

AD-A213 122

FILE COPY

21 / 11 / 85 33 pages

Q.

Feasibility Study for Ergonomic Analysis
And Design of Future Helicopter Cockpit Systems

NASA
Ames Research Center
Moffett Field, California 94035

Contract No. NAS2-12056

by

Harold L. Hawkins

May 1985

(NASA-CR-176942) FEASIBILITY STUDY FOR
ERGONOMIC ANALYSIS AND DESIGN OF FUTURE
HELICOPTER COCKPIT SYSTEMS (Bio-Dynamics
Research and Development Corp.) 52 p

N86-29811

Unclas
CSCL 01C G3/05 43277

DTIC
ELECTE
OCT 03 1989
S E D

Bio-Dynamics Research & Development Corporation
1000 Willagillespie Road, Suite 200
Eugene, Oregon 97401
(503) 343-8400

This document has been approved
for public release and sale; its
distribution is unlimited.

Table of Contents

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	<i>[Signature]</i>
By	<i>[Signature]</i>
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

	Page
Executive Summary	1
1.0 Introduction	6
1.1 Overview	6
1.2 The Problem	8
2.0 Review of prior efforts to treat the LHX crew workload problem	9
2.1 The Honeywell approach	10
2.2 The Perceptronics approach	16
3.0 The approach recommended by Bio-Dynamics	18
3.1 Step 1: Expert elicitation	20
3.2 Step 2: Principled analysis of crew workload problems posed by LHX systems/mission	30
3.3 Step 3: Development of low-cost, low or mixed fidelity simulations	44
3.4 Step 4: Testing on low-cost simulations	45
3.5 Step 5: Configuring high-fidelity simulation	46
3.6 Step 6: Performance testing in baseline LHX simulator	46
3.7 Modification and re-evaluation of the LHX simulator	47
4.0 Conclusion	47
5.0 References	49



EXECUTIVE SUMMARY

→ The Army's planned new family of scout-attack helicopters, the LHX, will be designed to fly nap-of-the-earth missions under conditions of poor visibility and atmospheric adversity, perhaps with a one-person crew.

The piloting demands likely under these conditions raise two human factors issues critical to success of the LHX mission:

1. How should the LHX information display/control suite be designed to optimize the compatibility with the pilot's information handling capabilities?
2. What information processing functions within the LHX system should be automated in order to ensure the pilot's mental workload under high-stress conditions remains within acceptable limits?

Resolution of these issues will be difficult because the LHX's mission and technologies extend well beyond those with which the military and human factors engineering communities are familiar, the system's mission has yet to be fully defined, and there are no rotorcraft pilots experienced with the demands of flight and mission management within the system. As a consequence, human factors engineering of the system cannot rely on extant knowledge of the workload demands of rotorcraft piloting. A new approach is required.

Bio-Dynamics recommends a seven-step approach to the analysis and resolution of the LHX pilot workload problem. Two key considerations underlie the approach. First, valid assessments of workload and automation opportunities

explore flight simulator; human factor engineering; (KT)

within the LHX system can only be achieved through use of a physical model (simulator) of the system so that objective performance measures can be acquired to substantiate subjective judgments. Second, due to the enormous cost of high fidelity simulation in this field, the development and use of easily modifiable, low-cost computer simulations -- to identify the most effective modes/forms of information presentation and control capability to incorporate into the high fidelity simulator -- must be an essential aspect of the proposed solution.

The seven steps entailed in the proposed program are as follows:

Step 1: Expert elicitation

The objective of expert elicitation within the present approach is to gain from experienced pilots a detailed picture of the information gathering and control activities associated with flight and mission management within each of a set of representative LHX mission scenarios. Of specific interest is information on the procedures, (likely) task concurrencies, task priorities, performance criteria, and modes of information representation governing the pilot's performance to be used during subsequent steps to identify 1) the most important pilot information gathering and control functions to focus on during simulator construction, 2) alternative modes/forms of information presentation and control to simulate and analyze, and 3) performance measures to be used during the conduct of this analysis.

Step 2: Principled Analysis of Elicitation Data

The objective of this step is to perform an analysis that will identify the

information gathering and control functions needed for incorporation into simulator design, to identify alternative modes/forms of these functions to model, and to comparatively evaluate within the simulator the tasks and performance measures to be used during task evaluations.

The analysis would incorporate the following information, acquired during Step 1:

- a. a specification of each of the pilot tasks identified within the scenarios studied, including the information needed and action required to complete the task successfully;
- b. a listing of all (likely) task concurrencies;
- c. the key performance criteria (error, timing or latencies tolerances) associated with each task under each of its various concurrencies;
- d. the relative priority of each constituent task for concurrent tasks.

These relationships and the principles of cognitive and human factors psychology that can be brought to bear on them, would define a set of constraints to serve as critical design criteria during efforts to identify alternative modes/forms of information presentation to be simulated during project Step 3.

Step 3: Development of Low-Cost Simulations

The objective of Step 3 is to produce computerized simulations of the alternative means of information presentation and control emerging from the Step 2 analysis. Because these simulations will be used to comparatively evaluate the alternatives specified during Step 2, they must include the capacities to:

- a. score task performance along the critical performance dimensions identified during Step 1;

- b. flexibly combine tasks to form the concurrencies identified in Step 1;
- c. flexibly combine the information presentation and control alternatives specified in Step 2 to variously configure each task studied.

Step 4: Test Subjects on Low-Cost Simulations

The objective of Step 4 is to empirically compare the information presentation and control alternatives identified in Step 2. The results of these comparisons will be an identified set of information presentation and control modes/forms yielding the most effective, single and concurrent task performance (as defined by the single and dual task performance criteria identified in Step 1) among those alternatives considered. The type of information being sought in this step is of the form, "performance on task combination A and B is better when task A information is presented in mode X as opposed to Y or Z". However, since the simulations producing these results will not be high in fidelity, it is inappropriate to draw conclusions about absolute levels of performance from these low-cost simulations requiring additional steps.

Step 5: Configuration of High-Fidelity Simulation

The objective of Step 5 is to implement the optimal solutions identified in Step 4 as components in a high-fidelity simulation that can be used for evaluation of automation needs within the LHX system. The assumption underlying this step is that neither subjective judgments drawn from pilots whose experience is in helicopter systems other than the LHX, nor analysis based on the application of psychological principles to judgmental data elicited from expert pilots, is sufficient a priori to produce sound decisions regarding automation. The most

valid procedures for determining which LHX pilot functions to automate are those based on analysis of the performance and subjective judgments of pilots functioning within an implemented system whose workload demands simulate those anticipated within the LHX itself.

Step 6: Performance Testing in Baseline LHX Simulator

The information display/control suite of the simulator configuration developed in Step 5 will serve as a baseline suite in the sense that it will contain no automated pilot functions. The objective of Step 6 is to conduct performance testing with skilled pilots to gather performance data and expert judgments that can be used to guide decisions on automation. If skilled helicopter pilots, reasonably trained on the baseline simulator, fail to perform the constituents of a set of concurrent tasks within specified tolerances, then some member(s) of the concurrent set must be considered for automation.

Step 7: Modification and Re-evaluation of the LHX Simulator

Based on performance data and pilot assessments (Step 6) and technological feasibility, certain pilot functions in the baseline simulator will be "automated" for further study using a modified simulator. Skilled pilots will be tested on the up-graded simulator to determine whether or not the automation produces acceptable levels of performance. Based on the results of this evaluation, further system refinement will be carried out as necessary.

