University of Maryland, College Park
Department of Aerospace Engineering

AN EXPERT SYSTEM FOR HELICOPTER CONCEPTUAL DESIGN

by

Vit Babuska

Thesis submitted to the Faculty of the Graduate School
of the University of Maryland in partial fulfillment
of the requirements for the degree of
Master of Science
1987

APPROVAL SHEET

Title of Thesis: An Expert System for Helicopter Conceptual Design

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ABSTRACT

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Thesis directed by: Dr. James A. Fabunmi
Assistant Professor
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The objective of this thesis is to demonstrate the applicability of expert systems in helicopter conceptual design by developing an expert assistant which aids the engineer in defining a feasible design configuration. The expert assistant combines some experiential knowledge of the design engineer with a typical conceptual design algorithm to guide the engineer to a reasonable baseline design. The expert assistant was developed on a personal computer using the expert system shell INSIGHT2+®. The design algorithm employed is SSP1, a helicopter weight and sizing program developed at the US Army Applied Technologies Laboratory. A set of heuristic rules was developed which attempts to simulate the thinking of an expert design engineer using SSP1 for helicopter conceptual design. The result, a prototype expert assistant which aids an engineer in the conceptual design phase, demonstrates the feasiblity of expert systems in helicopter design.

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LIST OF SYMBOLS

$\frac{C_t}{\sigma}$	Main rotor blade loading coefficient
$\left(\frac{C_t}{\sigma}\right)_o$	Blade loading coefficient for minimum weight
$\left(\frac{C_t}{\sigma}\right)_L$	Lower limit on blade loading coefficient
$\left(\frac{C_t}{\sigma}\right)_H$	Upper limit on blade loading coefficient
b	Number of blades of the main rotor
c	Main rotor blade chord, feet
dl	Main rotor disk loading, psf
dl_o	Disk loading for minimum weight, psf
dl_L	Lower limit on main rotor disk loading, psf
dl_H	Upper limit on main rotor disk loading, psf
R	Main rotor radius, feet
V_t	Main rotor tip speed, fps
V_{t_o}	Tip speed for minimum weight, fps
V_{t_L}	Lower limit on main rotor tip speed, fps
V_{t_H}	Upper limit on main rotor tip speed, fps
W_{Body}	Weight of the helicopter body, pounds
W_G	Helicopter gross weight, pounds
W_{MR}	Weight of the main rotor, pounds

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CHAPTER I

INTRODUCTION

Since the introduction of the computer, people have praised it for its ability to perform repetitive calculations with great speed and have attempted to endow it with the human ability to reason. The science of creating intelligent behaviour on computers has come be known as artificial intelligence (AI). AI technology has only recently emerged from the computer science laboratories to the applications world of engineering. One area of engineering which uses computers extensively is design engineering. The design process relies heavily on the expertise of the designer as well as on computational programs. Without the expert designer, most computations would be misdirected and useless. Thus, the integration of AI technology into a field such as design engineering appears most desirable.

Today, computational Computer-Aided Design (CAD) programs are used in all stages of the design process. In the early stages of aircraft design such programs are used to estimate weight, size and performance of the aircraft. In helicopter design, programs with these objectives include "HESCOMP"[1] (Helicopter Sizing and performance COMputer Program) developed at Boeing Vertol, "COMAP"[2] (COmprehensive Mission Analysis Program) developed at Sikorsky Helicopter and "SSP1" (System Synthesis Program 1) written at the US Army Technical Research Laboratories in St. Louis, Missouri.

Recently, expert systems have begun being combined with traditional design programs in several areas of engineering. The program "PAPER AIRPLANE"[3] developed at the Massachusettes Institute of Technology (MIT) is a designer workstation for designing fixed wing aircraft. In structural engineering, "HI-RISE"[4], written at Carnegie-Mellon University is a system which designs multi-storied buildings. While nothing has been published to date in the area of helicopter design, research is being conducted in this area at the Georgia Institute of Technology as well as at the Unversity of Maryland.

This chapter presents background information on artificial intelligence and engineering design, specifically expert systems and helicopter conceptual design. It concludes with a discussion of the expert systems tools considered for this thesis. Chapter 2 defines the scope of the program developed in this thesis and the methodology of its development. Results, in the form of sample designs which illustrate the goals of the thesis are presented in chapter 3. Chapter 4 contains the conclusions and recommendations for future work.

1.1 Expert Systems

Expert systems, also known as knowledge based systems (KBS), are the successful products of extensive research in artificial intelligence. They are computer programs having built-in knowledge which attempt to produce the same solution to a problem as would a human expert[6]. Expert systems embody experiential knowledge about a subject and thus must be able to manipulate symbols (non-numeric data) as well as numbers. To date, expert systems have been built to interpret data (DENDRAL is a program that interprets soil and geological deposit data[7]) plan, monitor processes, diagnose diseases (MYCIN is a program which diagnoses infectious blood diseases[7]), predict performance, instruct (SACON is a program which consults with the user about appropriate use of a finite element code[6]) and design (the program R1 configures VAX computers for Digital Equipment Corp.).

Regardless of the area of application, expert systems can be divided into three classes based on their purpose. The first class can be described as a "black box decision system". This type of expert system requires little or no interaction with people. It makes decisions based on data available from internal sources such as other programs and databases. Often this type of system is a subprogram in a larger decision support system. The second class of expert systems can be described as an interactive decision system because it requires active participation on the part of the user. The user, however, is simply a source of information for the expert system which it uses when it cannot reach a conclusion alone. This type of system is the stereotypical expert system. The third class of KBS is called an "expert assistant". This type of system incorporates the user into the decision process as well as using him as an information source. The assistant makes decisions based on its knowledge but requires the user's approval to execute the decision. Final control over the process rests with the user in this type of system.

The domain of application of an expert system is generally very narrow because expertise which can be captured and applied is usually in very specialized areas. Also, the development of a KBS is a labourious task as are all major programming efforts. To keep things at a workable size, the scope must be limited and well defined, in this case to exercising the conceptual design program SSP1. It is not unusual for the scope of the problem being modeled to be reduced in order to keep things managable as work progresses on the KBS.

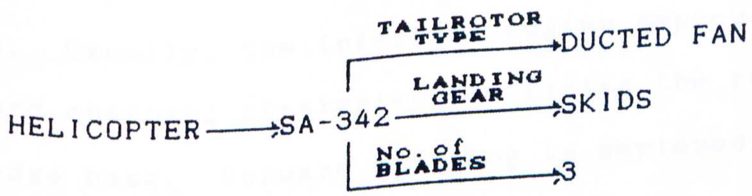
In developing an expert system, the structure of the knowledge being represented is a driving factor. The knowledge representation scheme must be consistent with the natural organization of the knowledge. To that end, several schemes such as production rules, semantic networks, and frame systems, have been developed to organize information[8].

Production rules are arguably the most common way to organize knowledge. They are probably the easist to understand. In a production rule system, the knowledge is organized in an antecedent-consequence format, i.e. IF-THEN rules. For example:

```
RULE SA-342 Characteristics
IF   the helicopter IS SA-342
THEN the landing gear IS skids
AND  the number of blades := 3
AND  the tail rotor type IS ducted fan
```

This rule contains information about the characteristics of the SA-342 helicopter. The first line is a header and the body of the rule, the IF-THEN block, contains the information regarding the type of landing gear, the number of blades (of the main rotor) and the type of tail rotor of the SA-342. The syntax of the rule is very English-like making it easy to understand and contains symbolic information as well as numeric data.

Semantic networks are a combination of nodes and links through which the knowledge is organized. Nodes represent objects, concepts, facts etc. and links are the connections between the nodes which represent their interrelations. The links also create an inheritance web by which data is linked to nodes higher than the parent node. Expressing the SA-342 characteristics in a semantic network would look like:



Frame systems are similar to semantic networks. The network structure is the same but objects are represented by frames rather than nodes. Whereas nodes are atomic, frames contain slots in which declarative and procedural information about an object is stored. Using the SA-342 example again, the information would be organized as:

SLOTS	Generic Frame Values	SA-342 Frame Values
Self	AIRCRAFT	HELICOPTER
Name	An AIRCRAFT TYPE	SA-342
Landing Gear	a GEAR TYPE (def = SKIDS)	SKIDS
No of Blades	the NUMBER of BLADES (def = 4)	3
Tail Rotor	the TAILROTOR TYPE (def = CONVENTIONAL)	DUCTED FAN

No matter what type of knowledge representation scheme is used, all expert systems have a common structure. There are three basic components in an expert system:

1. the user interface which is a means for the user to interact with the KBS;
2. the knowledge base which contains facts, heuristic rules and procedural rules (e.g. calls to external programs to provide data);
3. the inference engine or control strategy which acts upon the data in the knowledge base and any input data to solve the problem.

The most important of these components is the inference engine. Usually, the inference engine employs forward or backward chaining strategies for firing the rules in the knowledge base. Forward chaining is employed in synthesis KBSs', ones that design or plan. In the context of a production rule system, rules are fired using the antecedent condition (IF part) of the rule based on the current collection of known facts. As consequent propositions are defined, the set of known facts is expanded and the antecedent conditions of other rules are satisfied. Backward chaining is employed in analysis KBSs', ones that diagnose, interpret and analyze. Again in the context of a production rule system, rules are fired based on satisfying the antecendent condition of a rule whose consequent proposition is known from facts or from the consequences of other rules.

The person developing an expert system has numerous options regarding how to go about the task. An expert system can be built from the ground up, using list oriented languages such as LISP or PROLOG. These languages are appropriate for KBS development because of their recursive nature and their abilities to manipulate symbols. Other languages however, such as PASCAL and FORTRAN, have been successfully applied in writing expert systems.

A major drawback to building an expert system with LISP or PROLOG however, is the amount of effort required in the actual coding. All the expert system components must be developed along with formulating and organizing the knowledge for the system. An alternative is to use a general purpose representation language such as ROSIE[11], LOOPS[9] or OPS5[10]. These languages have been designed specifically for KBS development. They have an implied structure for the organization of the knowledge (OPS5 is rule-based; LOOPS is a frame system; ROSIE is rule-based with a very English like syntax) and retain some of the flexibility of a general programming language. Representation languages are often the choice for developing large complex expert systems.

A third tool for KBS development is an expert system shell such as KMS[9], EXPERT[9], Personal Consultant[12], or INSIGHT2+[13]. The discrete nature of the components of expert systems, i.e. the independence of the knowledge base from the inference engine, has spawned these systems which combine an inference engine with a knowledge base skeleton, user interface, explanation module, knowledge base editor etc. The expert system developer is relieved of a large portion of the work involved in using programming languages therby shifting the major focus to knowledge organization and formulation within the structure of the shell.

1.1.1 Engineering Expert Systems

Solving problems in engineering fields with expert systems differs from areas such as medical diagnosis (MYCIN) where expert systems have shown great success, in one critical respect. An engineering problem can rarely be solved on the sole basis of experience about the problem. The expert who is solving the problem, often employs computational programs to get information and accesses data in reference books. This implies that the engineering expert system must be able to combine reasoning about the problem with significant computations and access to relevent databases. Generally, the computations required already exist in the form of a stand alone program (e.g. in this case SSP1) so the expert system must be able to organize the input for the program, run it, and extract the needed information for inclusion in the knowledge base. As shown in figure 1.1, the components of a typical engineering expert system include the user interface, the inference engine and the computational element(s). The user interface should provide efficient communication between the engineer and the KBS. This can be done by using menus, graphics and natural language to solicit information from the user and report results. The logic element contains the rule database, which stores the experience and knowledge about a specific problem, the attribute or fact database which stores the information about the problem being solved, and the inference engine which fires the rules in the rule database. The computational element contains the application programs such as SSP1 which implement design or analysis calculations.

1.2 Engineering Design

The typical design process is usually formalized into at least four levels or components; the trend study, conceptual design, preliminary design and production design[14] (In practice however, there are feedback loops to previous stages when requirements are found to be unsatisfied). Each subsequent component of the design process represents a higher level of detail. The trend study is the least complex. In it, requirements are defined and direction is provided for the more detailed studies. During the conceptual design phase, configurations are analyzed and compared. Important aspects of the design are investigated and defined. In helicopter design, these include the type of helicopter, the number of blades, disk loading and tip speed, among others. Furthermore, preliminary weight, sizing and cost estimates are made along with recommendations for the next phases (fig. 1.2)[14]. Preliminary design is where the parameters identified in the conceptual design phase are defined more precisely. An in-depth study of the configuration is performed and data is obtained from physical models (e.g. wind tunnel tests) and from detailed computations. In the final phase, production design, a commitment is made to develop a prototype and detailed studies on all subsystems of the aircraft are done to support the production commitment[14].

The conceptual design phase of helicopter design includes, but is not limited to, the definition of major components such as the main rotor type (articulated, teetering, etc.), the tail rotor type (conventional or fenestron), and the engine. A typical sequence in conceptual design is shown in figure 1.3, adapted from reference 14.

Computers in the form of computer aided design systems

(CAD systems), are introduced in this phase to aid the designer. Generally, previous generation CAD systems have been deficient in three major areas[15]:

1. They are not intelligent; They accept inputs without checking for errors and they cannot provide answers to the designers questions.
2. Inconvenient user-program interface; The structure of the design input data is usually not consistant with the thought process involved in design. This promotes mistakes and decreases efficiency.
3. A non-integrated environment; Most CAD programs cannot interface with other programs and the designer must translate data from one system and feed it into another.

Integrating knowledge based systems with CAD systems is an effective way to overcome these problems.

In helicopter conceptual design, computational programs such as HESCOMP or SSP1 can be used to establish vehicle size (rotor diameter, boom length, fin size etc.), vehicle weight and engine size. These programs suffer from the problems of most CAD systems and combining them with an expert system would have obvious benefit. As shown in figure 1.2, 'rules of thumb' and the designer's experience are vital in the conceptual design phase. The designer knows how he wants to use HESCOMP or SSP1 to achieve a design configuration. This implies that the designer's experience and his 'rules of thumb' can be incorporated into an expert system to make the interface to the program intelligent, i.e. suggest proper input information, catch inconsistent input, and explain the relationships between parameters in the context of design and also in the context of the program. This also addresses the second problem, i.e. incomprehensible interface. The expert system can accept data from the user and reformat it to feed to SSP1 or HESCOMP. On output the results can be interpreted and evaluated by the expert system and suggestions can be made about which parameters to alter to achieve the best configuration ("best" must be predefined for the KBS). Later in the conceptual design cycle (fig 1.3), a cost analysis is usually done on the feasible designs with another computer program. This points to the third problem, program interface. The designer must extract relevant data from input and output parameters of the design program and feed them to the cost program. A KBS would link the two programs, extract data from one, reformat it and feed it to the other.

In reality, conceptual design is more complex than excersizing HESCOMP or SSP1 and a cost analysis program. Other analyses are performed, other computational programs are involved and more feedback loops are present. This only makes it more important to link systems, and provide intelligent interfaces throughout the design CAD system.

1.3 Thesis Expert System Tools

In this thesis, the focus is on codifying the knowledge and experience in helicopter conceptual design rather than on programming the components of an expert system. To that end, general purpose representation languages and shells were considered as development tools and a programming language such as LISP was not. ROSIE, a representation language, and INSIGHT2+, a small production rule shell, were chosen as models in the two classes within the scope of available resources. Each has advantages and disadvantages.

ROSIE, developed by the RAND corporation, is a rule based general representation language which structures rules using a form of stylized English. It separates rules into two categories, declarative and deductive. The knowledge base consists of a collection of declarative rules. For example, a declarative rule defining the SA-342 tail rotor would be written as:

The tail rotor type OF the SA-342 IS a ducted fan.

