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AN EXAMINATION OF PILOT INFORMATION REQUIREMENTS

PREPARED FOR
DOUGLAS AIRCRAFT COMPANY, INC.
LONG BEACH, CALIFORNIA

BY
DUNLAP AND ASSOCIATES, INC.
SANTA MONICA DIVISION



\$2.60

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PILOT INFORMATION REQUIREMENTS

Contract Nonr 1076(00)

Prepared for:

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Long Beach, California

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November 30, 1962

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FOREWORD

This report covers, in part, the work performed by Dunlap and Associates, Inc., for the Systems Research Group, Douglas Aircraft Company, Inc., under Revision 9 to DAC 56-416. The subcontract was administered by Dr. A. A. Burrows.

The study was performed by R. A. Westland, L. B. Weingarten and R. B. Kelly, under the Program Direction of Dr. J. W. Wulfeck.

The determination of pilot information requirements has constituted a continuing effort within the Army-Navy Instrumentation Program (ANIP) framework, and this report reflects earlier work in this area performed by Dunlap and Associates, Inc.,* and Douglas Aircraft Company, Inc.** The report treats, in part, information requirements arising from data link control and other control state considerations not previously treated. Additional, revised definitions and classifications have been proposed to more accurately reflect current flight operations.

* Dunlap and Associates, Inc., Integrated Instrumentation for Aircraft, December 10, 1954.

** Phalon, J. J., Pilot Information Requirements, Douglas Aircraft Engineering Report No. ES26840, October 9, 1957.

I. INTRODUCTION

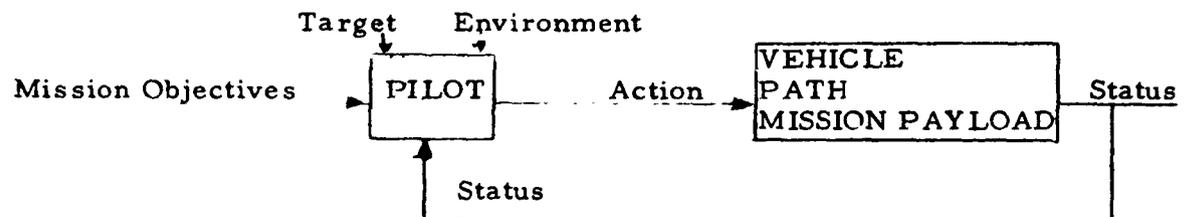
An examination of pilot information requirements must be based upon a systematic method for defining and analyzing the multitude of variables and parameters which prescribe the need for specific categories of data. The number of basic mission and flight variables to be considered is appreciable, and added complexity stems from the necessary consideration of the multitude of automatic devices which, in part, process and control the variables. The effect of such devices on information requirements has not been fully resolved; perhaps at the extreme is the contention that the information requirements for monitoring under automatic flight are the same as those for performing the task manually. The most recent addition to the requirements determination problem is the high speed data link control of aircraft flight from a central command point.

This report deals primarily with information requirements methodology. It proposes a method for structuring the total information demands during flight, and presents a discussion of techniques for analyzing the effects of variation in types of missions and types of aircraft control. The basic analysis treats the general case of aircraft control, irrespective of mission type or information display technique. It is intended, however, that the methods be readily adaptable to a specific vehicle or mission, and be of direct value in display design and evaluation.

II. INFORMATION REQUIREMENTS MODEL

A. MODEL FORMULATION

The determination of general pilot information requirements as in this report, or the specific determination as in the study of a particular vehicle, requires a detailed examination of the source, processing, and application of specific categories of data. One basic model for analyzing these requirements follows:



This study considers the pilot functioning implicitly as a planner and explicitly as a controller. The planning function consists of the general specification of the flight parameters and their relationships which are required for the successful accomplishment of the mission. The control function includes: 1) monitoring of status; 2) comparison of status with objectives; 3) decision with respect to the results of the comparison; and 4) action taken to implement the decision. This latter function may be accomplished in part by automatic means such as auto-pilot or automatic flight control equipment.

The information-decision-action process illustrated in the model above forms the basis for the analysis. The actions in the model are made with respect to the vehicle (attitude, power, configuration, etc.), path (heading, velocity, altitude, etc.) and mission payload (bomb release, camera turn-on, etc.). Those actions establish the requirement for specific categories of information:

Mission objectives
Status of vehicle, path and mission payload
Target
Environment

Determination of information requirements can be accomplished by a detailed analysis of the model, the dimensions implicit in the model, and the constraints imposed upon the system. One dimension of immediate concern is mission phase which represents the convenient division of the mission into relative steady-state conditions in the sense of objectives to be accomplished. A method proposed for

treating the dimensions of the basic model, that of mission phase and others, is by means of a diagrammatic matrix which shows the relations among the various factors. The steps in determining specific information requirements are described below and illustrated as matrix construction steps in Figure 1:

1. Define mission phases
2. Determine pilot actions required in each mission phase
 - a. Determine actions unique to specific missions (anti-air, reconnaissance, etc.)
3. Determine categories of information required for each phase
4. Determine specific data items required in each information category.