1. INTRODUCTION

1.1 Overview

The Army's family of light scout-attack helicopters (LHX), planned for deployment in the 1990's, will fly nap-of-the-earth (NOE) missions in high threat environments, often under poor visibility and adverse atmospheric conditions, and probably with a one man crew. The obvious complexities of flight and mission management under these conditions raise two human factors issues that are critical to success of the LHX mission:

1. How should the LHX information display/control suite be designed to optimize its compatibility with the information handling capabilities of the pilot?
2. What information processing functions within the LHX system should be automated in order to ensure the pilot's mental workload under high-stress conditions remains within acceptable limits?

Bio-Dynamics' objective for the present study is to describe a procedure for the analysis of pilot workload that will identify and explicate the demand characteristics of those LHX mission components holding overload potential. A major claim in the presentation that follows is that a principled, in-depth, explication of the cognitive demands of LHX piloting is essential to any effective effort to address the human factors issues listed above. Two previous studies have addressed these issues, one by Honeywell (1982), the other by Perceptronics (1984). While the solution methodologies advocated in these two studies have much to recommend in their treatment of the demands of piloting, they fail to achieve the level of detail needed to map those demands effectively into established know-

ledge and principles of human information processing. As a consequence, neither approach has succeeded in taking full advantage of the data and understanding available in the fields of cognition and human performance. The focal aim of the current effort is to describe a task-analytic procedure that will yield the detail and organization needed to achieve this mapping.

Bio-Dynamics' current effort paves the way for a multiple step approach to treat these mission critical, pilot-machine interface and automation issues. Several variants of the suggested approach are imaginable. One variant is as follows: Initially, expert pilot opinion on projected LHX flight and mission management is integrated with relevant principles of cognitive, human performance, and human factors psychology to define a plausible set of alternative information presentation and control modes/forms for further evaluation. These alternatives are then implemented as modular components in a relatively low-cost, computer-controlled simulator. The simulated alternatives are comparatively evaluated with respect to the quality of operator performance obtained. The modes/forms of information presentation and control yielding the most effective user performance are then implemented within a high fidelity baseline simulator containing only baseline levels of automation. Objective performance measures and subjective ratings taken from pilots tested in the baseline simulator are then used to determine the need for additional automation within the simulator. The performance and subjective reactions of pilots in the resulting (computer augmented) simulator would then serve to guide further refinements. The end product is conceptualized as an empirically validated model for LHX information display/control suite design and system automation.

Two key considerations underlie this approach and any plausible version. First, Bio-Dynamics believes that valid assessments of workload and of automation opportunities within the LHX system cannot be achieved in the absence of a physical realization (simulator) of the system within which both subjective judgments and objective performance measures can be taken. Second, there is an enormous cost of high fidelity simulation in this field, and therefore the need exists for preliminary use of easily modifiable, low-cost computer simulations of system components to identify the most effective modes/forms of information presentation and control capability to incorporate into the high fidelity simulator.

1.2 The Problem

Resolution of the human factors/automation issues surrounding the LHX system will be difficult for several reasons:

1. The likely mission repertoire of the LHX will differ significantly from what has been experienced by current Army rotary-wing pilots. Therefore, understanding the performance implications of the LHX mission will prove extremely challenging.
2. The range of possible missions has yet to be defined fully for the aircraft, and mission scenarios continue to evolve.
3. Since mission capabilities are not fully defined, human factors engineering criteria for the system cannot be specified.
4. Of those technologies that can be anticipated, many are currently undergoing development, and therefore are unavailable for empirical analysis.

Consequently, many questions exist regarding the likely information processing demands the LHX's technologies will impose on its crew. In sum, workload analysts will have available neither (a) pilots or other individ-

uals who are true experts on the LHX system and its demands, nor (b) a true LHX simulator within which estimates of pilot workload might be obtained.

These considerations clearly argue the need for novel approaches for the analysis of LHX crew workload. Since neither the LHX system nor a high fidelity simulation of it will be realized in the near future, it will not be possible to base initial analyses in any close way on experimentally derived performance data. Similarly, since there are no rotorcraft pilots who are experienced in the missions and technologies specific to the LHX system, it will not be possible for initial analyses to rely entirely, or in a significant manner, on subjective workload judgments. Rather, it would appear:

1. that initial analyses must rely to an unprecedented extent on the application of principles drawn from research in cognitive and human performance psychology;
2. that the mapping of such principles into the LHX problem must be constrained by an understanding of the generic information acquisition/analysis and control requirements of flight and mission management within the LHX system/mission; and
3. that because of the current incompleteness of the body of principles that can be applied to the problem, and other uncertainties related to the precision of the principle-to-problem mapping, the solutions yielded by such a mapping will, in many instances, need to be subjected to close empirical evaluation.

2.0 Review of prior efforts to treat the LHX crew workload problem

Prior to considering the approach that emerges from the foregoing considerations, it will be instructive to review two earlier efforts to

develop work load analytic procedures applicable to the LHX problem. These two studies (Honeywell, 1982; Perceptronics, 1984) contain some excellent, creative thinking which is taken advantage of in Bio-Dynamics' approach. However, the two studies also contain serious conceptual difficulties which significantly limit their ultimate utility.

2.1 The Honeywell approach

2.1.1 Summary of the approach

In brief, the approach advocated by Honeywell (1982) entailed the following steps:

1. Identification of crew tasks. A set of three representative LHX mission scenarios (projected by Boeing Vertol) was subjected to the analysis of an expert rotorcraft pilot. The results of this expert elicitation, together with information gathered from relevant written material on LHX systems and crew procedures, were used to identify a representative set of 43 crew tasks or workload demands within the LHX. Illustrative of these tasks are the following:

1. Flight control activities
 - a. descend to NOE
 - b. hover unmasked
 - c. NOE flight
2. Communications activities
3. Target acquisition activities
 - a. activate automatic target recognition (ATR) systems
4. Assess damage to target
5. Threat warning/counter-measures activities
 - a. assess TW display
 - b. select weapon

6. Fire control activities
 - a. arm gun
 - b. guide missile
 7. Data management and transfer
 - a. soft failure cues
 - b. request status information
2. Definition of baseline information display/control suite. Based on the task analysis carried out as Step 1 and a consideration of the LHX mission, as well as existing and anticipated avionics technologies applicable to the LHX, the characteristics of a feasible "baseline" information display/control suite were defined. This minimally automated baseline suite served as the context of Honeywell's workload analysis.
3. Identification of interface channels. Ten information flow interfaces, either to or from the crew, were identified within the baseline suite. Channels of information flow to the crew were defined by their sources (for example, Head-Up Display, Head-Down Display, Speech Generator, Radio Communications In). Channels of information flow from the crew were defined by their response modality and object (for example, Manual flight controller, Voice communications out, Manual discrete responses).
4. Assessment of single task workload. Each of the 43 individual crew tasks identified at Step 1 was assessed with respect to the workload demand imposed by the task on each of the 10 interface channels identified at Step 3. This assessment was based on the collective judgments

of a seasoned helicopter pilot and Honeywell staff knowledgeable in human factors engineering. The assessment consisted of the assignment of an ordinaly scaled value (0-3) to each interface channel for each task.

5. Assessment of multiple task workload. Workload under conditions of task concurrency was determined by the following rules:

- a. Consider cases in which concurrent tasks imposed either conflicting information acquisition demands (that is, one task requires information through the Head-Up Display Channel and the other requires information through the Head-Down Display Channel), or conflicting control output demands (concurrently utilizing Flight Controller and Manual Discrete interface channels). In these instances the index of workload demand at each of the conflicting interfaces is doubled to reflect the increased demands/costs of the time-sharing conflict involved, and the total workload imposed by the tasks is set as equal to the sum of these doubled estimates.
- b. Consider cases in which concurrent tasks create conflicts neither in information acquisition nor in control output. In these instances, the total workload imposed by the tasks is set equal to the sum of the workload ratings of the tasks when considered in isolation.

