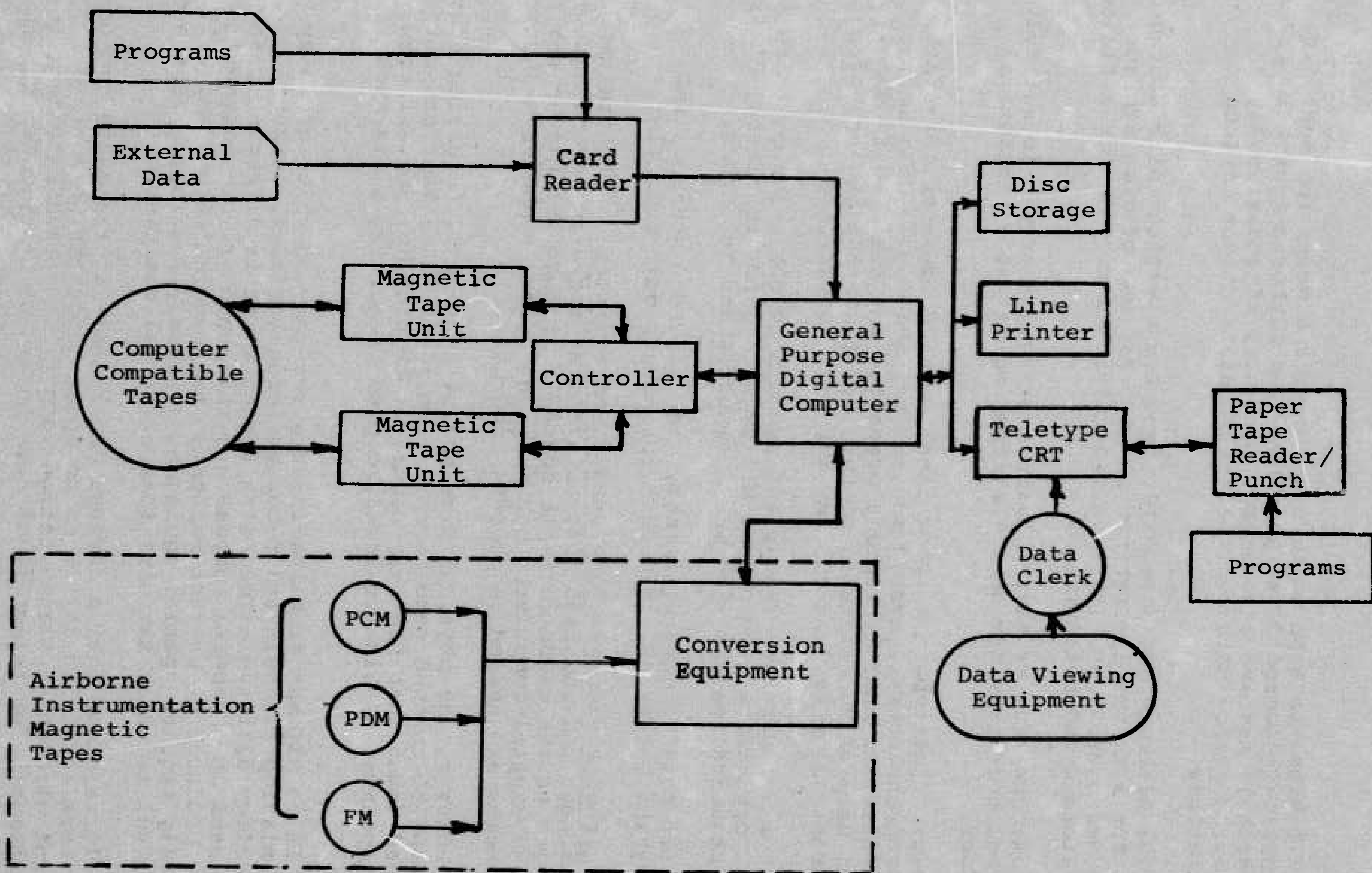


Figure 4. Dedicated Measurement Processing Facilities.

(2) Magnetic tape units also provide a means for entry of externally-collected data (possibly from airborne instrumentation recordings), and are also useful for entry of occasionally-referenced stored data, or the intermediate output of long calculations.

(3) Although it is possible to operate without disc storage units for many small experimental efforts, use of disc storage can speed operations, increase capacity, and provide for efficient data storage and retrieval.

(4) The line printer permits high-volume output in a timely fashion, necessary for data listings and multiple statistical analyses.

(5) A Teletype (or typewriter) permits operator interface for program control, system monitoring, and manual data entry. If information must be rapidly presented for training feedback, manual data entry, software or data editing, then the use of an electronic display (cathode ray tube) is recommended.

(6) A paper-tape reader and punch provides a low-cost input/output capability, and compatibility with other computers; this is a standard feature with many computers and Teletypes.

(7) Data viewing equipment, such as video monitors and photographic viewers, is needed for manual data reduction.

Airborne magnetic tape conversion equipment. 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 normal computer magnetic tape units are needed to process such data.

However, the physical size may be different, requiring that the tape be rewound onto another tape reel; if a tape cassette is used (such that the tape cannot be physically removed) then the tape must be electronically copied (requiring a playback unit).

In an attempt to maintain data accuracy in spite of noisy transmission channels and recorder irregularities, current technology dictates a recording format which is different than that used in a general purpose digital computer. The magnetic tapes produced by current airborne instrumentation systems will normally require special equipment (probably costing in excess of $100,000) to enter the data into a digital computer.

It is clear that a savings can be made if tapes are produced in a form requiring little or no special conversion equipment. Current airborne instrumentation formats are based on flight test requirements for telemetry of data to ground stations while the aircraft is in flight. It is possible, if there is no requirement for telemetry and if performance measurement data accuracy requirements are not as severe as those of flight test, that direct recording in computer compatible format will permit sufficient data accuracy. However, if high data accuracy techniques are necessary, or if compatibility with current airborne instrumentation recording is desired (to permit data collection with currently instrumented aircraft), the special conversion equipment is required. It should be noted that conversion equipment may be required for several types of recording, and that equipment capable of converting several types of data tapes may be desirable (such as pulse code modulation (PCM), pulse duration modulation (PDM), or frequency modulation (FM) as indicated in Figure 4.

Time-share computer. Current time-share computer facilities combine large-computer power and impressive software packages for a very small investment and small use charges. For example, a teletype terminal can be leased for approximately $75.00 per month and computer charges will average about $15.00 per hour (depending on the amount of storage and computer time actually used). The Teletype is limited in input/output speed, limiting input to manual entry and output to samples of file data or statistical analyses. Even with faster terminals now on the market, such an installation is best for programming, debugging, spot checks of data, and trial analyses.

A further complication is that connection with the time-share computer complex is through standard telephone lines. Adequate connections may not be possible through some USAF switchboards, requiring, perhaps, a special telephone installation. Tollfree calls to the computer complex are possible from most places in the country; however, if a toll charge should be necessary, the hourly cost will increase greatly.

Within the above restrictions, the time-share computer may provide an excellent inexpensive approach for manual data processing. As shown in Figure 5, a data viewer (video or film) and a Teletype provide a workstation for a data clerk to sample the desired information; the computer can be programmed to assist and check the data clerk. Through this process, edited data files can be accumulated at the time-share computer complex. The research scientist can program for measurement computations and analyses, using data collected as a basis for trial analyses. All the previous operations can be performed using the Teletype; however, more extensive analyses will probably be more efficiently conducted remotely at the time-share computer complex. Since both programs and data exist in files at the time-share computer complex, personnel at the large computer can perform large-scale calculations for the research team. Since the output will be extensive, high-speed printers at the computer complex will more efficiently do the job, to be transported to the research crew by courier or mail. Where such an operation is feasible, the end

