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ABSTRACT

A review of recent studies about the use of human resources data in system design tradeoffs suggests that it is necessary for military psychologists to enter into the decision process of the design problem. The design engineer may study many alternatives, each of which should be evaluated in terms of human resources data which describe what the people of an organization can contribute, how much they cost, how available they are, how perishable they are, and how many of them are needed. In addition, the psychologists may supply such scientific data as human reaction times, visual perception, reach distance, etc. This kind of communication between military psychologists and the design engineer could lead to development of products which make less demand on human resources. (CH)

AFHRL-TR-73-46

AIR FORCE HUMAN RESOURCES LABORATORY

HUMAN RESOURCES AND PERSONNEL COST DATA IN SYSTEM DESIGN TRADEOFFS

AND HOW TO INCREASE DESIGN ENGINEER USE OF HUMAN DATA

By

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This technical report has been reviewed and approved.

GORDON A. ECKSTRAND, Chief
Advanced Systems Division

Approved for publication.

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

A number of studies performed over a period of several years regarding the use of human resources and personnel cost data in system design tradeoffs were analyzed and the results integrated. Five questions were posed and answered. What are system design tradeoffs? What are human resources data? Why should military psychologists be interested in system design tradeoffs and human resources data? How much effect do system design tradeoffs have on human resources and personnel cost? And, what does this have to do with increasing engineer use of human data in design activities? The following conclusions were derived. Tradeoffs are a significant part of the weapon system design process. The choice of design alternative in a tradeoff study would, in many cases, substantially affect

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the human resources of the organization using the product of the design. It is feasible to use data describing these human resources in design tradeoffs. This use could lead to development of products which make less demand on those resources. Viewing system design as a human decision process involving choice points and options, gives the psychologist an orientation toward design which allows him to more effectively work with the engineer.

PREFACE

This report is a paper given in the symposium titled, "Human Resources Considerations in the Development of Complex Systems," Dr. Gordon A. Eckstrand, Chairman, for the Division of Military Psychology of the American Psychological Association, at the 81st Annual Convention, Montreal, Canada, 28 August 1973. Preparation of this paper and much of the research referenced was supported by the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio. This support was provided under Project 1124, "Human Resources in Aerospace System Development and Operations," Melvin T. Snyder, Project Scientist, and Task 112401, "Personnel, Training and Manning Factors in the Conception and Development of Aerospace Systems," William B. Askren, Task Scientist.

HUMAN RESOURCES AND PERSONNEL COST DATA
IN SYSTEM DESIGN TRADEOFFS

I. INTRODUCTION

This paper integrates the results of a number of studies performed over a period of several years regarding the use of human resources data in system design tradeoffs. The studies ranged over a variety of aircraft design situations, and produced a number of findings significant to military psychologists.

During review of these research efforts, two messages emerged. The prime theme, of course, relates to human resources data in system design tradeoffs. The second theme concerned the general topic of improving communications between military psychologists and the design engineer, and increasing the engineer's use of human data in his design activities. Thus evolved the subtitle for this paper.

I next tried to view this paper as a member of the audience. In such a role, I asked myself five questions: What are system design tradeoffs? What are human resources data? Why should military psychologists be interested in system design tradeoffs and human resources data? How much effort do system design tradeoffs have on human resources? Finally, what does this have to do with increasing the engineer's use of human data in design activities? The paper is organized around these five questions.

II. WHAT ARE SYSTEM DESIGN TRADEOFFS?

A system design tradeoff is an analysis and evaluation of two or more alternatives to a design requirement, with the choice of one of the alternatives for use in the design. A design tradeoff can be as simple as the mental exercise in choosing between two transistors with no evidence that a tradeoff was made, or can be as complex as the selection of an aircraft configuration requiring thousands of manhours, representing many different disciplines, and resulting in a formal written trade study report.

Many different kinds of tradeoff studies can be performed, such as: weapon system concept comparisons, for example, manned aircraft versus missiles; equipment comparisons, for example, jet engines versus turbofan engines versus reciprocating engines; and organizational plans, for example, flight line maintenance versus depot maintenance.