These rules can be organized into local knowledge bases to naturally separate information. Each helicopter has its own knowledge base which contains information about it. This information can be retrieved to a central knowledge base as it is needed. Deductive rules are stored separately in modules called rulesets. The inference engine fires rulesets as ordinary procedures. Relations between objects are defined using a special type of ruleset-generators. A generator ruleset defines elements of a computed set. For example, the ruleset defining the category of helicopter based on gross weight and useful load would be written as:

```
To Generate CATEGORY:
[1] Let the USEFUL_LOAD be (the GROSS_WGT - the
EMPTY_WGT).
[2] Choose situation:
    If the GROSS_WGT < (6000 lbs) and the USEFUL_LOAD <
    (1500 lbs)
        Produce "light observation"
    If the GROSS_WGT < (6000 lbs)
        Produce "light utility"
    Default:
        Produce "unknown".
End.
```

When another rule requires the category of helicopter, ROSIE will use this generator to define the category. Thus, attributes of objects are defined deductively as well as explicitly.

The flexibility in defining and organizing rules is the principal advantage of using ROSIE. However, there are significant disadvantages as well. Although external programs can theoretically be activated from within the ROSIE environment using INTERLISP functions, this proved very difficult on the VAX/VMS 750 on which ROSIE was implemented. The other major drawback is the proccessing time involved. Rulesets must be compiled through INTERLISP which requires a large amount of processing time (CPU time).

INSIGHT2+ is a production rule shell developed for MS-DOS® based personal computers. All information is represented in rules using a simple IF-THEN syntax like that presented in section 2.1. The system naturally uses a backward chaining strategy but can perform forward chaining as well. INSIGHT2+ pursues a goal or a hierarchy of goals which are proven or disproven by a network of rules. Two types of rules are supported; procedural rules which are independent of any antecedents and deductive rules which are typical IF-THEN rules that change the facts in the knowledge base. External programs can be called from within an INSIGHT2+ expert system with the only difficulty being the rigid format of passing parameters to external programs.

Because INSIGHT2+ is a PC based shell, there is a limit to the amount of numerical computing which can be done (in a FORTRAN program for example) in a reasonable amount of time. However, if the PC has math co-processor, computing power limitations are less critical.The advantage of using a personal computer for expert system programs is its input-output facilities. A PC provides greater flexiblity for presenting information (e.g. standard menus or custom designed screens) than is available on a main frame computer.

INSIGHT2+ has some advantages and drawbacks because it is a complete system for developing and executing knowledge bases. The primary advantage is that it provides facilities such as trace back and query procedures which the developer can use for debugging the knowledge base and the user can use for understanding the flow of control in the expert system. The disadvantage is that an expert system cannot exist as a stand alone program and hence is not transportable without INSIGHT2+.

Considering the advantages and disadvantages of both ROSIE and INSIGHT2+, it was decided that a main frame computer was not necessary for the computing that needs to be done. Also, the knowledge could be adequately represented in the rigid IF-THEN structure of INSIGHT2+ and the input/output and development facilities on the personal computer were better than that of ROSIE on the main frame computer. Thus, the expert system was developed with INSIGHT2+ on a PC.

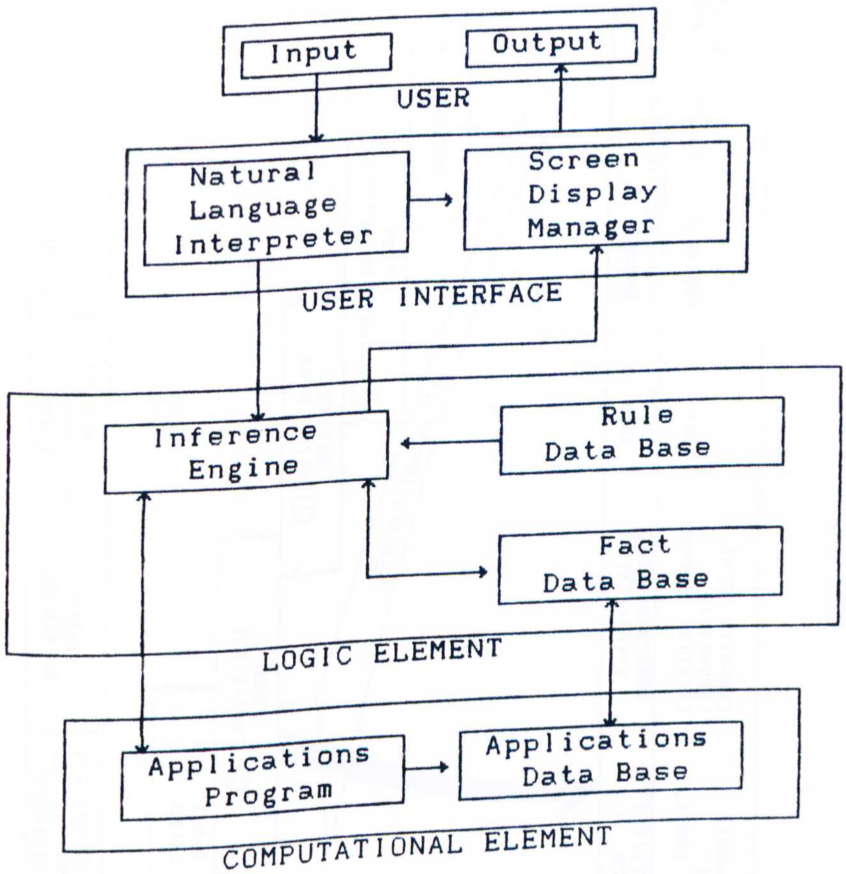
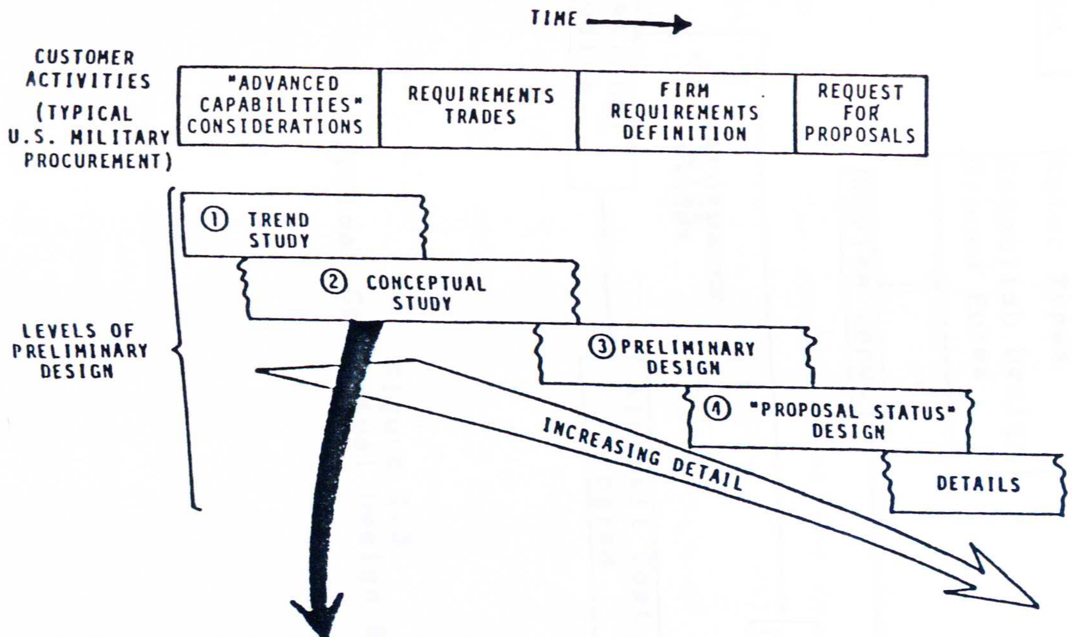


Figure 1.1 Components of an Engineering Expert System



LEVEL	DESIGN CONSIDERATIONS	ANALYTICAL CONSIDERATIONS	TEST STATUS	AMOUNT OF DETAIL	ACCURACY	TYPICAL DURATION
② CONCEP-TUAL DESIGN	"RULES OF THUMB", EXPERIENCE, SIMPLE LAYOUTS	EXISTING METHODS PARAMETRIC COMPUTER MODELS	NONE	MODERATE	10-15%	SEVERAL MONTHS

Figure 1.2
Definition of the Conceptual Design Phase

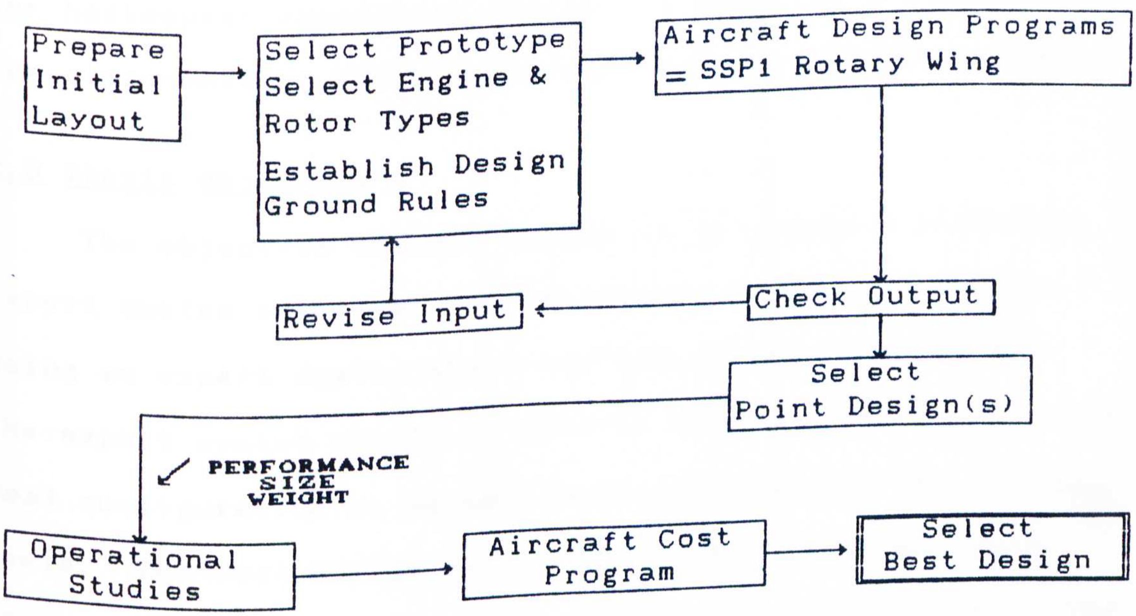


Figure 1.3
Typical Conceptual Design Sequence

CHAPTER II

PROBLEM FORMULATION AND METHODOLOGY

This chapter describes the goal of the thesis and presents XSP1 in the context of an ideal expert assistant for helicopter conceptual design. A detailed discussion of the components of XSP1 is included in this chapter as well.

2.0 Thesis Objective

The objective of this thesis is to create a prototype expert system assistant for helicopter conceptual design using an expert system shell and the design program SSP1. The expert system should be able to help the user define the *best* configuration or design which will satisfy the design goals. The *best* design is defined as one which achieves:

1) the acceptable gross weight within the constraints of the design specifications;
2) an overall size to satisfy the design goals.

As discussed in chapter 1, there are three classes of expert systems which can be defined. For conceptual design of aircraft, in this case helicopters, the best type of expert system is the expert assistant. This type of KBS contains the basic design knowledge and still allows the user flexibility to override decisions if he disagrees with a conclusion or if the knowledge base is found to be incomplete. Only when rules can be defined for *all* design possibilities, can the designer be removed from the decision control of the expert system. Since the problem of design is very complex and new considerations often arise, this is very difficult.

2.1 Characteristics of an ideal expert assistant for helicopter conceptual design

The ideal expert assistant in helicopter conceptual design would be able to support the complete conceptual design phase as shown in figure 3. It should be able to:

1) know what information must be extracted from an RFP (Request for Proposal) to achieve a design configuration;
2) accept other data, which may be unique to a specific RFP, into its reasoning sequence;
3) minimize the designer's effort in specifying parameters and conditions by maintaining a database of typical design specifications;
4) support a variety of complex design goals;
5) evaluate and compare different configurations and components and suggest improvements to the design within the confines of the RFP specifications;
6) organize different design and analysis tools such as weight/sizing programs, performance analysis codes, cost analysis programs and structural design programs so that they are consistent with the designer's thought process;
7) track the designer's decisions and identify trends for possible inclusion as rules or knowledge base data.

The first characterisitic, knowing what information is required from the RFP, is intended to help the user extract necessary information. RFPs will usually specify some basic requirements that are independent of the configuration such as the type of helicopter (attack, heavy lift etc.) or maximum downwash velocity. The expert assistant should know these requirements.

The second characteristic addresses the unique specifications found in all RFPs. Because RFPs contain different qualifications for the design, the expert assistant must be flexible enough to accept non-standard information and apply it toward the design configuration.

The expert assistant should maintain some common data such as a library of mission profiles which can be used by the designer. If the designer cannot use the data contained in the expert assistant, he can modify it or use his own data. This is the third feature.

The fourth feature, the capability of supporting various design goals, is required to give the expert assistant maximum flexibility. The design goals of a heavy lift helicopter are vastly different from an advanced attack helicopter. The expert assistant must be able to handle the objectives for these helicopters and those between them.

The expert assistant must have knowledge of different helicopter configurations such as tandems, compound helicopters and co-axial ones. It must be able to quickly eliminate those which cannot meet the design objectives and suggest ways to change parameters of each configuration to achieve the best design with that configuration. Finally, the expert assistant must be able to analyze the different designs and recommend one. This is the fifth feature.

The sixth characteristic addresses the expert assistant's role as an intelligent interface between various algorithmic programs. The designer should not be concerned with the details of using the computer programs (formatting design data from one program to fit another). The expert assistant should have the capability to move data between separately developed algorithmic codes with minimal action of the designer.

Finally, the expert assistant should be able to record sessions with the designer and reason about the way the designer uses the expert assistant so it can suggest improvements to its rules or additions to the data in its knowledge base. This feature is important as a self monitoring device so that the assistant's developer can keep it current and customized to the designer's needs.

2.2 The expert assistant XSP1

Obviously, the task of creating a knowledge based system to support the complete conceptual design process as outlined in the ideal expert assistant would be one of epic proportions. The expert assistant in this thesis, XSP1, does not attempt to be the ideal conceptual design KBS. It was developed using the helicopter design and expert system tools available (SSP1 and INSIGHT2+). It is a subset of the ideal expert assistant outlined both in the features it contains and in the scope of those features.

1) XSP1 asks the user to provide some minimum information which is standard in most RFPs.

2) XSP1 can handle some specifications which may be defined in some RFPs (e.g. limits on disk loading or constraints on overall size).

3) XSP1 maintains a database of mission profiles and helicopter parameters which reduces the user's data input efforts.

4) XSP1 supports only one design goal - minimum helicopter gross weight and acceptable size.

5) XSP1 only deals with conventional single rotor helicopters.

6) XSP1 only handles helicopter weight and sizing and does not incorporate any other design programs such as a helicopter performance analysis program.

7) XSP1 does not track sessions and suggest rule updates.

2.3 Components of XSP1

As stated previously, XSP1 is based around the design program SSP1. It is divided into two major components: parameter specification and design iteration. The first component is concerned with defining some baseline parameters on which to base the design. The second component is an iterative loop which combines numerical optimization with a knowledge based procedure to achieve the final design.