6. Identification of high workload points within representative LHX mission scenarios. One result of the analysis carried out at Step 1 is a second-by-second listing of the tasks and task concurrencies that might occur during the course of the LHX mission scenarios provided by Boeing Vertol. This task listing was subjected to the workload analysis developed at Steps 4 and 5. The results of this analysis provided running measures of instantaneous (momentary) and sustained (5-second averaged) crew workload through the representative scenarios. Tasks occurring during intervals with instantaneous workloads in excess of an arbitrarily chosen value were identified as candidates for automation or alternate redesigns were selected.

2.1.2 Critique of the approach

The 1982 Honeywell approach has several commendable features, among them:

1. the effort throughout the study to anchor analyses with expert (rotorcraft pilot) judgments;
2. the effort to systematically apply the theory and data of information processing and cognitive psychology in workload analysis;
and
3. the development of a simple but elegant task-analytic system based on information display/control interface channel utilization.

While attractive along these lines, the approach suffers some major difficulties in the method used to assess workload. The analysis of individual task workload, from which all subsequent estimates were derived, was based on the subjective judgments of an individual who, although a seasoned rotorcraft pilot, had little or no experience with many of the tech-

nologies, displays, and controls that will be implemented in the LHX. Subjective estimates of workload have often proven difficult to validate even when judges are experienced in the work situation. Accordingly, it is questionable whether any confidence can be placed in workload judgments about complex settings containing unfamiliar components.

An additional difficulty found in the Honeywell approach relates to a scaling issue. Each of a large number of tasks were "workload-assessed" in terms of the ten display/control interface channels described earlier. The assessment tool consisted of a 4-point ordinal scale, where 0 = no workload imposed on the interface channel, and 3 = high workload imposed on the channel. These values, summed across interface channels, defined the overall workload imposed by a task. Therefore, some tasks might have a high indexed workload because they impose heavy loadings on interface channels A and B, whereas other tasks are high in indexed workload because they impose heavy loadings on interface channels C and D. Thus, the scaling problem arises. On what basis can it be concluded that a high loading (a score of 3) on interface channel A (the heads-up display) is the same, workload wise, as a high loading (3) on channel C (the flight controller)? In fact, such a conclusion cannot be reached on any principled basis. Consequently, it is not legitimate to claim two individual tasks or two task concurrencies that have total workload ratings derived from different patterns of interface channel loading are in fact equal in true workload. This fact alone undermines the entire workload analysis of the Honeywell group.

Another difficulty of the Honeywell study relates to the simplifying assumption (Step 5b) that concurrent tasks not loading "conflicting" input or output interface channels will not suffer from dual task deficits. This assumption is invalid. There is ample evidence which proves marked dual task interference between tasks, one which is visual and one which is auditory, or one which is manual and the other which is vocal (see, e.g., Greenwald and Schulman, 1973); Karlin and Kestenbaum, 1969; Hawkins and Rodriguez, 1981). Whereas tasks utilizing common input or output channels will often produce more dual task interference than those not sharing channels, the difference in measured interference between the two situations is often small relative to the total (centrally mediated) interference produced by either (e.g., Hawkins and Rodriguez, 1981).

Finally, the Honeywell analysis is based on the assumption (Step 5a) that task pairings, in which "conflicting" input or output channels are used, will exhibit a multiple task cost fairly represented by a doubling of the indexed single task workload along the conflicting channel(s). As a single valued estimate of multiple task costs, doubling may or may not be reasonable. There is no empirical basis for estimating the validity of this particular value. Regardless, the use of a single value to estimate concurrent task costs, regardless of the source of the problem, represents a gross oversimplification of the available data on time-sharing performance. Depending on a wide range of factors, dual task costs in reaction time and/or error rate range from nearly zero to over 100%.

Because of the difficulties cited above, neither the single and dual task workload judgments, nor the overload determinations yielded by the Honey-

well procedures can be viewed with confidence. Unfortunately, it appears unlikely that the overall approach advocated by Honeywell can be upgraded sufficiently to remediate the problems it faces. The validity of the approach ultimately relies on:

- a. the judgments of individuals who must speculate about the demands of a system that is neither familiar nor well specified;
- b. invalid or untested assumptions about the nature and combinatorial characteristics of the processes producing mental workload.

2.2 The Perceptronics approach

2.2.1 Summary of the approach

The approach recommended by Perceptronics (1984) contains the following steps:

1. LHX mission scenarios are reviewed by an expert military helicopter pilot to identify the moment-to-moment procedural requirements of flight and mission management.
2. The expert elicitation data are then organized into Modified Petri Nets (MPNs), a form of network scheduling resembling PERT or CPM. The MPN analysis provides representations of (a) the set of transitional activities required of a pilot within a given time range to achieve a specified end state, and (b) the end state achieved through each transitional activity, or combination of these. The MPN analysis represents transitional activities in a hierarchical fashion such that the activity representation at a given level of abstraction can be decomposed into progressively more specific sets of activities and end states.

3. A further expert elicitation is used to estimate the range of times required by the pilot to complete each transitional activity. A Monte Carlo simulation is then carried out to establish likely activity concurrencies.
4. The mental workload associated with each activity and each set of concurrent activities is determined by expert judgment. The judgmental process consists of the expert pilot rating on a relative scale (0 to 100) the workload demand of each specified activity or activity concurrency.
5. The procedure for identifying functions which might profit from automation is not clearly indicated in the Perceptronics report, but presumably would be responsive to the high workload points identified during Step 4 above. (In the 1984 Perceptronics report, candidates for automation were generated on the basis of expert opinion. However, as noted in the report, this was simply an expedient since description of the more formal procedures recommended for this determination was beyond the scope of the research effort reported).

2.2.2 Critique of the Perceptronics Approach

The approach recommended by Perceptronics has two strongly positive features. First, all phases of the approach entail expert input, thereby increasing the fidelity and pilot acceptability of the outcome. Second, the use of the MPN methodology to represent and organize expert elicitation data seems an especially positive feature, yielding the same obvious dividends as does any good network scheduling device in planning and analyzing resource utilization around complex, time-limited operations.

However, several difficulties exist with this approach:

1. Since the pilot(s) used in expert elicitation had no experience in the LHX system, the elicited estimates of transition process completion times may be in error. Quite probably, the calculation of process concurrencies and the potential points of maximum workload are apt to be in error.
2. Again, because the experts used to judge the workload of piloting activities had no specific experience with the system, the accuracy of their workload estimates is open to serious question.
3. The use of an omnibus 100-point workload scale is a questionable practice. To what extent does a scale of this sort yield valid and reliable estimates, even under optimal conditions of judgment? No evidence is cited in behalf of the procedure. If supportive evidence exists, Bio-Dynamics is unaware of it.
4. No explicit effort is made to incorporate knowledge of human information processing capacities and limitations into the Perceptronics analysis. Rather, the analysis relies almost exclusively on the judgments and opinions of expert pilots, organized via network scheduling techniques, to assess crew workload and to identify opportunities for automation. This neglect of much of the literature of the cognitive sciences greatly compromises the conceptual quality of the approach.

3.0 The approach recommended by Bio-Dynamics

The Honeywell and Perceptronics groups sought to develop quantitative

measures of the momentary workload likely to be imposed on the crew of a system which has yet to be realized or simulated, and for which no genuine experts exist. As argued above, the efforts of both groups have made positive contributions to the analysis of the problem, yet have fallen short of their intended goal. The reason for the shortfall probably lies in the goal sought. Given that the LHX system is unrealized and indeed has yet to be well specified in structure and function, and given the unavailability of experienced system operators, Bio-Dynamics believes it is not possible, a priori, to develop and apply quantitative workload measurement procedures that will tolerate close conceptual and methodological examination. While it is true that the uncertainties of system mission and technology will achieve some resolution in the near term, this reduces the problem only slightly.