Chuprun[1] classifies aircraft tradeoffs into two types, major system tradeoffs and design tradeoffs. Major system tradeoffs include such evaluations as performance versus operational utility, performance versus availability, performance versus cost. Design tradeoffs include comparison

[1]Chuprun, J., Personal Communication, 1970.

of alternate configurations, comparison of alternate subsystems, and comparisons of alternate technologies.

The number of tradeoffs and tradeoff alternatives that could be considered during development of any one complex weapon system is astounding. Chuprun estimates that one million alternative combinations existed for major system tradeoff studies for one bomber development program. For the same bomber program, the number of design tradeoffs approached infinity.

The manner in which a tradeoff is performed is quite dependent upon the personal style of the engineer conducting the study. However, research by Lintz, Askren, and Lott (1971) did find a trend common to many engineers. In general, the engineer is presented with a problem which requires a design solution. The engineer may be presented with the design alternatives which are to be considered, or may have the additional task of determining the best possible alternatives to be traded off against each other.

Next, the engineer collects the necessary data on the different design alternatives such as weights, volumes occupied, power requirements, reliability, maintainability, safety, etc. Weighting factors are assigned to the different parameters by some manner and a total value is derived for each of the alternatives. The design which emerges with the highest value is recommended for use in the system. Frequently, the results are depicted in matrix form. Table 1 illustrates a simplified trade study matrix.

TABLE I
SIMPLIFIED TRADE STUDY MATRIX

PARAMETER	WEIGHTING FACTOR	BASELINE DESIGN	DESIGN ALTERNATIVE A	DESIGN ALTERNATIVE B
WEIGHT	15%	15	13	12
VOLUME	10%	10	9	8
PERFORMANCE	50%	31	31	50
COST	25%	25	22	19
TOTAL	100%	81	82	89

The number of alternatives considered in tradeoff studies varies considerably. An analysis of 61 trade studies performed for aircraft, missile, and command and control systems, showed that the number of design alternatives range from 2 to 32, with the median number of alternatives being 4, (Lintz, Askren, and Lott, 1971).

The number and kind of parameters that are used to evaluate the different design alternatives varies with the type of problem and the engineer performing the study. For example, Table 2 illustrates some of the different parameters, and the number of engineers using the parameters for an aircraft flight control tradeoff and an aircraft fire control tradeoff. These data were taken from the study by Lintz, Askren, and Lott (1971).

TABLE 2

SOME OF THE DECISION PARAMETERS
USED IN DESIGN TRADEOFFS FOR TWO AIRCRAFT SUBSYSTEMS
AND FREQUENCY OF USE BY ENGINEERS

Flight Control Tradeoff		Fire Control Tradeoff	
Parameter	Frequency of Use*	Parameter	Frequency of Use*
Cost	36	Cost	34
Mission Effectiveness	33	Volume	28
Handling Quality	30	Performance	27
Flight Reliability	28	Power	18
Pilot Acceptability	21	Cooling	15
Control Features	5	Growth Potential	3

*Maximum number of engineers possible was 36 in each case.

III. WHAT ARE HUMAN RESOURCES DATA?

A succinct, direct answer to this question could not be found. Therefore, I shall attempt to develop a definition at this time.

Human Resources refers, obviously, to the people of an organization, be it a military unit, an industrial corporation, a governmental agency, or an educational activity. Human Resources concerns the people as a resource that can be drawn upon in the accomplishment of the purpose of the organization. The purpose can be any activity of meaning to the organization such as, a military bomber strike of a target, or an industrial manufacture of an electric refrigerator. The Human Resources may be likened to the other resources of the organization, such as equipment, facilities, land, raw material, etc., which can be drawn upon to accomplish the purpose of the organization. Brummet, Flamholtz, and Pyle (1968) have carried this analogy quite far in the industrial world, and have developed a methodology called human resources accounting. This enables them to enter the value of the people of an organization into the accountants' ledger.

Viewing people as another one of the resources of an organization leads to a series of questions which may be asked about this resource: what can it do for, or contribute to, the purpose of the organization? how much does it cost? how available is it? how perishable is it? and, how much of it is needed by the organization? Other questions undoubtedly could be asked about the resources of an organization, but these seem sufficient to develop a first-cut definition of human resources data.