For purposes of evaluating total information requirements throughout the mission and the control states existing or predicted for various mission types, the following "output" steps are taken:

5. Correlate specific data items with actions within each mission phase
6. Determine control states associated with specific types of missions (anti-air, attack, etc.).

These steps represented by the development of the various matrices are described in the following paragraphs.

B. DEFINITION OF MISSION PHASES

All aircraft flights, irrespective of mission type, have a basic similarity in terms of how they are divided into phases. The phases are characterized by changes in actions and/or information requirements; the changes, in turn, can be in quality, rate of use or occurrence, relative importance, and/or density. There are various acceptable methods of categorizing the phases in terms of their events, and for this document they are as follows:

Take-off
Fly-out
Closing
Engagement
Return
Landing

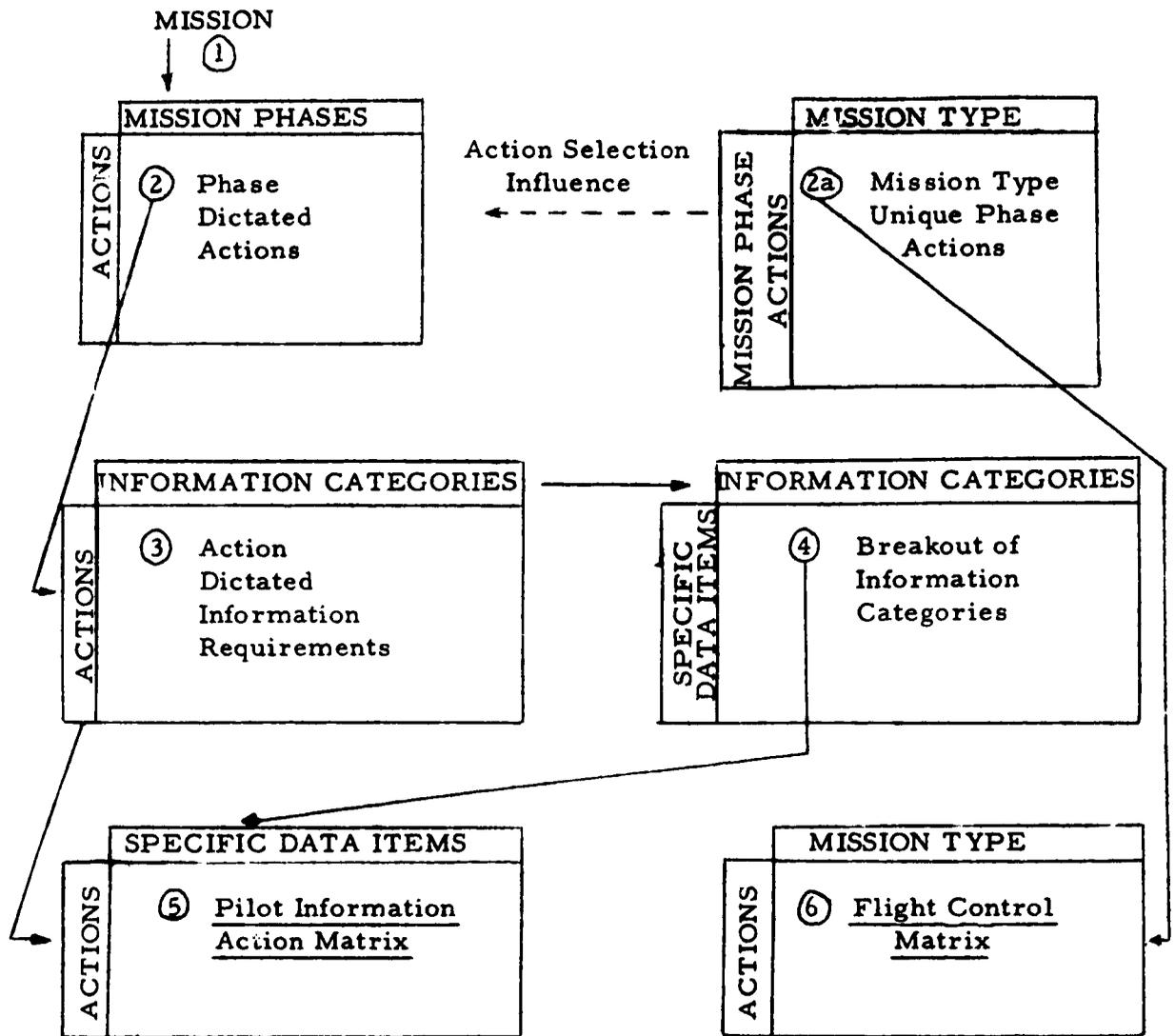


Figure 1 Steps in Formulation of Information Requirements

1. Take-off Phase

In this segment are found those actions performed after the order or decision to "scramble" in pre-flight checks, aircraft readiness operations, and actual take-off including flying through the take-off pattern.

2. Fly-out Phase

This phase starts in the same fashion for all flight types: departing the take-off pattern. It includes flying (self-controlled, ground-vectored, or pre-assigned) to a point which may be preassigned (as a rendezvous with a tanker), assigned in flight (as a vectored flight), or self assigned (first detecting the target on the aircraft radar). In the case of rendezvous, the actions required at the rendezvous point (fueling, formation, etc.) are included in this phase.

3. Closing Phase