2.3.1 Parameter Specification

The parameters which need to be specified to produce a baseline configuration for the design fall into two categories. In the first category are the macro parameters which are the helicopter prototype, the engine mission profile etc. The second category of parameters is the specific parameters such as the tail rotor type, the number of blades on the rotors, etc.

2.3.1.1 The Macro Parameters

In an RFP the type of helicopter required is often one of the first things specified. This categorization is usually based on activities in which the helicopter will be involved such as combat reconnaisance or search and rescue. Rather than categorizing helicopters on the basis of anticipated missions, XSP1 divides them by size and weight into four categories, attack, cargo utility, light utility and light observation, which cover the spectrum of possible uses. Specifically, XSP1 categorizes helicopters by their gross weight, useful load capability and passenger capacity (to represent volume). Helicopters are classified as:

attack if the passenger capacity (including the pilot) is

less than 3 people;

cargo utility if the gross weight is greater than 6000 lbs and the useful load is greater than 3500 lbs and the passenger capacity is more than 9 people;

light utility if gross weight is less than 6000 lbs and useful load is greater than 1500 lbs;

light observation if the gross weight is less than 6000 lbs and the useful load is less than 3500 lbs.

Using these designations, the eight helicopters in the database can be categorized:

attack { AH-1S

cargo utility { UH-1H, CH-3E

light utility { BO-105, SA-342

light observation { OH-6, OH-13S, OH-58A

(Only these eight prototypes are used because complete data needed to run SSP1 exists for these helicopters). Clearly these categorizations are very broad. To help the designer specify a category if these are not sufficient, XSP1 defines some subcategories:

cargo utility { - search and rescue; - personnel transport;

light utility { - VIP transport; - air ambulance;

light observation { - trainer; - personal transport;

Knowing the category of helicopter, XSP1 can reduce the set of helicopters on which to base the design. To reduce the set further, XSP1 separates the helicopters in each category by some defining characteristics. For attack helicopters this is not done for there is only one possible prototype in the attack category. If the user is designing an attack helicopter, XSP1 will always suggest the AH-1S.

In the cargo utility category, XSP1 uses the useful load to differentiate between the helicopters. The useful load is defined as the difference between the gross weight and the empty weight where the empty weight includes any residuals and a 170 lb pilot[16]. The UH-1H has a useful load capability of 3950 lbs compared to 8750 lbs for the CH-3E[16] (table 2.1). If the user's useful load requirement is greater than 5200 lbs then XSP1 will suggest the CH-3E. For useful loads between 3500 lbs and 5200 lbs, XSP1 will suggest the UH-1H. If the useful load specified is less than 3500 lbs, XSP1 gives the user the option to redefine the category of helicopter because either the BO-105 (useful load 2700 lbs) or the SA-342 (useful load 2200 lbs) may be a better choice. If the option is rejected, XSP1 suggests the UH-1H.

In the light utility category, the helicopters are differentiated by gross weight and overall performance (table 2.2). The BO-105 weighs 1000 lbs more than the SA-342 but flies faster (132 kts to 125 kts sea level cruise speed), has a higher service ceiling (17000 ft to 13500 ft) and has a better rate of climb (2000 fpm to 13500 fpm at sea level). Other features such as the yaw control device (the BO-105 has a conventional tail rotor and the SA-342 uses a fenestron) may be important but are not used to differentiate between the helicopters.

In the light observation category, the choice of parameters for differentiating the helicopters is not so clear. The OH-6 and OH-58A are very similar and either could be used as a baseline prototype for a light observation helicopter. The OH-13S is the oldest and slowest of the three[16] (table 2.3). Its mission capabilities are different from the other two and thus the OH-13S is separated from the OH-6 and the OH-58A. If the user does not want to use the OH-13S as a baseline prototype, XSP1 suggests that the user should use both remaining helicopters and compare the final designs. XSP1 will compare the final designs with each prototype on the basis of gross weight, total intermediate rated power (IRP), disk loading and $\frac{C_t}{\sigma}$ and recommend one configuration based on the relative values of these four parameters. If the user decides not to compare designs, he must specify which helicopter he wants as the baseline prototype.

Once the baseline prototype is defined, XSP1 fills in the hub type and the landing gear type for the helicopter selected. Again, if the user rejects the data, he must specify it himself. There are three hub types: articulated, teetering and rigid; and two types of landing gear: wheels and skids; available. This data is used by the design program to estimate weight of the hub and landing gear. The choice has no effect on the aerodynamic calculations in the design algorithm.

In defining an engine which will be used with the prototype helicopter, XSP1 divides the available engines into three classes: light, medium and heavy engines. The division is by intermediate rated power (IRP) at standard sea level conditions (tables 2.4a,b,c). All engines in the same class as the engine which is native to the helicopter are evaluated. The "best" engine is the one with the highest power to weight ratios (both IRP and maximum continuous power, MCP). All engines in the same class as the original one are displayed along with a power to weight rating and the user has the option to reject the original engine, the one suggested by XSP1. If the engine is rejected, the user defines the engine from the set of available engines.

The last macro parameter is the mission profile. XSP1 suggests a mission profile based on the category of helicopter being designed. There are six mission profiles in the XSP1 library (tables 2.5a,b to 2.10a,b) which are adapted from reference 19; an attack mission, a cargo mission, an escort mission, a medevac mission, a reconaissance mission and a search and rescue mission. The user has the option to accept, reject or modify the suggested mission profile. If he rejects it, he must specify one from the library. If no mission satisfies the user's requirements identically, one must be modified. In modifying a mission profile, the user can change any part of the mission to suit his requirements.

The only parameters defined by XSP1 without the user's approval are the engine sizing conditions. When computing the power required, SSP1 sizes the engine to conditions (altitude, temperature and velocity) which must be defined for it. The sizing point must be defined such that the power available from the installed engine is never less than the required power at any point in the mission. To that end, the engine sizing point is based on the mission profile and XSP1 does not solicit approval from the user in defining it. XSP1 sizes the engine to the point in the mission where the velocity is greatest and to hover at 4000 ft, 95 °F or the highest altitude required in the mission, which ever is greater. These conditions will almost always produce available power which is greater than required power. In the event that they do not, the speed at the sizing point is increased by 5 knots and the hover altitude is increased 1000 feet. In the event that this too fails to reconcile the available and required power, the user must change the mission requirements. It is however, very rare that an acceptable engine sizing point is not found so the user will almost never encounter this problem.

2.3.1.2 The Specific Parameters

Specific parameters are those which are unique to the prototype helicopter and engine. Using SSP1 in its original form (without XSP1), there are 62 specific parameters which can be adjusted. XSP1 is only concerned with 16 of them (table 2.11). It adds six parameters not in the original 62 to bring the total number of specific parameters to 22. The six are upper and lower limits on $\frac{C_t}{\sigma}$, disk loading (dl), and tip speed (V_t). They are used in the numerical optimization which minimizes gross weight as a function of $\frac{C_t}{\sigma}$, dl, V_t. Rather than altering any specific parameters, XSP1 lets the user change them. No advice is given regarding which parameter should be modified but information on the effects of changing a parameter are available to the user. The expert assistant in this thesis is not sophisticated enough to define an optimum parameter combination within the restrictions of a particular RFP. It can only explain to the user the ramifications of changing a parameter value. The most important parameter in the list is the required payload (parameter 10, RPL). The user *must* define the payload weight which the design is to support. The payload weight is not the same as the useful load, rather it is defined:

$$\textit{Payload} = \textit{Useful load} - \textit{fuel weight} + \textit{170 lb pilot}.$$

The default payload weight for all designs is 2000 lbs.

2.3.2 Design Iteration

The second part of XSP1 is the design loop in which SSP1 is used to define a design configuration. The process works on two levels. The first is a numerical minimization of gross weight as a function of $\frac{C_t}{\sigma}$, dl and V_t. The second level is an interactive loop which involves the remaining specific parameters and optionally the prototype helicopter. The design iteration loops are outlined in figure 2.1.

2.3.2.1 Numerical Minimization of Gross Weight

The numerical minimization of the gross weight is done in a FORTRAN program which uses the SSP1 design procedure as the functional. The minimum gross weight is determined using Powell's method of conjugate directions[17]. The search space is defined by the upper and lower limits on the design variables $\frac{C_t}{\sigma}$, dl, and V_t ($\left(\frac{C_t}{\sigma}\right)_L$, $\left(\frac{C_t}{\sigma}\right)_H$, dl_L, dl_H, V_{t_L}, V_{t_H}) and a penalty function type method is used to keep the functional in the feasible space. Powell's method is a zero order method which amasses information about the search directions in order to improve the design on each search iteration. The method should converge to the minimum after N+1 search directions (N is the number of design variables; in this case 3) for locally convex functions assuming the one dimensional searches produce true minimums in their respective directions. The one dimensional search is performed by computing three points at which the function is not always increasing or decreasing and fitting a parabola to them. The point at which the parabola is minimum is computed and the function evaluated. If the function is less than the function at the middle point of the three which defined the parabola, the directional minimum is determined. If the point is larger, it replaces one of the three and a new parabola is computed. This shrinking process is stopped after three tries and the minimum of the three points is defined as the directional minimum. Powell's method is a good choice as a minimization procedure because gross weight appears to be a convex function in $\frac{C_t}{\sigma}$ and dl (figures 2.2, 2.3). Furthermore, it is robust and easy to develop.

<u>2.3.2.2 Expert System Loop</u>

The expert system loop serves two purposes. One is to advise the user how to adjust the initial paramter combination if it is not feasible, i.e. SSP1 is unable to determine a gross weight. The other is to achieve the overall design goal which is to define a configuration with a minimum weight and an acceptable size.

Occasionally, if the mission requirements are very severe (e.g. 200 kts, 4000 ft, 95°F), SSP1 will not be able to converge to a gross weight with the initial parameter set. Since the optimization requires a feasible starting point, the user must adjust the initial parameter values. Usually, this only involves changing the initial values of the optimization parameters $\frac{C_t}{\sigma}$, dl, and V_t. The most important parameter is disk loading. XSP1 first advises the user to change the initial values of the optimization parameters, specifically dl. The second suggestion is to reduce the payload. The third is to try a new baseline prototype and the fourth is to relax the mission profile requirements.

After an optimized gross weight is determined, XSP1 can advise the user on how best to adjust the weight or change the size of the helicopter. These two objectives are not necessarily independent. To change the size of the configuration, XSP1 suggests three avenues which the user may want to follow. First, the number of blades of the main rotor can be increased. This will reduce the size of the main rotor which reduces overall size. The weights of the helicopter components are computed based on the main rotor radius and the number of blades among other parameters[18]. The weights of the body and rotor are defined as:

$$W_{Body} = 0.02665 \cdot W_G^{0.949} \cdot R^{0.654}$$

$$W_{MR} = \begin{cases} 1.54 \cdot b \cdot c \cdot R^{1.5} & \text{Articulated rotor} \\ 0.94 \cdot b \cdot c \cdot R^{1.75} & \text{Teetering and Rigid rotors} \end{cases}$$

This means that increasing the number of blades will also reduce the overall weight.

The second suggestion for reducing the helicopter size is to change the boundaries on disk loading. The size of the main rotor is a largely a function of disk loading. The relationship is such that $\frac{\partial R}{\partial dl} < 0$, i.e. higher disk loadings mean smaller rotors. Since disk loading is an optimization parameter, the user must reduce the search space by increasing the boundries on disk loading. If the minimum gross weight is located at ($\left[\frac{C_t}{\sigma}\right]_o$, dl_o, V_{t_o}) and $dl_o < dl_H$, then the user must at least increase dl_L so that $dl_o < dl_L$. If $dl_o = dl_H$, then the user must increase dl_H.

The third suggestion is to change the baseline prototype to a smaller helicopter. This is not guaranteed to produce a smaller helicopter because the objective of the design process is to support the required payload weight. When changing the baseline prototype, the hub type landing gear type and engine must be redefined. If a better engine is used the configuration may be smaller. Changing to a new prototype is a last resort which, in essence, is restarting the design.

These three suggestions are by no means the only possible ways to reduce the size of the configuration, however they are the most physically obvious. The user can change any specific parameter, not just the ones suggested. Thus, he retains final control over the design process.

The second half of the design objective is to achieve an acceptable weight. Because the weight determined by SSP1 is sometimes less than the designer expects, XSP1 gives the user the option to either increase or decrease the weight of the design. If the weight is lower than expected, the design can support a larger payload so XSP1's primary advice is to increase the required payload. Another option is to make the mission profile more severe. A lower than expected gross weight signifies that the design requirements can be met with a more severe mission profile. The relationship between power and gross weight is such that more installed power generates a higher gross weight. Hence, since a more severe mission profile requires more power, it will increase weight. The user can modify the mission requirements and run the design again. The third option which XSP1 presents is choosing a larger baseline helicopter.

More often the designer will try to decrease the design weight rather than allow it to increase. XSP1 offers the user four pieces of advise to reduce the design weight. First, the twist of the main rotor blades can be increased. The greatest benefit from increasing the twist is in missions, such as attack missions, which require high speed flight. Cargo helicopters which are not required to fly at high speeds experience smaller benefits. The reason behind this rule is that highly twisted blades (up to about 13°) delay blade stall since twist unloads the tips by reducing the tip angles of attack. Compressibility losses are reduced because the tip critical Mach number is increased at reduced lift coefficients.

The second piece of advice is to try a fenestron rather than a conventional tail rotor. This rule is based on the method by which SSP1 computes tail rotor power required.

The mathematical model for tail rotor power required produces lower induced power for a ducted fan[18]. This translates to a lower design gross weight for missions which are low speed and hover/vertical climb missions. For designs which require high speed flight, a ducted fan produces only small reductions in gross weight.

Third, the user can decrease the required payload. This will obviously reduce the weight of the design but it may violate some RFP constraints.

Finally, the user can try to change the baseline prototype to a smaller one, but the results are not certain. The engine, hub and landing gear will have to be redefined and it is possible that the mission requirements will not be satisfiable with a smaller prototype.

2.4 The design algorithm SSP1

As mentioned previously, the design program used in this thesis is SSP1 written by the US Army. It is one of a package of four programs which have end objectives similar to HESCOMP and COMAP. Unlike HESCOMP however, SSP1 only handles conventional single rotor helicopters. It combines mathematical models for helicopter performance, essentially based on simple momentum theory, with statistical models for engine performance, fuel consumption and helicopter component weights. For a detailed explanation of the methods used in SSP1, see reference 18.