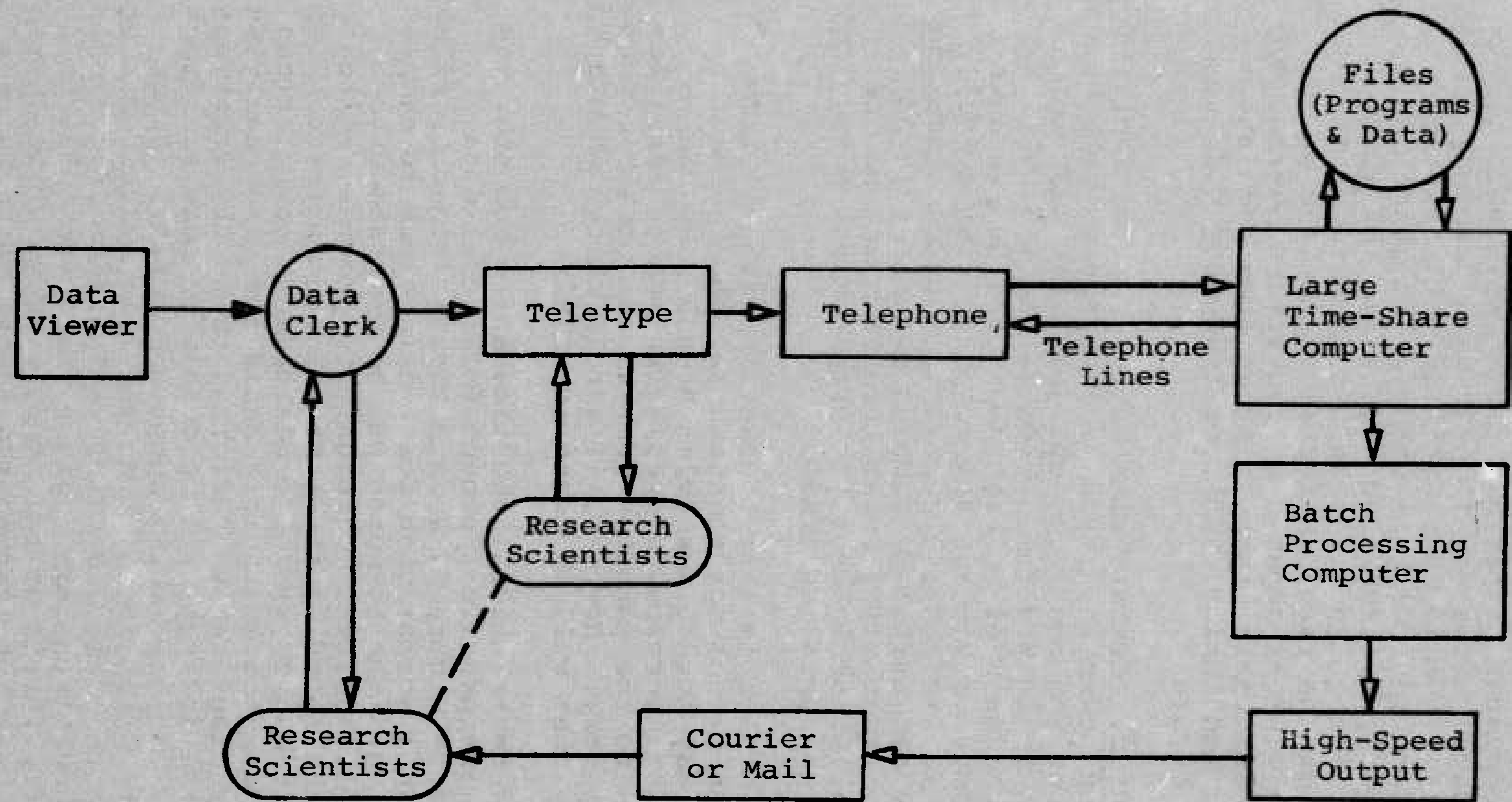


Figure 5. Measurement Processing with a Time-Share Computer Facility.

product will be nearly equivalent to that obtainable with a dedicated computer.

Remote computer. If access can be obtained to a properly equipped nearby computer as often as needed, then, of course, the result is equivalent to that of a dedicated computer. However, if extensive travel is required to reach a remote computer, and if access is limited, then the result may be lost data, slow response, and partial inadequate analysis.

Figure 6 depicts the use of a remote computer with manual data processing; conceivably, the operation can be conducted with automatic data collection, however, then no knowledge of data errors will be available until a computer listing is available, perhaps days later when little can be done to recover from the damage done to the experimental schedule.

In the extreme, the use of a remote computer introduces a two-step sequential process: (1) collect data, (2) analyze data. A completely open-loop approach to research does not permit any recovery from data errors or experimental design errors; it doesn't permit interactive iterative measurement and analysis development. This is not likely to be a successful approach unless only simple limited problems are encountered.

A closed-loop approach to research, which permits changes and improvements in technique as data are collected, requires guaranteed access to a computer, knowledge or much help in the use of the computer, unscheduled extensive use at critical periods, and fast turnaround equivalent to continuous man-computer interaction. Except in extraordinary circumstances, the conclusion is that such an operation is possible only with a dedicated computer facility.

Video Recording System Legibility

An electronic display (or a combination electro-optical display) system encodes information detected by the system sensors, transmits and processes these signals electrically and recreates this information in a symbolic or pictorial format on a display. In order for the symbols so presented to convey information to the observer, the symbols must be recognizable and identifiable by the observer. A relatively large number of system and environmental factors impact upon the legibility of the displayed symbology; too many, in fact, to be addressed here. The three more important factors as far as the observer is concerned, however, are the display resolution, the visual angle of the symbol displayed, and the degree of contrast between the symbol and the display background.

The literature. A recent review of the electronic display literature (Semple, et al., 1971) suggests that the resolution requirements for identification tasks on electronic displays

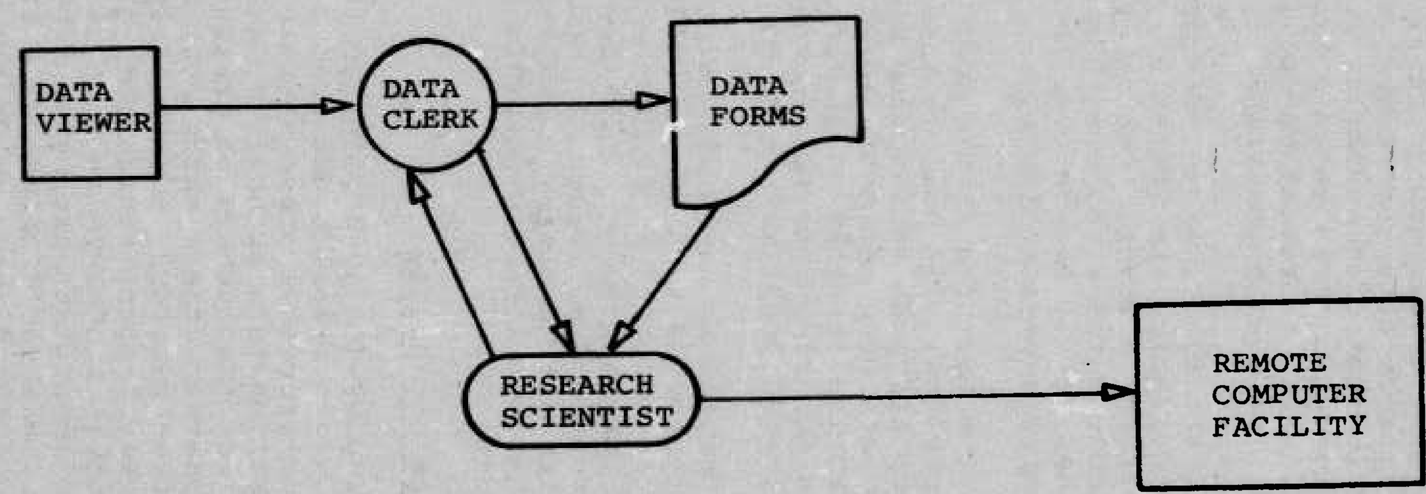


Figure 6. Measurement Processing with a Remote Computer Facility.

vary significantly with the type of targets being identified, the nature of the display and the environment in which it was recorded. Several studies reviewed (Shurtleff and Owens, 1966; Elias, 1965; Shurtleff, et al., 1966) suggest that resolution requirements for alphanumerics viewed under static conditions are less than for alphanumerics viewed under dynamic conditions. Likewise, alphanumeric targets required less resolution for identification than did geometric or more real-world symbology. The studies reviewed were relatively consistent in their findings and suggest that vertical resolution for alphanumeric characters should be 10 to 12 raster scan lines per symbol height for 90%-plus correct identification. Geometric or pictorial symbols required a minimum of 14 raster scan lines per symbol height for similar performance. These results were, however, conducted under laboratory conditions with no visual or resolution degrading factors present and assumed that the observer was familiar with the targets being identified.

Hemmingway and Erickson (1969) reviewed a number of resolution studies and conclude that a possible tradeoff exists between the number of raster scan lines per symbol height and the visual angle subtended by the symbol. As the number of lines per symbol height decreases, the same or equivalent performance levels may be maintained by increasing the angular subtense of the symbol. This tradeoff holds for symbols with visual angles between 7.8 and 16 minutes of arc. There appears to be an asymptote, however, at about 16 minutes of arc (see Figure 7).

Another important consideration in electronic displays, particularly if used in an airborne environment, is the contrast between the displayed symbol and the display background (or the light-dark contrast of pictorial displays). The higher the contrast ratio, the higher the probability of correct identification of the symbol under a wide range of viewing conditions. For the present application, a contrast of about 8/1 to 10/1 should be sufficient, provided consideration also is given to the nature and amount of ambient illumination present in the cockpit. Contrast greater than this is generally beyond the capability of standard TV systems.

The amount of ambient illumination present in the cockpit environment will directly influence the legibility (contrast) of the field being recorded. The amount of illumination incident upon the display face will deteriorate the contrast between the symbol and background. The amount of illumination incident upon the display face plus the reflectivity of the display face material are the primary factors producing display "washout". In the latter case, not only is the contrast of the display degraded, but intense ambient illumination is reflected (produces glare) into the recorder/sensor, saturates it, and thereby reduces its sensitivity to light and dark. Through the use of antireflective coatings and filters, in conjunction with high brightness symbols or display surface contrast, display washout may, for the most part, be overcome (Semple, et al., 1971).