This portion of the flight starts after the target (or radar checkpoint) is first detected, includes maneuvering the aircraft into position for the weapon system to lock onto the specific target, and includes actual lock-on (or selection).

4. Engagement Phase

This part of the flight starts after the weapon system has selected the specific target, continues with the aircraft maneuvering to solve the firing, bombing, or navigation problem; releasing the weapon (in the case of the reconnaissance mission this would represent the initiation of the photograph run or other sensor run) and disengaging.

5. Return Phase

This portion of the flight starts after the aircraft has broken away from its "target run," continues with maneuvering to a return flight path, following it, and arriving at a traffic control point.

6. Landing Phase

This, the final phase of the flight, starts with formal entry into the traffic pattern, continues with flying in accord with the pattern, landing, taxiing to the parking

area, running the pre-shut off procedure, and ends with shutting down.

The flight phases together with initiating and terminating conditions are illustrated in Figure 2.

C. DETERMINE ACTIONS REQUIRED

In determination of both action and information categories, an effort was made to develop an organic classification structure in the sense that the categories are universal across all vehicles and missions of general concern, and are basic in the sense that all other sub-categories evolve from them. Because of the correspondence between the decision and associated action, they are treated simultaneously in the general analysis; at a more detailed level, they are treated separately to insure the consideration of decisions which result in no action taken.

The organic decision-action categories together with major sub-groupings are as follows:

Vehicle

- Attitude
- Power
- Airframe
- Internal environment
- Other subsystems (electrical, hydraulic)

