Helicopter Configuration Optimization

By

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BS, Mechanical Engineering, Worcester Polytechnic Institute (1984)

MS, Mechanical Engineering, University of Bridgeport (1996)

Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management

at the

Massachusetts Institute of Technology

December 2000

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Abstract

Helicopter manufacturers must meet the individual needs of a wide variety of international customers. If a manufacturer does not offer many different choices of helicopter configuration to the customer the manufacturer will be non-competitive. The configuration consists of the base helicopter and a list of options. This thesis examines ways to optimize the configuration that is provided to the customer based on the amount of money the customer has to spend. The primary tool employed is an integer linear programming optimization algorithm that utilizes Microsoft Excel Solver software.

This thesis also examines ways to best discover the utility or relative worth of different options to the customer. The end result is a helicopter configuration that is optimized for the customer. This method should replace the current method of defining a customer's helicopter configuration that is very subjective and therefore hard to come to a consensus on.

Configuration optimization programming provides structure that helps to streamline the engineering proposal process.

The manufacturing process will also be streamlined if the program is set up to use the configuration output to generate an engineering Bill of Material. This Bill of Material would be a valuable input for a manufacturing Build To Order (BTO) system.

Biography

The author, Ronald Sadownick graduated from Worcester Polytechnic Institute in 1984 with a BS in Mechanical Engineering. He started working for Sikorsky Aircraft that same year. While at Sikorsky he earned an MS in Mechanical Engineering from the University of Bridgeport. He spent 12 years in the Test Engineering Department at Sikorsky and the last four years in the Applications Engineering Department. As an Applications Engineer he is responsible for the engineering content of proposals to numerous international customers. He has been an Officer and Helicopter Pilot for the Connecticut Army National Guard for the past ten years. He is an aviation enthusiast with FAA Flight Instructor Ratings in both Helicopters and Fixed Wing Aircraft. He is married with two young sons.

Acknowledgements

I am grateful to my wife, Marina, for her support during my time in the Systems Design and Management Program. I am also grateful to the numerous people at MIT that had a hand in conceiving and developing this fine program. Thanks also to those Professors and Administrators that are currently working to make the program even better. I would also like to thank Professor Nightingale for her support and guidance that helped me to complete this thesis.

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Chapter 1: Introduction

Background

This thesis presents a method for optimizing a helicopter configuration to best meet a customer's needs while not exceeding the customer's budget. The helicopter configuration consists of a baseline helicopter and options selected specifically for an individual customer.

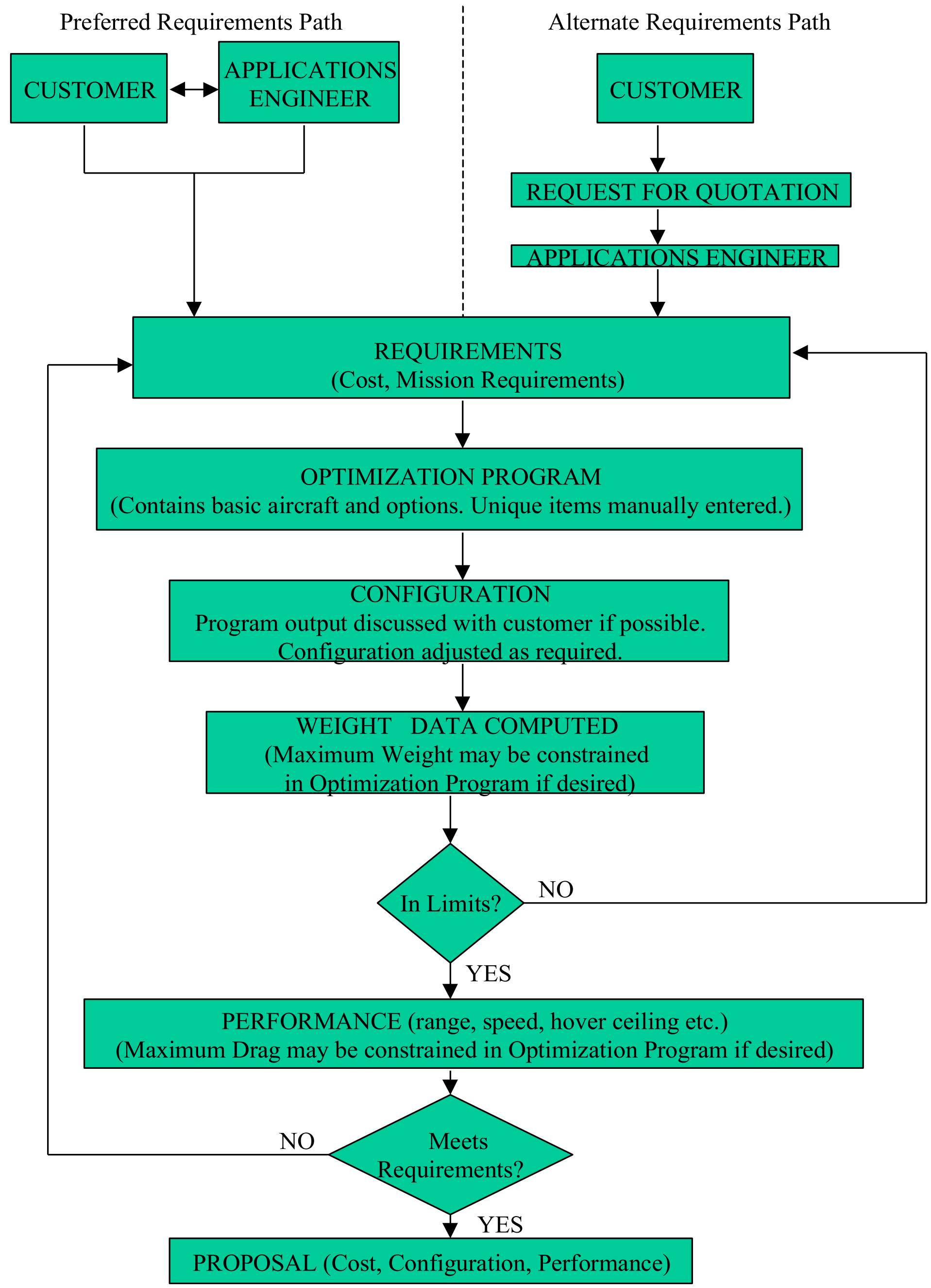
Helicopter configuration optimization can give a helicopter manufacturer an advantage in the international helicopter market that is highly competitive. Unlike the case with many products, the market for new helicopters is expanding very slowly. The largest market segment for helicopters is the militaries of the world. The U.S. military services that were once buying large numbers of helicopters have scaled back their purchases due to budget constraints. The U.S. Army is currently operating many Vietnam era helicopters that are expensive to maintain and do not perform well. However, again due to budget restraints and other procurement needs the Army will be replacing these aircraft very slowly. The situation within the United States has forced U.S. helicopter manufacturers to increase their share of the international market to survive. Market realities have also reduced the number of helicopter manufacturers because some have been purchased by others. Also, strategic alliances have been formed between some helicopter companies when developing new helicopters. These alliances cut down on the development costs and risks that have to be borne by any one manufacturer. These alliances also have political implications. For example, Bell Helicopter in Texas has formed an alliance with Agusta Helicopter in Italy. This alliance makes it easier for Bell to get a piece of the European market. Without a European partner it is politically difficult to sell American helicopters in Europe.

Because of the large amount of competition, the customer has a lot of power when negotiating a helicopter sale. To make a sale helicopter manufacturers must cater to the individual needs of each customer. The helicopter manufacturer must be flexible about aircraft configuration while being competitive on price. This is why the ability to do configuration optimization can provide a real competitive advantage. Currently there is no methodology for consistently providing optimal configurations to different customers. The current method is subjective and largely a trial and error technique. This thesis will present a methodology to streamline and optimize the configuration to best meet the customer's needs within his budget constraints.

Recommended Customer Requirements Identification and Configuration Optimization Approach

Defining the helicopter configuration is a very important part of the manufacturer's proposal process. Figure 1 illustrates how configuration definition starting from customer needs fits into the entire proposal process. Two paths to requirements definition are shown. One path starts with a Request For Quotation (RFQ) document given to the manufacturer by the customer. The second path initiates with face to face requirements talks between the manufacturer and the customer. The second path is the preferred method. It is preferred because there is less chance of misunderstandings so that the customer is more likely to end up with equipment that meets his needs.