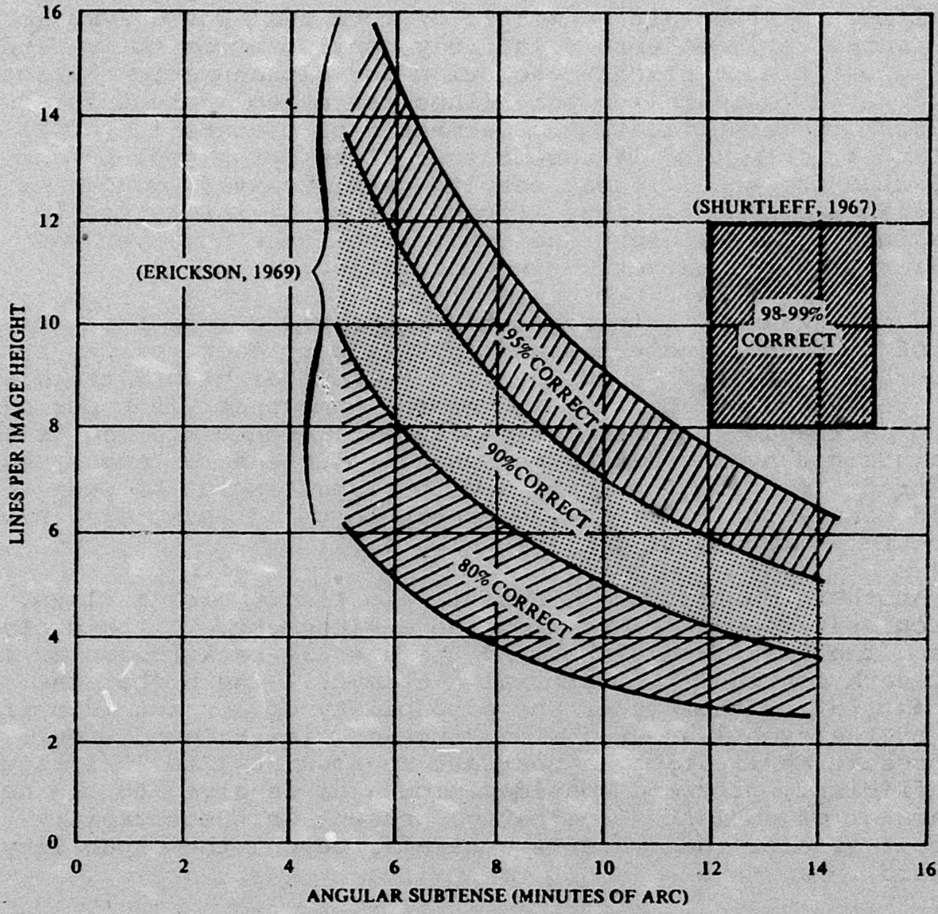


Figure 7. Trade-Off Bands for Angular Subtense Versus Line Number for Four Levels of Performance (from Bruns, et al., 1970).

A number of factors limit the utility of the above resolution data in predicting resolution requirements for airborne electronic equipment. Obviously, one factor is the static nature of the displays used in the above studies contrasted to the dynamic nature of operational airborne environments. In the latter environment, instrument readings are constantly changing, and the external imagery is in constant flux as a result of rapidly changing aircraft attitude and performance parameters. Specifically, external imagery is continually changing in size, perspective, contrast, and orientation as the aircraft maneuvers. Add to these the fact that overall image quality is degraded in airborne systems as a result of aircraft interference (EMI, vibration, g-forces, etc.), and atmospheric attenuation (haze, distortion, rapidly changing ambient illumination and contrast levels, etc.), and the value of laboratory resolution data appears limited indeed.

A second consideration is the fact that the human visual system is degraded by many of the factors that affect display system resolution. Visual acuity, for example, deteriorates rapidly with the introduction of high rates of acceleration, angular velocity and vibration. Miller (1962) found that acuity degrades relatively slowly at angular velocities of from 10 to 30 degrees per second. With angular velocities above 30 degrees per second, however, acuity degrades rapidly. (Angular velocity, in this case, included rotation of the display, the observer, and both display and observer.) Van Der Brink (1969) suggests that the sharpness of an image on a screen is determined, in part, by the summating properties of the eye itself. He found that the brightness of luminous targets had to be increased as the angular velocity of the targets was increased to maintain the same level of identification performance. His data suggest that low contrast targets on television, which are just above the observer's visual threshold when static, would drop below that threshold if motion were introduced.

A third point of consideration is suggested by the fact that the results of a number of studies (reviewed in Semple, et al., 1971) show that modest decreases in resolution or contrast and modest increases in environmental degradation may not individually affect target identification performance. When combined, however, significant reductions in identification performance occur. Johnson (1968), for example, compared displays using 5, 7, and 9 shades of gray and found no significant difference in detection and identification performance in her subjects, as long as horizontal resolution was held constant. When horizontal resolution was reduced (from 525 lines to 400 lines to 200 lines), however, performance deteriorated as the number of shades of gray was reduced. The results of other studies (Gould, 1968, D'Aiuto, 1969, Bruns, et al., 1970) and reviews (Luxemberg and Kuehn, 1970) suggest that a number of other display parameters interact in a non-additive fashion to affect display resolution. Therefore, results from studies that attempt to isolate and examine individual parameters must be accepted with caution.

In an effort to control for some of the above discussed variables, Bruns, et al., (1970) conducted a study to examine target identification accuracy on a television display as a function of several target motion rates, display degradation levels and aircraft flight profile conditions. Air-to-surface attacks were simulated by video-taping actual reconnaissance transparencies of real-world targets (oil storage tanks, bridges, SAM sites, etc.). Aircraft speeds were simulated at between 150 and 900 knots with dive angles varying from 10 to 60 degrees. Attack runs commenced at altitudes ranging from 8,000 to 46,000 feet and terminated at altitudes of from 800 to 4,600 feet. All targets were presented across all major independent variables. Sony Model 120A (3.5 megahertz) video recorders were used to record the attacks while four 525-line TV monitors (5 x 7 inch with degraded resolution, 5 x 7 inch nondegraded, 3.4 and 4.4 inch and a 2.4 x 3.0 inch) were used to display the films to the subjects. Ambient room illumination along the subject's line of sight was approximately 50 foot-Candles. The subject's task was to identify targets as quickly as possible on the televised displays that correspond to circled targets on briefing photographs.

A number of interesting conclusions are observed as a result of this study. For one thing, the results indicate that the video target "attacks" preceded to a given point in the missions whereupon the subjects identified the targets. Each target was identified at the same time during the attack, regardless of the display being viewed. Bruns interprets this to mean that the number of raster scan lines passing through the target is the critical parameter affecting identification. Since the number of lines was identical on the four different size monitors and each monitor was displaying the same video tape, the number of scan lines passing through the target at any point in the simulated attack is also identical. (Individual lines are proportionately smaller on smaller monitors, but they subtend the same visual angle when the angle subtended by the various sized displays is held constant.)

Secondly, Figure 8 indicates that dynamic real-world targets used in this study required larger angular size and more scan lines per target height than did the symbols used in earlier studies for equal probability of detection. (It might be noted that the symbols used in the Hemmingway and Erickson study were of equal size and uniformly high contrast while the targets used in this study had neither uniform size nor contrast.)

Field studies. In 1970, the Air Training Command conducted a flight evaluation of a relatively inexpensive commercial television-camera video recording system installed in an F-4E aircraft. The purpose of the evaluation was to examine the feasibility of using this type of system in an airborne environment and to examine the training potential offered by immediate mission playback as soon as the mission is over. The equipment consisted of two small TV cameras, a briefcase size video recorder