Path

- Heading
- Altitude
- Velocity and acceleration
- Rate of climb

Mission Payload

- Activation
- Employment aids
- Aiming
- Delivery/employment

Communications

Auto-flight

- Autopilot
- Automatic flight control equipment

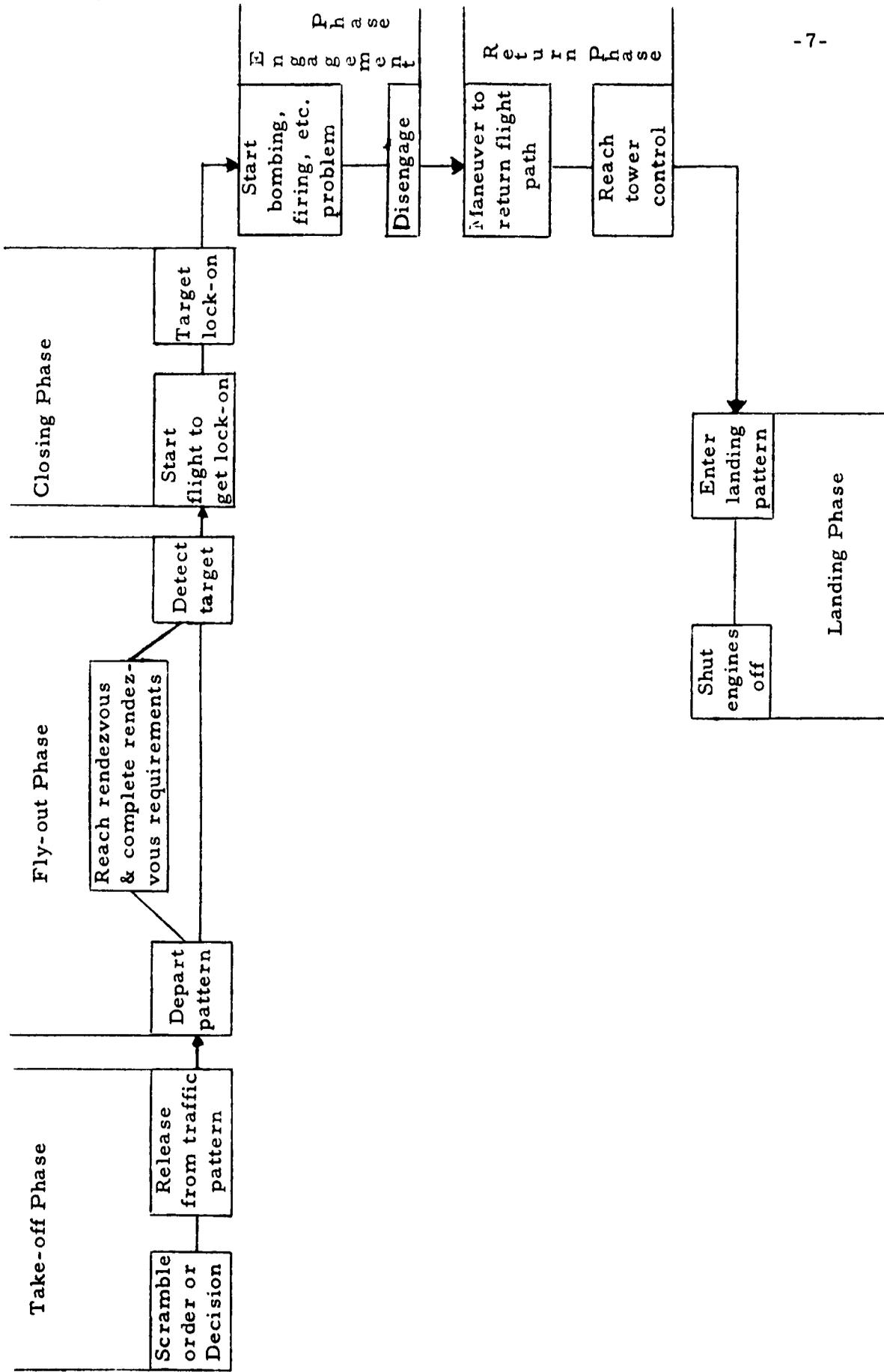


Figure 2 Mission Phases

The generic term, mission payload, is introduced to represent weapons as well as other types of vehicle capabilities. An illustrative break-out by mission would be as follows:

<u>Mission</u>	<u>Mission Payload</u>
Anti-air	air-to-air missiles
Attack	air-to-surface missiles
Airborne early warning	search radar
Anti-submarine	sonar/torpedoes
Reconnaissance	photo, radar, etc.

A similar coverage of equipments is included under the heading of employment aids such as ECM, sounding devices, and the like.

Communication and auto-flight categories do not actually satisfy all of the criteria of an organic classification framework, and for this reason are frequently considered as part of the other subsystem sub-category under vehicle.

The phase-action matrix shown in Figure 3 provides the framework for determining the specific actions which will be analyzed subsequently for information requirements. The majority of terms used in the matrix are in common use; definitions are given below for those requiring additional comment.

Aircraft adjust: Manipulation of aircraft controls to ready for, achieve, and/or maintain path adjustment. Such elements as aircraft trim, throttle setting, etc., are contained in this category.

Navigational systems adjust: Updating (automatically or manually) input data for use in solving the overall navigation problem.

Communications systems adjust: Switching channels, using a "squelch" mode, etc.

Pattern flight: Actions required to fly in a controlled traffic pattern (take-off or landing).

Path adjustment: Changes in aircraft heading, velocity, rate of descent or climb, acceleration, altitude, etc.

	TAKE-OFF	FLY-OUT	CLOSE	ENGAGE	RETURN	LANDING
VEHICLE	Aircraft prestart check Run-up	Aircraft check Aircraft adjust Navigation system adjust Other subsystems adjust	Aircraft check Aircraft adjust Navigation system adjust Communications system adjust	Aircraft check Aircraft adjust Navigation system adjust	Aircraft check Aircraft adjust Navigation system adjust	Aircraft check Aircraft adjust Navigation system adjust Aircraft check and turnoff
PATH	Taxi Roll Take-off Pattern Flight	Path adjust Objective identification Rendezvous actions	Path adjust	Closing path adjust Breakaway	Path adjust Landing system follow	Pattern flight Landing system follow Path adjust Touchdown and roll Taxi
MISSION PAYLOAD			Fire control system adjust	Weapons adjust target identification Weapons release	Weapons system adjust	

Figure 3 Phase-Action Matrix

Objective identification: Recognizing tanker for rendezvous, finding radar checkpoint, recognizing aircraft for formation, etc.