Based on analysis of the problems associated with prior efforts to analyze likely crew workload in the LHX, Bio-Dynamics recommends a different approach. This approach does not have as its goal the generation of quantitative workload estimates. Rather, it proceeds:

1. by applying principles from cognitive and human performance psychology to create information display/control suite design alternatives likely to minimize pilot workload;
2. by comparatively evaluating these alternatives through performance testing under conditions of low fidelity simulation; and
3. by recommending the automation of pilot functions within the optimal design alternative based on empirical necessity.

This approach is markedly different in a fundamental way from those advocated by Honeywell and Perceptronics. Bio-Dynamics believes that the LHX workload problem cannot be treated adequately by a priori or subjective analysis. Rather, it will be necessary to combine principle and subjective analysis with empirical evaluation. Bio-Dynamics feels strongly that this approach will provide the most valid solution.

The proposed approach entails the seven steps that follow.

3.1 Step 1: Expert elicitation

The objective of expert elicitation is to gain from seasoned rotorcraft pilots a detailed picture of the information gathering and control activities likely to be associated with flight and mission management for each set of plausible LHX mission scenarios. Of specific interest are information on the procedures, likely activity concurrencies, task priorities, performance criteria, and action consequences that determine crew performance. A problem immediately arises in elicitations at this level of detail. Available experts on the crewing of attack helicopters have gained their experience in craft where flight and mission management responsibilities are divided between two crew members, a pilot and a gunner (as in the AH-1G or S series), and are carried out in the context of information display/control suites and flight dynamics that are unique to those craft. Based on interviews with a rotorcraft pilot during the present project, Bio-Dynamics believes this problem can be reduced substantially by asking the expert:

1. to respond to elicitation probes based on the supposition of a single crew craft;

2. to focus both on the abstract nature of the information and action required at the moment (as distinct from the specific displays and manipulanda providing them); and separate from this,
3. to discuss only the specific instrumentation with which he is familiar.

The importance of the informational focus is that it enables the researcher to define the generic information processing demands involved. The value of the instrumentation focus is that it can provide experience-based clues relating to potentially advantageous and disadvantageous modes/forms of information presentation.

To gain the detailed information required for specification of relevant psychological principles, the elicitation procedure should include the following steps:

1. Using the timeline analysis of Honeywell, the modified Petri Net procedure of Perceptronics, or other network scheduling device, the expert is first asked to translate LHX mission scenarios into a flow of specific crew activities. It should be noted that with scenarios as non-specific as those provided Honeywell and Perceptronics, significant individual differences should be expected among pilots regarding the specifics of their scenario translations. This variability probably reflects the entrepreneurial norms of the culture of U.S. military pilots. Tables 1a and 1b illustrate the point. Table 1a was derived by Bio-Dynamics from the expert timeline analysis of three LHX scenarios carried out by Honeywell (1982). The table shows the frequency of all task concurrencies identified during expert elicitation by the Honeywell group. Table 1b contains the pattern and

Table 1a. Task concurrencies identified in the Honeywell expert's analysis of selected LHX mission scenarios

Tasks	Concurrent Task Pairs							Concurrent Task Triples											
	1	2	3	4	5	6	7	2/8	2/16	2/27	2/35	3/33	6/12	6/16	6/27	7/16	7/20	7/25	2/12
1 Descend to NOE																			
2 Hover NOE																			
3 NOE flight																			
4 Contour cruise																			
5 Unmask																			
6 Mask																			
7 Hover unmasked																			
8 Check TMD	1	13	34	3		3											2	1	
9 Update TMD				9	1														
10 Request course				3															
11 Read course				4															
12 Communications out	1	26	7	5	1	10		1											
13 Receive communications			3	1	1														
14 Select sensor			2		1														
15 Adjust sensor			2															1	
16 External observation			1				1											5	
17 Target hand-off					1														
18 Manual target search						2													
19 Verify target																	1	7	
20 Assess damage																			
21 Select sensor mode			2																

Table 1a, continued

Tasks	Concurrent Task Pairs							Concurrent Task Triples											
	1	2	3	4	5	6	7	2/8	2/16	2/27	2/35	3/33	6/12	6/16	6/27	7/16	7/20	7/25	2/12
22 Override ATR																		2	
23 Activate ATR					1														
24 Deactivate ATR																			
25 Assess ATR display					1												1		
26 Links HMS to ATR																			
27 Assess TW display		2	1		1	1	1		1										
28 TW alarm		1										1	1				1		
29 NBC warning													1						
30 Select weapon				1			1			1			1				1		
31 Verify countermeasure		1	1																
32 Verify integrity															1				
33 Aim gun				1			1							1					
34 Fire gun																			
35 Launch missile				1			1					1		1				1	
36 Guide missile			1	1			1											1	
37 Link HMS to gun		1												1					
38 Soft failure cue					1											1			
39 Acknowledge failure					1														
40 Perform checklist		4																	
41 Request status information		2																	
42 Review status information		1																	
43 Speech recognition feedback		14		1	2				1		1			1		1	1	8	

Table 1b. Task concurrencies identified in the Bio-Dynamics expert's analysis of the same selected LHX mission scenarios

Tasks	Concurrent Task Pairs							Concurrent Task Triples											
	1	2	3	4	5	6	7	2/8	2/16	2/27	2/35	3/33	6/12	6/16	6/27	7/16	7/20	7/25	2/12
1 Descend to NOE																			
2 Hover NOE																			
3 NOE flight																			
4 Contour cruise																			
5 Unmask																			
6 Mask																			
7 Hover unmasked																			
8 Check TMD							10										1		
9 Update TMD																			
10 Request course																			
11 Read course																			
12 Communications out																			
13 Receive communications																			
14 Select sensor																			
15 Adjust sensor																			
16 External observation																			
17 Target hand-off																			
18 Manual target search																		3	
19 Verify target																			
20 Assess damage																		1	
21 Select sensor mode																			
22 Override ATR																			

Table 1b, continued

Tasks	Concurrent Task Pairs							Concurrent Task Triples											
	1	2	3	4	5	6	7	2/8	2/16	2/27	2/35	3/33	6/12	6/16	6/27	7/16	7/20	7/25	2/12
23 Activate ATR							1												
24 Deactivate ATR																			
25 Assess ATR display							1										1		
26 Links HMS to ATR							2												
27 Assess TW display		3	3																
28 TW alarm		1		1															
29 NBC warning																			1
30 Select weapon				1			3												1
31 Verify countermeasure																			
32 Verify integrity																			
33 Aim gun				1			2												
34 Fire gun																			
35 Launch missile				2															
36 Guide missile				2															
37 Link HMS to gun				1															
38 Soft failure cue				1															
39 Acknowledge failure							1												
40 Perform checklist		6		2															
41 Request status information		2																	
42 Review status information																			
43 Speech recognition feedback		10		6			4				1			1				2	

frequency of concurrencies occurring within the same scenarios, but this time as envisioned by the expert used by Bio-Dynamics. The following preliminary information was provided for Bio-Dynamics' pilot expert to constrain his analysis:

1. a copy of the three scenarios used with the Honeywell expert;
2. a description and picture of the baseline information display/control suite recommended by the Honeywell group and other material relating to the LHX mission and capabilities; and
3. a timeline containing major events, way points, and flight modes added by the Honeywell group to the basic scenarios provided to them by Boeing Vertol (for example, ZSU detection and engagement, DIVARTY call and damage assessment, and Hind detection and engagement).

It will be noted from a comparison of the two tables that a sizable difference in scenario analysis exists between the two experts, even with the constraints listed above. While not totally unexpected, this between-expert variation must be taken into consideration in designing procedures for the acquisition and analysis of elicitation data.