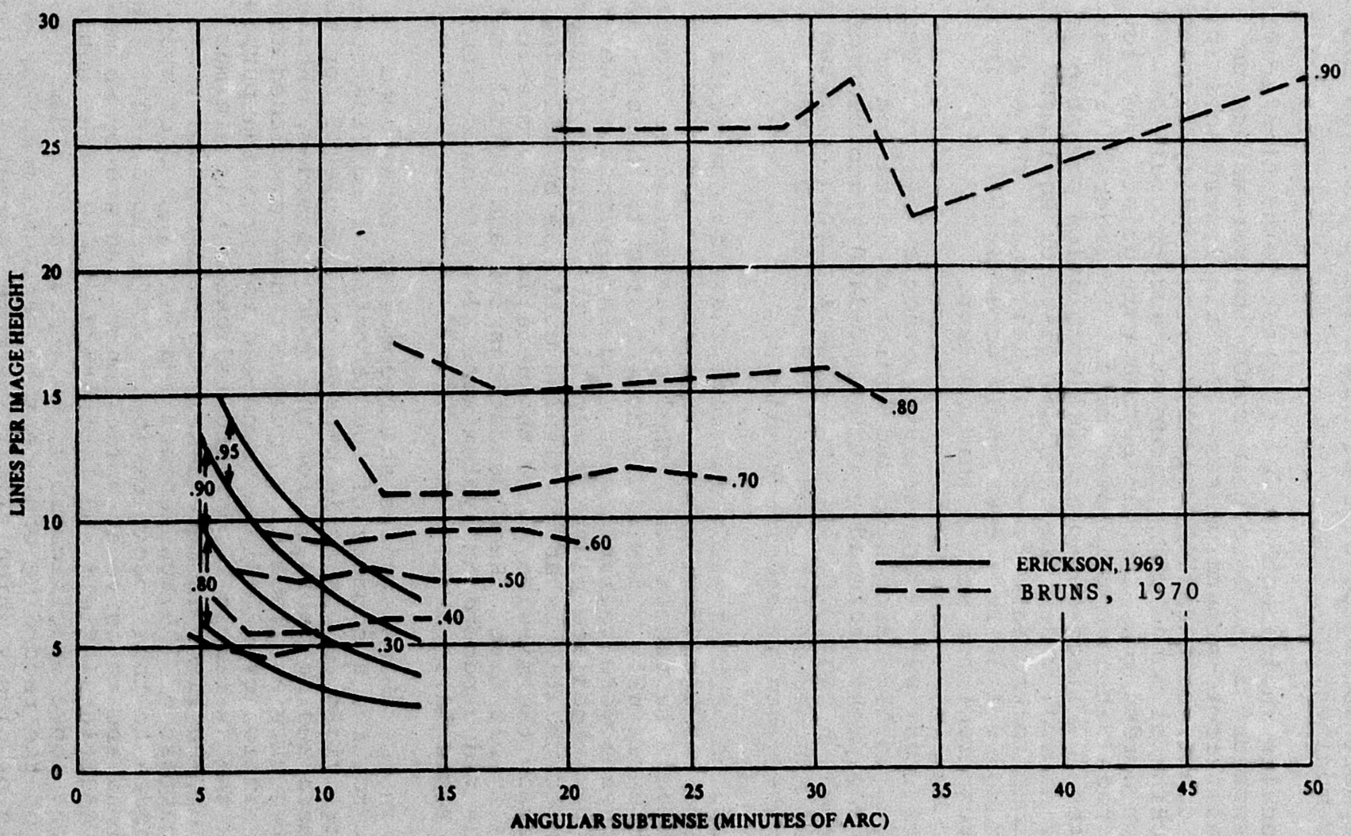


Figure 8. Probablility of Correct Target Identification. Comparison of Erickson's results with Bruns results. (From Bruns, et al, 1970).

(produced by Sony) and special electronics to integrate the imagery from the two cameras onto a single tape. The associated ground equipment consisted of a standard (Sony) CV-2100 playback deck and TV monitor.

The results indicate that low playback resolution prevented precise assessment of some release condition parameters on virtually all air-to-ground passes. Certain instruments (pipper placement, draft, bank angle), however, were readily discernable. Pipper tracking of maneuvering aircraft targets could be adequately recorded to 4 Gs, but beyond this point, the picture quality degraded at an accelerated rate. In general, it was felt that the 200 lines of horizontal resolution possible in the DVK-2400 TV camera, video recorder and playback equipment was not sufficient to warrant use of this equipment. The study recommended a 500 line TV system would be desirable (a minimum of 300 lines required) for use in this context.

Another study was conducted by the Tactical Fighter Weapons Center at Nellis AFB using upgraded equipment installed in an A-7D. The equipment included a (Sony) AV-3400 video recorder and Vidicon Camera, a control unit, and a small combining glass and glare shield mounted in front of the HUD combining glass. (Equipment described in TAC-TR-70A-113F.)

The results of this study indicate that the commercially available off-the-shelf equipment, when used as a gun camera system, was able to record HUD symbology and ground references or target areas. With a few minor modifications, the off-the-shelf components were reliable when used in aircraft. The study found that the immediate playback capability provided by the video recorder greatly enhanced mission critique by allowing the pilot to review the mission while the details of the mission were still fresh in his mind. Recommendations for additional improvements in the video recording system were also provided (summarized in Table 14).

Based on the above studies and recommendations found in the display literature, a summary of the technical specifications for a typical video recording is presented in Table 15 for the Vidicon Camera and in Table 16 for the video recorder. While field studies of video recording equipment have concluded that a minimum resolution of 300 lines is needed for training purposes, research in the available literature indicates that minimum resolution of 400 lines is more likely to be acceptable. Further, contrast of 700-800 percent and 8-10 shades of gray should be added to this specification. It is noted that these specifications are to serve as guides only, and are by no means absolute. Additional field and laboratory studies are required to verify the above specifications, to arrive at optimum configuration of the recording equipment in various cockpits, and to ascertain precisely which flight instruments/real-world image combinations are best for given missions.

TABLE 14. SUGGESTED EQUIPMENT AND CONFIGURATION IMPROVEMENTS (TAC-TR-70A-113F)

Brightness controls for indicator illumination levels.
Indicator showing recording time remaining on the tape presently installed.
Provisions for an audio call button to permit the pilot to verbally annotate tapes without necessity of transmitting over the radio at same time.
Pilot-operated controls should be configured for left (or right) hand control, depending upon placement in aircraft cockpit.
Pilot operated controls should be configured for visiblity in either right or left hand configuration.
Remove existing (Sony) potentiometers in camera control units and replace them with trimpots centrally located in area which is accessable from outside (for ease of adjustment). This allows find boresight adjustment to be accomplished electrically with the vidicon horizontal and vertical centerling pots.
Include an audio filter circuit to eliminate aircraft electromagnetic interference (EMI). EMI can be isolated from the recording unit by the addition of a 500 Ω audio transformer.
The control pack video monitor should be realigned for inflight viewing by the pilot (or completely removed, as it cannot be seen in its present position).
Require dual (gunsight and instrument panel) recording capability - Split Image recording.
Lens should be locked in the f/5.6 position with focus at infinity to avoid accidental changes in flight. This setting was most effective in previous studies.
Replace the 5-position mode selection switch with a 4-position switch and relocate said switch so that the pilot can view and manipulate it while inflight.
Mode indicator lamps are not required since they are too dim for daylight viewing and too bright for night operation.
It might be possible to remove light baffle by fabricating a polarized beam splitter and using a polarized filter on the vidicon lens.

TABLE 14. SUGGESTED EQUIPMENT AND CONFIGURATION IMPROVEMENTS (TAC-TR-70A-113F) (Cont.)

Add a slide arrangement on the recorder unit itself to facilitate film change and unit maintenance.

If a fixed lens is used, a 25mm lens is recommended over the standard 17mm lens to increase FOV.

Install a permanently attached lens cover for use when camera is not in operation. It should be designed for easy removal and replacement, but should not swing freely when not in use.

Camera should be mounted vertically instead of horizontally to minimize the effects of vibration.

If Sony model 2400 is selected, the automatic shut off wire whould be bent so as to hold tape against the recording heads during negative g's.

Include an audio signal to indicate manual weapon release time. A 28V input from the pickle switch (4-10 seconds at 1,000 cps) would do nicely.

TABLE 15

VIDEO CAMERA SPECIFICATIONS

VIDICON TUBE:	Diode Matrix Vidicon
SCANNING SYSTEM:	Standard 2:1 Interlace
SYNC SYSTEM:	External or Internal
HORIZONTAL RESOLUTION:	500 Lines Desired, 400 Lines Minimum
VERTICAL RESOLUTION:	500 Lines Desired, 400 Lines Minimum
VERTICAL FREQUENCY:	60 Hertz
SIGNAL-TO-NOISE RATIO:	Greater than 400 dB
VIDEO OUTPUT:	1V (p-p) Composite Video Signal, 50 ohms
AMBIENT ILLUMINATION SENSITIVITY CONTROL RANGE (AUTOMATIC):	25 - 10,000 Foot Candles
LENS (ZOOM TYPE):	12½ to 50 mm, f/2, C-type mount
LENS (FIXED):	25 mm, f/2, C-type mount - outside viewing 17 mm, f/2, C-type mount - cockpit panel viewing
VIEWFINDER:	Built-in Viewfinder/Monitor, 1 inch Tube
MICROPHONE:	Electret Condenser Microphone
POWER REQUIREMENTS:	12V DC
POWER CONSUMPTION:	8W
AMBIENT TEMPERATURE:	32° to 105° F
FILTERS REQUIRED:	Medium Green (Used to Optimize HUD Symbology Contrast

TABLE 16

VIDEOCORDER SPECIFICATIONS

VIDEO RECORDING SYSTEM:	Rotary dual-head helical scan with full field designed to American TV standards.
HORIZONTAL RESOLUTION:	500 lines desired, 400 lines minimum.
VERTICAL RESOLUTION:	500 lines desired, 400 lines minimum.
TAPE WIDTH:	Standard ½ inch.
TAPE SPEED:	7½ inches per second.
TAPE PATTERN:	EIAJ type I VTR.
VIDEO MODULATION:	Frequency modulation.
VIDEO SIGNAL-TO-NOISE	Ratio greater than 40 dB.
VIDEO INPUT:	1.0V (p-p), 75 ohms, unbalanced.
VIDEO OUTPUT:	1.0V (p-p), 75 ohms, unbalanced.
RF OUTPUT:	75 ohms, 80 dB.
AUDIO OUTPUT:	(Microphone Input) 3.6K ohms, -75 dB, AGC.
AUDIO INPUT:	(Earphone Output) High impedance type.
AUDIO FREQUENCY RESPONSE:	100 Hertz to 10K Hertz.
AMBIENT TEMPERATURE:	32° to 105° F.
POWER:	DC, 12V AC, 117V 10% with use of AC adapter.
POWER CONSUMPTION:	12W @ 12V DC.
RECORDING TIME:	30 minutes minimum.
CONTRAST	700 - 800 Percent.
SHADES OF GRAY	8-10

Airborne Instrumentation Data

Sources. A number of visits were made to obtain data about costs, personnel, equipment, operations and schedule to allow comparison between electronic airborne instrumentation and other alternatives. Visits were made to some of those considered to be most experienced in airborne instrumentation operations, i.e., the airframe manufacturers who must constantly flight test their products. Other manufacturers also involved in flight instrumentation were sampled. The survey was by no means complete or highly structured; the information which resulted was approximate, rule-of-thumb, or statement of extreme cases. It would therefore be unfair to associate specific experience or cost data with particular manufacturers. Although it would be desirable to credit individuals and companies by name, no specific identifications will be made.