Figure 1
Requirements Path from Customer to Proposal



Once the requirements are known they are input into the configuration optimization program (details of this program are presented in chapters 3 and 4). When the optimization program yields a configuration it also calculates the weight and equivalent flat plate drag of the helicopter. This ensures that the solution configuration is below the threshold weight and drag required for the helicopter. This configuration weight and drag information can be given to the aerodynamacist so that the performance of the helicopter as configured can be detailed in performance graphs and tables as required. Typical measures of performance are maximum speed, maximum range and maximum altitude at which the helicopter can hover, etc. If any element of performance can not be met then the configuration will have to be reexamined or the requirements for performance will have to be reexamined with the customer.

At the end of the data gathering and optimizing process the aircraft configuration is known and its cost is known. The cost will be less than or equal to the customer's budget. The performance data is also known. All of the data will then be presented in a proposal to the customer. When possible configuration items are shown pictorially rather than only in a list. This is because the interconnections between systems are important to understand. An example of a configuration pictorial for helicopter avionics is shown in Figure 2. It is evident that configuration definition is at the core of a proposal effort. Thus a more optimized configuration will yield a more optimized proposal and make the proposal process more efficient.

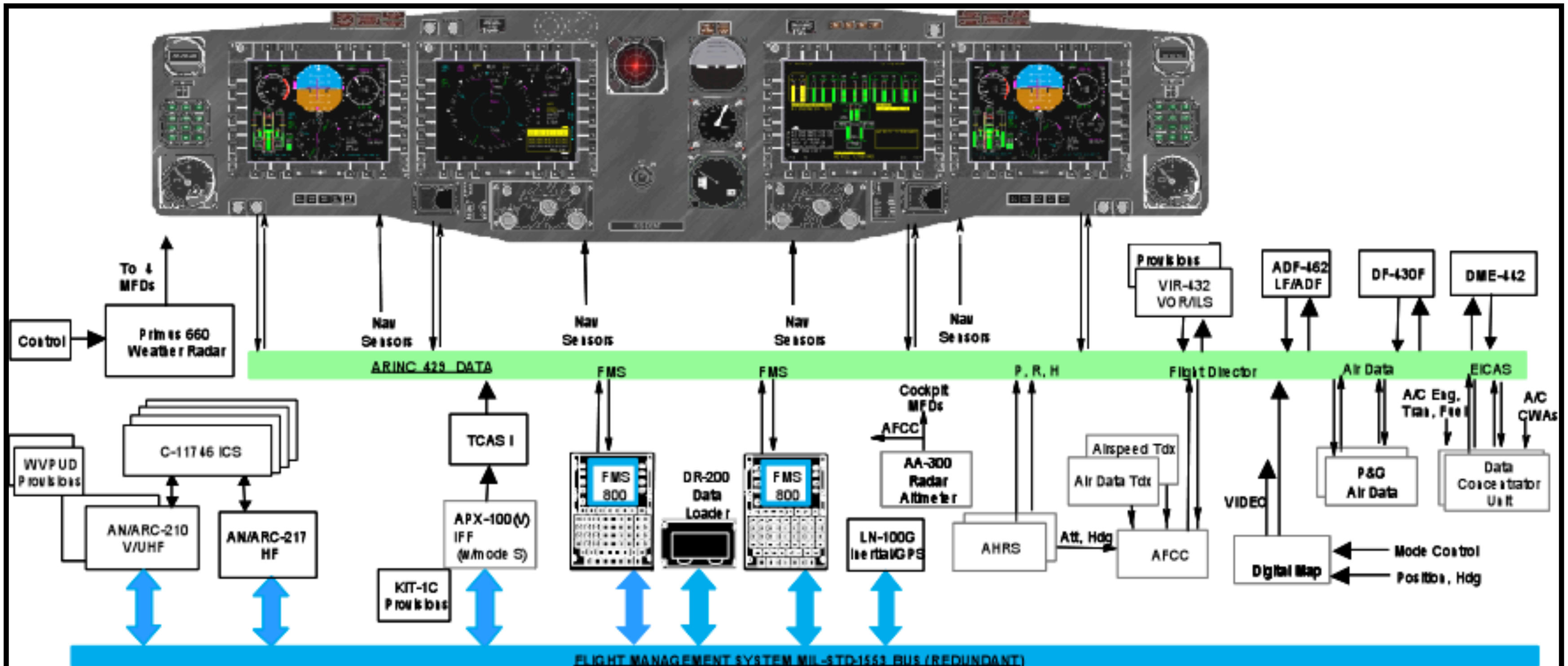


Figure 2 – Avionics Pictorial

Thesis Outline

Chapter 2 presents detailed analysis on methods of obtaining customer requirements. Current methods are examined and recommendations are made for more efficient ways to understand customer requirements.

Chapter 3 examines the current way that helicopter configuration decisions are made. A methodology for employing integer linear programming for determining a more optimal helicopter configuration is presented.

Chapter 4 presents a case study in helicopter configuration optimization based on a real life example starting from a customer's Request For Quotation. This example demonstrates how helicopter configuration optimization can be achieved even when the customer input was not designed with optimization programming in mind.

Chapter 5 presents the thesis conclusions and recommendations. It is concluded that current methods do not result in optimal helicopter configurations. It is concluded that utilizing integer linear programming will result in an optimal helicopter configuration. It is further concluded that both the proposal process and the manufacturing process will benefit from the use of integer linear programming. It is recommended that integer linear programming be used for all but simple helicopter configuration optimization problems.

Chapter 2: Obtaining Customer Requirements

i. Current method:

The current method of obtaining customer requirements can be a loose process. The following are a few of the ways that the manufacturer gets customer requirements.

1. The customer may give a general description of what he/she is looking for in a verbal request.
2. The customer may submit a brief written request for a proposal. The request would list top level generic missions that the helicopter must perform. For example they may need a helicopter for VIP Transport, Search and Rescue, Troop Transport, or an Off-Shore Oil Support mission. The majority of helicopters sold are used for a limited number of different missions by their operators. However, recently some international militaries have been trying to have their aircraft perform a wide variety of public service and military missions. This helps the government justify the expense of the helicopters to the tax payers.
3. The customer may give the manufacturers a Request For Quote (RFQ) that very specifically identifies mission requirements. An example of a very specific mission requirement would be that the helicopter must carry 12 troops, in light icing conditions, 300 miles in less than 2 hours at an altitude of 12,000 feet above sea level. A detailed RFQ may contain hundreds of these types of detailed requirements. The RFQ may also list Aeronautical and Military specifications that must be conformed with.

4. The customer may give mission requirements and also list specific equipment that must be installed. The list may include weather radar and night vision goggles for example. Sometimes the customer will even specify a specific model of a piece of equipment that must be installed. The customer may specify Litton ANVIS6 night vision goggles rather than just generic night vision goggles.

As shown above there is a wide variety of ways that requirements get from the customer to the manufacturer. Regardless of the form of the requirements, there are usually questions in the engineers' mind when he initially puts together a configuration for the customer. What is required is a good line of communication between the customer and the engineer. However, this communication line is not always available. This occurs for a number of reasons. The customer may be restricted from directly discussing the RFQ in the case of a competitive RFQ with multiple manufacturers involved. Or the rules of the procurement competition may limit the engineer to a limited number of occasions to make official clarification requests. Sometimes it is the manufacturer's own fault. The marketing and programs people may not understand the importance of communication between the customer and the manufacturer's engineering department. Mcquarrie in his book, Market Research Toolbox, states "Do get engineers and other non-marketers involved in customer visits"[Mcqua1995a]. I believe this is critical for discovering customer needs in the helicopter industry. The product is highly technical and most marketing personnel do not have the depth of knowledge required to work with the customer to define a helicopter configuration. Mcquarrie also suggests " Don't ask customers for solutions, ask them to identify problems that need solving. The customer is the authority on what the real problems are, but the vendor is the authority on what a profitable solution to those problems might be"[Mcqua1995a]

ii. Recommendations for obtaining customer requirements:

The main element in understanding customer technical requirements is a good line of communication between the customer and the engineering department. This can be accomplished by having customer visits. The engineer involved may be called a sales engineer or an application's engineer or by some other name. The important thing is that he/she must develop a good relationship with the customer and he/she must maintain a good relationship with all elements of the manufacturer's engineering and pilot departments. The responsible engineer must also work closely with the marketing and programs groups to understand the implications of specific strategies being employed to win the customers business. The manufacturer may not be able to afford to keep engineering personnel on the road to the same extent as the marketing people. Therefore the engineers should supply the marketing people with the tools that will help them to extract accurate technical requirements from the customer. These tools would include surveys to help determine technical requirements that the engineer could convert to a proposed helicopter configuration.

Customer Visits:

McQuarrie categorizes customer visits as "Programmatic" and Ad Hoc" [McQua1996a]. Programmatic visits are specifically designed to discover customer needs. Ad Hoc customer visits are interactions with potential customers at trade shows and other events. Field service representatives for customers currently operating helicopters also are making Ad Hoc customer visits. Although the field service representative may be there for a specific problem with current equipment he/she should not waste an opportunity to discover the future needs of the customer. The important thing is that people in all functions that have contact with current and potential customers should help to gather information on customer needs.