Rendezvous actions: Getting into formation; getting lined up with tanker, hooking-up, fueling, and separating; etc.

Fire control system (FCS) adjust: Updating (automatically or manually) input data for use in solving the bombing, firing, etc. problem.

NOTE: In the case when the FCS takes over navigation of the aircraft, it assumes the dual role of FCS/NAV.

Weapons adjust: Uncaging missile gyros, arming warheads, warming-up seeker heads, etc.

D. DETERMINE INFORMATION REQUIRED

The organic information categories and sub-categories required for the performance of all mission actions are as follows:

Objectives

- Mission plan
- Command requirements

Vehicle Status

- Attitude
- Power
- Airframe
- Internal environment
- Other subsystems

Path Status

- Path made good (i. e., position)
- Present path (velocity, heading, etc.)
- Objective path (velocity, heading, etc.)

Mission Payload Status

- Arming
- Delivery parameters

Target

- Identification
- Location
- Activity

Environment

Weather

Topographic constraints

Traffic

Air defense networks

Objective data constitute the primary input to all decision-action sequences, and can be categorized:

Mission Plan: The general and specific sequence of operations to be performed in accomplishment of the mission. The range of data includes the general objectives laid out by the pilot in his flight plan or equivalent, and the exact flight equations which might be inserted into an automatic flight control system.

Command Requirements: These represent modifications to the basic mission plan (e. g. , selection of alternate targets) or addition of specificity which was not contained in the basic plan (e. g. , vectoring commands in an anti-air mission). Such requirements are generally transmitted to the pilot via a command voice or data link channel. A second class of command requirements would include routine navigation commands such as those associated with traffic control, ground control approach and the like.

The status categories of information (vehicle, path and mission payload) comprise the data which are monitored for comparison with the plan for the purpose of formulating a decision-action sequence. Target and environment information represent data acquired extrinsic to the aircraft and constitute modifiers or a framework for the decision-action sequence.

The action-information matrix shown in Figure 4 constitutes the category-level correlation between actions and information. Figure 5 shows the subcategorization of information requirements to the specific data item level.

ACTION INFO	VEHICLE					PATH				MISSION PAYLOAD			
	Attitude	Power	Int. Env.	Airframe	Other S. S.	Heading	Altitude	Vel. & Accel.	R. of Climb	Activation	Emply. Aids	Aiming	Del/Employ
OBJECTIVES													
Mission Plan	X	X	X	X	X	X	X	X	X	X	X	X	X
Com. Req.	X	X	X	X	X	X	X	X	X	X	X	X	X
VEHICLE													
Attitude	X			X		X	X	X	X			X	X
Power	X	X		X	X	X	X	X	X			X	X
Airframe	X			X	X	X	X	X	X			X	X
Int-Env.			X				X						
Other S. S.	X	X			X								
PATH													
Position					X	X	X	X	X	X	X	X	X
Present Path	X	X		X	X	X	X	X	X	X	X	X	X
Objective Path	X	X		X	X	X	X	X	X	X	X	X	X
PAYLOAD													
Status										X	X	X	X
Parameters						X	X	X	X		X	X	X
TARGET													
I. D.						X	X	X	X	X	X		
Location						X	X	X	X	X	X		
Activity						X	X	X	X	X	X		
ENVIRONMENT													
Weather						X	X	X	X		X	X	
Topo						X	X	X	X		X		
Traffic						X	X	X	X				
Air Def.						X	X	X	X		X		

Figure 4 Category Level Action Information Matrix

Vehicle Status

Pitch angle
Roll angle
Yaw angle
Throttle
Manifold pressure
RPM
Fuel quantity
Fuel flow rate
Oil pressure
Oil Level
Engine temperature
Canopy
Trim
Landing gear
Drag chute
Air brake
Oxygen quantity
Oxygen flow rate
Cabin temperature and pressure
Electrical power
Hydraulic pressure
Panel indicators
Voice communications
Data link
IFF
Fire control system
ILS, TACAN, etc.