Statement of problem. The requirements for training performance measurement, including a preliminary list of parameters and alternative system types to be compared, were discussed during these visits, resulting in the model form shown in Figure 9. Analysis of combat-crew training information needs has indicated that a total of more than 90 parameters may be required for measurement throughout all phases of flight training, but no more than about 20-30 parameters need to be recorded during any given training phase. A patch panel is used to select the parameters for recording during a specific flight. Recording is accomplished on a magnetic tape in a pulse code modulation (PCM) format if state-of-the-art technology is to be used; otherwise, frequency modulation, pulse duration modulation, or pulse amplitude modulation techniques may be used in the degree of sophistication of PCM is not warranted. Conversion equipment appropriate to the form of modulation will be needed to obtain quick-look data, or second-generation measurement, through the use of a general-purpose digital computer. Of course, the nature of facilities needed must be considered in a full definition of an instrumentation system and a complete assessment of costs. A large proportion of the total costs, and degree of system success, is due to the equipment, personnel, parts, documentation and logistics associated with system calibration, operation, maintenance and repair.

Flight test operations. The costs of flight test instrumentation were discussed within the context of the system model shown in Figure 9; however, prior to detailed discussion of these cost estimates, the nature of flight test operations in most airframe companies should be understood.

First, no detailed breakdown of costs is available; consequently, accurate cost estimates of any system are not possible. A given instrumentation engineer may be working on a number of programs at any time; instrumentation problems tend to grow like Topsy; and, instrumentation costs are generally buried among other program costs.

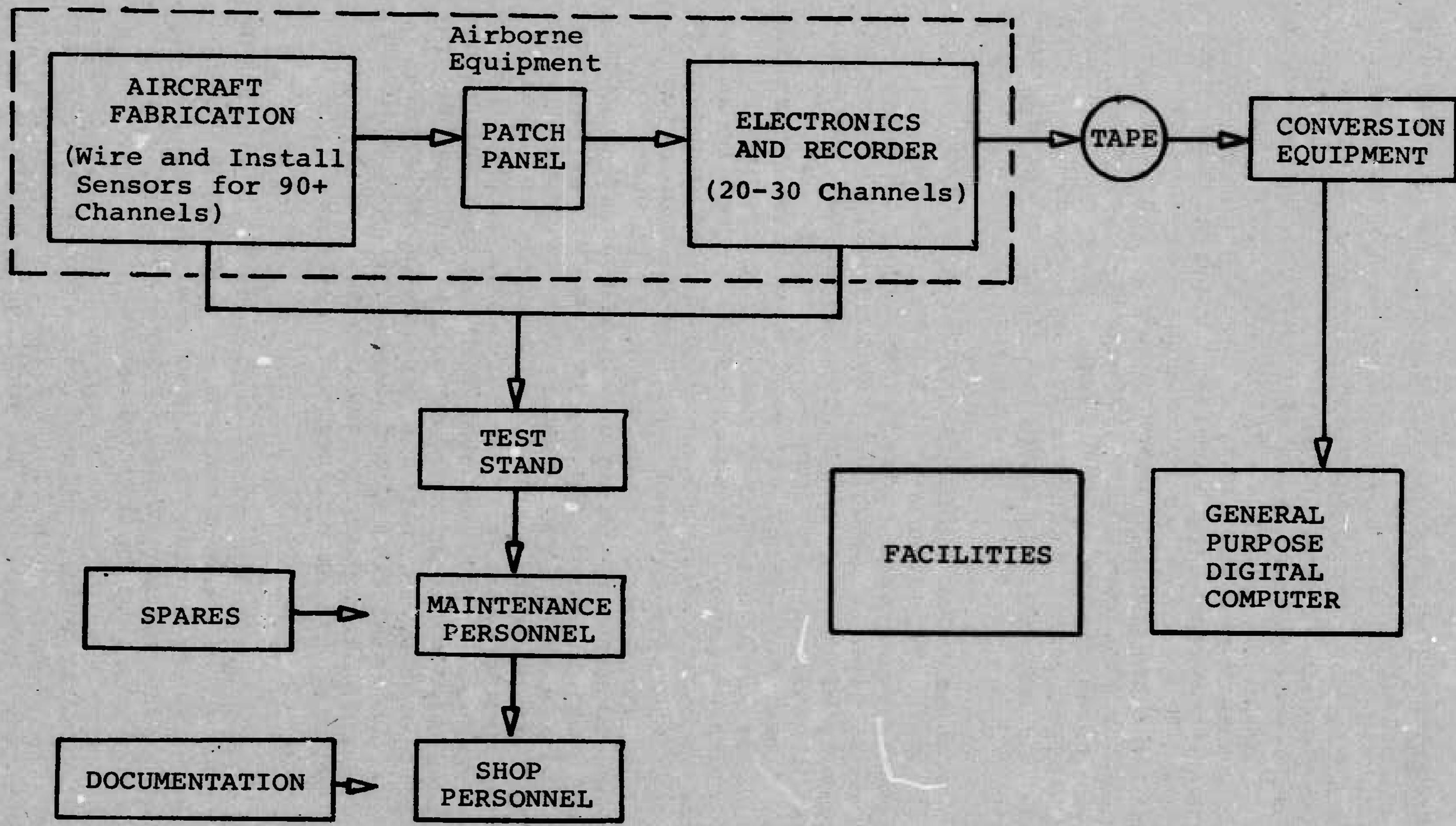


Figure 9. Airborne Instrumentation System Model.

Second, flight test instrumentation operations include all of the following phases:

(1) Instrumentation system design.
(2) Instrumentation calibration.
(3) Test, diagnostics, maintenance.
(4) Spare parts inventory.
(5) Equipment calibration.
(6) Quick-look capability.
(7) Repair shop.
(8) Ground test equipment.
(9) Analog/digital conversion and play-back equipment.
(10) Configuration and efficiency bookkeeping.

The overall costs include contributions from each of the above phases, and, any estimates of an airborne instrumentation system will be based on cost experience reflecting such an operation. The specific cost items corresponding to Figure 9 are:

(1) Aircraft fabrication, including wiring and installation of sensors.
(2) Instrumentation and recording system.
(3) Conversion equipment.
(4) Test stand and test equipment.
(5) Spares.
(6) Documentation.
(7) Design, integration, and operating personnel.
(8) Return of aircraft to original condition.

The operation is not perceived to be as extensive or detailed as that required for flight test; however, cost estimates for the preceding eight items will reflect flight test experience.

Last, instrumentation for flight test is entirely first-class; there is little room for any second-rate equipment or procedures which may permit the loss of extremely valuable flight test data (e.g., may reflect on causes for the loss of a prototype aircraft). Much of the flight instrumentation electronics may be specially designed by the instrumentation engineers, manufactured in small assembly lines, and stocked in extensive inventories--all at the facilities of the airframe manufacturer. Accuracies of less than 1% are achieved through the use of precision sensors, special calibration at specialized laboratories of expensive facilities, and complex corrections during data processing. All in all, flight test operations are exceedingly expensive and probably more expensive than the requirements for combat-crew training dictate; therefore, compensations must be made when using flight test experience for predicting training measurement system costs.

Five cases. As might be expected, data obtained from various sources differed since the assumptions made, approaches, specific experience and hardware used generally differed from manufacturer to manufacturer. The range of data collected is typified by five cases which are summarized in Table 17; each of these is more fully discussed in the following paragraphs.

Cases I, II, and III. The estimates obtained in Cases I, II, and III are based on a definition of the problem closely corresponding to the model presented in Figure 9. These estimates indicate that the cost of instrumenting one aircraft (wire 90 channels and record 20-30 at any given time) with associated equipment for operation and repair may range between $716,000 and $1,200,000. It should be understood that the grossest rules-of-thumb for estimating overhead and general-and-administrative rates have been made. Approximately one year lead time is needed prior to detailed checkout of the system; the aircraft will be needed for installation for the majority of this time. The flight test of a training measurement instrumentation system could become lengthy and expensive if acceptance testing were conducted for each phase of training (transition, instruments, formation, air combat, ground attack, air refueling, air-air intercept, etc.). Various amounts of operating labor were predicted, depending on (1) assumption that system accuracy and complexity would be like that used in flight test, (2) the reliability of the equipment (which is ordinarily unknown for long-term repetitive use), and (3) the assumed intensity of the flight schedule. Highly complex flight test instrumentation requires a large crew to calibrate, test, and maintain; very large crews are required to sustain a flight schedule of as much as two flights a day. Hopefully, measurement equipment for training research can be simpler and more reliable; however, if not, it may not be possible to keep pace with normal experimental schedules with such equipment.

Case IV. The fourth case is based on the use of a miniature commercial airborne computer which can accept most of the signal forms normally available from airborne sensors and format the digitized signals on a cassette-type incremental tape recorder with a standard IBM head. In addition to recording, such a computer could also compute measures for direct read-out. A further assumption associated with Case IV is that aircraft modification and wiring would be performed by USAF personnel or another contractor. The suggested devices are reported to be highly reliable with a mean-time-between-failures of approximately 1500 hours; on this basis, only occasional maintenance is assumed to be necessary. An approximate cost estimate for sufficient equipment and services for four aircraft is $750,000; additional costs of wiring four aircraft for 90 channels of data (at approximately $2,000 per channel) is about $720,000, bringing the total to about $1,470,000. This estimate is significantly lower than the cost estimates found in Cases I-III, but it is based on equipment much different than that normally used in flight test. It should be noted that some integration and checkout costs may also not be included in this cost estimate.