2. Once the sequencing and concurrencies of scenario-related crew activities or tasks has been established, more detailed probing can be initiated. The following probes are examples of those that should prove useful in elaborating the processing demands pertaining to each identified crew task:

- a. Perceptual information required to carry out the activity. What is the natural source (modality, locus) of the information

required, and what is the nature of the information itself? For some tasks, little option exists regarding the modality and relative locus of required information (as in the task of NOE flight). For other tasks, options exist in the modality and/or location of required information (as with system status information, systems failure information, threat warning information, and the like). This distinction is a significant one because it helps to define the design constraints and opportunities to be subjected to principled analysis at subsequent points in the proposed procedure. The same distinction, with the same design implications, applies to the nature (form) of the required information (e.g., alphanumeric vs. graphic, visual displays, or tonal frequency-coded vs. speech-coded auditory signals). For cases in which information modality or form is optional, the expert can be usefully probed regarding possible preferences and the reasons for them.

- b. Mental operations (computations, analyses, judgments) required to complete the activity. Much of the logically or theoretically necessary mental operations underlying the performance of complex cognitive tasks are inaccessible to awareness (Ericsson & Simon, 1980). However, many are, particularly those that are especially demanding of attention, reflect conscious computations, or involve rote (check list) procedures. Efforts undertaken to retrieve the expert's understanding of the mental operations necessary to complete specified activities are efforts well spent. When combined with principled analyses described in later sections of the report, this information can provide valuable hints about the

mental models used by the expert, and therefore the most effective way to present information.

c. Action required to complete the activity. Of the 43 scenario related piloting tasks identified by Honeywell, 28 tasks required some sort of overt action; either manual or vocal. The 15 tasks that require no overt action entail the monitoring of informational source, external or internal to the craft. The possibility exists that this monitoring will uncover data requiring overt action; however, in such cases the call for action entails a separately defined task. Of those 28 tasks requiring overt action, some are locked into a particular response modality (as in flight control tasks), whereas others exhibit some flexibility in the response assignment they can accept (as in sensor selection or target hand-off). Where options exist, the expert should be probed regarding his perspective on the relative advantages and disadvantages of each option. Here, as in the case of information display optionality, an understanding of the locus and extent of output optionality should have important implications for system design constraints and opportunities.

d. Once the information outlined above has been obtained for all piloting activities associated within the scenarios under analysis, probes can be directed toward identified instances of task concurrency. The following probes will be of use in defining the processing demands and implications of each n-wise task concurrency:

1. Are there unique qualities of information acquisitions, men-

14

tal operations, or actions for task A that are special to the fact that it is paired with task B? For instance, are the perceptual/cognitive/action demands of external observation, damage assessment, TMD check, or TMD update different in NOE flight than in contour cruise? How specifically do the demands differ?

2. What is the appropriate strategy for treating the demands of each identified concurrency? That is, which activity has the higher priority? Are the tasks sequenced or should the pilot attempt to carry them out simultaneously? Under the conditions specified in the scenario, can completion of either or both tasks be delayed, and if so, for how long?
3. For each concurrency, how could pilot performance be degraded relative to situations in which the component tasks or activities are carried out in isolation? For example, does the possibility increase under concurrent conditions:
 - (a) that the cue signaling task A (or B) will be missed or detected with unacceptable delay;
 - (b) that the total processing demands of all n concurrent tasks cannot be completed within acceptable time limits;
 - (c) that performance deadlines will force incomplete perceptual or cognitive analysis leading to incorrect or imprecise action; or
 - (d) that performance on one or both tasks will be degraded by cross-talk within response modalities or cross-masking within sensory modalities?

4. For each concurrency, what are the potential consequences of the performance degradations described in (3) above for mission accomplishment? For example, how important is it to ensure that degradation is minimized or eliminated?

Two summary comments are in order regarding the relationship between the elicitation procedure outlined above and those carried out in the Honeywell and Perceptronics analyses. First, Bio-Dynamics' suggested procedure will produce relatively greater detail on perceived task characteristics and demands in addition to the expert's strategic reactions to these. This added detail should enhance the analyst's ability at later stages to identify and map relevant psychological principles into the workload problem domain within the LHX. Second, the Bio-Dynamics elicitation procedure does not seek to extract from experts a numerical judgment of the workload demands of specific tasks (as in Honeywell) or task concurrencies (as in Perceptronics). For reasons elaborated above, quantitative judgments of this sort have questionable validity under the special circumstances surrounding the LHX system. Rather, the recommended approach is to seek from skilled pilots qualitative information pertaining to tasks and demands and to use this information to guide or form hypotheses useful in subsequent analyses. The following sections will discuss these analyses.

3.2 Step 2: Principled analysis of crew workload problems posed by the LHX systems/mission.

At the conclusion of Step 1, the analyst will have available:

- a. a substantial amount of information regarding the functional qualities of the LHX system understood at the time the analysis

is conducted;

- b. the information processing demands potentiated by the system mission on its crew; and
- c. the strategic implications of these as perceived by experts knowledgeable in the piloting of other attack helicopter systems.

The ultimate aim of the Step 2 analysis is to isolate principles available in the literatures of cognitive and human performance psychology that are relevant to the potential workload problem faced by the LHX pilot (as revealed in the information generated at Step 1), and to use these principles to make recommendations on LHX information display/control suite design and automation.

However, the mapping of principles into the LHX pilot workload problem will be challenging. Two examples illustrate the complexity of the problem. In discussing the relative merits of auditory and visual forms of information presentation, Deatherage (1972) stated a number of recommendations which in fact reflect established principles. He recommended that (a) if the message is simple, use auditory presentation, and if complex, use visual presentation; (b) if the message is short, use auditory presentation, and if long, use visual presentation; and (c) if the visual system is over-burdened, use auditory presentation, and if the receiving location is acoustically noisy, use visual presentation. While valid as general observations, of what practical value are such principle-based recommendations in any given design situation? How do researchers know a priori that a message is sufficiently "short" or "simple" to conclude in favor of auditory presentations? How do analysts know a priori whether the

visual system is sufficiently overloaded to conclude in favor of auditory presentation? Additionally, many, perhaps most, design commitments reflect uncertain trade-offs. For example, suppose the acoustic environment in which messages are received is noisy, but messages are short, or simple. How can the designer decide a priori between visual and auditory presentation or between unimodal and bimodal presentation? The problem arises that even if what is meant by a "simple" message could be stated more precisely, there are often no data or other valid bases for deciding how this variable interacts or trades-off with other factors operative in a real system.

Given these difficulties and others of similar kind, any type of "principled" analysis of workload and workload minimization must be validated by empirical means. More specifically, it can be expected that an analysis of the kind proposed will yield design arguments of varying force. Some will have strong and direct support in the research literature, others will be hypotheses that must be verified by empirical test. The empirical validation issue will be discussed in Steps 3, 4, 6 and 7.

3.2.1 Conceptual framework for analysis

The intent in this section is to describe a general conceptual framework for organizing and applying cognitive principle to the LHX problem. Because this framework constitutes a set of general theoretical claims about the nature of the human information processing system, it will generate some controversy. The framework, which may be thought of as a cognitive systems approach, begins with the following general claims:

1. The flow of information between stimulus and response is through a set

of cognitive sub-systems whose constitution is determined by the modality of input, the modality of output, and the nature of the transformations required to map input into output (Wickens, Mountford and Schreiner, 1981).