Table 2.1 Cargo-Utility Prototype Helicopter Parameters

	UH-1H	CH-3E
Maximum Gross Weight	9500 lbs	20000 lbs
Useful Load	3950 lbs	8800 lbs
Sea Level Standard Range	266 nm	404 nm
Sea Level Cruise Speed	110 kts	125 kts
Sea Level Rate of Climb	1600 fpm	1310 fpm
Service Ceiling	12700 ft	11100 ft

Table 2.2 Light Utility Prototype Helicopter Parameters

	SA-342	BO-105
Maximum Gross Weight	4415 lbs	5511 lbs
Useful Load	2212 lbs	2697 lbs
Sea Level Standard Range	383 nm	381 nm
Sea Level Cruise Speed	125 kts	132 kts
Sea Level Rate of Climb	1535 fpm	2000 fpm
Service Ceiling	13448 ft	17000 ft

Table 2.3 Light Observation Prototype Parameters

	OH-13S	OH-6	OH-58A
Maximum Gross Weight	2950 lbs	3000 lbs	3200 lbs
Useful Load	1050 lbs	1462 lbs	1384 lbs
Sea Level Standard Range	193 nm	246 nm	355 nm
Sea Level Cruise Speed	83 kts	125 kts	115 kts
Sea Level Rate of Climb	1250 fpm	1900 fpm	1300 fpm
Service Ceiling	16000 ft	14700 ft	13500 ft

Table 2.4a Light Engine Power Ratings

	Light Engines		
	250-C20R	250-C20B	T63-A-5A
Intermediate Rated Power (shp)	450	420	317
Intermediate Rated Power to Weight Ratio	2.678 $\frac{shp}{lb}$	2.658 $\frac{shp}{lb}$	2.281 $\frac{shp}{lb}$
Maximum Continuous Power to Weight Ratio	2.658 $\frac{shp}{lb}$	2.658 $\frac{shp}{lb}$	1.942 $\frac{shp}{lb}$
Engine Rating	1.000	0.992	0.788

Table 2.4b Medium Engine Power Ratings

	Medium Engines			
	LTS101-650	T702-L-700	PT6B-34	ASTAZOU XVI
Intermediate Rated Power (shp)	550	579	960	590
Intermediate Rated Power to Weight Ratio	2.067 $\frac{shp}{lb}$	2.363 $\frac{shp}{lb}$	2.682 $\frac{shp}{lb}$	1.671 $\frac{shp}{lb}$
Maximum Continuous Power to Weight Ratio	2.067 $\frac{shp}{lb}$	2.012 $\frac{shp}{lb}$	2.430 $\frac{shp}{lb}$	1.671 $\frac{shp}{lb}$
Engine Rating	0.809	0.930	1.000	0.654

Table 2.4c Heavy Engine Power Ratings

	Heavy Engines			
	T53-L-13B	T53-L-703	T58-GE-5	T700-GE-700
Intermediate Rated Power (shp)	1400	1485	1400	1565
Intermediate Rated Power to Weight Ratio	2.592 $\frac{shp}{lb}$	2.725 $\frac{shp}{lb}$	4.000 $\frac{shp}{lb}$	3.581 $\frac{shp}{lb}$
Maximum Continuous Power to Weight Ratio	2.222 $\frac{shp}{lb}$	2.385 $\frac{shp}{lb}$	3.571 $\frac{shp}{lb}$	3.016 $\frac{shp}{lb}$
Engine Rating	0.636	0.675	1.000	0.871

Table 2.5a
Typical Attack Mission Description in SSP1 Format

Segment	Description
1	Warm-up and taxi
2	Takeoff Hover
3	Flight to Staging area at Cruise Speed
4	Engage Target - High Speed Flight
5	Not Used
6	Engage Target - High Speed Flight
7	Return to Base at Cruise Speed
8	Reserve - 10 minutes at Cruise Speed
9	Landing Hover
10	Taxi and Shutdown

Table 2.5b Specific Attack Mission Profile Data

Segment	Altitude(ft)	Temp.(°F)	Time(min)	Hover $\frac{Z}{D}$	Vel.(kts)
1	Sea Level	95	2.0		
2	Sea Level	95	2.0	2.0	
3	2000	95	30.0		120
4	500	95	20.0		175
5	Not Used	--	----	-------	-----
6	500	95	20.0		175
7	2000	95	35.0		120
8	4000	95	10.0		120
9	Sea Level	95	2.0	2.0	
10	Sea Level	95	2.0		

Table 2.6a
Typical Cargo Mission Description in SSP1 Format

Segment	Description
1	Warm-up and taxi
2	Takeoff Hover
3	Outbound Cruise at Altitude 1
4	Outbound Cruise at Altitude 2
5	Hover to Accept or Deliver Cargo
6	Return Cruise at Altitude 3
7	Return Cruise at Altitude 4
8	Reserve - 10 minutes at Cruise Speed
9	Landing Hover
10	Taxi and Shutdown

Table 2.6b Specific Cargo Mission Profile Data

Segment	Altitude(ft)	Temp.(°F)	Time(min)	Hover $\frac{Z}{D}$	Vel.(kts)
1	Sea Level	95	2.0		
2	Sea Level	95	2.0	2.0	
3	2000	95	20.0		110
4	4000	95	30.0		110
5	4000	95	10.0	-------	-----
6	4000	95	30.0		110
7	2000	95	20.0		110
8	4000	95	10.0		110
9	Sea Level	95	2.0	2.0	
10	Sea Level	95	2.0		

Table 2.7a
Typical Escort Mission Description in SSP1 Format

Segment	Description
1	Warm-up and taxi
2	Takeoff Hover
3	Flight at Cruise Speed to meet escortee
4	Escort Flight to Staging Area
5	Hover at Staging Area
6	Dash to Attack and Neutralize Target
7	Escort Back to Base at Cruise Speed
8	Return to Home Base
9	Landing Hover
10	Taxi and Shutdown

Table 2.7b Specific Escort Mission Profile Data

Segment	Altitude(ft)	Temp.(°F)	Time(min)	Hover $\frac{Z}{D}$	Vel.(kts)
1	Sea Level	95	2.0		
2	Sea Level	95	2.0	2.0	
3	2000	95	20.0		130
4	4000	95	30.0		110
5	2000	95	10.0	2.0	
6	500	95	15.0		160
7	4000	95	20.0		110
8	2000	95	30.0		130
9	Sea Level	95	2.0	2.0	
10	Sea Level	95	2.0		

Table 2.8a
Typical Medevac Mission Description in SSP1 Format

Segment	Description
1	Warm-up and taxi
2	Takeoff Hover
3	Flight to Emergency Area
4	Loiter Seeking Objective
5	Hover to Retrieve Objective
6	High Speed Return at Altitude 1
7	High Speed Return at Altitude 2
8	Ten Minute Cruise Speed Reserve
9	Landing Hover
10	Taxi and Shutdown

Table 2.8b Specific Medevac Mission Profile Data

Segment	Altitude(ft)	Temp.(°F)	Time(min)	Hover $\frac{Z}{D}$	Vel.(kts)
1	Sea Level	ISA + 20	2.0		
2	Sea Level	ISA + 20	2.0	2.0	
3	2000	ISA + 20	15.0		125
4	4000	ISA + 20	30.0		40
5	2000	ISA + 20	15.0	2.0	
6	500	ISA + 20	10.0		140
7	4000	ISA + 20	15.0		140
8	2000	ISA + 20	10.0		125
9	Sea Level	ISA + 20	2.0	2.0	
10	Sea Level	ISA + 20	2.0		

Table 2.9a
Typical Reconnaissance Mission Description in SSP1 Format

Segment	Description
1	Warm-up and taxi
2	Takeoff Hover
3	Flight to Staging Area
4	Area Reconnaissance
5	Not Used
6	Area Reconnaissance
7	Enagage Ground Target
8	Return to Base
9	Landing Hover
10	Taxi and Shutdown

Table 2.9b
Specific Reconnaissance Mission Profile Data

Segment	Altitude(ft)	Temp.(°F)	Time(min)	Hover Z/D	Vel.(kts)
1	Sea Level	ISA + 20	2.0		
2	Sea Level	ISA + 20	2.0	2.0	
3	4000	ISA + 20	15.0		130
4	1000	ISA + 20	35.0		80
5	----	--------	----	---	---
6	500	ISA + 20	15.0		80
7	1000	ISA + 20	25.0		130
8	4000	ISA + 20	15.0		110
9	Sea Level	ISA + 20	2.0	2.0	
10	Sea Level	ISA + 20	2.0		

Table 2.10a
Typical Search & Rescue Mission Description in SSP1 Format

Segment	Description
1	Warm-up and taxi
2	Takeoff Hover
3	Flight to First Emergency Area
4	Search for Objective
5	Hover to Rescue Objective
6	Flight to Second Emergency Area
7	Search for, and Rescue Second Objective
8	Return to Base
9	Landing Hover
10	Taxi and Shutdown

Table 2.10b
Specific Search & Rescue Mission Profile Data

Segment	Altitude(ft)	Temp.(^{o}F)	Time(min)	Hover $\frac{Z}{D}$	Vel.(kts)
1	Sea Level	95	2.0		
2	Sea Level	95	2.0	2.0	
3	2000	95	20.0		150
4	200	95	35.0		80
5	Sea Level	95	15.0	2.0	
6	500	95	10.0		150
7	200	95	30.0		80
8	2000	95	25.0		130
9	Sea Level	95	2.0	2.0	
10	Sea Level	95	2.0		

Table 2.11
XSP1 Helicopter Specific Parameters

Parameter Name	Description
ALFAFN	Vertical fin absolute angle of attack
ARMRO	Ratio of fin arm to tail rotor arm
BM	Number of main rotor blades
BTR	Number of tail rotor blades
FD	Flat plate drag area factor
GWE	Gross weight estimate
NENG	Number of engines
NYWCTR	Yaw control device flag
OMGRTR	Tail rotor tip speed
RPL	Required payload
THETA1	Main rotor blade twist
X	Main rotor blade root cutout
XTR	Tail rotor blade root cutout
CTSIG	Starting value of $\frac{C_t}{\sigma}$
DL	Initial value of main rotor disk loading
V_t	Initial value of main rotor tip speed

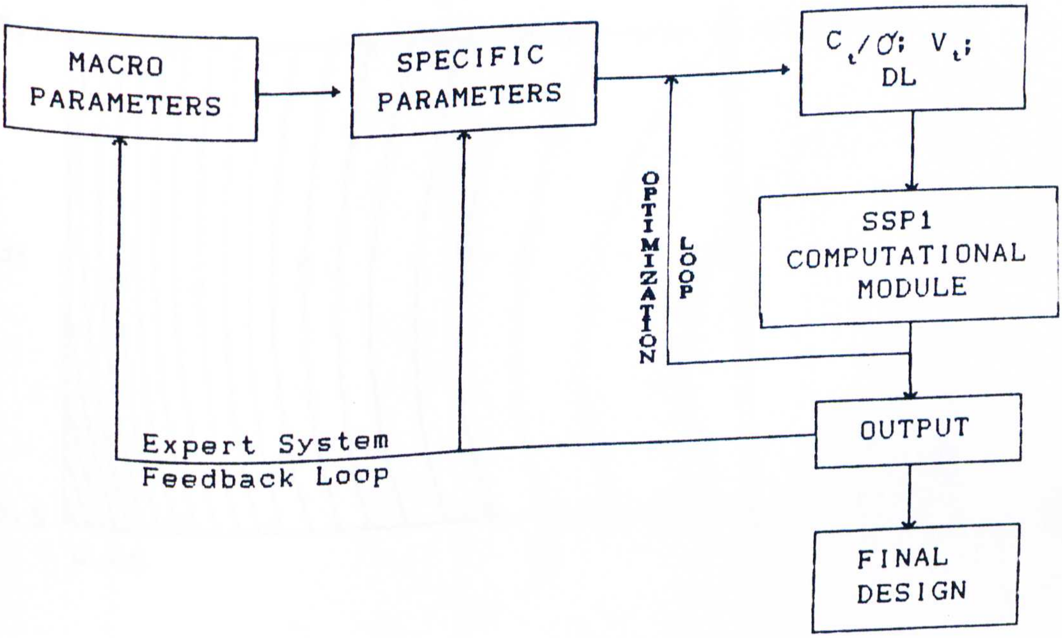
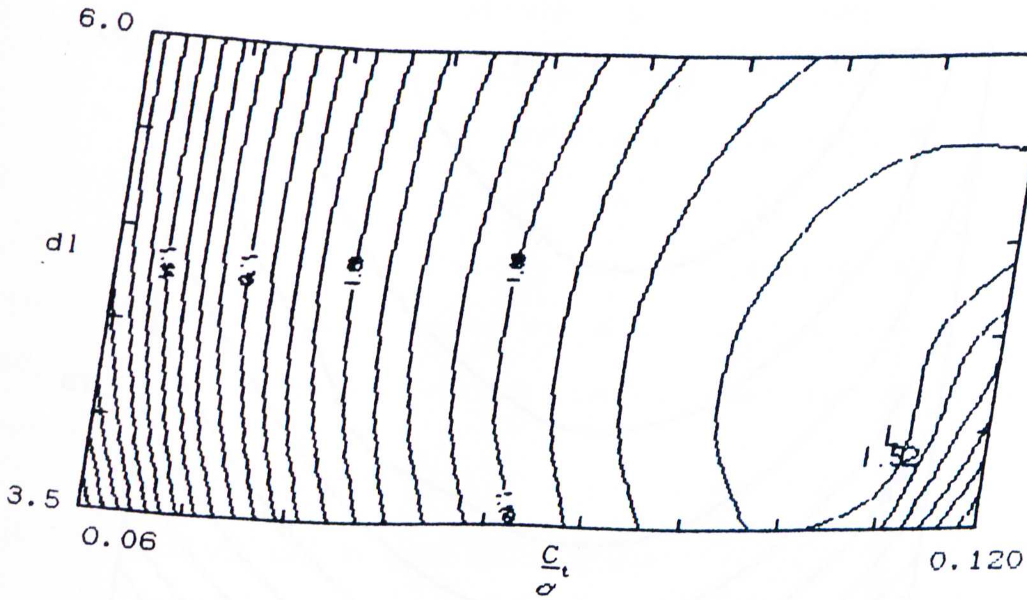


Figure 2.1
XSP1 Design Iteration Process



Payload = 5000 lbs; Tip Speed = 659 fps
Minimum Weight = 15200 lbs

Figure 2.2
2-D Contour Plot of Cargo Helicopter Design Space

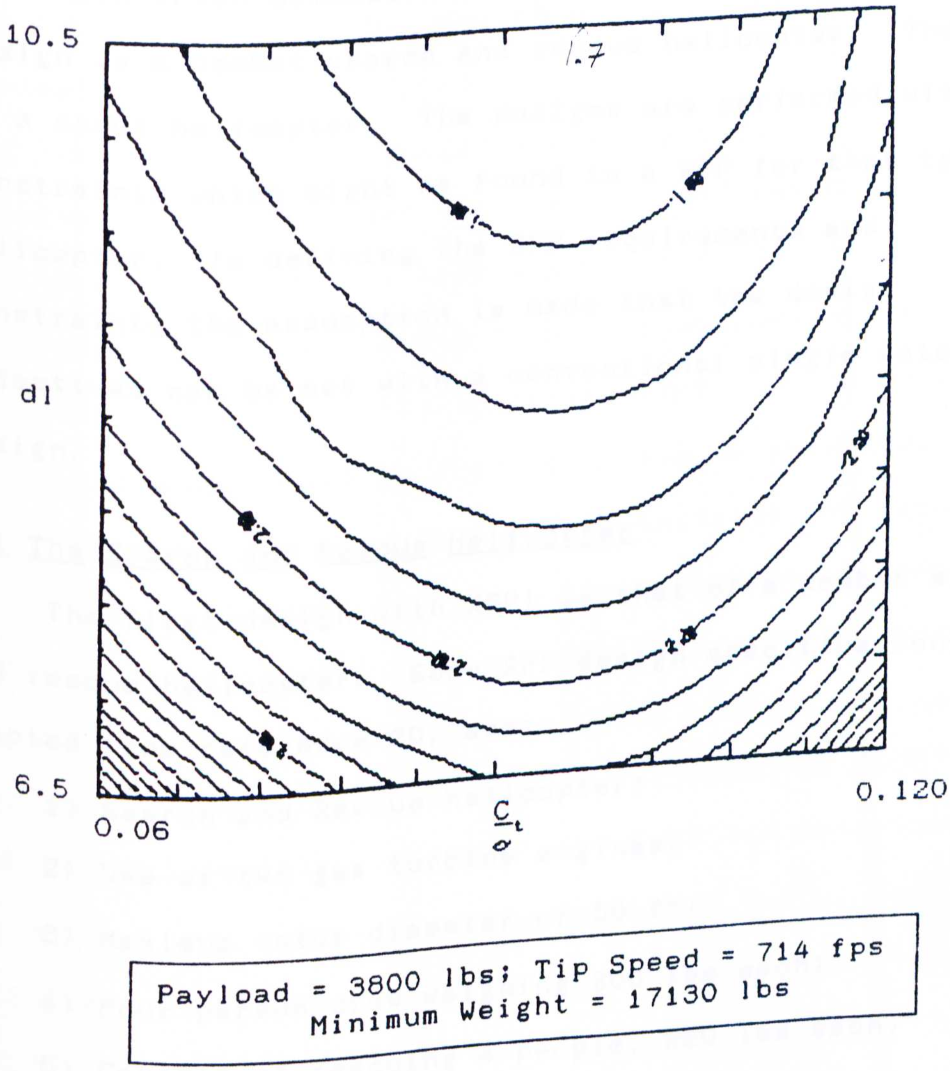


Figure 2.3
2-D Contour Plot of Attack Helicopter Design Space

CHAPTER III

RESULTS AS EXAMPLE DESIGNS

In this chapter, the results of the development of XSP1 are presented in the form of design examples. Two designs are shown which demonstrate the use of XSP1. The first design is a combat search and rescue helicopter. The second is a scout helicopter. The designs are performed within constraints which might be found in a RFP for that type of helicopter. In defining the RFP requirements and constraints the assumption is made that the design objectives can be met with a conventional single rotor design.