Case V. The last case is interesting because it goes beyond the model shown in Figure 9 to include digital computer facilities and a multiple-target tracking radar. A facility of this type is

TABLE 17. SUMMARY OF INSTRUMENTATION SURVEY DATA

CASE	SYSTEM ASSUMPTIONS	COSTS	PERSONNEL	SCHEDULE NOTES
I.	Wire 90+ chan. (patch 20+); Recording system; Conversion equipment; Test stand; Spares, Documentation.	One Aircraft Materials $ 140 K Labor 1,060 K Total $1,200 K	2 flight test eng/acrft. 2 technicians/acrft. 2 eng + 2 tech shop-work. (Total for 2 shifts).	
II.	Same as Case I.	One Aircraft Materials $216 K Labor 360 K Spares 40 K Document. 100 K Total $716 K	1 eng for 2 acrft. 1 tech/acrft. 1 tech for 4 acrft.	12 mo. to first flight. Need acrft for 8 mo.
III.	Same as Case I.	"Approx. million-dollar effort." "Multi-million-dollar effort to fly intensively."	9 eng to fly twice/day. > 1 eng + 2 tech/acrft. + repair shop men.	Number of test flights depends on definition of acceptance tests.
IV.	Commercial airborne computer; Synchro, DC, serial digital inputs; Incremental IBM-head recorder; 1500 hrs MTBF; Assume USAF wire acrft.	4 Aircraft Computer, Cassette rec, Hdw, Converter, Field service, Eng test equipment for 4 acrft + $750 K.	Field Service. 1 man-yr init design eng Engineer services.	Need interface spec < 3 mo. Need acrft at month 5. 6 months lead time.
V.	USAF wiring, Pod instrument 4 acrft ground station for analysis multiple-tgt tracking radar.	4 Aircraft $1.6-1.8 million for 4 acrft up to first flight. $16.8 K/wk (65 K/mo) recurring costs.	1 eng + 8 techs. 1 programmer, 2 operators. 2 data analysts. 2 radar technicians.	12 mo. through checkout , acrft from mo. 4, on ground for 5 mo.

probably necessary for measurement during air combat maneuvers, and is desirable for most training phases. The cost estimated for such a facility, excluding the costs of wiring aircraft, is approximately $1,600,000 to $1,800,000 for four aircraft; however, the initial cost is overshadowed by the estimated $16,800 per week recurring costs. The recurring costs are largely due to the number of people required for maintenance and operation (about 16 people).

Summary. The range of estimates of costs, procedures and equipment required to obtain training performance measurement through an airborne instrumentation system are quite varied. The data obtained are inconclusive with regard to a specific type of system or in bracketing the costs.

All are quite expensive. The total cost for instrumenting enough aircraft to permit collecting performance data on about 10 students through training is staggering. If any less expensive alternative is available, it follows that one should reduce or eliminate the need for measurement through an instrumented digital recording system.

If aircraft instrumentation is found to be necessary, the reliability of the system should be examined closely. System reliability is a key factor in (1) reducing the need for engineer and technician personnel along with extensive repair facilities and spares, and (2) ensuring that data collection can keep pace with intensive flight schedules. The second factor is perhaps the more important. The first reduces costs associated with system maintenance; the second factor permits needed information to be collected. If a measurement system does not work frequently enough to collect needed information, then there is little reason for its existence.

Another factor worthy of serious concern is the amount of time an aircraft must be withdrawn from service for the purpose of modification for an instrumentation system. Various estimates indicate that an aircraft may be required for instrumentation modification for 5-8 months. If an aircraft is providing a useful existence (e.g., being used for combat-crew training), the costs of withdrawing it from service must also be considered.

The total cost viewpoint provided by Case V indicates the high recurring cost. These costs must be justified in terms of the value of the research toward which such an operation contributes. The value of research is not possible to estimate unless the specifics are known. On the other hand, it is clear such a facility and crew must be regularly occupied in a productive fashion; a high-level continuous operation is implied.

Personnel Requirements

The personnel required to collect and analyze data follows directly from the operations they must perform and the amount of data to be collected: One individual will be required for each daily flight to attend briefings and debriefings, monitor flight progress, and follow the data through the data reduction and analysis process; in addition, a lead scientist will be needed to coordinate the total effort and to prepare analyses to meet the research objectives. A system programmer will be needed the first year to prepare necessary executive and monitor programs and many utility routines which increase overall system efficiency. Data clerks are needed to interpret data viewers for manual data entry, and to perform many manual operations during the various steps of computer processing instrumentation recordings. Manual measurement developed in this study has attempted to permit manual reduction of a 30-minute visual recording in approximately 1-½ hours; as there are other activities associated with manual reduction, it is assumed that one individual should be able to process two flight recordings a day. If manual measurement is to be completely verified by another individual, then two individuals will be required two flight recordings a day. A secretary will also be needed to assist data collection (such as transcription of audio recordings) and to prepare technical reports.

The engineer and technician labor required to install, calibrate, replace and repair measurement equipment is much more difficult to specify since this depends in large measure on the reliability of the equipment. Estimates collected from various concerns performing flight tests have varied widely; estimates collected from commercial avionics concerns indicate that a significant improvement in reliability, with reduction of engineer/technician labor, is possible. Since equipment complexity should be less for performance measurement than Category II flight test (accuracies less, fewer specialized sensors, continued use of a fixed equipment configuration), it is assumed that reliability should be greater, permitting a middle-of-the-road estimate (based on flight test experience) to be considered conservative. These estimates, along with those made for other types of labor, are presented in Table 18.

Based on these estimates a manloading is developed in Table 19 for manual and automatic measurement processing, for one and four flights a day. Note that engineer and technician labor depends on the number of aircraft to be supported, while manual processes depend, to a larger extent, on the number of flights which may occur on a given day; for current purposes, it is assumed that these are the same, that support of four aircraft result in four flights per day.

Note that an automated system apparently results in increased manpower, rather than a reduction, and that the primary benefit of automation is more accurate data in greater quantities.

TABLE 18. PERSONNELL ASSUMPTIONS

TYPE	LEVEL REQUIRED
Research Scientest	One lead, one per daily flight.
Programmer	One system programmer first year, one thereafter if four or more flights per day.
Data Clerk	Manual: One for two flights per day, double for data verification. Auto: One for two flights per day for computer operations.
Engineer/Technician	Manual: One tech. for two acrft. Auto: One eng. for 2 acrft, two tech. per acrft. One technician for ground equip., if four or more acrft.
Secretary	One for clerical assistance and report preparation.

TABLE 19. MANLOADING* WITH DIFFERENT SYSTEMS AND DEGREES OF USAGE

TYPE LABOR	MANUAL		DIGITAL RECORDING	
	1 flight per day	4 flights per day	1 flight per day	4 flights per day
Research Sci.	2	5	2	5
Programmer		1		1
Data Clerk	1	4	1	2
Eng./Tech.	1	2	3	11
Secretary	1	1	1	1
Total	5	13	7	20

*Not including field service for computer and larger equipment, and also not including technicians for a ground radar station.

If a ground station radar is to be maintained for flight tracking, two radar technicians should be added to these estimates. Field service contracts for service of the computer and other larger pieces of equipment will also be needed.

III. DESIGN TRADEOFFS

The design analyses result in tradeoff comparisons at two levels: (1) comparison of competing data sources, i.e., audio, X-Y, video/photo, and instrumentation (digital recording), and (2) comparison of systems built around only video/photo sensors and only digital recording. Tradeoff comparisons at the first level reveal the rule of alternative data sources, while second-level comparisons establish cost-effective system combinations.

Alternative Data Sources

Audio. Recording of voice communications was found to be of value in all phases of combat-crew training. Since audio recording is relatively inexpensive and simple to implement, there is no apparent reason to exclude auditory data from a measurement system.

Audio recordingsrequire manual data processing methods and often must be synchronized with other recorded information to be of value. Auditory information is particularly valuable for measurement related to crew coordination, but voice-operated relays must be used to uniquely identify which crewmember is talking, even if two attempt to talk simultaneously.

X-Y. The cases where X-Y data are required for measurement have been considered carefully since these portend the use of expensive equipment (such as a multiple-target tracking radar) and the collection of difficult-to-process recordings. It was therefore interesting to find cases where equivalent results could be obtained with video/photo sensors (not in the form of a tabulation of X- and Y-values, but position information such as the relationship between tanker and refueling aircraft from the tanker lights).

All cases of X-Y data requirements uncovered in the current analyses are listed in Table 20, showing that most requirements can be met with video/photo recording. If video/photo recording, with manual processing, is adopted then many of the problems associated with X-Y data are resolved. Table 20 also reveals that a number of parameters are not obtainable with video/photo sensors; these are: (1) lateral drift across the runway during transition, (2) relative position of aircraft during intercept prior to lockon, (3) enroute cross-track error during airdrop, (4) inflight ranging (out of sight) during formation, and (5) space paths of multiple aircraft during air combat maneuvers.