2. Use of a limited capacity subsystem (attention) is required to select specific stimuli as bases for action and to organize and carry out transformations underlying the mapping of stimuli into actions. The attentional subsystem functions in a manner analogous to a spotlight (Laberge, 1973), which can be directed to differentially facilitate or to enable processing activity within specific subsystem pathways.
3. Decrements in performance under dual task, relative to single task, conditions can result from either of two central events: (a) structural (or processing) interference within subsystems, occurring when two tasks create simultaneous patterns of activation within one or more common subsystems (Navon, 1984); and/or (b) simultaneous demand for the limited capacity attentional subsystem.
4. Decrements in performance under dual, relative to single task conditions, also can result from either of at least two classes of peripheral events:
 - a. sensory masking, in which processes at or very near the receptor surface are simultaneously activated by stimuli from the two different tasks, yielding a confluence of activity that may be difficult or impossible to analyze into its separate constituents; and
 - b. in the case of vision (a directional sensory system with steep

spatial acuity gradients), decrements will result when acquisition of the stimulus for one task requires a retinal orientation that prevents acquisition of or reduces acuity for the stimulus of the other task.

As a simplifying assumption, attentional utilization is treated as an all-or-nothing, rather than divisible, process. The attentional mechanism is construed as a source of activation which, when applied to already active neural codes, (e.g., those driven by external stimuli), will boost their excitatory outputs to associated "down stream" codes (e.g., motor programs), thereby increasing the probability the latter will be triggered. The assumption that attentional utilization is all-or-nothing means that the attentional mechanism, like a spotlight, may be directed to one, and only one, code at a given instant in time boosting activity levels for that code and to a graded degree all codes which, by prior learning, are linked to it.

3.2.2 The identification and application of cognitive human performance for the design of LHX/pilot interfaces

The examples given above illustrate and frame some of the kinds of work-load-related problems which might profitably be addressed through careful application of principles drawn from cognitive and human performance psychology. In this section principles useful for LHX/pilot interface design will be illustrated. The principles discussed constitute only a small portion of those that will prove relevant to the problem. The development of a more complete listing awaits research extending beyond the scope of the current study.

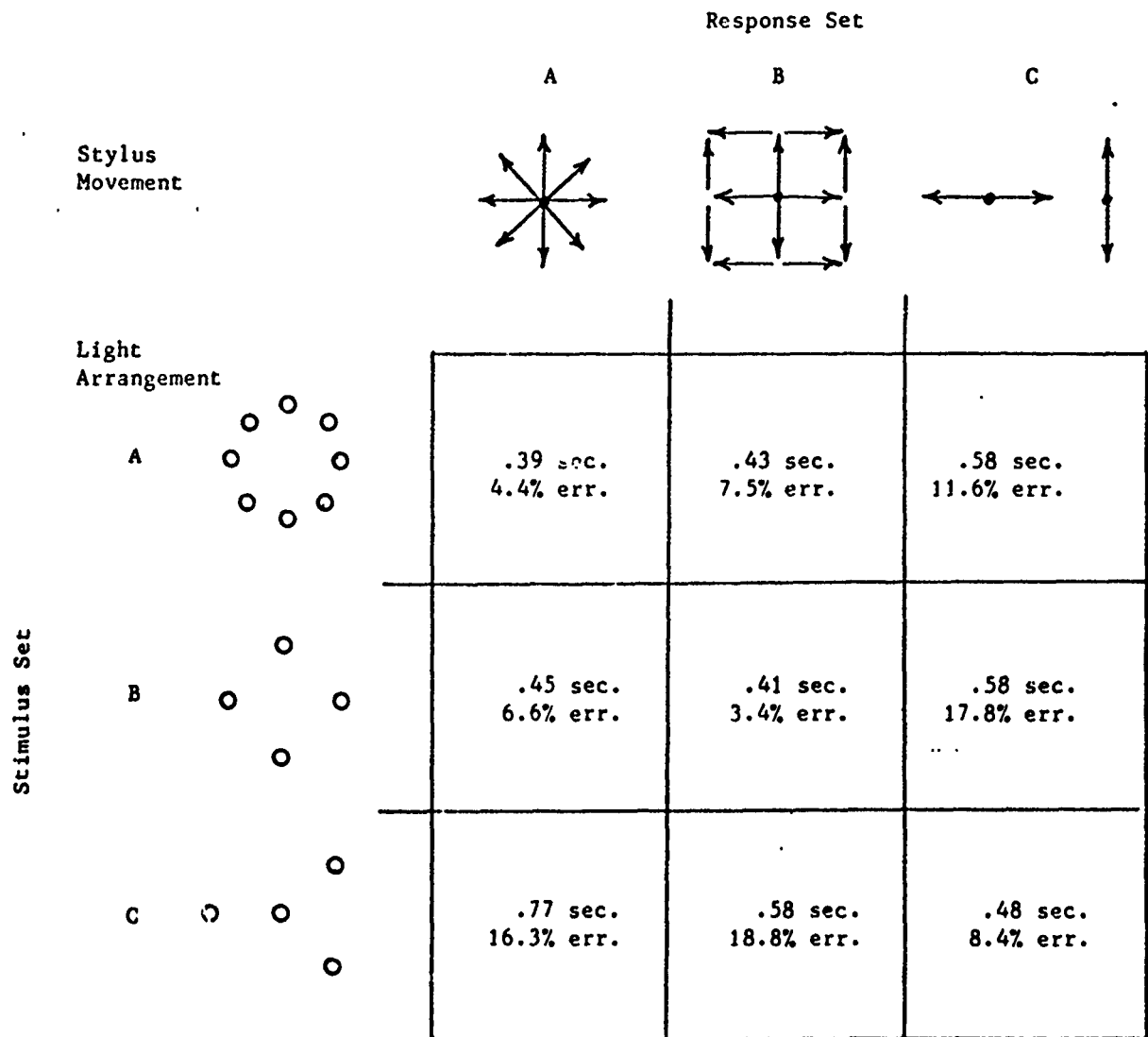
Reducing attentional dwell time. One class of principles, whose relevance surfaced in the material presented in the preceding section, concerns means by which the duration of the attentional demand imposed by piloting tasks in the LHX can be minimized. All else being equal, the less the attentional (or controlled) processing time demanded by a task, the more quickly the attentional mechanism will be free to service the demands of other demanding tasks. Stimulus-response (S-R) compatibility, the familiarity of "naturalness" of the stimulus-response mapping imposed, is a major determinant of the total attentional dwell time required by a task. As a general rule, the higher the compatibility between stimuli and their associated responses, the shorter the central processing time required to effect the S-R mapping. The prolonged processing time observed under conditions of low compatibility is often interpreted as the result of competing response tendencies; that is, competition between required responses and inclinations to initiate more familiar (but now inappropriate) responses. Human factors and human performance psychologists (e.g., Fitts and Seeger, 1953; Loveless, 1963; Vidulich and Wickens, 1982) have summarized a number of principles pertaining to S-R compatibility, included among them are the following:

1. Spatial correspondence between stimuli and associated loci of action. The principle is that the arrangement of stimuli in space should correspond to the spatial arrangement of the actions required by them. This principle reflects what appears to be a very basic tendency to move toward a source of visual stimulation (Simon, 1969), and to respond more rapidly and accurately when the spatial arrangement (left-right, top-bottom) of responses

correspond to those of stimuli, even when stimuli and action loci are well separated in space. (Cotton, Tzeng & Hardyck, 1980; Hartzell, Dunbar, Beveridge & Cortilla, 1982). A classic demonstration of the behavioral effects of spatial compatibility with complex arrays was reported by Fitts and Seeger (1953). The study utilized eight stimuli and eight responses, but as illustrated in Figure 1, the stimuli and responses were of varying forms. Stimulus set A consisted of a circle of 8 lights, any one of which could illuminate on a given trial. Set B had four lights arranged as a diamond. Any one light could come on (four alternatives) or any adjacent pair could come on (four more alternatives). Set C also had four lights, two in a horizontal line and two in a vertical line. Any of the four lights could come on alone or any of the four combinations of one horizontal and one vertical light could come on. There were also three response sets. Subjects held one stylus for sets A and B, and two styluses for set C. The styluses were moved along tracks as indicated in the figure. In set C, subjects either moved one or two styluses on a trial depending on whether one or two lights illuminated. The key finding is that reaction times and accuracy are determined by the relationship between stimulus and response sets, rather than by stimulus or response sets per se. The more compatible the spatial relations between stimuli and responses, the better the obtained performance. The magnitude of the spatial compatibility effects reported in laboratory (Fitts and Seeger, 1953) and applied settings (Hartzell, et al, 1982), and the fact that under stress, higher compatible but incorrect responses can replace less compatible but correct ones, points to the extreme importance of this

Figure 1

Reaction time and percentage of errors for different combinations of stimuli and responses (after Fitts and Seeger, 1953)



factor in the layout of the LHX information display/control suite.