Mcquarrie suggests that all personnel in contact with the customer be trained to ask “perennial” questions. These are questions designed to open up a discussion of what is on the customers’ mind. Mcquarrie uses the following examples of perennial questions:

1. Why did you choose our product?
2. What is the worst difficulty you have in working with us?
3. What business problems are causing you to lose sleep?
4. How do you compare us with our competitors? What are our strengths and weaknesses?

For the helicopter industry I would add the following question:

What missions would you like to perform that you currently can not?

And

Walk me through a typical mission or a worst case scenario.

The idea is that all personnel that are in contact with the customer can gather useful information about customer needs even if this is not their primary function. Sometimes a field service representative may learn more by talking to flight line personnel then you can from talking to customer representatives that are involved in procurement but not the everyday operation of the unit and its helicopters.

Of course gathering information is of little use if that data is not readily available to those that need it. The manufacturer should have a database that stores information gathered by all the manufacturer's sources about the customer's current operations and future aspirations. The database could be organized by country. This could help the manufacturer to understand the big picture that may include the needs of more than one entity in any one country (for example an Army and an Air Force helicopter procurement). The database should be searchable. This will enable the manufacturer to look for trends such as a common need that has not been met in the industry. This database could be accessible to company personnel with a secure web-site. This would enable data to be accessed and entered from the field. Ad-Hoc customer visits will not uncover all customer needs. The advantage is that contact is occurring with the customer any way so Ad-Hoc visits are an inexpensive way to gather data. There is also an important psychological factor to be considered. You will generate goodwill with the customer if it appears that all of the manufacturers' personnel are committed to understanding their current and future needs. Of course, some discretion must be used so that you do not become an annoyance to the customer.

The second type of customer visit is the programmatic visit. Because this is a deliberate visit McQuarrie suggests having a discussion guide to direct the visit. The discussion guide need not be strictly adhered to as long as information is being gained. McQuarrie suggests the following four objectives:

1. Identify user needs.

This would include mission requirements and available funding (if disclosed).

2. Explore customer perceptions concerning market events or trends.

It is important to make sure that the customer understands that the manufacturer is using the latest technology where appropriate.

3. Generate ideas for product enhancement.

Generally the manufacturer will be trying to sell something that has been done before to keep the price down. However if needs cannot be met you have to be open to the idea of making changes. Also this is good information to collect for the next generation helicopter.

4. Describe how customers make their purchase decision.

It is important to try to understand the relative importance of various factors in the decision process. For example:

How important is it to the customer to have the latest technology?

How important is it for the helicopter to be delivered with components made in the customers' country?

How important is it that the aircraft is similar to other aircraft in the customer's fleet for simplified cross training between aircraft.

How important is it to have a low purchase or operating cost?

To get a sense of the answers to these questions it is important to talk with a variety of people at the customer's location. Of course it is very important to know where the final decision will be coming from. Will the units operating the aircraft have a lot of say in which aircraft is procured or will that be mandated to them by the government.

It is best to get a wide exposure to the customer that includes talking to the Program Manager, Engineers, Pilots, Crew-chiefs and Technicians etc. For the manufacturer a cross-functional interview team is also important and may include personnel from Programs, Marketing, Customer Logistics Support as well as an Applications or sales Engineer.

Initially it is best to have open-ended discussions so that you can find out from the customer what is important to him. Be open-minded and don't try to immediately force a solution or a particular piece of equipment on the customer. It is important to make the customer feel that the team is there to listen to their needs and not just to sell them whatever they can as quickly as possible.

In his discussion of customer visits McQuarrie deals primarily with new product development but the ideas are applicable to marketing derivative aircraft in the international market. An example of a derivative aircraft is the S-70A helicopter. The international versions of this helicopter are all based on the Sikorsky UH-60 BlackHawk helicopter designed and built to U.S. Army specifications. The customers are spending a lot of money and expect the manufacturer to meet their individual needs. Visiting the customer at his site and seeing where he must operate and maintain his aircraft is important to understanding the needs of the customer. The face to face meeting is still the best way to gather information from the customer. Since you are going to the customer it is important to bring visual aids that will give the customer a good sense of the manufacturer and his products. It is important not to dominate the conversation or arrive with blinders on. Let the customer lead and you may be surprised with a powerful insight into what is important to this customer.

Ulrich and Eppinger [Ulric1995a] address “Identifying Customer Needs” in their “Product Design and Development” text. Many of the concepts that they present for developing new products are useful when selling derivative helicopters in the international market. Ulrich and Eppinger state that their goals are to:

1. Ensure that the product is focused on customer needs
2. Identify latent or hidden needs as well as explicit needs.
3. Provide a fact base for justifying the product specification. (In the case of the derivative helicopter I will be justifying the aircraft configuration.)
4. Create an archival record of the needs activity of the development process. (In this case I am documenting the proposal process.)
5. Ensure that no critical customer need is missed or forgotten.
6. Develop a common understanding of customer needs among the development team members. (In this case it is equally important for members of a derivative aircraft proposal team to develop this understanding).

Ulrich and Eppinger state “The philosophy is built on the premise that those who directly control the details of the product, including the engineers…must interact with customers and experience the use environment of the product.” This is in agreement with

McQuarrie and with what I have experienced. This holds true for a new product or a derivative product. Ulrich and Eppinger present the following six step methodology to identify customer needs:

1. Define the scope of the effort.

(Any systems engineering effort such as this should be tailored to the job at hand. Otherwise you are wasting resources.)

2. Gather raw data from the customers.

(The raw data I will gather is from Ad-Hoc and Programmatic Customer Visits as well as Surveys completed by the customer. Other raw data on needs may include articles in periodicals such as Aviation and Space Weekly. Budget information may even be available in newspapers printed in the country of interest.)

3. Interpret raw data in terms of customer needs.
4. Organize the needs into a hierarchy of primary, secondary, and (if necessary) tertiary needs.
5. Establish the relative importance of the needs.
6. Reflect on the results and process.

It is also a good idea to have the customer visit the manufacturer's facility if possible. The customer will be impressed by a state of the art, clean, and efficient manufacturing assembly line. The customer can also be impressed with other high technology areas such as flight simulators. If the customer comes to the manufacturer's facility then he can interface with a large number of technical experts without the manufacturer having to pay large travel expenses. Showing the customer your products and capabilities first-hand adds credibility to your marketing campaign and helps to open up a good requirements dialog.

Quality Function Deployment and Derivative Aircraft Sales

Quality Function Deployment is used for new product development and is also useful in showing how customer mission needs/requirements ultimately match to the configuration of a derivative helicopter. First, customer needs are matched to metrics. Then the metrics can be matched to the specific equipment that is to be installed on the aircraft. The difference between working with derivative aircraft and new products is that instead of defining the specifications for a new product I am defining the specifications that must be met by a system of existing items to be packaged for a specific customer. Of course, if the needs cannot be met then additional design work and product development may have to be done.

Surveys are used in QFD to discover what is most important to the customer. Surveys with absolute importance rating scales can be used. In his book “Quality Function Deployment, How to Make QFD Work For You” [Cohen1995a] Cohen states that in QFD absolute importance scales usually range from 3 to 10 different quantitative choices. Cohen uses this example of a five-point scale:

Value1 Not at all important to the customer

Value 2 Of minor importance to the customer

Value 3 Of moderate importance to the customer

Value 4 Very important to the customer

Value 5 Of highest importance to the customer

In specifying helicopter requirements it is important also to have a category for those things that are absolutely mandatory in the customer's mind. Cohen states that a difficulty with the absolute rating system is that "customers tend to rate almost everything as being important".

A survey with an ordinal importance scale has the customer list his needs in order of importance from 1 through however many needs he/she has. The problem with ordinal importance is that it is not possible to compare the utility of any two items on the list except to say that one is more important than the other.

Cohen "finds relative importance the most useful measure of importance for QFD."

A relative importance scale allows you to discover, for instance, that not only is one need more important than another but that it is twice as important.

Therefore, a relative importance rating of requirements will be the basis for my customer surveys that are used to gather helicopter configuration requirements. Figure 3 shows how a Quality Functional Deployment type mapping is used to determine the helicopter configuration.