Mission Payload Status

Weapons select
Weapons max. range, etc.
Weapon ready
Home-on-jam, etc.
Weapons release

Path Status

Aircraft position (mission ref.)
Aircraft position (geo. ref.)
Altitude
Heading
Airspeed
Groundspeed
G's
Rate of climb
Bank
Checkpoints
Command velocity
Command acceleration
Command altitude
Command heading
Slant range to objective
Command time to objective

Target

Target position (geo. ref.)
Target position (relative)
Target velocity (absolute)
Target velocity (relative)
Target acceleration
Number of targets
ECM
IFF

Environment

Wind velocity and direction
Topographic obstruction
Weather or air defense location
Number of other aircraft
Location of other aircraft

Figure 5 Specific Data Items

E. DEVELOPMENT OF PILOT INFORMATION - ACTION MATRIX

The output step of the information-determination process is illustrated in Table 1, the Pilot Action-Information Matrix. This matrix together with the Flight-Control Matrix (Table 2) forms the basis and frame of reference of further analysis. The headings of the rows and columns of the matrix (actions and specific data items) are obtained from the preceding steps. The matrix entries indicate the requirement for the specific data item in the performance of the action, and represent the first level of analysis of information requirement -- functional proximity level. The functional proximity level indicates the significance of each information category to each action as defined below:

1. Information essential to maintaining within-control condition for the achievement of mission phase objectives.
2. Information concerning establishment of a framework for performance of essential mission actions.
3. Information used in advanced planning, and that which achieves significance through a rapid change of value or emergency condition.

The identification procedure directs attention to those categories which should receive primary attention in any detailed analysis. Within each category, the information may be additionally classified:

- a. Continuous variable
- b. Discrete states
- c. Binary (go-no go)

Concerning specific entries in the matrix, the rule has been applied that if type of missions or action interpretation would lead to assignment on two or more level classifications, the higher level of proximity would be entered.

The matrix provides a gross indication of the total and time variation of information requirements, and through the level of generality employed, includes the functional actions required for all mission types. Thus, target identification could refer to an enemy aircraft, a ground target, or an area to be photographed or searched for submarines. These differences will be treated in somewhat greater detail in a general description of mission control. The functional proximity level coding represents a first level of analysis; other

measures of information, both functional and analytical will be considered below together with general concepts related to control states. The latter topic is of particular concern in airborne systems under consideration where part of the control task is assumed by automatic equipment, or the command requirements significantly affect the information requirements. One objective in the use of the matrix would be establishment of control equations for each row of the action-information matrix, and the analysis of information requirements in each control state. One significant dimension of this problem is described below.

F. DEVELOPMENT OF THE FIGHT CONTROL MATRIX

The control states of primary concern are manual and automatic control intrinsic to the weapon system and control exerted from an external source (ground, shipboard or airborne command point). The Fight Control Matrix illustrated in Table 2 provides cognizance data for actions by type of mission. The categories of control are:

- S the aircraft (pilot and/or computer) controls the actions within the overall mission framework
- s as above but the surface (or airborne) control center monitors closely
- C the control center constitutes the decision point and source of command
- c as above but the aircraft monitors closely, especially to assume command in case of emergency.

The mission categories are broken into two levels; one deals with the performance of a generic type of performance action and the second breaks those down to subcategories peculiar to various air command organizations. The categories are:

- Medium Range Strike
- Reconnaissance
- Anti-submarine Warfare
- Long Range Strike
- Anti-Air
- Close Support

Medium Range Strike: This mission type deals with medium range penetration to accomplish semi-strategic/semi-tactical missions. These types of missions are performed in essentially identical fashion by both the Air Force and Naval Aviation (USN and USMC).

Reconnaissance: This category of mission is performed by all services in virtually identical fashion, although the less complex Army aircraft are unlikely to receive commands via data-link communications.

Anti-submarine Warfare: This Navy-peculiar mission deals with detecting, identifying, and sinking enemy submarines (or keeping them under surveillance pending arrival of surface vessels).

Long-Range Strike: This aircraft mission is peculiar to the Air Force Strategic Air Command.

Anti-Air: The mission of enemy aircraft interception and destruction has evolved into a highly-controlled procedure based upon data linked vectoring from a central command point.

Close Support: This mission by both the USN and USAF deals with the support of ground forces in an offensive tactical role.

III. APPLICATIONS

Information requirements can be analyzed at two levels: first at an engineering level where frequency, accuracy, rate, rate of change and range limits are typical measures; and secondly at the functional level where measures include criticality, tolerable lag and permissible degradation. The application of the latter measures to an information-exchange problem is illustrated in Table 3.* The concept of functional proximity level introduced in the preceding section constitutes one method for applying both measures within the pilot information requirement context. It identifies categories of data having varying degrees of importance in the performance of specific tasks within mission phases. Ideally, each level or class of data could be measured and analyzed within a well defined control system model; combination of all levels need only be considered as a final step to assess overall information requirements