2. Compatibility as population stereotype. While S-R compatibility by spatial correspondence appears to be pre-programmed into the nervous system, other kinds of compatibility appear to be more a function of experience, as indicated by their cultural dependence. This type of preferred S-R correspondence is called a population stereotype. Several forms of population stereotypy have been identified.

- A. Display control stereotypy. Loveless (1963) has summarized findings on the nature of population stereotypes in display-control relations, generating several principles of potential relevance to the present problem.

1. Clockwise stereotype. There is a basic tendency to rotate a dial clockwise in order to create a change in the state of an associated display variable.
2. Clockwise-to-increase stereotype. A stereotype exists to rotate a dial clockwise or move a linearly moveable indicator to the right or upwards to increase the value on a display.
3. Proximity of movement stereotype. With any rotary control, the arc of the rotating element that is nearest to the moving indicator should move in the same direction as the indicator. Thus, for instance, a rotary control

located beneath a horizontal linear display should be rotated clockwise to produce a rightward displacement of the displayed indicator.

4. Congruence stereotype. Linear movements of displays and controls should be along the same axis and in the same direction. Rotational movements of displays and controls should be in the same direction.

B. Verbal-pictorial stereotypy. Smith (1981) reports the results of a questionnaire study investigating population and group (engineers, women, and Human Factors Society members) preferences regarding the relationship between pictures and descriptive words or phrases. The method and results of this demonstration study are of great relevance to the LHX problem for both the selection of voice interactive and radio communication phase structures, and the design of visual symbology. Some examples drawn from the Smith questionnaire are as follows:

1. Question 3: Flying in an aircraft cockpit, the co-pilot says "Left wing down." How should the pilot act to change his roll position?
_____ Lower the left wing?
_____ Raise the right wing?

2. A picture is shown depicting a refrigerator with its door open. The door is hinged on the right, facing the refrigerator. Question 7: Here is a refrigerator. Is its door

☐ Left opening?

☐ Right opening?

3. (A picture is shown of a river extending from right to left with arrows indicating a left-to-right current flow. On the upper side of the river in the drawing is a church.) Question 11: Here is a river flowing from East to West. Is the church on the

☐ Left bank?

☐ Right bank?

4. (A square is shown) Question 15: An adding machine is designed to be operated with one hand. On the pane to the left draw in how you consider its keys should be positioned for the 10 numerals.

The results of the questionnaire showed that for some kinds of questions (e.g., number 15) high levels of agreement appear across population sub-groups, whereas with other questions (number 3) low agreement exists between or across sub-groups. While it is not currently possible to make broad statements of principle regarding cultural stereotypy for verbal-pictorial relations, the kinds of results obtained by Smith indicate the desir-

ability of empirically evaluating the issue with respect to specific systems interfaces and user populations.

3. Compatibility of input-output modality. Sometime ago Brainard, Irby, Fitts, and Alluki (1962) reported that reaction time to a visual stimulus is faster when the response is manual rather than vocal, but when the stimulus is an auditory symbol, a vocal identification response is quicker than one that is manual. This basic relation -- the higher compatibility of auditory-vocal and visual-manual over auditory-manual and visual-vocal mappings -- tends to hold up across a variety of conditions (Teichner and Krebs, 1974); Hawkins and Rodriguez, 1981). It appears that when the feedback produced by a response is in the same sensory modality as the stimulus giving rise to the response, the S-R mapping can be carried out relatively more quickly than otherwise (c.f., Greenwald and Schulman, 1973).
4. Transformational complexity as attentional demand. Numerous factors influence the complexity of the information transformation required between stimuli and responses. Indeed, S-R compatibility should be viewed as one sub-class of such factors. Another important sub-class consists of the informational properties for the task, e.g., the number and relative frequencies of alternative S-R correspondences and the extent to which sequential dependencies exist among stimuli (Hyman, 1963). A particularly important set of factors relates to the degree to which the meaning (environmental referent) of a signal can be interpreted without extensive transformation. In general, the more direct

the relation between a signal and its environmental referent, the more rapidly it will be interpreted. For example, the speed and accuracy of an individual's interpretation of an auditory alarm signal, particularly under conditions of stress, will be higher if the signal is a word or word phrase rather than a tone, hum, or chime of a particular frequency, amplitude, or periodicity.

5. Increasing the speed and probability of signal detection. A second critical determinant of performance apparent in Figure 1 is the speed and probability with which critical (action demanding) signals are detected. The faster the detection of a critical stimulus, the greater will be the likelihood that the stimulus will be analyzed and acted upon, both accurately and prior to possible response deadlines. Expert elicitation is a valuable source of information on which to base design strategies aimed at maximizing the speed with which critical signals are enhanced. Data such as those summarized in Figures 1a and 1b, reveal where stimulus concurrencies are apt to appear in the LHX system/mission, and thus, where special attention must be given to the problems of signal detection under perceptual overload.

For purpose of illustration, consider the problem of timely and accurate detection of critical visual cues. The demands of modern military aviation impose a substantial load on the pilot's visual system, perhaps at or near the point of saturation. The visual information processing demands of NOE flight in the LHX are even more acute, involving on an ongoing basis:

1. the detection and analysis of environmental factors relevant to path selection (obstacles, backdrops, location of friendly craft,

- surface covering, and the like);
2. the detection and analysis of potential targets/ground threats;
 3. the frequent assessment of information contained on head-down displays such as the terrain map display and the multi-function CRT display.

Under these conditions, the loci of potentially critical visual information extend across a range far exceeding the spatial limits of the visual system's effective sensitivity. An important first step in the analysis of the problems posed here is to conduct expert elicitation to determine the nature, priority, and spatial origins of potentially critical visual information; the likelihood of possible concurrencies among signals containing this information; and possible sequential dependencies among signals. These "link-analytic" data, combined with other information such as whether or not signals of a particular type or origin can be registered electronically; the anticipated visual and auditory complexity of the pilot's environment; and the nature of signals to which the system is already committed; can serve to guide decisions about issues such as the following:

- a. Whether to enhance signal detectability by electronic means;
- b. Whether to employ visual, auditory or tactile modality as the channel through which the detection-enhancing signal is transmitted to the pilot;
- c. Where to locate various head-down displays relative to the pilot's head-up line-of-sight;
- d. Where to locate signal enhancing symbology within the head-up display;

- e. How much redundancy to include in signaling systems for highly critical information; and
- f. The nature of the electronically generated signal (word, phrase, tone, horn, buzzer or bell).

In summary, the objective of the second step of the recommended procedure is to identify principles and analytic methods in the literature of cognition and human performance that are relevant to the workload problem anticipated for the LHX pilot, and to apply these to the conceptualization of a baseline avionics/display and control suite for the system. The attempt in this section of the report has been to offer a general theoretical framework and to illustrate principles and analytic methodologies of the types that can emerge from the more intensive research effort proposed.