3.1 The Search and Rescue Helicopter

The first design with XSP1 is that of a combat search and rescue helicopter. Some RFP design specifications, adapted from reference 20, are:

1) Search and Rescue helicopter;
2) Use of two gas turbine engines;
3) Maximum rotor diameter of 50 ft;
4) Four person crew weighing 200 lbs each;
5) Capable of rescuing 4 people, 220 lbs each;
6) A maximum disk loading of 7 psf to mimimize rotor downwash during rescue;
7) A maximum tip speed of 700 fps to minimize aircraft noise;
8) Capability to accomplish the mission described in

figure 3.2.

The configuration determined with XSP1 is described in figure 3.24 and the procedure used is outlined here and in figures 3.1, 3.4 through 3.23. Figure 3.1 is the decision control diagram for this design which is representative of a typical procedure.

The first screen inquires about the category of helicopter (fig 3.4) and since search and rescue is not one of the four listed, the help screen is called (fig 3.5). The screen shows search and rescue helicopters as a subcategory of cargo utility helicopters. The cargo utility type is chosen. Data on the prototypes is presented in figure 3.6 and the user is asked to estimate the required useful load. Because the objective is to rescue four people, a total of 880 lbs, and factoring in 800 lbs for the crew and another 500 lbs for equipment such as medical supplies, the total payload can be estimated at 2200 lbs. Doubling this weight to account for fuel (as described in fig 3.7) yields 4400 lbs as the estimated useful load and XSP1 suggests the UH-1H as the baseline prototype (fig 3.8). The UH-1H has a teetering rotor and uses skids as the landing gear (fig 3.9) but because a rigid rotor allows greater flexibility in choosing the number of main rotor blades and using wheels as a landing gear yields an aerodynamically cleaner aircraft these parameters are chosen to replace the default values. XSP1 then presents a list of available engines and their relative ratings based on power to weight ratios (fig 3.10). The UH-1H uses the T53-L-13B engine but the T58-GE-5 engine has a higher rating (it is the best in its class) so the recommendation is rejected and the T58GE5 is used. With the baseline prototype configuration defined, the mission profile is defined. XSP1 displays a typical cargo mission profile (described in the previous chapter; figs 2.6a,b) and it is modified to correspond to the requirements shown in figure 3.2 (fig 3.11). The alternative would have been to consider another mission profile such as the search and rescue profile (figs 2.10a,b) but since all mission segments are performed at 4000 ft, 95°F, the cargo mission is easier to modify. Finally, the specific parameters such as disk loading and tip speed limits and the required payload are defined for the design. The initial values are shown in figure 3.12. The upper limit on disk loading is changed to 7.0 psf, the upper bound on tip speed is made 700 fps and the tip speed is set to 650 fps. The number of engines is set to 2 per the RFP requirements and the flat plate drag factor is lowered to 0.05 because wheels cause less drag than skids. The updated values are shown in figure 3.13.

XSP1 defines the engine sizing point in this design as:

1) Hover @ 4000 ft, 95°F;

2) 150 kt forward flight @ 4000 ft, 95°F.

Upon execution of the design program (SSP1), the initial values of $\frac{C_t}{\sigma}$, dl and V_t did not provide a feasible design point (i.e. SSP1 was not able to estimate a gross weight). Because the user must provide a feasible point for SSP1, XSP1 suggests four options as shown in figure 3.14. The first option, changing the values of $\frac{C_t}{\sigma}$, dl and V_t, is selected. The values of the parameters are increased as suggested (fig 3.15) and the design iteration is restarted. This time the combination of $\frac{C_t}{\sigma}$, dl and V_t defines a feasible point and SSP1 is able to generate a configuration (figs 3.16, 3.17).

The main rotor is larger than allowed so an attempt is made at reducing the size. Three options are presented to the user (fig 3.18) and the first option, increasing the number of blades, is tried since the upper boundry on disk loading is fixed by the RFP (fig 3.19). The number of blades is increased to four and this reduces size of the design configuration from R = 25.75 ft to R = 24.09 ft (figs 3.20, 3.21). The weight of the configuration decreased as well which indicates that a four bladed rotor is more efficient than a rotor with two blades for this case.

An attempt is now made to further reduce the weight. Because the mission requires relatively high speed flight and the payload is properly defined, XSP1's first suggestion, to increase the main rotor blade twist (fig 3.22), is tried (figs 3.23). The resulting configuration proves to be both lighter and smaller (figs 3.24, 3.25).

The design configuration is accepted, the design data is echoed and the user can start another design or stop.

Looking at figure 3.26, the final configuration, the empty weight ratio (0.61) is comensurate with helicopters of similar gross weight. The required power is well within the capability of today's engines (the engine prototype; T58-GE-5 produces enough power). The weight could be reduced further by altering the tail rotor configuration but the gain would be small. Overall, the configuration is quite good for conceptual design.

3.2 The Scout Helicopter

The motivation for using a scout helicopter as the second example is to present the features of XSP1 not found in the previous design example. Rather than defining the complete design path for this case, only aspects not discussed earlier will be presented. The design specifications for the scout are:

1) Combat reconnaissance type helicopter;
2) Two person crew with each person weighing 200 lbs;
3) Capable of firing 4 missles 80 lbs each;
4) Maximum tip speed of 750 fps to minimize aircraft noise;
5) Capability to accomplish the mission described in figure 3.3.

The final configuration determined with XSP1 is summarized in figure 3.40 and figures 3.27 through 3.39 outline the design options not shown previously.

As with the search and rescue helicopter, the category is defined (light observation) and the performance data of the available helicopters displayed (fig 3.27). At this point the user decides if the OH-13S is a suitable prototype (fig 3.28). If not, XSP1 advises the user to carry out the design excersize with both the OH-6 and OH-58A and compare the designs at the end (fig 3.29). If this idea is rejected (because the user wants to specifically use one prototype), he must define the helicopter. In this case, the advice is accepted and the OH-6 prototype is used first. The hub and landing gear data are displayed and the engine is suggested as in the previous example. The reconnaissance mission profile is modified to reflect the specifications in figure 3.3 (fig 3.30). The specific parameters are defined (Upper limit on tip speed and disk loading, required payload etc) (fig 3.31) and XSP1 defines the engine sizing point from the mission profile as:

1) Hover @ 4000 ft, 95°F;

2) 150 kt forward flight @ 4000 ft, 95°F.

The optimized design is shown in figures 3.32 and 3.33. This configuration is accepted and XSP1 returns to carry through a design with the OH-58A. The OH-58A uses a teetering type hub and this is changed to an articulated hub to permit flexibility in specifying the number of main rotor blades. XSP1 knows to retain the mission profile and only requires the user to update the specific parameters. The updated values for the OH-58A are shown in figure 3.34. XSP1 returns with the configuration shown in figures 3.35 and 3.36. An attempt is made to reduce the weight by increasing the number of blades, similar to the search and rescue case. Figures 3.37 and 3.38 manifest the new configuration. This configuration is accepted and XSP1 compares the two final configurations on gross weight, intermediate rated power, disk loading and $\frac{C_t}{\sigma}$ and recommends one configuration with a level of confidence based on the combination of the parameters (fig 3.38). A 100% confident recommendation of one configuration is made when:

1) Its weight is less than that of the other design;
2) Its required power is less than that of the the other configuration;
3) The disk loading is less than that of the other design;
4) Its $\frac{C_t}{\sigma}$ is greater than that of the other design.

The weight and power required parts are considered more heavily than the other parts. The disk loading and $\frac{C_t}{\sigma}$ values are included because they represent rotor propulsive efficiency. In this example, the OH-6 based configuration is lighter, requires less power, and has a higher $\frac{C_t}{\sigma}$. Since the disk loadings are the same, the OH-6 based configuration is recommended with a confidence of 90%.

The final configuration (fig 3.40) has an empty weight ratio of 0.46. This may be too optimistic. The fuel weight (292 lbs) is suspiciously low which may account for the optimistic weight estimate. This is a characteristic of the weight and sizing program SSP1 and is not addressed in XSP1. The total power is somewhat higher than expected but acceptable nevertheless. This comparison of design configurations illustrates the senstivity of the design to the helicopter prototype. The deciding parameter was probably the drag factor FD. For the OH-6 it was 0.031 and for the OH-58A it was 0.05. It reflects the relationship between overall size and flat plate drag area.