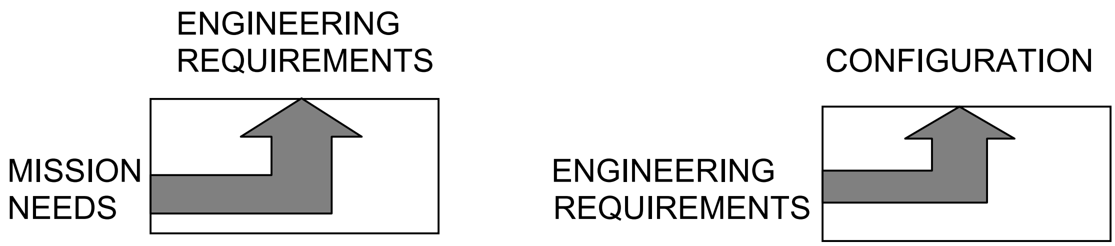


Figure 3 : QFD Mapping from Mission Needs to Helicopter Configuration

Surveys:

Examples of surveys designed to extract helicopter requirements are shown in Tables A-1 through A-3. More than one level of survey is required. A top level survey (Table A-1) will give the manufacturer an idea of the customer's mission and will get the customer thinking about helping to define what he/she requires. A more in depth survey will help to define the detail mission requirements (Table A-2). Table A-3 would be a survey for a very technically sophisticated customer that knows his detailed mission requirements as well as his equipment preferences. It is important to match the level of survey with:

1. The stage at which the customer is in understanding his own requirement.
2. The person who will be completing the survey. A top-level military officer may not be able to answer detailed helicopter performance questions. It is also important to remember that if you press for an answer you may be given one that is erroneous. (The survey must state that it is acceptable to leave areas blank or to make a note when something is a guess or approximation).

3. The amount of involvement the customer wants in decisions. Some international customers want a lot of control over the configuration while others want to be able to rely on the helicopter manufacturer’s recommendations completely.

Chapter 3: Making Helicopter Configuration Decisions

After customer requirements have been determined, helicopter configuration decisions must be made.

i. Current Method:

Currently, when configuration decisions are made by the manufacturer, they are made quite subjectively. The manufacturer's engineers and pilots make decisions based on their experience and judgement. Marketing and programs people may be quite vocal here as well. The problem is that different people have different experiences and often make different judgements and recommendations. This leads to arguments and it is often unclear whose opinion best represents that of the customer. Also, due to the subjectivity, it is difficult to document exactly why configuration decisions were made. This can make it difficult to go back and understand the complete requirement when time has passed or when the customer wants to modify his requirement.

ii. Optimizing Helicopter Configuration Decisions:

A method is required to optimize the way in which the helicopter configuration is defined. But what should I optimize for? The answer is to optimize the configuration based on a fixed price for the customer. The customer will be best served by having a configuration that is optimized but that does not exceed his budget. This is consistent with the Design To Cost (DTC) approach to engineering. There are a number of ways that the manufacturer can determine what price he should optimize for:

Case 1 The customer may divulge his budget to the manufacturer.

Case 2 In military sales the appropriation made by the government to the military to buy helicopters may be public knowledge.

Case 3 The price that the manufacturer can charge may be limited by what the competition has been known to charge or is expected to charge. In this case Design To Cost (DTC) may be part of the manufacturers competitive “Win Plan”.

It is not always possible to know what price to optimize for, but many times the manufacturer will have a good idea.

With the selling price known, I can optimize the overall utility of the helicopter to the specific customer with the price constrained. I have written an optimization program using Microsoft Excel Solver software that will accomplish this. “In 1947, George Dantzig developed an efficient method, the simplex algorithm, for solving linear programming problems (also called LP)” [Winst 1994a]. The Solver software utilizes the simplex algorithm. Linear programming can be used to solve problems where the objective function (what is to be optimized) has a mathematically linear relationship to each of the decision variables (what can be changed).

For example:

$\$ Cost = aX_1 + bX_2 + cX_3 + dX_4$

Here cost is the objective function.

X_1, X_2, X_3, X_4 are the variables.

a, b, c, d are the numerical values of each of the variables.

(If any of the variables were not to the first power, for example aX_1^2, then linear programming methods could not be used.)

An integer linear program has variables whose values are constrained to be equal to 0 or 1. That is, a, b, c, and d above would be equal to 0 or 1 with no other possibilities. All linear programs have “Decision Variables”. The set of decision variables for the problem is everything that you can control and change to influence the outcome. All linear programs also have an “Objective Function”. This is the linear equation that shows the relationship between what you want to optimize (maximize or minimize) and the decision variables. Linear programs can also have “Constraints” that bound the values that the decision variables are able to take. (For example, there are only 24 hours in a day. Therefore you can not have a valid optimization solution that says that you will maximize the profit of a business by running a machine for 25 hours each day. The upper bound on hours the machine can run must be set to 24 hours.)

Once you have decided upon constraints, variables and the objective function, relatively simple problems can be solved graphically as described by W. L. Winston [Winst1994a]. For more complex problems computer processing power is required. There is a variety of software packages that will solve linear optimization programs when the constraints, variables, and objective function are input. Examples of tools available are “LINDO” (Linear Interactive and Discrete Optimizer computer package) and “Solver” which is a plug in software package for Microsoft Excel spreadsheet software. I elected to use Microsoft Excel Solver because it is user friendly, inexpensive, and has all the capabilities that I required to do helicopter configuration optimization.

To run the optimization program I must be able to quantify the customer's requirements. I must be able to quantify the utility of different helicopter options to the customer. The way that the utility is quantified depends on the way that the requirement comes to me. If the requirement is the result of my surveys then the data is easily quantified. The surveys ask the customer to attempt to quantify their own preferences. If the data comes in via a Request For Quote (RFQ) under the customer's own format it is more difficult to quantify and more judgement is necessary. A real life example of how judgement can be applied to quantify the importance of different customer requirements in a Request For Quote is presented in the next chapter.

Chapter 4: Helicopter Configuration Optimization: An Example

I use a recent Request For Quotation (RFQ) that I received to show how configuration optimization can be done in a real world example. In this case the requirements path from the customer followed the “alternate” path as shown in Figure 1. (Recall that this is not the “preferred” path where I am able to interact with the customer personally and with surveys to be able to most easily quantify their requirements.)

The customer expressed the requirements in the following way:

Requirement Types	Subjective Meaning
Shall	This equipment must be in the helicopter for the aircraft to be considered
Should 1	It is very important for this equipment to be in the helicopter
Should 2	It is highly desirable for this equipment to be in the aircraft
Should 3	It is desirable for this equipment to be in the aircraft, however having or not having this equipment will not have a large influence on which competitor wins the contract.

In this case I had no survey data. However, the customer did a good qualitative job of specifying his preferences.

In this particular case I had a good estimate of the customer’s budget that was available for each helicopter. The other thing that I needed to do the optimization was the ranking of the available options by the customer. The customer gave me one objective rating (shall) and three subjective ratings of equipment importance (should 1, should 2, should

3). However I had to quantify these subjective ratings for input into my optimization program. The optimization program is constrained to include all of the “shall” items in the helicopter configuration (list of equipment on the helicopter). The “should 1”, “should 2”, and “should 3” ratings are assigned values of importance based on my best judgement, using my experience and knowledge of the customer’s missions and the customer’s subjective definitions. I am making an educated guess as to the relative importance of the “should 1”, “should 2” and “should 3” equipment items to the customer. Because I am making an educated guess, I will do iterations with different relative rankings of the “should” requirements. This will allow me to see how sensitive the resulting configuration is to the relative importance of the “should” requirements. I will use a scale of 1 through 10 because this scale has been utilized successfully in QFD for quantifying requirement importance. I then use my judgement to set up three different iterations with different relative ratings on the scale of 1 through 10. The three iterations for relative utility values are presented in Table 1.

Utility Points Awarded (Importance)

	Should 1 Requirement	Should 2 Requirement	Should 3 Requirement
Iteration 1	3	2	1
Iteration 2	5	3	1
Iteration 3	10	4	2

Table 1
Three Utility Iterations

The utility points given to a particular item show its relative importance with the higher utility points awarded for the most important item. Three iterations are shown. In the first iteration the “should1” requirements are 3 times as important as the “should 3” requirements. In the third iteration the “should 1” requirements are five times as important as the “should 3” requirements. Other iterations, besides these three, can easily be done. Table A-4 in Appendix A lists the helicopter options that were considered as well as their price.

The maximum helicopter price and the quantified requirements data was input into the optimization program. The optimization program did a trade-off of the utility of each option to the customer versus the price of each option. The optimization program maximized the utility function for the customer, subject to the constraint that the customer’s budget can not be exceeded. The program also constrained the weight of the helicopter so that it did not exceed its maximum gross weight and so that it could perform the required missions. The program also constrained the helicopter’s total

Equivalent Flat Plate Drag. This constraint is necessary if a high speed is required to perform a mission or if the customer has explicitly defined a minimum cruise speed requirement. This may also be required to meet some other requirement such as helicopter range without refueling.