3.3 Step 3: Development of low-cost, low or mixed fidelity simulations

As noted earlier, the current state of knowledge in cognition and human performance does not permit unequivocal conclusions regarding all or even most design features of complex man-machine interfaces. While much is known about the determinants of performance overall, available psychological principles can be extended to touch only a portion of the problem. The effects of variables in isolation are understood, but less is understood about how variables combine. In particular, the details of how conflicting variables trade-off with one another are not yet known.

For these reasons, the analysis carried out at Step 2 will produce questions nearly as often as answers. However, the proposed methodology should produce questions that are well defined, contained, and empirically resolvable, often in the form: is A mode (or form) of signal presentation

better than B in the context of moderating variables C and D? A might be visual, B auditory, C an acoustic environment with specified parameters, and D a visual environment with specified parameters.

The objective of Step 3 would be to produce low-cost computerized simulations of the alternative solutions suggested as plausible by the analysis carried out in Step 2. These simulations can be relatively low in cost if they can be designed to contain simulacra of only a small portion of the LHX system (in the instance above, only A, B, C and D, which in principle wholly define the set of relevant factors). Of course they must also contain the capacity to score task performances along dimensions that by common sense or principle are most relevant to the task(s) involved. It should be apparent that the total number of simulations required by this analysis may be fairly large.

3.4 Step 4: Testing on low-cost simulations

The objective of Step 4 is to compare empirically the alternatives identified at Step 2 and manifested in the simulations developed at Step 3. The results of this comparison will be an identified set of information presentation and control modes/forms yielding the most effective single and concurrent task performance (as defined by the single and dual task performance criteria specified at Steps 1 and 2) among those alternatives considered. Thus, the arguments to be made from data taken at Step 4 are relative: that is, they are of the form, "performance on task combination A and B is better when task A information is presented in mode X as opposed to Y or Z". However, since the simulations producing these results will not be high in fidelity, it would be inappropriate to draw conclusions

about absolute levels of performance. Accordingly, it would be inappropriate to conclude from the results of Step 4 that a particular function ought to be automated because the function is too highly disruptive of performance on functions (tasks) concurrent with it. This latter issue will be addressed in Steps 5, 6, and 7.

3.5 Step 5: Configuration of high fidelity simulation

The objective of Step 5 is to implement the optimal solutions identified at Step 4 as components in a high-fidelity simulation that can be used for evaluation of automation needs within the LHX system. The assumption underlying this step is that neither subjective judgments drawn from pilots whose experience is in helicopters systems other than the LHX, nor analysis based on the application of psychological principles to judgmental data elicited from expert pilots, seems sufficient a priori to produce sound decisions regarding automation. To the contrary, the most valid procedures for determining which LHX pilot functions to automate are those based on analysis of the performance and subjective judgments of pilots functioning within an implemented system whose workload demands simulate those anticipated within the LHX .

3.6 Step 6: Performance testing in baseline LHX simulator

The information display/control suite of the simulator configured at Step 5 will be a baseline suite in the sense that it will contain no automated pilot functions. The objective of Step 6 is to conduct performance testing with skilled pilots to gather performance data and expert judgments that can be used to guide decisions on automation. If skilled helicopter pilots, trained on the baseline simulator, fail to perform the constituents of a set of concurrent tasks within specified tolerances, then some

member(s) of the concurrent set should be considered for automation.

3.7 Step 7: Modification and re-evaluation of the LHX simulator

Based on performance data and pilot assessments from Step 6 and on technological feasibility, certain pilot functions in the baseline simulator will be "automated"; that is, their automation will be simulated. Skilled pilots will then be tested on the up-graded simulator to determine whether or not the automation enables desired levels of performance. Based on the results of this evaluation, further system tuning will be carried out as necessary.

4.0 Conclusion

Bio-Dynamics believes that the seven step program outlined in the preceding section offers a viable, cost-effective means to address three critical LHX-related issues:

- a) the extent and nature of pilot potential workload demands imposed under feasible alternative information display/control solutions within the LHX system;
- b) the feasibility of a single pilot solution to the LHX crewing issue; and
- c) the necessity and nature of function automation within one and two crew solutions.

The first five steps of the proposed program can be completed within one and a half years by a single contractor with continuous access to a small

number of experienced attack helicopter pilots, and computer systems programmers capable of developing the low-cost simulations described in Steps 2 and 3. Completion time for Steps 6 and 7 will be contingent upon the development and accessibility of high fidelity LHX simulators.

5.0 References

- Brainard, R.W., Irby, T.S., Fitts., P.M. and Allruse, E.A., 1962. Some variables influencing the rate of gain of information. Journal of Experimental Psychology, 63, 105-110.
- Cotton, W., Tzeng, O., and Hardyck, C., 1980. Role of cerebral hemispheric processing in the visual half field stimulus-response compatibility effect. Journal of Experimental Psychology: Human Perception and Performance, 6, 13-23.
- Deatherage, B.H. Auditory and other sensory forms of information presentation. In H.P. Van Cott and R.G. Kinkade (Eds), Human engineering guide to system design. Washington, D.C., U.S. Government Printing Office.
- Ericsson, K.A. and Simon, H.A., 1980. Verbal reports as data. Psychological Review, 87, 215-251.
- Fitts, P.M. and Seeger, C.M., 1953. SR compatibility: Spatial characteristics of stimulus and response codes. Journal of Experimental Psychology, 46, 199-210.
- Greenwald, A.G. and Schulman, H., 1973. On doing two things at once: II. Elimination of the psychological refractory period. Journal of Experimental Psychology, 99, 156-161.
- Hartzell, E.S., Dunbar, S., Beveridge, R. and Cortilla, R., 1982. Helicopter pilot response latency as a function of the spatial arrangement of instruments and controls. Proceedings of the 18th Annual Conference on Manual Control. Wright Patterson AFB, Dayton OH.
- Hawkins, H.L. and Rodriguez, E., 1981. Is time-sharing a general ability? University of Oregon Technical Report (#3), prepared for the Office of Naval Research.
- Kirk, R.J., 1982. Refined baseline avionics/display and control systems for LHX-armed scout. Technical report, Honeywell Systems and Research Center, Minneapolis, MN.
- Hyman, R. 1953. Stimulus information as a determinant of reaction time. Journal of Experimental Psychology, 45, 188-196.
- Karlin, L. and Kestenbaum, R., 1968. Effects of number of alternatives on the psychological refractory period. Quarterly Journal of Experimental Psychology, 20, 167-178.
- LaBerge, D., 1973. Attention and the measurement of perceptual learning. Memory and Cognition, 1, 268-276.
- Loveless, N.E., 1963. Direction of motion stereotypes: A review. Ergonomics, 5, 357-383.

- Madni, Azad M., 1984. Artificial Intelligence Approaches in Intelligent Helicopter Automation for Nap-of-the-Earth Missions, Perceptronic Technical Report, PFTR-1136-84-3, NASA Ames Research Center.
- Navon, D., 1984. Attention division or attention sharing? Paper presented at Attention and Performance XI. Eugene, Oregon.
- Teichner, W., and Krebs, M., 1972. The laws of simple visual reaction time. Psychological Review, 79, 344-358.
- Vidulich, M., and Wickens, C.D., 1982. The influence of S-C-R compatibility and response competition on performance of threat evaluation and fault diagnosis. In R.E. Edwards (Ed.) Proceedings of the 26th. Annual Meeting of the Human Factors Society, Santa Monica, California.
- Wickens, C.D., Mountford, S.J., and Schreiner, W., 1981. Multiple resources, task hemispheric integrity, and individual differences in time-sharing. Human Factors, 23, 211-229.