Human Resources Data, it would follow, are those data which describe the people of an organization in terms of what they can contribute, how much they cost, how available they are, how perishable they are, and how many of them are needed.

What the people of an organization can contribute to its purpose, refers, of course, to their performance, capability, productivity, etc. This could be the skill of the pilot in driving the aircraft to a target, the capability of a maintenance man to troubleshoot and repair a failed equipment, the ability of a teacher to educate the students, the capability of a manager to plan his operations, etc. The data that describe these contributions vary with the task, but are such measures as time, errors, accuracy, affect on morale, etc.

What the people of an organization cost is measured quite simply as dollars. However, arriving at the dollar figure is an exceedingly complex issue. The development of formulas, analytical procedures, and raw data for calculation of personnel dollar costs has been, and is today, the subject of considerable research. The dollar cost of the personnel of an organization requires cost data from many sources, such as salary, recruiting, training, bonuses, retirement, medical care, etc. Connelly, (1967) proposed a personnel cost formula which contained 79 elements.

How available the people are to the organization can be understood at various levels. Availability could be conceived of as the availability for hire of new employees in the labor market. Availability could also be thought of as availability of specific skills within an organization for use on new operations to be performed. We are defining availability as the probability that a given quantity of personnel of specific skill capability will be on-site at the operational unit as required by the weapon system schedule. Such an availability measure is influenced by many factors such as quantity and kind of career airmen, recruiting rate for new airmen, training time for new personnel, transfer of experienced personnel from phasing-out systems, and attrition rate of older personnel.

Perishability of the human resources of an organization is partially measured by the attrition or turnover rate of the people. However, a large part of perishability would have to do with the retention of useful skills by the people, and the efforts required to preserve the skills at a needed level. Statements have been made that the skill half-life of an engineer is ten years, meaning that every ten years he loses one-half of the engineering capability he possesses. Obviously, efforts are made by organizations to prevent such an erosion of skill. Quantitative measures of these efforts would provide a useful metric of the human resources. It is quite likely that these retraining efforts would vary considerably for different types of skills within the organization. Other dimensions of perishability that could be measured include such factors as, physical health and safety, and psychological motivation and morale.

How many people are needed by an organization resolves to how many people, of what type of skill, and what level of proficiency. In the Air Force we are measuring this parameter by how many airmen, by which career fields and at what skill level, are needed to perform the required tasks. The quantity, type, and proficiency of personnel needed ultimately evolves from their capability, cost, availability, and perishability. In one sense, this is the ultimate question asked by the manager of an organization, or the engineer with regard to his design.

Which of these five classes of data have been found useful for design tradeoff studies? Information on this comes from three investigations. The first, (Lintz, Askren, & Lott, 1971) indicates the type of maintenance personnel data useful to engineers in conduct of two design tradeoffs. The other studies, (Askren, Korkan, & Watts, 1973; and Askren, Korkan, & Woodruff, 1973) describe maintenance personnel data which discriminate between design alternatives of nine tradeoff problems. Results from these three studies are given in Table 3. Inspection of the table shows that data classed as "How Much Resource Needed" were used in all three studies. Data classed as "Availability" were not used in any of the studies. Data representing the other 3 classes were used in one or two studies.

IV. WHY SHOULD MILITARY PSYCHOLOGISTS BE INTERESTED IN SYSTEM DESIGN TRADEOFFS AND HUMAN RESOURCES DATA?

Military psychologists should be interested in system design tradeoffs, because design tradeoffs offer a promising point of entry into the mystique of the engineering design process. Military psychologists should be interested in human resources data, because this is a class of data which describes man, and which potentially can significantly influence the design characteristics of new military products.

The design tradeoff is of particular interest as a point of entry into the system design process, because often the design tradeoff, in the form of a trade study, is an objective, quantified evaluation of alternatives.