A. CONTROL STATE CONSIDERATIONS

The spectrum of control states which are applicable to all action categories can be represented by the three levels shown in Figure 6. In those illustrations, actions are taken with respect to path and mission payload. An example of problem solution in the three states consisting of altitude control is presented in Figure 7. The first two states represent control systems with continuously varying inputs and outputs; and may be viewed as tracking problems from the standpoint of the human operator. The first example represents the simpler control problem in many instances assuming the rate of change of input (mission plan) is less than that which might be expected from an external command point. The third state is characterized by the low frequency at which a precise assessment of flight status is necessary. A basis for quantifying the control problem and the associated information requirement is given:

$$\text{Required solution rate} = S = \sum_{i=1}^n O_i R_i$$

* Bond, N. A. Jr. and R. A. Westland, Aircraft Information Exchange Requirements, A Projection for 1966-70, Dunlap and Associates, Inc., Santa Monica, California, June 8, 1961.

Table 3 Functional Message Measures

CHARACTERISTIC	BRIEF DEFINITION	CATEGORIES USED
Criticality	Tactical importance to mission.	<ol style="list-style-type: none"> 1. Absolutely essential to mission. 2. Probability of abort or reduced effectiveness unless message received. 3. Minor importance or unnecessary.
Tolerable Lag	Time required for total encoding of message and reception by addressee.	<ol style="list-style-type: none"> 1. Under 10 seconds. 2. 10 to 60 seconds. 3. Greater than 1 minute.
Confirmation	Proof that addressee has received transmission under appropriate conditions.	<ol style="list-style-type: none"> 1. Always required. 2. Required for critical events. 3. Never required.
Flexibility	Fraction of message which must be left "free" for operator selection of alternative words.	<ol style="list-style-type: none"> 1. Maximum flexibility (over 50%). 2. Some flexibility (10-50%). 3. Little or none (10% or less).
Indication of Source Quality	Extent to which transmission provides built-in "modifiers" which define equipment and personnel capability (e.g., whether sensor system is peaked or operating at a marginal level).	<ol style="list-style-type: none"> 1. Detailed and (nearly) continuous indication of status. 2. Status indication during critical phases of mission. 3. Minimum indication of status.
Data Degradation	Extent of error introduced by transmission-reception process.	<ol style="list-style-type: none"> 1. Error rate acceptable. 2. Mission effectiveness affected. 3. Mission accomplishment questionable.
Storage and Referability	Retention of information for later reference.	<ol style="list-style-type: none"> 1. Permanent storage. 2. Buffer storage for all information. 3. Minimum storage.
Security	Degree of security provided to prevent enemy detection of information-exchange.	<ol style="list-style-type: none"> 1. Full protection required. 2. Some protection required. 3. Little or no protection required.