Details of the Configuration Optimization Program for the Example Configuration Optimization:

The optimization model is an integer linear programming model. It is integer because all decision variables (configuration options) are either 1 or 0. The decision variable is set equal to 1 if the option is in the configuration. The decision variable is set equal to 0 if the option is not in the configuration. Microsoft Excel Solver uses the “simplex method” to solve the integer linear program model. Using the Microsoft Solver software I can set up a configuration from as many as 200 different options.

When selecting which options will be in the configuration, the optimization program considers dependent constraints. Many of the options cannot be considered separately. For example a Low-light Television cannot be installed on the helicopter if a FLIR system (Forward Looking Infrared) is not installed on the helicopter. This is because the Low-light Television is located in the same turret housing as the FLIR. Another example of dependency is the Digital Map and the Digital Cockpit. The Digital Map can not be installed if the Digital Cockpit is not installed because there will be no place to display the information.

Also some items will not be chosen if another item has already been chosen with the same functionality. Also an item will not be chosen if it is in conflict with an item that has already been chosen (it may need to occupy the same space in the helicopter). For example the analog and digital cockpit options could not both be chosen.

Dependency and conflict resolution are handled in the program in the following way:

If an option is not in the configuration it is assigned a value of 0.

If an option is in the configuration then it is assigned a value of 1.

(Thus it is a binary integer linear problem).

The dependency equation can be stated as follows:

Digital Map value (0 or 1) – Digital Cockpit value (0 or 1) <= 0 (Equation 1)

This ensures that the optimization program done in Microsoft Excel Solver will only choose the Digital Map option in the solution if the Digital Cockpit option is also in the optimal solution.

The conflict resolution equation can be stated as follows:

Digital Cockpit (0 or 1) + Analog Cockpit (0 or 1) <= 1 (Equation 2)

This ensures that an Analog Cockpit and a Digital Cockpit option could not end up simultaneously in the optimized configuration.

Although this ensures that both the Digital Cockpit and Analog Cockpit options are not both chosen I must add a further constraint. The customer must be constrained to choose a cockpit type (Digital or Analog) because the helicopter will not be functional without instruments in the cockpit (either Digital or Analog).

The following statement ensures that a cockpit type is chosen:

Digital Cockpit (0 or 1) + Analog Cockpit (0 or 1) = 1 (Equation 3)

Equations of the type represented by Equations 1 through 3 are used to model all of the constraints for all of the options.

The program starts with the base helicopter and its price ($10,250,000) and then adds the price of all options to give the final price which is constrained to be less than or equal to the customer's budget.

As options are chosen (receive a value of 1 by the program) their weights are summed with the weight of the base aircraft to arrive at the weight of the aircraft and all of its options. The program will constrain the weight to a threshold dependent on the customer's mission. A weight threshold (max allowable weight) for the optimization program may be determined in the following way:

Maximum Gross Weight for the Helicopter (22,000 pounds)
Minus
Full Fuel Weight (360 gallons X 6.7 pounds/gallon = 2,412 pounds)
Minus
Pilot and Co-Pilot Weight (200 pounds X 2 = 400 pounds)
Minus
Troop Weight Required (12 troops X 240 pounds/troop = 2,880 pounds)
Minus
Miscellaneous Mission Equipment Weight (200 pounds)

Performing the calculation:

22,000 – 2,412 – 400 – 2,880 – 200 = 16,108 pounds = Threshold Helicopter Weight

The program will constrain the weight to a threshold that is dependent on the customers mission. The weights of the options are listed in Table A-5.

As options are chosen (receive a value of 1 by the program) the equivalent flat plate drag of each option external to the helicopter is summed with the equivalent flat plate drag of the base aircraft to arrive at the equivalent flat plate drag of the aircraft and all of its options. The program will constrain the equivalent flat plate drag to a threshold that is dependent on the customer's mission. The equivalent flat plate drags for the options are listed in Table A-6.

In summary the program is constrained to find a solution that optimizes helicopter utility with the helicopter's price constrained. The program is also constrained to keep the weight of the options summed with the aircraft base weight less than or equal to the threshold weight (in this example 16,108 pounds). The program is also constrained to keep the total equivalent flat plate drag equal to or less then its threshold (for example 120 square feet). The final program solution optimizes helicopter utility to the customer (the objective function) while ensuring that all constraints are met.
Table A-7 lists the utility points that can be awarded for each option for each of the three iterations.

Tables A-8 through A-10 show the results of the optimization and the answer printout for each of the three iterations. (These are Excel files for each of the three iterations) Table A-11 is the Tableau that was entered into Excel Solver to set up all of the relationships and constraints necessary for the optimization. Table A-12 lists the optimal configuration for each of the three iterations. Running the three iterations showed that the configuration is not too sensitive to the relative utility values chosen. The resulting aircraft price, weight and drag data is shown in Table 2. The configurations determined by the optimization program were identical for iterations 1 and 2. There was some variation in iteration 3 but the resulting aircraft price was not significantly different (0.1 % less). There were a total of 8 configuration differences between iterations 2 and 3. This is not a large number of differences when you consider that there are 69 different options. The differences are summarized in Table 3. A few of the differences are significant such as whether the aircraft will have a flotation system or not. The decision whether or not to offer flotation would have to be decided by using judgement or if possible by consultation with the customer. Because the iterations demonstrated that the configuration is not too sensitive to the subjective relative utilities the program can be used with confidence that the configuration will to a great extent meet the customer’s intent. This confidence would not be possible without using a structured method such as the optimization program.

Table 2

Summary of Results for Iterations with Different Relative Values

	Price	**Weight**	**Drag**
Iteration 1	13,975,000	13,756	175
Iteration 2	13,975,000	13,756	175
Iteration 3	13,955,000	13,415	158

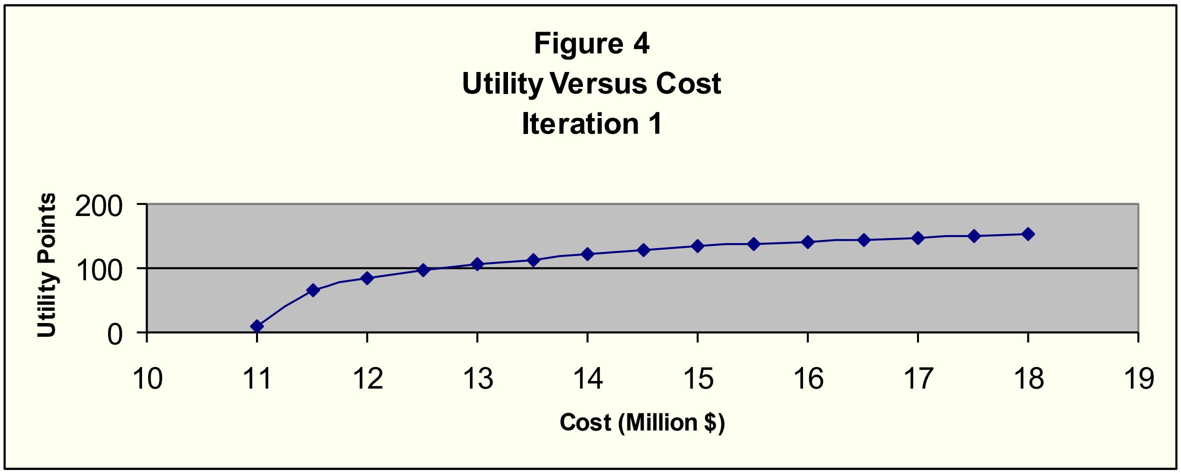
Table 3

Difference in configuration between different iterations
(1 is in the configuration, 0 is not in the configuration)

OPTION	**ITERATIONS 1 and 2**	**ITERATION 3**
Flight Director	1	0
Forward Looking Infra-red	1	0
Forward Looking Infra-red with Laser Range-finder	0	1
Flotation	1	0
Infra-red Countermeasures	1	0
Directional Infra-red Countermeasures	0	1
Missile Approach Warning System	1	0
Fixed Sight	1	0
Helmet Mounted Sight	0	1

Figure 4 shows a plot of utility versus cost for iteration 1 option utility values. Utility values were calculated by the optimization program with the maximum cost constrained in intervals between 11,000,000 and 18,000,000 dollars. The program was run 15 times with the maximum allowable cost constraint increased each time by 500,000 dollars and the program calculated the corresponding utility. This method resulted in the 15 data points for utility versus cost that are plotted.

The plot of utility versus cost is important if the customer's budget is not fixed or if the customer is trying to establish a budget. It can be seen from this graph, that once the price reaches 16 million dollars, very little additional utility is gained as the price is increased. Therefore 16 million dollars would be a logical ceiling for the price. This type of analysis can be done internally by the manufacturer to arrive at a competitive pricing strategy. This type of analysis can also be shared with the customer as the situation dictates. This plot is an example of useful data that would not be available without using a helicopter configuration optimization technique.