TABLE 3

CLASSES OF HUMAN RESOURCES DATA
FOUND USEFUL FOR DESIGN TRADEOFFS
IN THREE RESEARCH STUDIES

Classes of Human Resources Data	Research Study and Kind of Data		
	Lintz, Askren & Lott, 1971	Askren, Korkan & Watts, 1973	Askren, Korkan & Woodruff, 1973
1. What the Resource Can Do	--	Equipment Troubleshooting Time	Time to Perform Equipment Test & Checkout & Troubleshoot & Repair
2. Resource Cost	10-year Life Cycle Cost	--	10-year Life Cycle Costs
3. Resource Availability	--	--	--
4. Resource Perishability	Re-enlistment Rate	--	--
5. How Much Resource Needed	Quantity By Career Field & Skill Level	Quantity by Career Field	Quantity By Career Field & Skill Level

The trade study matrix and report provide documented evidence showing how the engineer or team reached the final choice. The parameters which were considered are listed, with weighting factors assigned. Cell entries indicate weighted values for the design alternatives under consideration (Table 1).

One attractive aspect of the trade study is the explicit statement given of the decision process. Much that ordinarily remains subjective and undocumented becomes quantified and public. If the Air Force desires assurance that some parameter, for example human resources data, has been considered adequately, the trade studies interspersed throughout the design process appear to be ideal mechanisms for providing such assurance.

The concern for using Human Resources Data as criteria in design is growing, and extends beyond the parochial interests of the military psychologist. There is growing recognition by managers and planners of new systems that the human resources have a substantial impact on the dollar costs, and operational capabilities of systems. There is also increasing awareness that the quantity and quality of human resources available to the Air Force of the future will change. This change will be brought about by the effects of such factors as congressional limitation, Air Force personnel plans, re-enlistment rates, an all-volunteer force, and national economic conditions.

The feasibility and acceptability of using Human Resources Data as criteria in design tradeoffs was demonstrated in a recent study (Lintz, Askren, & Lott, 1971). In this investigation, 50 experienced engineers were asked to perform design tradeoffs for aircraft flight control and fire control subsystems. Data supplied to the engineers for use in the tradeoffs included Human Resources Data. Forty-seven of the fifty engineers used the Human Resources Data along with engineering data to perform the tradeoff studies. In addition, the engineers assigned substantial weighting points to Human Resources Data, with Human Resources Data ranking in the top 1/3 of all data inputs to the tradeoff studies.

A final thought on why military psychologists should be interested in design tradeoffs comes out of the work of Askren and Korkan (1971), Askren and Korkan (1972), and Askren, Korkan, and Watts (1973). Based on the findings of these studies, it is hypothesized that much of system design can be visualized as a series of tradeoffs progressing from a design objective to the finished product. The first study shows, for aircraft jet engines, that the series of tradeoffs required for resolution of a design problem can be identified before design begins. This study also shows that the options available for each tradeoff can be identified, and the resulting information and data can be depicted in decision tree form. Figure 1 illustrates a portion of a Design Option Decision Tree for jet engines.

The second study tested the generalizability of Design Option Decision Trees to other design problems. It was found feasible to develop Design Option Decision Trees for aircraft landing gear, airframe, and weapons delivery subsystems. The third study shows the feasibility of developing a Design Option Decision Tree to a level of detail that incorporates all the significant tradeoffs required for a design problem. It was found feasible to expand a turbofan jet engine tree to a level of detail that includes, for example, the tradeoff for choice of bearing for the engine compressor.

The combined results of these three studies shows that a considerable portion of the work of the design engineer can be viewed as a series of tradeoff decisions. As such, system design can be conceptualized as a human decision process. This can establish the orientation for future research by military psychologists regarding system design. Much research has been conducted about human decision making, and it would seem that the application of the findings concerning decision making, in general, to system design, specifically, would lead to many new insights regarding the design process. The mystique of design could give way to the structure, quantification and measurement of the researcher. The result could be a greater influence on the nature of the design product by the military psychologist.