It has been previously pointed out that a multiple-target tracking radar is quite expensive (current radar approximately \$1-3 million; future laser versions estimated at \$300,000) and require two radar technicians to operate and maintain it. Unless sustained critical research is planned, it may be preferable to operate within existing instrumented ranges (e.g., Edwards AFB,

TABLE 20. REQUIREMENTS FOR X-Y DATA

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

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

Eglin AFB) when spatial tracking data are needed. Of course the schedules at existing ranges are often filled, and it may be difficult to arrange for segments of training to occur at such ranges.

Video/photo. It is clear that many kinds of information can be obtained with video/photo recording which would otherwise be difficult to acquire, while at the same time allowing acquisition of information from the cockpit panel to be sampled at will (if an instrument is in view the information may be sampled later if desired). Out-the-window information is quite important to combat-crew training measurement in all phases, except, of course, during instrument flying. Through video/photo recording, information can be gleaned from the view of the runway, the radar scope picture, other aircraft through the windscreen, the path over the drop zone, the relationship of ground targets to the pipper, and the position of the dart throughout firing. These are, indeed, important information.

Digital recording. The primary virtues of automatic digital recording are: (1) high speed and accuracy, (2) ability to sense information which cannot be directly seen with a camera in the cockpit, and (3) automated computer processing with data in electronic format compatible with computing equipment. Recording of information such as pilot control stick movements is difficult to acquire without direct recording of control stick sensors, since it will be impossible to gain a proper camera view in a fighter-type aircraft. Any data required for complex calculations (as simple as a mean or standard deviation) will necessarily be at a relatively high sampling rate (i.e., often enough to render manual processing impractical) requiring digital recording to permit automatic high-speed processing. While video/photo sensing has an advantage for acquisition of out-the-window information, instrumentation can record unseen items critical to measurement computations (i.e., start-stop parameters such as weight-off-wheels), and permit complex sophisticated measurement unlikely to be exceeded by future research demands.

Comparison of Video/Photo and Digital Recording Techniques

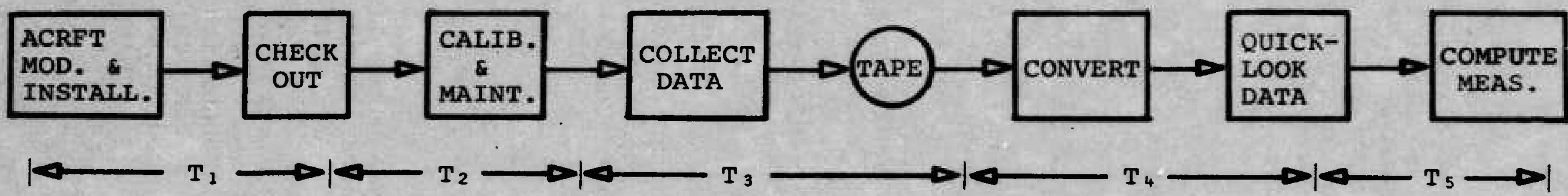
The remaining tradeoff comparisons are between the two primary methods of data acquisiton: measurement systems based on video-photo techniques as contrasted with systems based on digital recording techniques. For these purposes, to achieve a degree of simplification, two candidate systems will be considered based entirely on one approach or the other. The comparisons will be conducted according to guidelines of previously established system criteria.

Provide needed information. Neither video/photo nor digital recording techniques can generate all measurement desired. Video/photo techniques provide convenience in collecting out-of-the-window information, while digital recording techniques can accurately determine specially sensed information and permit sophisticated computation. It can be argued that for many applications the out-of-the-window information is most relevant to combat-crew training, and could be least dispensed with; however, the relative value of the information presented by these two system types depends clearly on specific research goals, and cannot be resolved for even a given training phase without detailing precise information objectives. Neither video/photo nor digital recording techniques are universally superior as sources of performance information.

Useful format. One approach presents a pictorial presentation of events, while the other allows a numerical or graphical form. The superiority of formats depends on the use of the information. The video/photo format presents information in much the same way as the information is presented in flight; this should permit ease of interpretation by the instructor pilot and student, forming a framework to improve communication between instructor and student, or between either of these and the research scientists. In previous analyses (e.g., air combat) it has been shown that the instructor may be required to participate in the measurement process, and in all cases it will be necessary to maintain a high level of communication to enhance the development of new measurement. On the other hand, a quantitative presentation of information, in a much different form than that presented in the cockpit, promises hope for greater objectivity and the solution of problems which appear vague when discussed in terms of ordinary flight parameters. Thus the specific format desired apparently also depends on specific usage.

Both pictorial and numerical/graphical formats are likely to be desired. It should be noted that quantitative information can often be derived from the pictorial format, and that much of the cockpit displays may be recreated from digital recording. If a manual process is desirable on other grounds then it is probably more convenient to extract desired quantitative data from video/photo display; an automated process would create an environment for re-creating cockpit displays, but additional costly equipment is involved.

Research cycle time. Five research periods which are of concern in estimating the time needed to conduct research are illustrated in Figure 10. Estimates of time periods for both digital recording and video/photo recording appear in the table incorporated in the figure. The digital recording instrumentation time periods are based on information collected during a survey of flight test experience (reported in Chapter II, Supporting Analyses); these are therefore considered typical of complex high-accuracy data collection. The video/photo time periods are based on U. S. Air Force video recorder tests and estimated resulting from analysis in the current study. Neither set of estimates is considered optimistic as probably shorter time periods could be realized as a result of sustained use; in any case, it should be understood that these estimates include gross approximations.



	INSTRUMENTATION	VIDEO/PHOTO
T_1	6 mo. - 1 year	60 - 120 days
T_2	2 - 8 hrs./day	1 - 2 hrs./day
T_3	1 flight/day max.	-----
T_4	½ - 1 hr.	None - Video 24 hrs. - Photo
T_5	Negligible	Approx. 1½ hrs./flight

Figure 10. Time Allocations for Measurement Processing.

The installation and checkout time for a digital recording system is extensive because of engineering to determine sensors, wiring, black box changes, signal conditions, and labor in performing aircraft modification. Because of the complexity of a large recording system (i.e., 90 channels) a significant amount of flight test and trouble-shooting is anticipated.

Calibration and maintenance is also expected to be extensive with a large-scale recording system. If the system should be like most flight test instrumentation, a crew of engineers and technicians may work most of the day to ensure that a test flight can occur each day. A video/photo system will also require checkout, calibration, trouble-shooting and repair, but it is believed that a moderate amount of time and labor can achieve multiple test flights each day.

Digital recording will require some form of conversion and digital processing to provide visible data; video recording can be played-back readily, but photo processing may require as much as 24 hours for a heavy sustained data processing load.

After quick-look data are available and data corrections are made, measurement computation is almost immediate with digital recording, while manual video/photo processing is expected to average 1-½ hours for a flight (video recording for about 30 minutes), and twice as long to get manually verified results (two data clerks checking each other).

Data collection (T_3) is a critical period. It is probable that concerted effort will be required to process measurement in pace with a training squadron schedule with either video/photo or digital recording systems. The unreliability and complexity of large-scale digital recording may require much manpower to ensure that each instrumented aircraft will collect data for one flight each day. On the other hand, hours of video/photo manual processing are needed for each data collection flight, raising the possibility that a backlog of unprocessed data may accumulate. The danger with digital recording is that training may progress without data collection, or that the data collection schedule will slip; while manual video/photo data may overload the processing system so that data collection proceeds without measurement feedback and data analysis schedules slip.

If it is assumed that either approach can keep pace then it may be seen that the major remaining difference is the time for modification, installation and checkout. Estimated research time is shown in Table 21.

If research is conducted in a new aircraft or simulator (i.e., one that has not been used to conduct research with either measurement system technique), digital recording and video/photo recording techniques will require 18 months and 9 months, respectively, but research time becomes about 6 months with either technique for repetitive application in a fixed environment.

TABLE 21. ESTIMATED RESEARCH TIME (MONTHS)

Phase	DIGITAL RECORDING New Application	DIGITAL RECORDING Repetitive Application	VIDEO/PHOTO RECORDING New Application	VIDEO/PHOTO RECORDING Repetitive Application
Install & Checkout	12	-	3	-
Data Collection	4	4	4	4
Analysis	2	2	2	2
Total	18	6	9	6