Cost (M$)	Utility
11	10
11.5	67
12	84
12.5	97
13	106
13.5	113
14	121
14.5	128
15	133
15.5	138
16	141
16.5	144
17	148
17.5	149
18	153

Chapter 5: Conclusions and Recommendations

Helicopter configuration optimization starts with good customer requirements definition. Good requirements definition can best be achieved through customer visits and carefully written surveys. The requirements should be written in a quantitative rather than subjective form wherever possible. It is important for the manufacturer to keep a requirements database. A database allows requirements gathered from different sources to be merged. Once the requirements are known, optimization programming can lead to a helicopter configuration (equipment list) that best meets the customer's needs while not exceeding his budget.

The integer linear programming model I formulated allows me to calculate a utility function for the customer based on his budget. If the customer's budget changes then I can calculate a new utility function and easily evaluate the changes to the helicopter configuration. In each case the helicopter configuration is optimal for the given budget. If the customer changes the relative importance of some mission or piece of equipment then I can quickly make the change in my program and evaluate the effect on the helicopter configuration.

Using a structured technique such as my optimization program makes it apparent to people that did not make the configuration decisions, why the decisions were made. This adds credibility to the solution and helps to avoid arguments within our company.

If systems optimization techniques are not used for helicopter configuration definition then a trial and error method is used. If there are many options the trial and error method is unwieldy and results in a sub-optimal solution. Even with the optimization technique some judgement is required when quantifying the relative importance of items to the customer (If possible it is best to have the customer involved in this process). Optimization programming also streamlines the proposal process by making it more structured.

Once a proposal becomes a contract, optimization programming will also benefit the manufacturing process. The optimization program generated configuration could automatically generate a Bill Of Material for a Build To Order (BTO) system. Automating the process of generating the bill of material will save a lot of man-hours for the manufacturer. Demonstrating this manufacturing automation starting from the configuration optimization program could be the subject of future work. Figure 5 illustrates how the output of the configuration optimization program feeds the manufacturing process.

For simple customer requirements, helicopter configuration optimization programming may not be required. However it is recommended that optimization programming be used in all other cases. The time spent inputting data into the optimization program will produce great benefits for the manufacturer and the customer. The result can be success for the helicopter manufacturer in the highly competitive international marketplace.

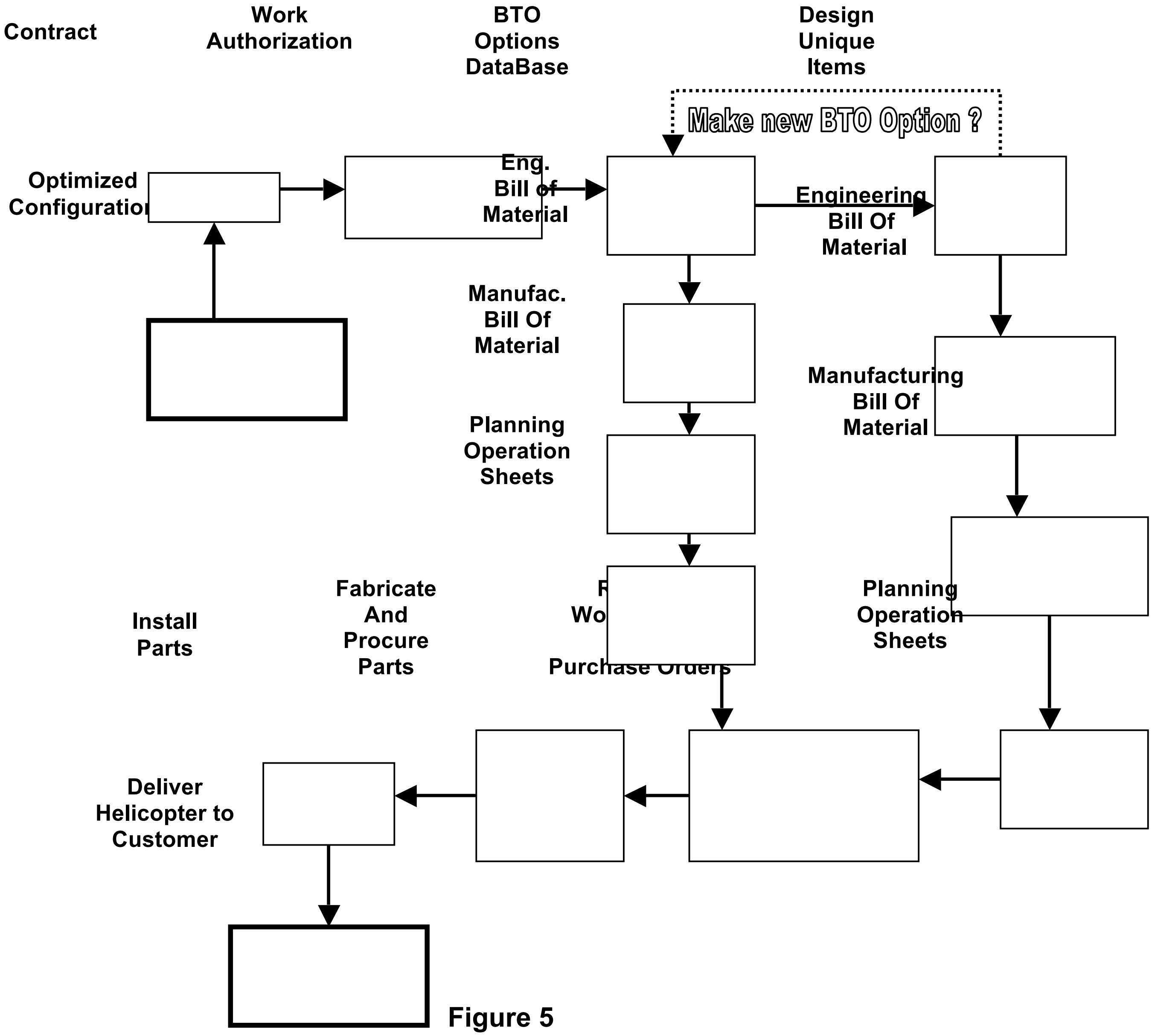


Figure 5
Optimized Configuration Feeds the Manufacturing System

APPENDIX A

Table A-1
Initial Survey to Determine Customer Requirements
Top Level Requirements

Customer Data:

Name _________

Organization _____

Title _____

Phone Number _____

Fax Number _____

Mailing Address _____

E-mail Address _____

Date Survey Completed _____

Missions:
Please rank the following missions from 0 through 10 with 10 being the most important and 0 being not important at all.

Search and Rescue _____

Combat Search and Rescue _____

Anti-Submarine Warfare _____

Anti-Ship Warfare _____

Anti-Tank Warfare _____

VIP Transport _____

Medical Evacuation _____

Combat Assault Operations _____

Shipboard Vertical Replenishment Operations _____

Limited Shipboard Operations _____

Long Term Shipboard Operations _____

Table A-2
Initial Survey to Determine Customer Requirements
Detailed Mission Requirements

Note: If unsure then it is perfectly correct to leave a question blank or add a note that the information is uncertain

Customer Data:

Name _________

Organization _____

Title _____

Phone Number _____

Fax Number _____

Mailing Address _____

E-mail Address _____

Date Survey Completed _____

Missions:
Please rank the following missions from 0 through 10 with 10 being the most important and 0 being not important at all.

Search and Rescue _____

Combat Search and Rescue _____

Anti-Submarine Warfare _____

Anti-Ship Warfare _____

Anti-Tank Warfare _____

VIP Transport _____

Medical Evacuation _____

Combat Assault Operations _____

Shipboard Vertical Replenishment Operations _____

Limited Shipboard Operations _____

Long Term Shipboard Operations _____

NATO Interoperability _____

Instrument Flight Rules Operation in Civil Airspace _____

Tactical Nap Of the Earth (NOE) Operations _____

Night Vision Goggle Missions _____

Environment and Mission Capabilities:

What temperature range (Celsius) will the helicopter operate in? __________

What types of terrain will the helicopter operate in? (Mountainous, flat etc.) __________

Will the helicopter operate in a sand environment? _____

Will the helicopter operate in a salt water environment? _____

Will the helicopter make snow landings? _____

Will the helicopter fly in icing conditions? _____

What is the maximum altitude the aircraft will operate at? Enroute _____ Hover _____

What is the minimum ceiling and visibility the helicopter will operate in? _____

What percent of time will be spent flying over water? _____

What is the range required? _____

What time on station is required at this range? _____

What is the required endurance (minutes)? _____

What is the required Service Ceiling enroute? _____

What are the required In Ground Effect and Out of Ground Effect Hover Ceilings ? _____ , _____

Is One Engine Inoperative (OEI) performance required? _____

Is Category A takeoff performance required? _____

What Reliability/Availability is required for each mission? _____

How many troops/passengers must be carried and what are their weights? _____

What is the maximum amount of weight that must be carried internally and externally? _____ , _____

What are the dimensions of large loads that may be carried internally? _____

What communications frequencies are required? _____

What is the range required for the communications? _____

Is secure communications required? _____

How important (0 to 10) are the following navigational aids?