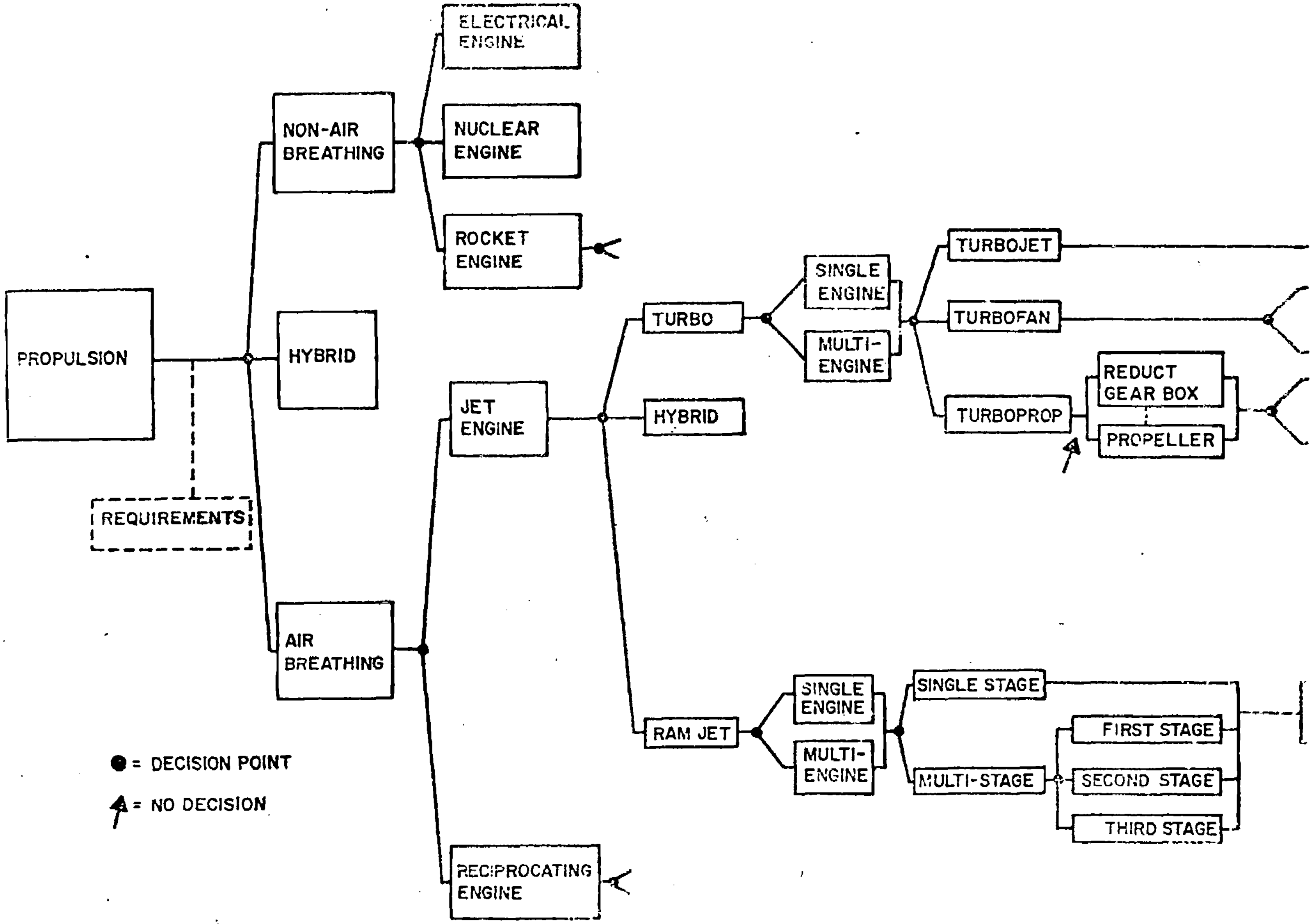

Figure 1. Segment of Propulsion Decision Tree.

V. HOW MUCH EFFECT DO SYSTEM DESIGN TRADEOFFS HAVE ON HUMAN RESOURCES?

Based on the results of three investigations, it has been found that the design option selected by the engineer in a tradeoff problem can have a significant impact on the human resources of the organization.

In the study of Lintz, Askren, and Lott (1971) two different design tradeoff studies were performed by a group of experienced engineers. The tradeoff studies were for aircraft flight control and fire control subsystems. Each tradeoff study included three design alternatives. The effect each alternative would have on the human resources of the Air Force was calculated.