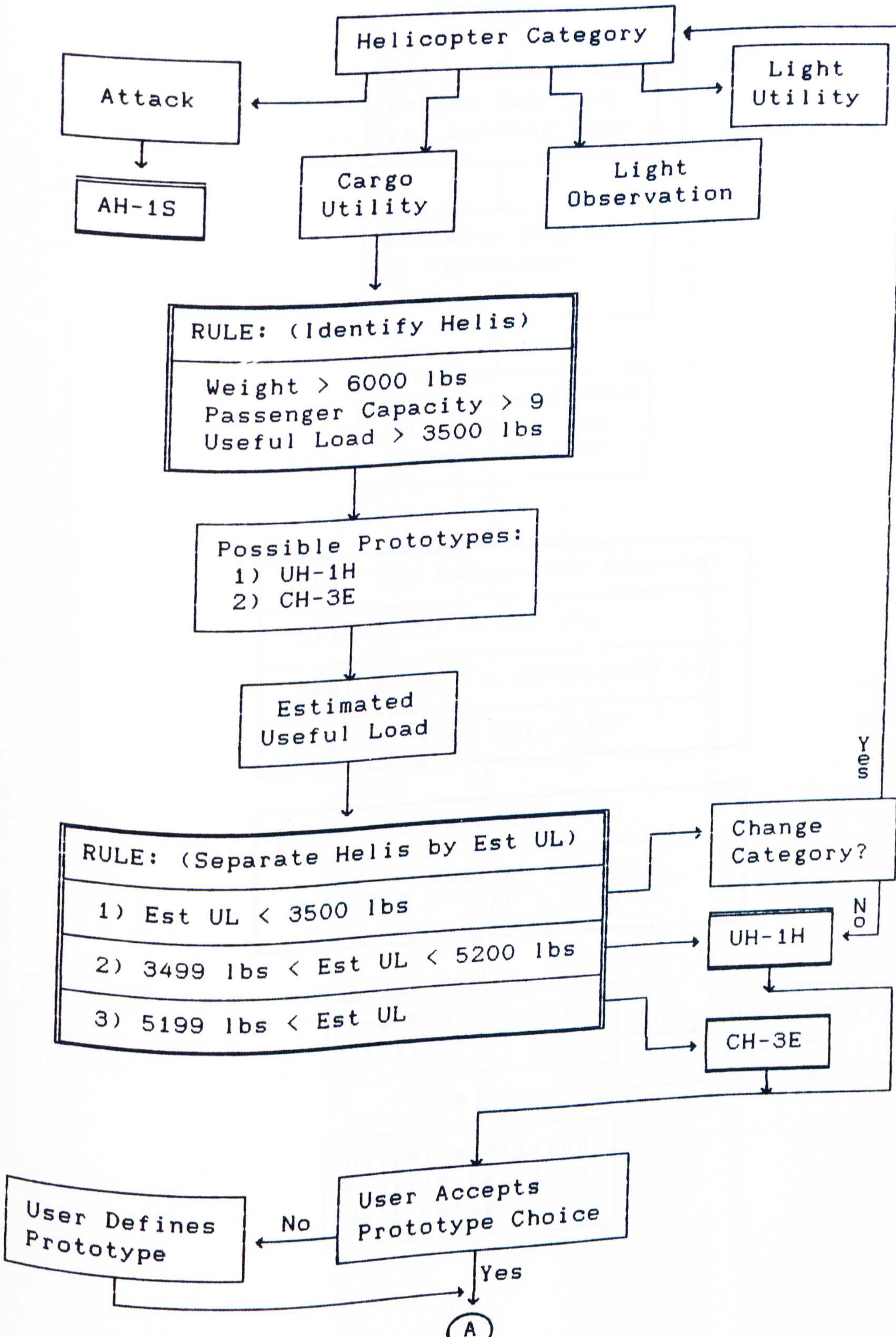


Figure 3.1a
Decision Flow Diagram for Search & Rescue Design; Part A

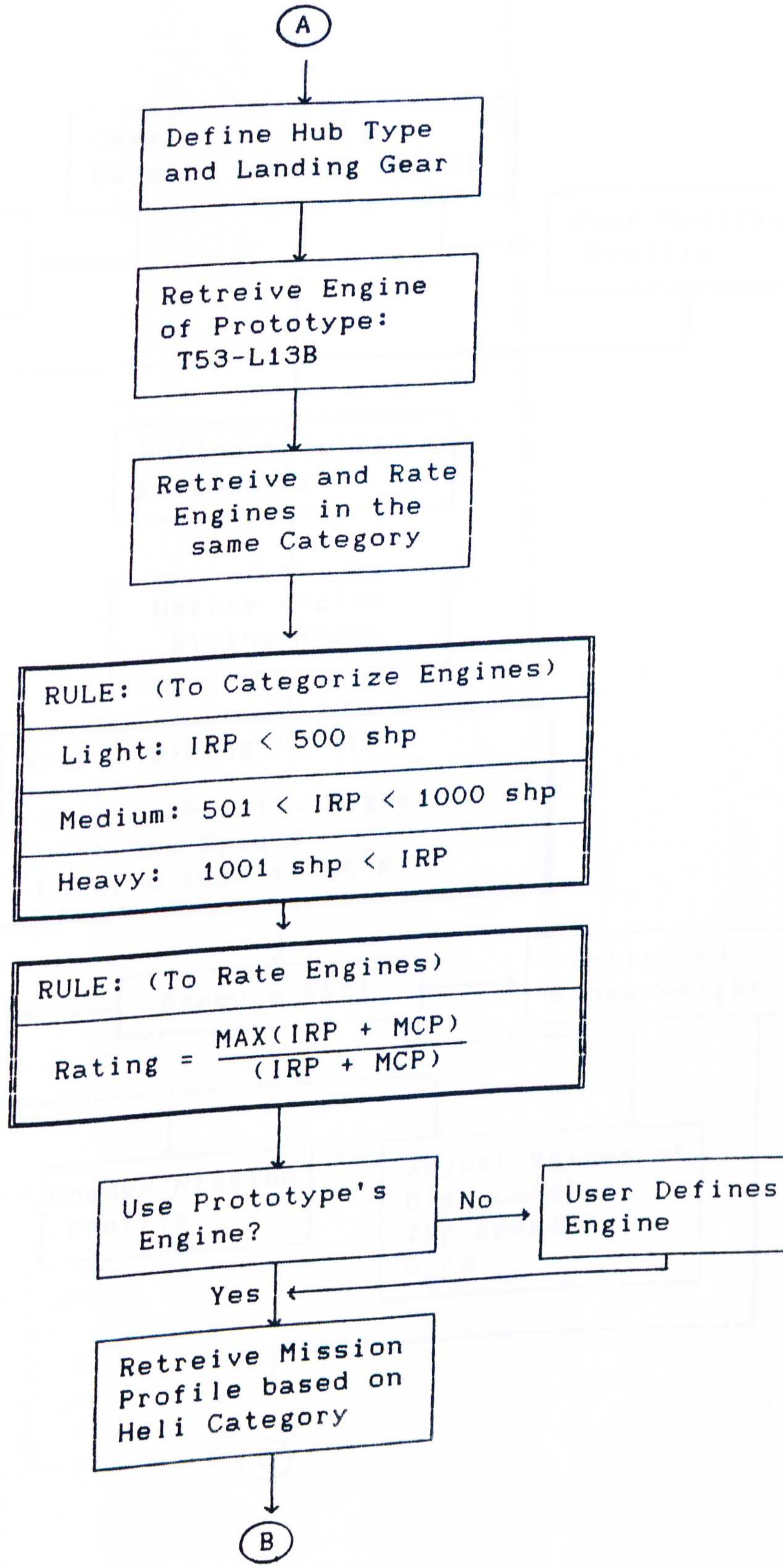


Figure 3.1b
Decision Flow Diagram for Search & Rescue Design; Part B

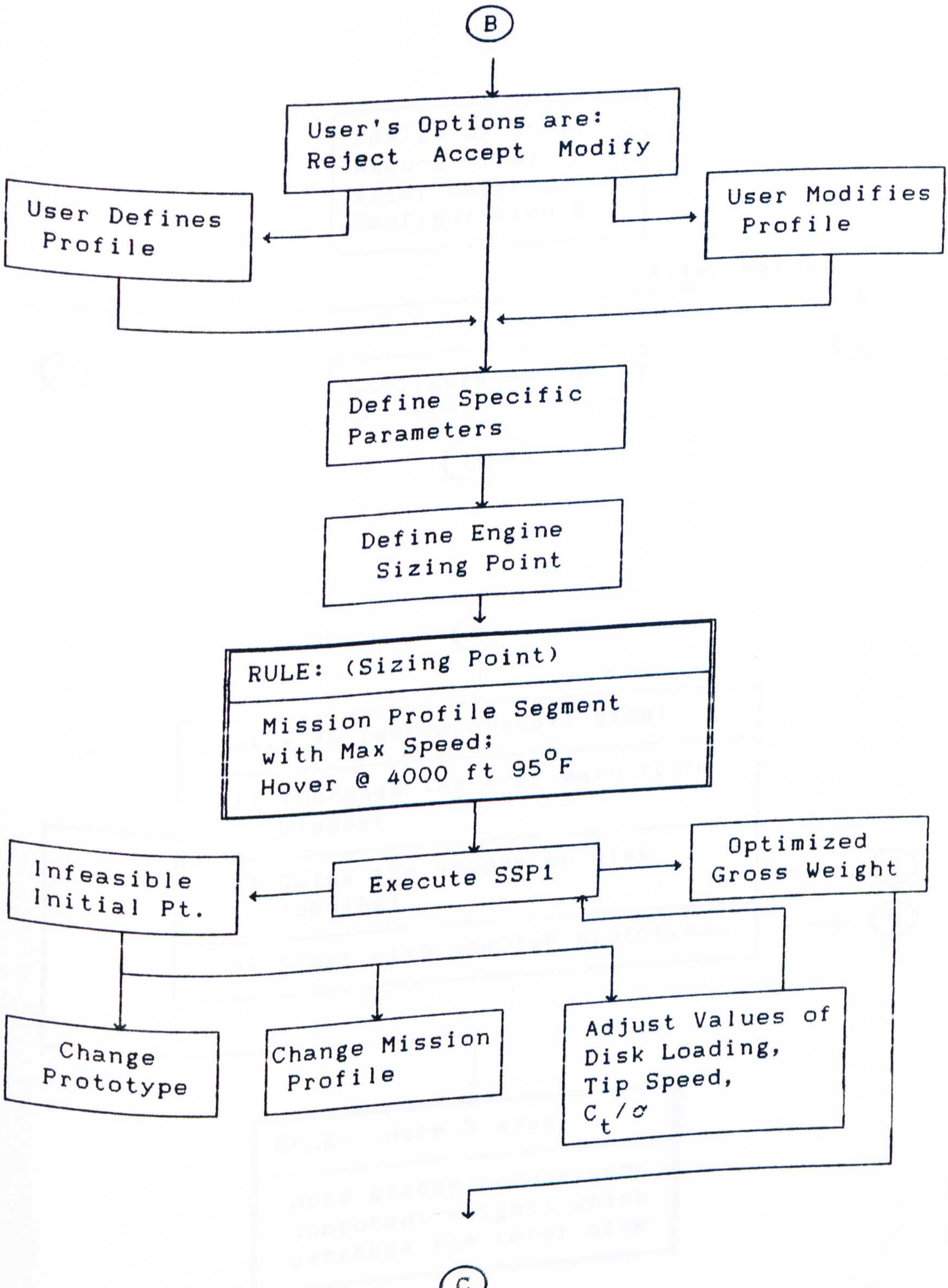


Figure 3.1c
Decision Flow Diagram for Search & Rescue Design; Part C

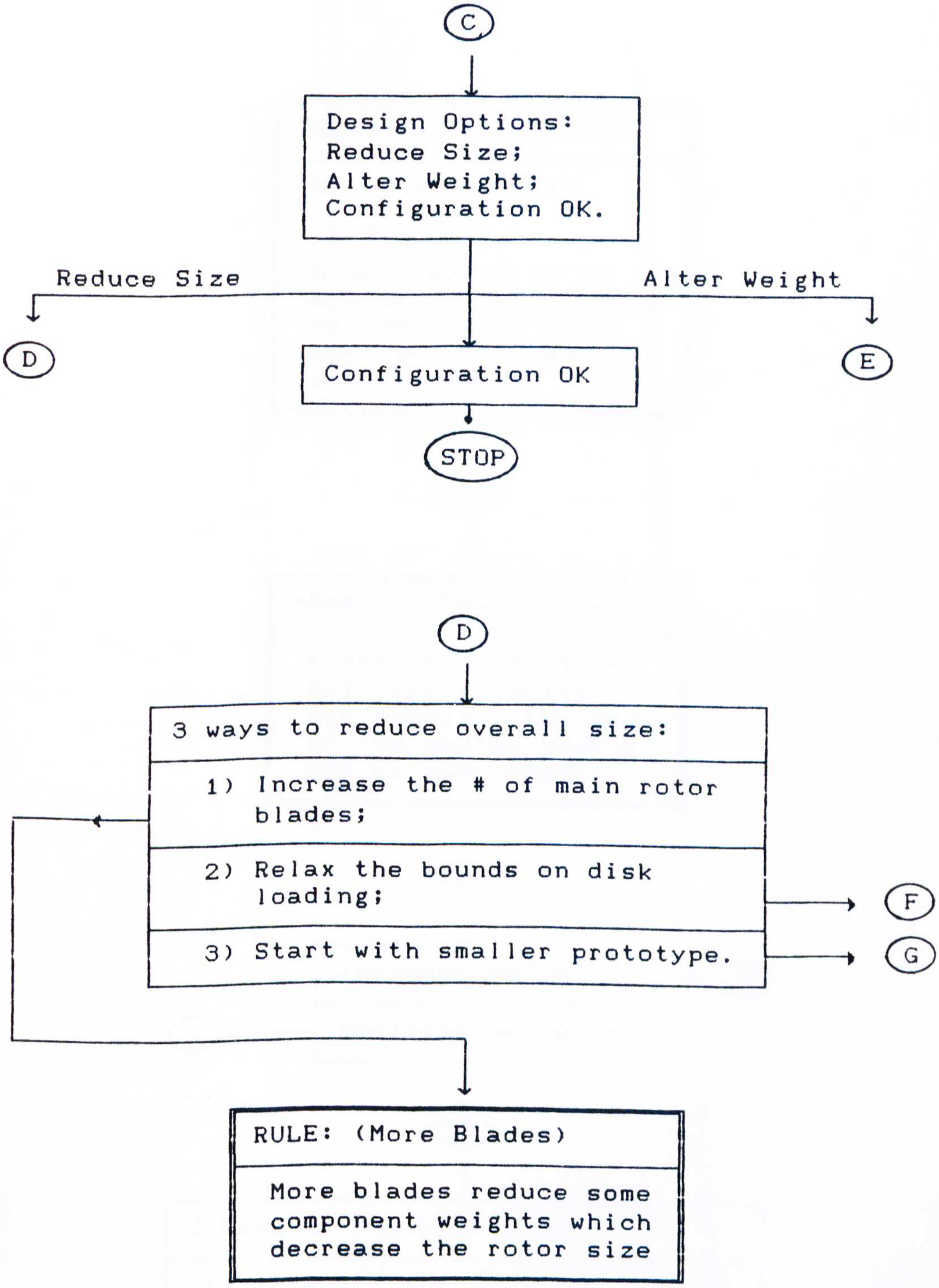


Figure 3.1d
Decision Flow Diagram for Search & Rescue Design; Part D

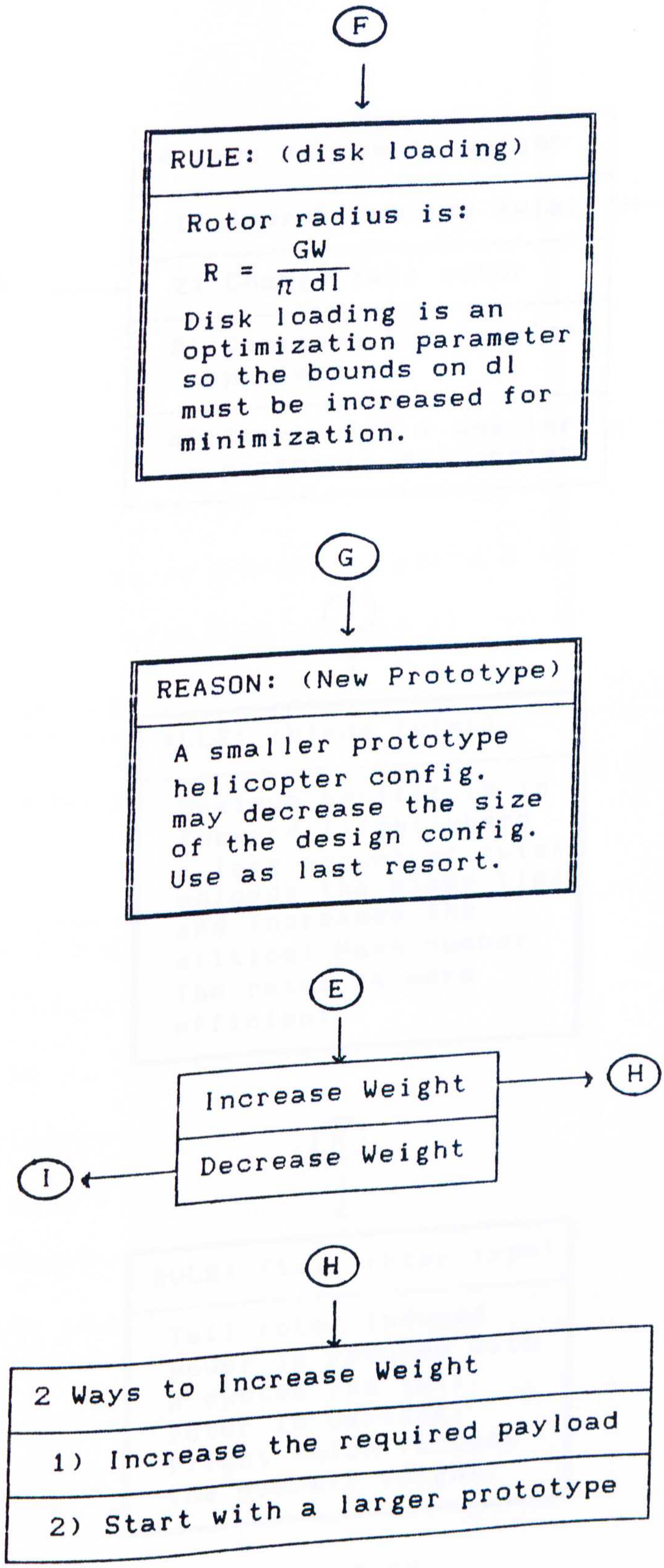


Figure 3.1e
Decision Flow Diagram for Search & Rescue Design; Part E

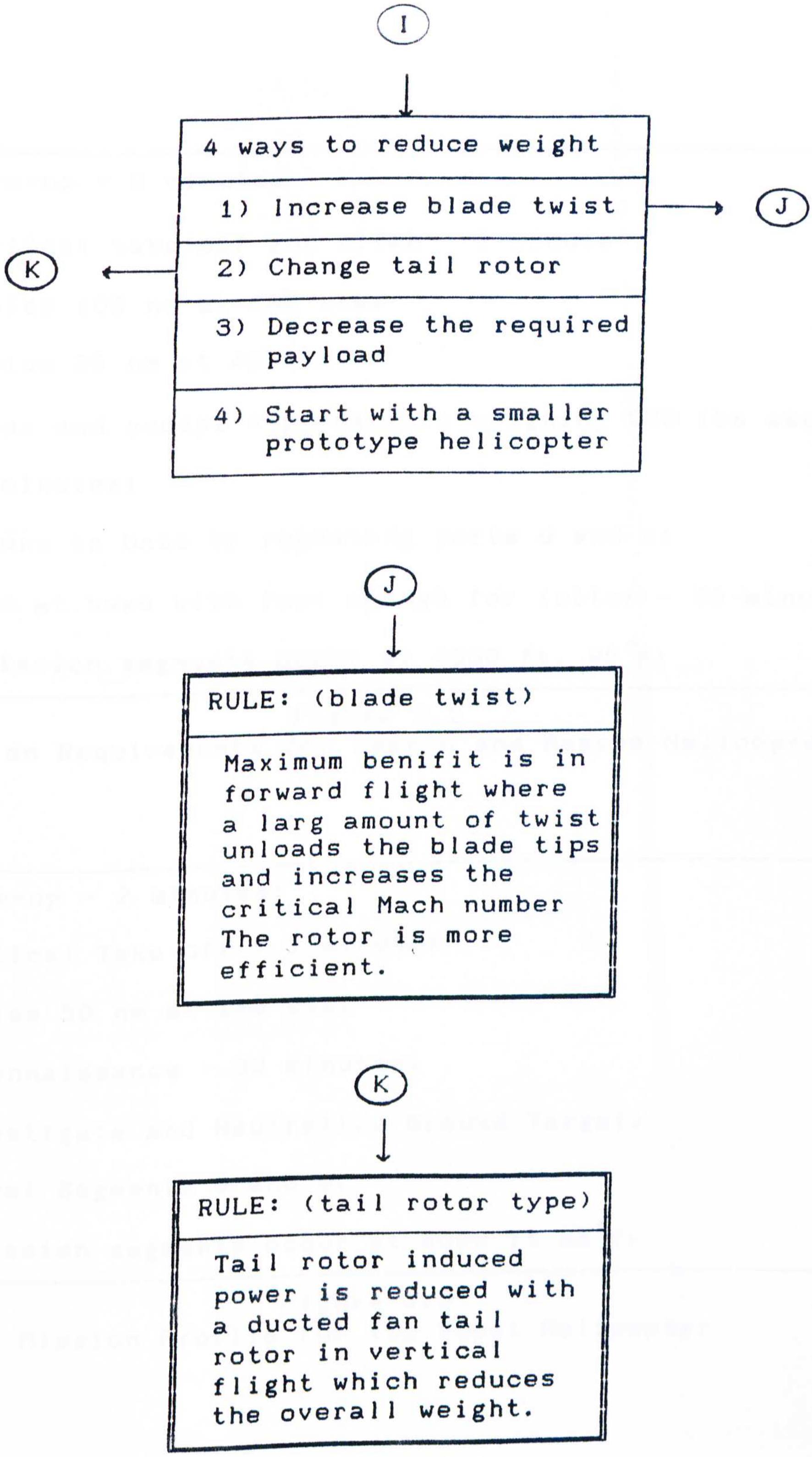


Figure 3.1f
Decision Flow Diagram for Search & Rescue Design; Part F

a) Warm-up - 2 minutes

b) Vertical take-off and climb - 1 minute

c) Cruise 100 nm at 150 kts;

d) Cruise 25 nm at 40 kts;

e) Hover and accept 4 passengers weighing 220 lbs each 15 minutes;

f) Return to base by repeating parts d and c;

g) Land at base with fuel enough for loiter - 30 minutes

(All mission segments occur at 4000 ft, 95°F)

Figure 3.2
Mission Requirements for Search and Rescue Helicopter

a) Warm-up - 2 minutes;

b) Vertical Take-off - 1 minute;

c) Cruise 50 nm at 140 kts;

d) Reconnaissance - 30 minutes;

e) Investigate and Neutralize Ground Target;

f) Repeat Segments d and e.