Non-Directional Beacon (NDB)?_____

VHF Omni Range (VOR)? _____

Tactical Navigation (TACAN) _____

Distance Measuring Equipment (DME) _____

Instrument Landing System (ILS) _____

Global Positioning System (GPS) _____

What if any aircraft will be used to air-transport the helicopter? _____

How important (0 to 10) is it to guard against the following threats?

Small Arms Fire _____

Surface to Air Missiles (SAM) _____

Radar Controlled Weapons _____

What are the certification requirements if any? (FAA, CAA, JAA) _____

Administrative:

How many helicopters do you plan to procure? _____

When would you like delivery of the helicopters? _____

Do you have funding for the helicopters? _____

If no current funding, when is funding expected? _____

Would you procure the helicopters directly form the manufacturer or through the U.S. Government? _____

When do you expect to release a Request For Information (RFI)? ______

When do you expect to release a Request For Proposal (RFP)? _____

Will the procurement be sole source or a competition? _____

Table A-3
Initial Survey to Determine Customer Requirements
Detailed Mission and Equipment Requirements

Note: If unsure then it is perfectly correct to leave a question blank or add a note that the information is uncertain.

Customer Data:

Name __________

Organization _____

Title _____

Phone Number _____

Fax Number _____

Mailing Address _____

E-mail Address _____

Date Survey Completed _____

Missions:
Please rank the following missions from 0 through 10 with 10 being the most important and 0 being not important at all.

Search and Rescue _____

Combat Search and Rescue _____

Anti-Submarine Warfare _____

Anti-Ship Warfare _____

Anti-Tank Warfare _____

VIP Transport _____

Medical Evacuation _____

Combat Assault Operations _____

Shipboard Vertical Replenishment Operations _____

Limited Shipboard Operations _____

Long Term Shipboard Operations _____

NATO Interoperability _____

Instrument Flight Rules Operation in Civil Airspace _____

Tactical Nap Of the Earth (NOE) Operations _____

Night Vision Goggle Missions _____

Environment and Mission Capabilities:

What temperature range (Celsius) will the helicopter operate in? __________

What types of terrain will the helicopter operate in? (Mountainous, flat etc.) __________

Will the helicopter operate in a sand environment? _____

Will the helicopter operate in a salt water environment? _____

Will the helicopter make snow landings? _____

Will the helicopter fly in icing conditions? _____

What is the maximum altitude the aircraft will operate at? Enroute _____ Hover _____

What is the minimum ceiling and visibility the helicopter will operate in? _____

What percent of time will be spent flying over water? _____

What is the range required? _____

What time on station is required at this range? _____

What is the required endurance (minutes)? _____

What is the required Service Ceiling enroute? _____

What are the required In Ground Effect and Out of Ground Effect Hover Ceilings ? _____ , _____

Is One Engine Inoperative (OEI) performance required? _____

Is Category A takeoff performance required? _____

What Reliability/Availability is required for each mission? _____

How many troops/passengers must be carried and what are their weights? _____

What is the maximum amount of weight that must be carried internally and externally?
_____ , _____

What are the dimensions of large loads that may be carried internally? _____

What communications frequencies are required? _____

What is the range required for the communications? _____

Is secure communications required? _____

How important (0 to 10) are the following navigational aids?

Non-Directional Beacon (NDB)?_____

VHF Omni Range (VOR)? _____

Tactical Navigation (TACAN) _____

Distance Measuring Equipment (DME) _____

Instrument Landing System (ILS) _____

Global Positioning System (GPS) _____

What if any aircraft will be used to air-transport the helicopter? _____

How important (0 to 10) is it to guard against the following threats?

Small Arms Fire _____

Surface to Air Missiles (SAM) _____

Radar Controlled Weapons _____

What are the certification requirements if any? (FAA, CAA, JAA) _____

Equipment Manufacturer Preference:
The following equipment is available as a standard option from more than 1 supplier. Please note your preference for a specific manufacturer by placing a number from 0 to 10 next to the manufacturer with 10 being the most desirable manufacturer.
Communication Radios:

Collins _____

Honeywell _____

Navigation Equipment:

Collins _____

Honeywell _____

Weather Radar:

Bendix 1400C _____

Primus 700 _____

Forward Looking Infra-red:

Elbit _____

FLIR Inc. _____

Rescue Hoist:

Breeze Eastern _____

Lucas Aerospace _____

Administrative:

How many helicopters do you plan to procure? _____

When would you like delivery of the helicopters? _____

Do you have funding for the helicopters? _____

If no current funding, when is funding expected? _____

Would you procure the helicopters directly form the manufacturer or through the U.S.

Government? _____

When do you expect to release a Request For Information (RFI)? ______

When do you expect to release a Request For Proposal (RFP)? _____

Will the procurement be sole source or a competition? _____

Table A-4 : List of Helicopter Options and Associated Price Data

(Note: Pricing policy is company sensitive information. Therefore, the prices shown are not accurate but are useful in demonstrating how the optimization program works.)

Base Aircraft **Price = $ 10,000,000**

The final price of the aircraft will be based on the helicopter base price and the price of the options chosen from the following list:

OPTIONS:	**PRICE ($1,000)**
Analog Cockpit	100
Digital Cockpit	600
Flight Director	210
Flight Director with 4-Axis Coupled Navigation	700
Communications:	
Very High Frequency/Amplitude Modulation (VHF/AM) Radio	50
Very High Frequency/Frequency Modulation (VHF/FM) Radio	40
VHF/FM Radio Encryption	70
Ultra High Frequency/Amplitude Modulation (UHF/AM) Radio	70
High Frequency (HF) Radio	70
Cellular Telephone	25
Microwave Data Link System	310

Transponder	15
Transponder with Mode S	25
Emergency Locator Beacon	7
Navigation Equipment :	
VHF Omni Range/ Instrument Landing (VOR/ILS)	110
Low Frequency Automatic Direction Finder (LF/ADF)	40
Global Positioning System (GPS)	55
Inertial Navigation System (INS)	47
Doppler Navigation	58
Distance Measuring Equipment (DME)	40
Digital Moving Map	80
Search And Rescue Direction Finder (SAR/DF)	130
Mission Equipment :	
Weather Radar with Ground Mapping	120
Weather Radar without Ground Mapping	160
360 Degree Search Radar	500
Forward Looking Infra-Red Optronics	210
Forward Looking Infra-Red w/laser Range-finder and Designator	410
Low-Light Television	50
Cargo Hook	20
Rescue Hoist	80

Flotation System	200
Medical Evacuation Kit	60
Cargo Loading Kit	40
Kit for Operation at Extreme Temperatures	20
High Power Searchlight	66
Loud-speaker System	17
External Mirrors	9
Storm-scope Lightening Detector	44
Radar	57
Air conditioning	240
Cockpit Voice Recorder and Flight Data Recorder (CVR/FDR)	470
Rotor Brake	100
Fast Rope System for Deploying Troops	22
Rappelling System for Deploying Troops	5
Underwater Sonic Locator	7
Helicopter Emergency Egress Lighting System (HEELS)	87
Auxiliary Fuel System	350
Engine Inlet Particle Separator (IPS)	247
Automatic Blade Fold	756
Snow Ski Kit	11
Fire-Fighting Kit	12

VIP Interior	568
VIP Removable Interior Kit	345
Bubble Windows in Cabin	8
Aircraft Survivability Equipment :	
Chaff/Flare Dispensers	2
Infra-red Countermeasures	30
Directed Infra-red Countermeasures	270
Laser Warning System	170
Missile Warning System	200
Radar Warning System	300
Weapons Systems:	
7.62 mm Guns	18
.50 Caliber Machine Guns	60
Aircraft Fixed Sighting System	40
Helmet Mounted Sighting System	190
Hell-Fire Anti-Tank Missiles	1,000
Stinger Air-To-Air Missiles	800
Penguin Anti-Ship Missiles	1,200
2.75 inch Unguided Rockets	270

Table A-5: List of Helicopter Options and Associated Weight Data
The maximum allowable gross weight for the helicopter is 22,000 pounds. The threshold weight for the program is dependent on the specific mission requirements.
The helicopter weight is determined by adding the option weights to the base aircraft weight. (Note the weights used are to demonstrate the concepts involved and are not necessarily exact weights for the systems).