The design alternatives were evaluated as to their impact on the quantity, skill type, and skill level of personnel required to provide maintenance for the product of the design. In addition, the dollar cost to provide these personnel was calculated, and the number of new enlistees required to man the design product during the life of the system was determined. A ten-year system life, with 400 aircraft, each flying 45 hours per month was assumed.

The resulting data are given in Tables 4 and 5. A comparison of the human resources data between design alternatives illustrates the significance of the choice of design option. Design option C, in each case, makes substantially less demand on the human resources of the Air Force.

TABLE 4

IMPACT OF FLIGHT CONTROL DESIGN TRADEOFF ALTERNATIVES ON HUMAN RESOURCES OF THE AIR FORCE

Human Resources Data	Flight Control Subsystem Design Alternatives		
	A	B	C
Quantity Personnel By Skill Level:			
3	26	22	16
5	38	31	26
7	18	16	16
Total	82	69	58
Personnel Costs (Millions)	5.5	5.0	4.2
Number New Enlistees	144	117	102

TABLE 5

IMPACT OF FIRE CONTROL DESIGN TRADEOFF
ALTERNATIVES ON HUMAN RESOURCES
OF THE AIR FORCE

Human Resources Data	Fire Control Subsystem Design Alternatives		
	A	B	C
Quantity Personnel By Skill Level:			
3	7	5	1
5	14	16	1
7	12	13	1
Total	33	34	3
Personnel Costs (Millions)	16.1	16.2	1.7
Number New Enlistees	73	74	8

A study by Askren, Korkan, and Watts (1973) illustrates the range of impact that different tradeoff problems can have on the human resources. In this study the design alternatives for eight jet engine tradeoff problems were analyzed for affect on the human resources. Each design alternative was evaluated for impact on maintenance crew size and job specialty, amount of training and experience required, time to troubleshoot a failure in the equipment, and ease of maintenance on the equipment.

Table 6 shows the effect the eight tradeoff problems would have on these factors. For one tradeoff problem, number VI, the choice of design alternative would affect four of the six human resources measures. For one tradeoff problem, number VIII, the choice would affect none of the human resources measures. Problem VI concerns selection of type of engine compressor from among three alternatives. Problem VIII concerns selection of type of compressor bearing between two alternatives.

In this study it was found, also, that the amount of effect varies with the tradeoff problem. For example, for tradeoff problem VI, the design alternative ranked first (of 3) would require 60 percent less training and experience to do satisfactory maintenance work than the design alternative ranked third. For problem VII there would be 22 percent less training and experience required for the design alternative ranked first than the one ranked second. For problem VIII, there would be no difference between design alternatives regarding amount of training and experience required.

TABLE 6

IMPACT OF 8 JET ENGINE DESIGN TRADEOFF
PROBLEMS ON THE HUMAN RESOURCES OF THE AIR FORCE

Tradeoff Problem		HUMAN RESOURCES MEASURES				
No.	No. of Design Altern.	Crew Size	Job Specialty	Training & Experience	Troubleshoot Time	Ease Of Maintenance
I	2	0	0	0	X	X
II	3	0	0	X	X	X
III	5	0	X	X	X	X
IV	3	0	0	X	X	0
V	2	0	0	X	X	0
VI	3	X	0	X	X	X
VII	2	0	0	X	X	X
VIII	2	0	0	0	0	0

X = A significant difference between design alternatives.

0 = No significant difference between design alternatives.

The third investigation (Askren, Korkan, & Woodruff, 1973) evaluated in considerable detail the impact on human resources of three design alternatives of one tradeoff problem. The tradeoff problem concerned the selection of type of power controller unit to use in the electrical subsystem of an aircraft. The three alternatives were evaluated as to impact on: the maintenance personnel requirements to test and checkout all power controller units, and to troubleshoot and repair failed units; the type and amount of training for these personnel; the time and manhours to do test and checkout, and troubleshoot and repair operations; and the dollar costs to provide the maintenance personnel for the life of the system.

Table 7 presents the results of this investigation. It is clear that design option B would make the least demands on the human resources. The advantage of option B shows up most strikingly in the dollar costs to provide personnel to troubleshoot and repair failed power controller units during a ten year life of the system.