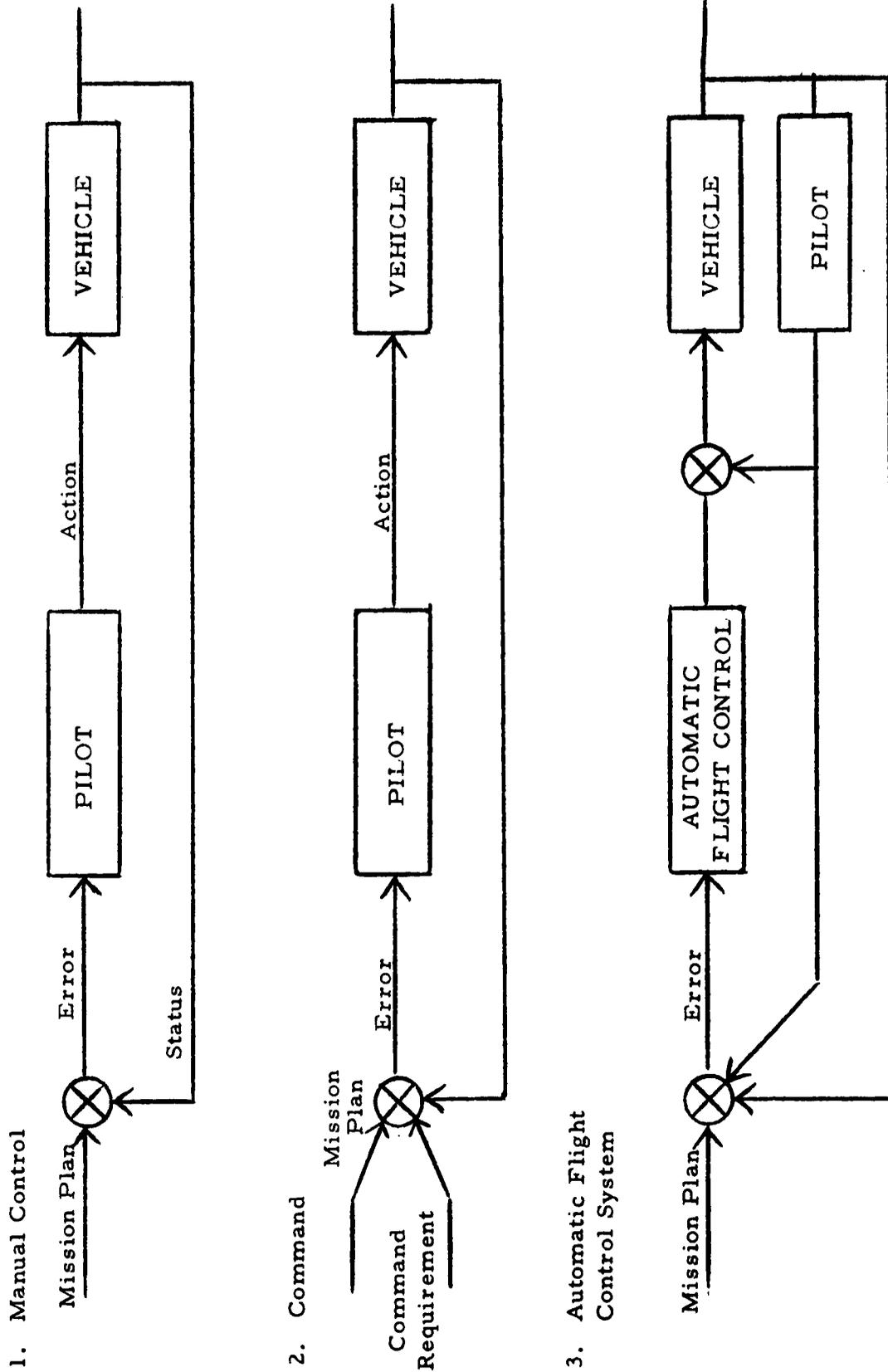


Figure 6 Control State Modes

PILOT CONTROL FUNCTIONS				
Information Required	Comparison	Decision	Actions	
Control State				
1 Manual Control	Plan: 5,000 ft. Status: 4,900 ft. Pitch angle Rate of climb	Difference equal + 100 ft	Increase altitude 100 ft.	Modify pitch angle, assume rate of climb, etc.
2 Command requirement superimposed on manual control	Plan: 5,000 ft. Status: 4,900 ft. Command: 8,000 Pitch angle Rate of Climb	1. Command & plan difference indicates plan modified 2. Status-command difference equals + 3,100 ft.	Increase altitude 3,100 ft.	Modify pitch angle, ---
3 Automatic flight control system	Plan: 5,000 ft. Status: 4,900 ft. Auto flight status Pitch angle Rate of climb	1. Plan-status difference 2. Pitch angle and rate of climb in accordance with difference	Auto flight functioning properly Yes → No →	Next action Check, disengage, etc.

Figure 7 Illustrative Control Task

S = seconds per solution

O_i = operations of type i per solution

R_i = seconds per operation of type i

The term S represents the mission requirement and can be determined from general mission objectives for a specific vehicle under a range of flight modes and conditions; the spectrum of modes extends from vectored flight or terrain following to normal flight, and the range of flight conditions is illustrated by control frequency in turbulent weather versus calm. R_i represents a human performance (or control element) measure. O_i represents the operations required per solution and constitutes an index of control problem complexity. In reference to the three control states above, the operations vary considerably in terms of input frequency, typical error signal and comparison and decision sequence.

Since increased aircraft performance and specific requirements such as data link vector control tend to reduce the permissible solution rate constantly, attention is focused on the alteration of the human performance and operations terms. Since the limits of pilot performance for various tasks are fixed, the solution to the problem lies in the elimination of required operations through the introduction of automatic control elements or through the conversion of the operation to another which can be performed more readily by the pilot. The information requirements derived from each elemental operation can thus be significantly changed by the introduction of control elements, automatic data processing, and/or display techniques.

IV. SUMMARY

A number of procedures have been described for the analysis of pilot information requirements. Organic classification structures are proposed for a systematic examination of information and decision-action categories. Secondly, a functional proximity level concept is introduced to define categories of data having varying degrees of importance in specific tasks. Finally, a control model is introduced to take into account various control states, pilot performance, and various trade-offs involved in meeting control requirements: automatic control elements; data processing; and display techniques. While representing an attack upon an already well-recognized problem area, an attempt has been made to reduce the problem of information requirements determination to a systematic basis.

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