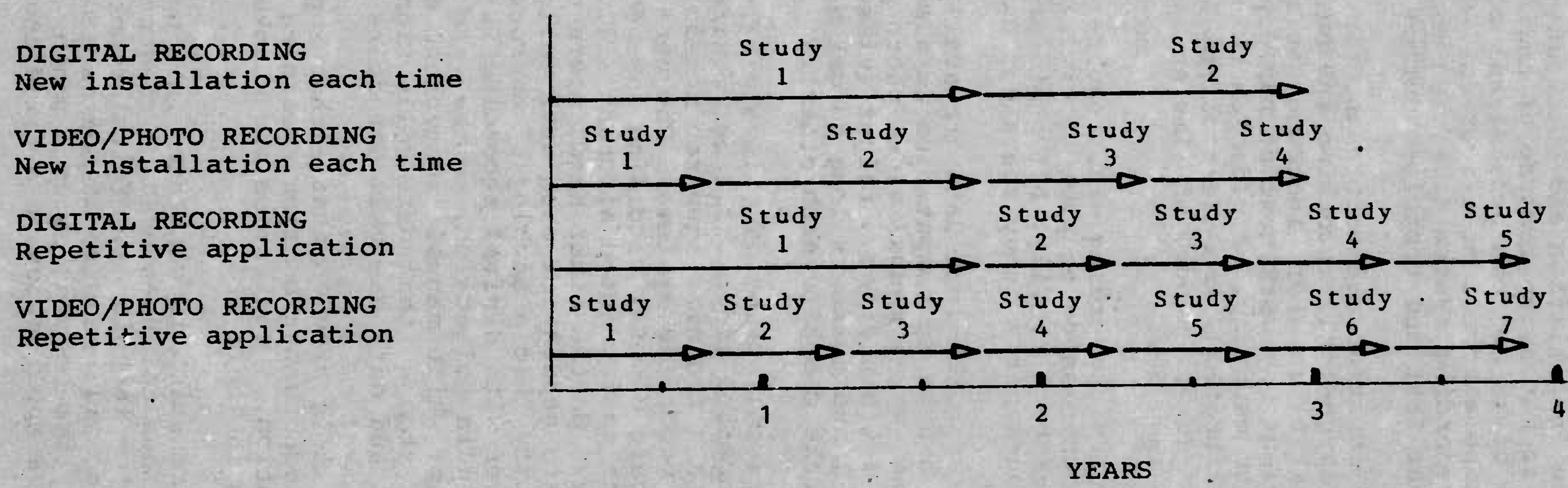


Figure 11. Comparison of Digital Recording and Video Photo Research Schedules.

If a sequence of studies is to be conducted, progress will be as shown in Figure 11. If a new installation is required for each research study, two studies can be conducted with video/photo recording for every study conducted with digital recording, assuming that video/photo data reduction provides needed measurement and keeps pace with the flying schedule. When research is repetitively conducted in the same environment, the two types of systems will eventually perform studies at the same rate, although two extra studies will be initially accomplished with video/photo techniques.

It is assumed for each of the above comparisons that each technique produces the same measurement so that time is one of the major remaining tradeoff factors; however digital recording processing is capable of measurement more sophisticated than video/photo techniques, allowing the future pursuit of research objectives which may require more complex information than normally specified for combat-crew training.

Costs. While system costs are difficult to accurately determine without detailed definition and soliciting of competitive manufacturer estimates, rather gross estimates appear to be satisfactory. The digital recording instrumentation estimates collected have ranged (approximately) from $200,000 to $1,000,000 per system, while a video/photo system would range (approximately) from $75,000 to $125,000. Consequently, digital recording involves about 5-10 times the expense of video/photo recording acquistion; processing requirements are about the same, although manual processing will permit a more austere approach to data reduction. The cost factor therefore weighs heavily in favor of the video/photo approach.

Data distortion. Data distortion and losses are possible and inevitable with either system technique.

Digital recording techniques clearly permit greater accuracy and protection against interference with modern digital coding techniques; however, equipment complexity and associated failures promise that some channels of data will be occasionally lost. Much will depend on specific sensors needed for digital recording; some sensors, and some signals from within avionics black boxes, will present engineering challenges for reliable measurement without distortion.

Video/photo recording will be susceptible to sun angle, electronic interference, vibration and maneuvering g's. Engineering challenges are presented here also, but it is believed that solutions will generally be found. It is expected that some sun angles may wash-out the picture, destroying data collection at some aircraft-sun relationships. Video recording resolution is limited, requiring specific contrast ratios, shades-of-gray, and visual-angle subtense for data processing.

After preliminary testing, when initial difficulties subside, it is expected that a digital recording system can achieve sufficient reliability (with adequate maintenance) to be clearly superior to video/photo techniques with respect to data distortion and losses.

Compatibility with training devices. Perhaps the most prominant disadvantage of digital recording for research is the time and effort required for training device modification, installation and checkout. The effort required for the first installation in one type of aircraft are, for the most part, to be repeated each time an installation in a new type of aircraft is desired. Sensors must be installed, black-box modifications engineered, wiring-type determined, signal conditioning devices designed, recording system installed, and aircraft wiring and modification performed, for each new training device used in research.

Video/photo recording provides a system which may be installed, removed and reused from aircraft to aircraft. Each new installation must be engineered, but primarily with respect to mechanical features and electronic interference.

Of course, performance measurement may be desired in the simulator, or part-task trainer, as well as in the aircraft. Again, it may be seen that video/photo recording is more easily installed since no electrical interface is required (or reprogramming of a digital simulator). In special cases there may be some argument for using one type of system in aircraft and another in simulators, but it is believed there is merit in using one system for all applications to provide a common input for data processing.

Iterative measurement development. Iterative measurement development requires the ability to change measurement as a result of preliminary measurement tests. The research team will want the ability to change to new, perhaps much different, measurement forms with sufficient ease to allow train-and-error comparisons.

Digital recording will permit the examination of any measurement based on the specific parameters recorded through appropriate computer programs. It may be quite difficult to obtain a new measure which requires recording another parameter (i.e., adding another recording channel, or adding new sensors).

Video/photo recording permits new measurement though new instructions to the manual processing clerks if (1) the measure is tractable with manual techniques, and (2) the basic parameters can be included in the field of view.

It is believed that both techniques have advantages for iterative measurement development, but video/photo recording provides greater ease for measurement experimentation.

Minimum training interference. Any measurement device interferes to some degree with the process being measured, but any amount is undesirable. One must therefore attempt to minimize the extent and likelihood of interference from a training measurement system.

Both recording approaches are likely to require either student or instructor to start and stop equipment, and possibly to mark special events. In addition to these disturbances, the presence of the video/photo system will be evident in the cockpit, and may even be occasionally visible by the crew; consequently, training interference is more likely with video/photo recording.

External data correlation. It may be necessary for data from radar ranges, subjective questionnaires, manuals, or other experiments, to be merged with video/photo or digital data acquisition output. Merging of data will be performed in the data processing computer, or manually if in small amounts, so that this requirement does not greatly impact on the decision between approaches to data acquisition.

Space, weight and power. Space, weight and power are highly equipment-specific, but it is believed that video/photo recording will present lesser demands on physical requirements. A recorder will be needed with either approach, but more electronic equipment will be needed for digital recording (although not necessarily a significant amount with projected technology).

Effective personnel/facility. Any personnel/facility combination will require powerful tools to pursue research goals; however, the personnel/facility considerations do not materially affect a tradeoff between video/photo and digital recording, except as already reflected in the preceeding discussion of criteria. Otherwise it should be noted that video/photo processing will require greater numbers of manual data clerks, while digital recording will require more engineers and technicians.

IV. RECOMMENDATIONS

A clear uncomplicated choice is not possible between video/photo and digital recording approaches to measurement system design, but if such a choice must be made, video/photo recording will be chosen for cost, information provided, flexibility and ease of use.

However, a hybrid system, combining the advantages of both, is preferable to either type of recording alone. Due primarily to cost, the bulk of measurement parameters would be derived from a video/photo system, and the remainder with a small digital recording capability. It would be desirable for the major components of a hybrid system to have a stand-alone capability of modest means and power for all combat-crew training measurement when used together. Auditory data recording should be incorporated together with the option for merging data with that from ground-tracking radar. All data recording must include provision for synchronization with all other data sources.

A broad implementation plan is shown in Figure 12. Existing sources of data must be used initially with existing processing facilities. A two-camera video recording system and an auxiliary camera (motion or time-lapse) together with a time-share computer terminal provides the simplest and least-expensive first facility. A dedicated digital computer next adds power and prepares the way for addition of digital recording capabilities (conversion equipment will be needed for digital processing). Such a facility will permit processing of spatial information when used on an instrumented range. Addition of a multiple-target tracking radar would be the last step if research requirements dictate the need for a dedicated radar.

I. EXISTING SOURCES OF DATA

II. DUAL VIDEO + PHOTO + TIME-SHARE

III. DUAL VIDEO + PHOTO + DATA PROCESSOR

IV. DUAL VIDEO + PHOTO + SMALL DIGITAL RECORDER + CONVERSION EQUIP.

V. DUAL VIDEO + PHOTO + SMALL DIGITAL RECORDER + CONVERSION EQUIP. + RADAR

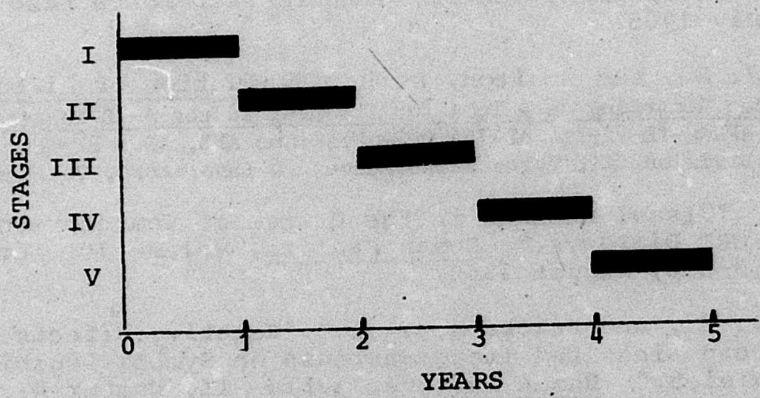


Figure 12. Implementation Stages.

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