TABLE 7

IMPACT OF POWER CONTROLLER UNIT DESIGN
ALTERNATIVES ON HUMAN RESOURCES
OF THE AIR FORCE

Human Resources Data	Design Alternatives		
	A	B	C
Maintenance Personnel Crew	1 5-level Electrician 1 3-level Electrician	1 5-level Avionics	1 5-level Avionics 1 5-level Electrician 1 3-level Electrician
Training for a Crew (Manhours)	308	250	945
Manhours for Crew to Perform: Test & Check at all PCU's	19.6	1.7	7.6
Troubleshoot & Repair a Failed PCU	6.0	3.1	7.0
Personnel Cost to Troubleshoot & Repair Failed PCU's During 10-year Life of 200 Aircraft (Million)	$3.1	$ .4	$1.4

In general, it can be stated that choice of a design alternative in a tradeoff study will affect the human resources of the organization. In the 11 tradeoff problems described here, it was found that choice of design alternative would affect the human resources in ten cases. Of the ten, the impact is substantial in five cases, and moderate in five problems.

VI. WHAT DOES THIS HAVE TO DO WITH INCREASING DESIGN ENGINEER USE OF HUMAN DATA?

In the applied setting, in the face-to-face interaction between the design engineer and the psychologist, what can be done to influence the engineer to more readily accept and use data about man? From the foregoing sections of this paper, I believe three principles can be extracted which will help this effort. In addition, a fourth principle, coming from earlier work, is relevant.

First, system design should be viewed as a human decision process in which the engineer makes a series of choices. The engineer generally has a physical goal to reach. He must design a product that will fly, or float, or shoot, or lift, etc. He will, in general, follow a path from design objective to product characteristics. Along this path, he will make judgments, decisions about the characteristics of the system he is designing. Many times he will face choice points with options to choose between.

This leads to the second principle. As psychologists, knowledgeable about human decision making, we should enter into this decision process with the engineer. We should help him map out the main, critical choice points for his design problem. And, we should help him determine the options available at these choice points. The work with Design Option Decision Trees described earlier in the paper, shows this to be feasible. The level of detail, the number of choice points, the number of choice point options to which this effort should be carried, depends, of course, upon time and resources available.

The third principls is: provide data to the engineer regarding the effect on man of choice point alternatives. These human effects can be human resources data as described in this paper, or other data describing man which are relevant to the problems. Such data as human reaction times, visual perception, auditory perception, display-control interaction, reach distance, etc., could indeed be relevant to certain types of tradeoff problems. The data, to be most effective, should be quantitative in nature, and in tabular or graphic form. Detailed presentations of data seem to be preferred to short, summarized statements (Lintz, Askren, & Lott, 1971).

It is also important to submit the data to the engineer with confidence. Human data compare quite favorably with engineering data in terms of validity and reliability when the data are prepared for a new design problem. It has been characteristic of psychologists to be too cautious about their data. Not so the engineer. He acquires 3 or 4 data points and makes decisions of major consequence regarding his design. The psychologist should learn to do the same.

The fourth principle is from earlier work, but extremely relevant to the topic of influencing design. Simply stated, the psychologist should enter early into the design problem. Studies by Meister, Sullivan, and Askren (1968); and Meister, Sullivan, Finley, and Askren (1969) show that in many respects the design of a weapon system is like an artistic rendering. The engineer receives a design problem, acknowledges constraints, studies it, suffers over it, and then drawing on his own personal experiences works very quickly to develop a concept. Once the concept is formed he resists making changes to it, much as the artist resists changes to his creation. Therefore, if the psychologist wishes to significantly influence the design product, he must work with the engineer during design conceptualization. Human data inputs made later, as during design reviews, have little chance of affecting the design product.

VII. CONCLUSIONS

Tradeoffs are a significant part of the weapon system design process. The choice of design alternative in a tradeoff study would, in many cases, substantially affect the human resources of the organization using the product of the design. It is feasible to use data describing these human resources in design tradeoffs. This use could lead to development of products which make less demand on those resources. Viewing system design as a human decision process involving choice-points and options, gives the psychologist an orientation toward design which allows him to more effectively work with the engineer.

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