(All mission segments occur at 4000 ft 95°F)

Figure 3.3
Mission Profile for the Scout Helicopter

Helicopter Conceptual Design Expert System

Is this to be a LIGHT OBSERVATION, LIGHT UTILITY,
CARGO UTILITY or ATTACK helicopter?

Position the pointer with the ARROW KEYS and press ENTER.

Press Function Key F5 EXPL for explanation

a Attack

b Light Observation

c Light Utility

d Cargo Utility

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.4 Helicopter Category Screen

Explanatory Information

The category defines the type of helicopter to be used as a prototype. Some subcategories of the four main categories are:

Light Observation
- Trainer
- Personal Transportation

Light Utility
- Medevac (Up to 2 person Search/Rescue)
- VIP Transportation

Cargo\Utility
- Search + Rescue
- Personnel Transportation

Press Function Key F8 BACK to return to question

1 PAGE 3 STRT 7 PRNT 8 BACK 9 HELP 10 EXIT

Figure 3.5 Helicopter Category Help Screen

Helicopter Conceptual Design Expert System
In the CARGO UTILITY category there are 2 helicopters available. Performance data on them is presented here.

	UH-1H	CH-3E
Max Gross Weight	9500 lbs	20000 lbs
Useful Load	3950 lbs	8795 lbs
Est Fuel Weight	1371 lbs	4150 lbs
SL Std Range	266 nm	404 nm
SL Cruise Speed	110 kts	125 kts
SL Rate of Climb	1600 fpm	1310 fpm
Service Ceiling	12700 ft	11100 ft

Press Function Key F2 CONT to continue

2 CONT 3 STRT 6 WHY? 7 PRNT 8 MENU 9 HELP 10 EXIT

Figure 3.6 Cargo-Utility Helicopter Data Screen

Explanatory Information

The obvious parameter to separate the Cargo\Utility helicopters is the useful load. Useful load is defined as:

Useful load = Gross weight - Empty weight

where the empty weight includes any residuals and a 170 lb pilot.

To get a ball park estimate on the useful load, calculate the payload (including the expected crew weight) and double it.

A lower bound on Cargo/Utility useful load capacity is 3500 lbs.

Press Function Key F8 BACK to return to question

3 STRT 7 PRNT 8 BACK 9 HELP 10 EXIT

Figure 3.7 Useful Load Help Screen

Helicopter Conceptual Design Expert System

The category of helicopter is cargo utility
From your responses, the recommended prototype is UH1H . If you accept this prototype, then choose TRUE. If you wish to define the prototype yourself, choose FALSE.

Use the ARROW KEYS to toggle between TRUE and FALSE.

<u>TRUE</u> FALSE

2 UNKN 3 STRT 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.8 Prototype Helicopter Information Screen

Helicopter Conceptual Design Expert System

The UH1H helicopter uses a Teetering main rotor hub and has Skids for a landing gear.
If this type of hub and landing gear are acceptble, choose TRUE.
If you want to change one or both, choose FALSE.

Press Function Key F5 EXPL for explanation

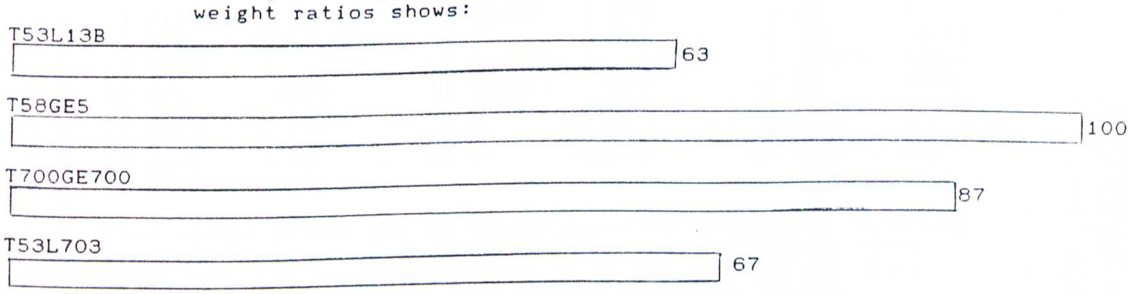
TRUE <u>FALSE</u>

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.9 Hub Type and Landing Gear Screen

Helicopter Conceptual Design Expert System

The UH1H uses the T53L13B engine.
Rating the engines in the same power class by power to weight ratios shows:



Press Function Key F5 EXPL for explanation

Do you want to use the T53L13B engine?

TRUE FALSE

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.10 Engine Rating Screen

Helicopter Conceptual Design Expert System

Cargo Mission Profile

Segment	Altitude(ft)	Temp(F)	Time(min)	Z/D	Vel(kts)
1	4000.0	95.0	2.0		0.0
2	4000.0	95.0	1.0	2.00	
3	4000.0	95.0	40.0		150.0
4	4000.0	95.0	37.5		40.0
5	4000.0	95.0	15.0	2.00	
6	4000.0	95.0	37.5		40.0
7	4000.0	95.0	40.0		150.0
8	4000.0	95.0	30.0		40.0
9	4000.0	95.0	1.0	2.00	
10	4000.0	95.0	2.0		0.0

Seg 5 Payload decrease: WSTR = -900 lbs. WSTR < 0 is increase.

To change any value, enter Segment No., Name and Value.
For ISA Temp, use -500; For ISA+20 Temp use -600
(Ex. 1<CR> Alt<CR> 5000<CR>). Terminate with Seg=99.

Segment Name Value
99

Figure 3.11 Modified Cargo Mission Profile

Helicopter Conceptual Design Expert System

Specific Parameters for the UH1H

Parameter	Value	Parameter	Value	Parameter	Value
1 ALFAFN	4.0	2 ARMRO	0.878	3 BM	2
4 BTR	2	5 FD	0.052	6 GWE	9000
7 NENG	1	8 NYWCTR	0	9 OMGRTR	736.0
10 RPL	2000	11 THETA1	-10.0	12 X	0.092
13 XTR	0.180	14 CTSig	0.068	15 CTSLO	0.045
16 CTSHI	0.125	17 DL	4.97	18 DLLO	4.00
19 DLHI	7.00	20 Vt	814.0	21 VtLO	600.0
22 VtHI	850.0				

This window allows you to change specific helicopter parameters and get information about them. To change a parameter value enter "C", the parameter number (1 to 22) and the new value.
To get information enter "Q" and the parameter number.
To exit enter "E".

Command:
Param Number:

Figure 3.12
Initial Specific Parameter Values for UH-1H Prototype

Helicopter Conceptual Design Expert System

Specific Parameters for the UH1H

Parameter	Value	Parameter	Value	Parameter	Value
1 ALFAFN	4.0	2 ARMRO	0.878	3 BM	2
4 BTR	2	5 FD	0.050	6 GWE	9000
7 NENG	2	8 NYWCTR	0	9 OMGRTR	736.0
10 RPL	2200	11 THETA1	-10.0	12 X	0.092
13 XTR	0.180	14 CTSig	0.068	15 CTSLO	0.045
16 CTSHI	0.125	17 DL	4.97	18 DLLO	4.00
19 DLHI	7.00	20 Vt	650.0	21 VtLO	500.0
22 VtHI	700.0				

This window allows you to change specific helicopter parameters and get information about them. To change a parameter value enter "C", the parameter number (1 to 22) and the new value.
To get information enter "Q" and the parameter number.
To exit enter "E".

Command: E
Param Number:

Figure 3.13
Updated Specific Parameter Values for UH-1H Prototype

Helicopter Conceptual Design Expert System

The helicopter gross weight could not be determined by the SSP1 design routine with the initial values of CTSIG, DL, and VT.

There are 4 things to try:

1) Change the initial values of CTSIG, DL, and VT;
2) Check that the payload is correctly defined and reduce it;
3) Change the prototype helicopter and/or engine;
4) Change the mission profile - it may be too demanding in certain phases for the engine and prototype;

Be advised that changing the prototype requires re-defining other parameters such as hub type and landing gear.

Try changing the initial values first.

Press Function Key F2 CONT to continue

2 CONT   3 STRT   6 WHY?   7 PRNT   8 MENU   9 HELP   10 EXIT

Figure 3.14 Infeasible Initial Point Information Screen

Helicopter Conceptual Design Expert System

Specific Parameters for the UH1H

Parameter	Value	Parameter	Value	Parameter	Value
1 ALFAFN	4.0	2 ARMRO	0.878	3 BM	2
4 BTR	2	5 FD	0.050	6 GWE	9000
7 NENG	2	8 NYWCTR	0	9 OMGRTR	736.0
10 RPL	2200	11 THETA1	-10.0	12 X	0.092
13 XTR	0.180	14 CTSig	0.080	15 CTSLO	0.045
16 CTSHI	0.125	17 DL	6.90	18 DLLO	4.00
19 DLHI	7.00	20 Vt	695.0	21 VtLO	500.0
22 VtHI	700.0				

This window allows you to change specific helicopter parameters and get information about them. To change a parameter value enter "C", the parameter number (1 to 22) and the new value.
To get information enter "Q" and the parameter number.
To exit enter "E".

Command:
Param Number:

Figure 3.15 Updated UH-1H Initial Design Point

```
                Helicopter Conceptual Design Expert System

                           SSP1 Design Data

                          Ct/Sigma    = 0.108
                        Disk loading =   6.876
                         Tip Speed    = 700.0

Size: Main rotor radius = 25.75    Fin Arm   = 27.24
      Main Rotor chord  = 2.738    Fin Area = 45.0
      Tail Rotor radius =  4.77    Tail Rotor Arm   = 31.02
      Tail Rotor chord  = 1.727    Flat plate Area = 29.58

Weight: Empty Weight =  8802.6
        Payload      =  2200.0     Useful Load = 5347.96
        Fuel Weight  =  3318.0
        Gross Weight = 14320.6

         Dimensions are in ft; Area is sq.ft; Weights are in lbs.

             Press Function Key F1 PAGE to view next page


1 PAGE  2 CONT  3 STRT              6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
```

Figure 3.16
UH-1H Baseline Minimized Gross Weight Screen 1

```
                Helicopter Conceptual Design Expert System

                           SSP1 Design Data

                          Ct/Sigma    = 0.108
                        Disk loading =   6.876
                         Tip Speed    = 700.0

Power: Total intermediate rated power = 3286.0
       Total maximum continuous power = 2934.0

       IRP drive system power limit = 2030.9
       MCP drive system power limit = 2030.9


                        Power is given in shp.

                Press Function Key F2 CONT to continue

           Press Function Key F1 PAGE to view previous page


1 PAGE  2 CONT  3 STRT              6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
```

Figure 3.17
UH-1H Baseline Minimized Gross Weight Screen 2

Helicopter Conceptual Design Expert System

There are a number of things one can do to reduce the overall size of the helicopter. Three are listed here.

Keep in mind that reducing size will increase something else; downwash velocity, weight, power required etc.

Position the pointer with the ARROW KEYS and press ENTER.
Don't worry, your choice here is not binding.

Increase the number of blades on the main rotor

Relax the boundries on disk loading

Use a smaller prototype helicopter

2 UNKN 3 STRT 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.18 Size Reduction Advice Screen

Helicopter Conceptual Design Expert System

Increasing the number of blades (parameter 3, BM) will reduce the rotor size which translates to overall helicopter size.

Because the component weights are formulated as functions of both rotor radius and blade number, the overall weight will likely decrease.

You will have to change this parameter in the next screen.

What would you like to do?

Try this

Try something else

2 UNKN 3 STRT 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.19 Info Screen on Changing the No. of Blades

```
Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma     = 0.100
Disk loading =   7.000
Tip Speed    = 700.0

Size: Main rotor radius  = 24.09    Fin Arm   = 25.53
      Main Rotor chord   = 1.405    Fin Area = 39.5
      Tail Rotor radius  =   4.49   Tail Rotor Arm   = 29.08
      Tail Rotor chord   = 1.631    Flat plate Area = 27.39

Weight: Empty Weight =   7608.2
        Payload      =   2200.0     Useful Load = 4980.48
        Fuel Weight  =   2950.5
        Gross Weight = 12758.7

Dimensions are in ft; Area is sq.ft; Weights are in lbs.

Press Function Key F1 PAGE to view next page

1 PAGE  2 CONT  3 STRT        6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
```

Figure 3.20

UH-1H Four Bladed Optimized Configuration Screen 1

```
Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma     = 0.100
Disk loading =   7.000
Tip Speed    = 700.0

Power: Total intermediate rated power = 2892.8
       Total maximum continuous power = 2582.9

       IRP drive system power limit = 1759.6
       MCP drive system power limit = 1759.6

Power is given in shp.

Press Function Key F2 CONT to continue

Press Function Key F1 PAGE to view previous page

1 PAGE  2 CONT  3 STRT        6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
```

Figure 3.21

UH-1H Four Bladed Optimized Configuration Screen 2

Helicopter Conceptual Design Expert System

There are a number of things one can do to reduce the gross weight of the helicopter. Four are listed here.

Position the pointer with the ARROW KEYS and press ENTER.
Don't worry, your choice here is not binding.

1 Increase the main rotor blade twist

2 Change the tail rotor type

3 Increase the number of main rotor blades

4 Change the prototype helicopter

2 UNKN 3 STRT 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.22 Blade Twist Increase Screen

Helicopter Conceptual Design Expert System

If your mission requires high speed flight, such as in ATTACK mission, increasing the twist of the blades will decrease the weight because highly twisted blades are more efficient at high speeds.
The tradeoff is that hover performance deteriorates and the blade loads increase.

A reasonable maximum twist is 12 - 14 deg.

The blade twist is parameter 11, THETA1 in the next screen.
What would you like to do?

Try this

Try something else

2 UNKN 3 STRT 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.23 Info Screen on Increasing Blade Twist

Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma = 0.101
Disk loading = 7.000
Tip Speed = 700.0

Size: Main rotor radius = 23.55
Main Rotor chord = 1.368
Tail Rotor radius = 4.39
Tail Rotor chord = 1.570

Fin Arm = 24.97
Fin Area = 37.1
Tail Rotor Arm = 28.44
Flat plate Area = 26.58

Weight: Empty Weight = 7204.7
Payload = 2200.0
Fuel Weight = 2791.6
Gross Weight = 12196.4

Useful Load = 4821.63

Dimensions are in ft; Area is sq.ft; Weights are in lbs.

Press Function Key F1 PAGE to view next page

1 PAGE 2 CONT 3 STRT 6 WHY? 7 PRNT 8 MENU 9 HELP 10 EXIT

Figure 3.24
UH-1H Configuration with Increased Blade Twist Part 1

Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma = 0.101
Disk loading = 7.000
Tip Speed = 700.0

Power: Total intermediate rated power = 2715.6
Total maximum continuous power = 2424.7

IRP drive system power limit = 1661.3
MCP drive system power limit = 1661.3

Power is given in shp.

Press Function Key F2 CONT to continue

Press Function Key F1 PAGE to view previous page

1 PAGE 2 CONT 3 STRT 6 WHY? 7 PRNT 8 MENU 9 HELP 10 EXIT

Figure 3.25
UH-1H Configuration with Increased Blade Twist Part 2

Main Rotor Data

Disk Loading = 7.0 psf

Tip Speed = 700 fps

$\frac{C_t}{\sigma} = 0.101$

Number of Blades = 4

Blade Length = 23.55 ft

Blade Chord = 1.37 ft

Blade Twist = -12°

Tail Rotor Data

Tip Speed = 736 fps

Number of Blades = 2

Blade Length = 4.39 ft

Blade Chord = 1.57 ft

Distance from Main Rotor Shaft = 28.44 ft

Helicopter Weight

Gross Weight = 12196 lbs

Empty Weight = 7405 lbs

Useful Load = 4822 lbs

Empty Weight Ratio = 0.607

Engine Data

Installed Power (IRP) = 2716 shp

Installed Power (MCP) = 2425 shp

Drive System Power Limit = 1661 shp

Figure 3.26
Final Configuration of the Search and Rescue Helicopter

Helicopter Conceptual Design Expert System
In the LIGHT OBSERVATION category there are 3 helicopters available. Performance data on them is presented here.

	OH-13S	OH-6	OH-58A
Max Gross Weight	2950 lbs	3000 lbs	3200 lbs
Useful Load	1050 lbs	1462 lbs	1384 lbs
Est Fuel Weight	388 lbs	402 lbs	619 lbs
SL Std Range	193 nm	246 nm	355 nm
SL Cruise Speed	83 kts	125 kts	115 kts
SL Rate of Climb	1250 fpm	1900 fpm	1300 fpm
Service Ceiling	16000 ft	14700 ft	13500 ft

Press Function Key F2 CONT to continue

2 CONT 3 STRT 6 WHY? 7 PRNT 8 MENU 9 HELP 10 EXIT

Figure 3.27 Light Observation Helicopter Data Screen

Helicopter Conceptual Design Expert System

As the previous screen showed, there are 3 helicopters in the light observation category. Two of them, the OH-6 and OH-58A have comparable performance characteristics and similar payload capacities. The OH-13S is the smallest slowest, oldest and cheapest of the three. It is best used for missions such as crop dusting and training.

You must decide if you want to use the OH-13S as a prototype or one of the others as the prototype.

Press Function Key F5 EXPL for explanation

a OH13S

b OH6 or OH58A

2 UNKN 3 STRT 5 EXPL 6 WHY? 8 MENU 9 HELP 10 EXIT

Figure 3.28 OH-13S Decision Screen

Helicopter Conceptual Design Expert System

The OH-6 and OH-58A are very similar and either one can be used as a prototype for designing a light observation helicopter. If you do not have a preference about which to use, the best thing to do is to carry out the design process with both and compare the data at the end.

Do you wish to perform designs with both helicopters and compare the results at the end?

<u>TRUE</u>   FALSE

2 UNKN   3 STRT   6 WHY?   8 MENU   9 HELP   10 EXIT

Figure 3.29 Design Comparison Approval Screen

Helicopter Conceptual Design Expert System

Reconnaisance Mission Profile

Segment	Altitude(ft)	Temp(F)	Time(min)	Z/D	Vel(kts)
1	4000.0	95.0	2.0		0.0
2	4000.0	95.0	1.0	2.00	
3	4000.0	95.0	22.0		140.0
4	4000.0	95.0	30.0		50.0
5	4000.0	95.0	0.0	2.00	
6	4000.0	95.0	7.0		150.0
7	4000.0	95.0	30.0		50.0
8	4000.0	95.0	22.0		140.0
9	4000.0	95.0	1.0	2.00	
10	4000.0	95.0	2.0		0.0

Seg 5 Payload decrease: WSTR = 200 lbs. WSTR < 0 is increase.

To change any value, enter Segment No., Name and Value.
For ISA Temp, use -500; For ISA+20 Temp use -600
(Ex. 1<CR> Alt<CR> 5000<CR>). Terminate with Seg=99.

Segment   Name   Value
99

Figure 3.30 Modified Reconnaissance Mission Profile

Helicopter Conceptual Design Expert System

Specific Parameters for the OH6

Parameter	Value	Parameter	Value	Parameter	Value
1 ALFAFN	1.0	2 ARMRO	1.000	3 BM	4
4 BTR	2	5 FD	0.031	6 GWE	2400
7 NENG	1	8 NYWCTR	0	9 OMGRTR	693.0
10 RPL	1000	11 THETA1	-9.0	12 X	0.150
13 XTR	0.300	14 CTSig	0.077	15 CTSLO	0.045
16 CTSHI	0.125	17 DL	4.41	18 DLLO	4.00
19 DLHI	7.50	20 Vt	666.0	21 VtLO	500.0
22 VtHI	750.0				

This window allows you to change specific helicopter parameters and get information about them. To change a parameter value enter "C", the parameter number (1 to 22) and the new value. To get information enter "Q" and the parameter number. To exit enter "E".

Command: E
Param Number:

Figure 3.31 Updated Specific Parameters for the OH-6

Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma = 0.077
Disk loading = 7.500
Tip Speed = 750.0

Size: Main rotor radius = 10.04 Fin Arm = 12.46
Main Rotor chord = 0.717 Fin Area = 0.0
Tail Rotor radius = 1.92 Tail Rotor Arm = 12.46
Tail Rotor chord = 0.629 Flat plate Area = 5.53

Weight: Empty Weight = 1083.3
Payload = 1000.0 Useful Load = 1121.92
Fuel Weight = 291.9
Gross Weight = 2375.3

Dimensions are in ft; Area is sq.ft; Weights are in lbs.

Press Function Key F1 PAGE to view next page

1 PAGE 2 CONT 3 STRT 6 WHY? 7 PRNT 8 MENU 9 HELP 10 EXIT

Figure 3.32 OH-6 Optimized Configuration Screen 1

Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma = 0.077
Disk loading = 7.500
Tip Speed = 750.0

Power: Total intermediate rated power = 416.5
Total maximum continuous power = 416.5

IRP drive system power limit = 312.1
MCP drive system power limit = 312.1

Power is given in shp.

Press Function Key F2 CONT to continue

Press Function Key F1 PAGE to view previous page

1 PAGE 2 CONT 3 STRT 6 WHY? 7 PRNT 8 MENU 9 HELP 10 EXIT

Figure 3.33 OH-6 Optimized Configuration Screen 2

Helicopter Conceptual Design Expert System

Specific Parameters for the OH58A

Parameter	Value	Parameter	Value	Parameter	Value
1 ALFAFN	1.0	2 ARMRO	1.000	3 BM	2
4 BTR	2	5 FD	0.050	6 GWE	3000
7 NENG	1	8 NYWCTR	0	9 OMGRTR	709.8
10 RPL	1000	11 THETA1	-8.0	12 X	0.210
13 XTR	0.210	14 CTSig	0.077	15 CTSLO	0.045
16 CTSHI	0.125	17 DL	3.06	18 DLLO	3.00
19 DLHI	7.50	20 Vt	655.0	21 VtLO	500.0
22 VtHI	750.0				

This window allows you to change specific helicopter parameters and get information about them. To change a parameter value enter "C", the parameter number (1 to 22) and the new value.
To get information enter "Q" and the parameter number.
To exit enter "E".

Command: E
Param Number:

Figure 3.34 Updated Specific Parameters for the OH-58A

```
                    Helicopter Conceptual Design Expert System

                              SSP1 Design Data

                              Ct/Sigma     = 0.077
                            Disk loading =   7.500
                             Tip Speed     = 750.0

Size: Main rotor radius = 11.72    Fin Arm   = 14.46
      Main Rotor chord  = 1.665    Fin Area = 30.8
      Tail Rotor radius =  2.24    Tail Rotor Arm  = 14.46
      Tail Rotor chord  = 0.924    Flat plate Area = 10.96

Weight: Empty Weight =  1746.9
        Payload      =  1000.0     Useful Load = 1317.47
        Fuel Weight  =   487.5
        Gross Weight =  3234.5

        Dimensions are in ft; Area is sq.ft; Weights are in lbs.

              Press Function Key F1 PAGE to view next page


1 PAGE  2 CONT  3 STRT               6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
```

Figure 3.35 OH-58A Optimized Configuration Screen 1

```
                    Helicopter Conceptual Design Expert System

                              SSP1 Design Data

                              Ct/Sigma     = 0.077
                            Disk loading =   7.500
                             Tip Speed     = 750.0

Power: Total intermediate rated power =  757.1
       Total maximum continuous power =  757.1

       IRP drive system power limit =  552.5
       MCP drive system power limit =  552.5


                          Power is given in shp.

                 Press Function Key F2 CONT to continue

              Press Function Key F1 PAGE to view previous page


1 PAGE  2 CONT  3 STRT               6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
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Figure 3.36 OH-58A Optimized Configuration Screen 2

```
Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma     = 0.075
Disk loading =   7.500
Tip Speed    = 750.0

Size: Main rotor radius = 11.41    Fin Arm   = 14.09
      Main Rotor chord  = 0.824    Fin Area = 29.4
      Tail Rotor radius =  2.18    Tail Rotor Arm   = 14.09
      Tail Rotor chord  = 0.909    Flat plate Area = 10.58

Weight: Empty Weight =  1600.2
        Payload      =  1000.0     Useful Load = 1295.28
        Fuel Weight  =   465.3
        Gross Weight =  3065.5

Dimensions are in ft; Area is sq.ft; Weights are in lbs.

Press Function Key F1 PAGE to view next page


1 PAGE  2 CONT  3 STRT                6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
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Figure 3.37

Four Bladed OH-58A Optimized Configuration Screen 1

```
Helicopter Conceptual Design Expert System

SSP1 Design Data

Ct/Sigma     = 0.075
Disk loading =   7.500
Tip Speed    = 750.0

Power: Total intermediate rated power =  723.6
       Total maximum continuous power =  723.6

       IRP drive system power limit =  527.8
       MCP drive system power limit =  527.8


Power is given in shp.

Press Function Key F2 CONT to continue

Press Function Key F1 PAGE to view previous page


1 PAGE  2 CONT  3 STRT                6 WHY?  7 PRNT  8 MENU  9 HELP  10 EXIT
```

Figure 3.38

Four Bladed OH-58A Optimized Configuration Screen 2

Helicopter Conceptual Design Expert System

Compare Designs

OH6 Gross Weight = 2375.3 lbs
IRP Power = 416.5 hp
Disk Loading = 7.500
Ct/Sigma = 0.077

Confidence level of OH6 as the best design:
90

OH58A Gross Weight = 3065.5
IRP Power = 723.6 hp
Disk Loading = 7.500
Ct/Sigma = 0.075

Confidence level of OH58A as the best design:
10

Press F2 CONT to continue.

2 CONT 3 STRT 6 WHY? 7 PRNT 8 MENU 9 HELP 10 EXIT

Figure 3.39 Comparison of Design Configurations

Main Rotor Data
Disk Loading = 7.5 psf
Tip Speed = 750 fps
$\frac{C_t}{\sigma} = 0.077$
Number of Blades = 4
Blade Length = 10.04 ft
Blade Chord = 0.717 ft
Blade Twist = -9°

Tail Rotor Data
Tip Speed = 693 fps
Number of Blades = 2
Blade Length = 1.92 ft
Blade Chord = 0.63 ft
Distance from Main Rotor Shaft = 28.44 ft

Helicopter Weight
Gross Weight = 2375 lbs
Empty Weight = 1083 lbs
Useful Load = 1122 lbs
Empty Weight Ratio = 0.456

Engine Data
Installed Power (IRP) = 416 shp
Installed Power (MCP) = 416 shp
Drive System Power Limit = 312 shp

Figure 3.40
Final Configuration for the Reconnaissance Helicopter

CHAPTER IV

CONCLUSIONS & RECOMMENDATIONS

4.1 Conclusions

The primary goal of this thesis was to demonstrate how expert systems might be used in helicopter conceptual design. From the development of XSP1, three conclusions can be stated:

1) The ideal expert assistant outlined in chapter 3 is possible. The development of XSP1 demonstrates one way expert systems can be applied to helicopter conceptual design, as an expert assistant. By being a subset of the ideal expert assistant, XSP1 validates the concept of applying expert systems to helicopter design.

2) The concept of developing a helicopter design expert system on a single user computer is valid. The scope of an expert system like XSP1 is not so large that it cannot be handled by a small computer.

3) Two other types of expert systems can be developed for helicopter design. XSP1 represents a branch point for the application of expert systems in helicopter design. First, the concept of the expert assistant can be extended so that the KBS is a teaching tool. The emphasis would be on explaining the process used in conceptual design and on the various trade-offs which can be made in the design iteration to achieve a configuration. Alternatively, the user's approval can be minimized in the expert system's decisions and the program would be relatively stand alone

and would act as the designer. This requires an extensive, adaptive and well defined ruleset for the system to arrive at configuration.

4.2 Recommendations

The program developed here only scratches the surface of an expert system for helicopter conceptual design. The most important addition would be a tracing feature which monitors the user's decisions regarding advice given by the assistant. This feature keeps the program from stagnating and becoming obsolete by allowing the rule and knowledge bases to grow. Second, other algorithmic programs (eg. SSP2 - helicopter performance program) should be added to the system to increase the design capabilities. Third, more design goals, such as designing for minimum cost, should be incorporated into the system.

The three enhancements listed are the most important, but some others should not be ommitted. The expert system should be able to accept a greater range of RFP specifications. Also, different optimization methods should be explored. First order methods such as the Fletcher-Reeves method of conjugate gradients, might be more appropriate than zero order methods because the gradient of the gross weight function can be steep. Third, graphics should be incorporated to aid explaining concepts and presenting information. Finally, the deficiencies of SSP1 should be addressed. For example, SSP1 uses the blade root cutout for weight estimation only. The aerodynamic effects on rotor size and weight are not considered.

4.3 Summary

In summary, the expert assistant developed in this thesis has shown one way to employ expert systems in helicopter design. In should not be viewed as the end of development in the application of KBS in helicopter design but rather as the beginning. XSP1's development has raised many interesting questions which should be examined.

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