Base Aircraft Weight	**14,000 lb**
OPTIONS:	**WEIGHTS (lb)**
Analog Cockpit	200
Digital Cockpit	100
Flight Director	50
Flight Director with 4-Axis Coupled Navigation	150
Communications:	
Very High Frequency/Amplitude Modulation (VHF/AM) Radio	20
Very High Frequency/Frequency Modulation (VHF/FM) Radio	20
VHF/FM Radio Encryption	10
Ultra High Frequency/Amplitude Modulation (UHF/AM) Radio	20
High Frequency (HF) Radio	25
Cellular Telephone	10
Microwave Data Link System	80
Transponder	15
Transponder with Mode S	15

Emergency Locator Beacon	5
Navigation Equipment :	
VHF Omni Range/ Instrument Landing	28
(VOR/ILS)	
Low Frequency Automatic Direction Finder (LF/ADF)	22
Global Positioning System (GPS)	23
Inertial Navigation System (INS)	32
Doppler Navigation	59
Distance Measuring Equipment (DME)	30
Digital Moving Map	45
Search And Rescue Direction Finder (SAR/DF)	56
Mission Equipment :	
Weather Radar with Ground Mapping	60
Weather Radar without Ground Mapping	60
360 Degree Search Radar	150
Forward Looking Infra-Red Optronics	140
Forward Looking Infra-Red	189
w/laser Range-finder and Designator	
Low-Light Television	30
Cargo Hook	20
Rescue Hoist	120
Flotation System	400
Medical Evacuation Kit	65

Cargo Loading Kit	25
Kit for Operation at Extreme Temperatures	15
High Power Searchlight	45
Loud-speaker System	26
External Mirrors	11
Storm-scope Lightening Detector	22
Radar Altimeter	18
Air conditioning	170
Cockpit Voice Recorder and Flight Data Recorder (CVR/FDR)	27
Rotor Brake	102
Fast Rope System for Deploying Troops	29
Rappelling System for Deploying Troops	13
Underwater Sonic Locator	3
Helicopter Emergency Egress Lighting System (HEELS)	49
Auxiliary Fuel System	450
Engine Inlet Particle Separator (IPS)	46
Automatic Blade Fold	202
Snow Ski Kit	69
Fire-Fighting Kit	102
VIP Interior	578
VIP Removable Interior Kit	604

Bubble Windows in Cabin	12
Aircraft Survivability Equipment :	
Chaff/Flare Dispensers	22
Infra-red Countermeasures	8
Directed Infra-red Countermeasures	102
Laser Warning System	29
Missile Warning System	33
Radar Warning System	33
Weapons Systems:	
7.62 mm Guns	36
.50 Caliber Machine Guns	102
Aircraft Fixed Sighting System	10
Helmet Mounted Sighting System	9
Hell-Fire Anti-Tank Missiles	207
Stinger Air-To-Air Missiles	124
Penguin Anti-Ship Missiles	231
2.75 inch Unguided Rockets	127

Table A-6
List of Helicopter Options and Associated Equivalent Flat Plate Drag Data

The threshold flat plate drag for the program is dependent on the specific mission requirements.

The helicopter flat plate drag is determined by adding the option flat plate drag to the base aircraft flat plate drag. (Note the flat plate drags used are to demonstrate the concepts involved and are not necessarily exact for the systems).

Base Aircraft Flat Plate Drag	**105 Square Feet**
OPTIONS:	**Equivalent Flat Plate Drag (Square Feet)**
Microwave Data Link System	5
Weather Radar with Ground Mapping	4
Weather Radar without Ground Mapping	4
360 Degree Search Radar	10
Forward Looking Infra-Red Optronics	5
Forward Looking Infra-Red w/laser Range-finder and Designator	5
Rescue Hoist	3
Flotation System	20
High Power Searchlight	3
Loud-speaker System	6
External Mirrors	1
Auxiliary Fuel System	7
Engine Inlet Particle Separator (IPS)	2

Automatic Blade Fold	2
Snow Ski Kit	3
Fire-Fighting Kit	12
Bubble Windows in Cabin	2
Chaff/Flare Dispensers	2
Infra-red Countermeasures	1
Directed Infra-red Countermeasures	6
Laser Warning System	2
Missile Warning System	2
Radar Warning System	1
.50 Caliber Machine Guns	2
Hell-Fire Anti-Tank Missiles	5
Stinger Air-To-Air Missiles	4
Penguin Anti-Ship Missiles	5
2.75 inch Unguided Rockets	5

Table A-7				
Utility Points that can be Awarded for each of Three Iterations				
(0 points are awarded if option is mandatory for the customer or is not required by the customer)				
OPTION	**Requirement Type (Shall, Should 1, Should 2, Should 3)**	**UTILITY POINTS ITERATION 1**	**UTILITY POINTS ITERATION 2**	**UTILITY POINTS ITER 3**
Analog Cockpit	Not Required			
Digital Cockpit	Should 1	3	5	10
Flight Director	Should 2	2	3	4
Flight Director with 4-Axis Coupled Navigation	Should 1	3	5	10
Communications:				
Very High Frequency/Amplitude Modulation (VHF/AM) Radio	Shall	Shall	Shall	Shall
Very High Frequency/Frequency Modulation (VHF/FM) Radio	Shall	Shall	Shall	Shall
VHF/FM Radio Encryption	Should 3	1	1	2
Ultra High Frequency/Amplitude Modulation (UHF/AM) Radio	Shall	Shall	Shall	Shall
High Frequency (HF) Radio	Shall	Shall	Shall	Shall

Cellular Telephone	Should 2	2	3	4
Microwave Data Link System	Not Required			
Transponder	Shall	Shall	Shall	Shall
Transponder with Mode S	Should 1	3	5	10
Emergency Locator Beacon	Shall	Shall	Shall	Shall
Navigation Equipment				
VHF Omni Range/ Instrument Landing (VOR/ILS)	Shall	Shall	Shall	Shall
Low Frequency Automatic Direction Finder (LF/ADF)	Shall	Shall	Shall	Shall
Global Positioning System (GPS)	Should 2	2	3	4
Inertial Navigation System (INS)	Should 2	2	3	4
Doppler Navigation	Should 3	1	1	2
Distance Measuring Equipment (DME)	Should 1	3	5	10
Digital Moving Map	Should 2	2	3	4
Search And Rescue Direction Finder (SAR/DF)	Should 3	1	1	2
Mission Equipment :				
Weather Radar	Should 2	2	3	4

Weather Radar with Ground Mapping	Should 1	3	5	10
360 Degree Search Radar	Not Required			
Forward Looking Infra-Red Optronics	Should 2	2	3	4
Forward Looking Infra-Red w/laser Range-finder and Designator	Should 1	3	5	10
Low-Light Television	Should 2	2	3	4
Cargo Hook	Should 1	3	5	10
Rescue Hoist	Shall	Shall	Shall	Shall
Flotation System	Should 2	2	3	4
Medical Evacuation Kit	Should 1	3	5	10
Cargo Loading Kit	Should 3	1	1	2
Kit for Operation at Extreme Temperatures	Should 2	2	3	4
High Power Searchlight	Should 2	2	3	4
Loud-speaker System	Should 3	1	1	2
External Mirrors	Should 3	1	1	2
Storm-scope Lightening Detector	Not Required			
Radar Altimeter	Should 1	3	5	10
Air conditioning	Shall	Shall	Shall	Shall
Cockpit Voice Recorder and Flight Data Recorder	Should 3	1	1	2

Rotor Brake	Should 2	2	3	4
Fast Rope System for Deploying Troops	Should 1	3	5	10
Rappelling System for Deploying Troops	Should 1	3	5	10
Underwater Sonic Locator	Should 3	1	1	2
Helicopter Emergency Egress Lighting System (HEELS)	Should 2	2	3	4
Auxiliary Fuel System	Should 1	3	5	10
Engine Inlet Particle Separator (IPS)	Should 1	3	5	10
Automatic Blade Fold	Not Required			
Snow Ski Kit	Shall	Shall	Shall	Shall
Fire-Fighting Kit	Not Required			
VIP Interior	Not Required			
VIP Removable Interior Kit	Not Required			
Bubble Windows in Cabin	Should 1	3	5	10
Aircraft Survivability Equipment :				
Chaff/Flare Dispensers	Should 1	3	5	10
Infra-red Countermeasures	Should 2	2	3	4

Directed Infra-red Countermeasures	Should 1	3	5	10
Laser Warning System	Should 2	2	3	4
Missile Warning System	Should 2	2	3	4
Radar Warning System	Should 2	2	3	4
Weapons Systems:				
7.62 mm Guns	Shall	Shall	Shall	Shall
.50 Caliber Machine Guns	Should 1	3	5	10
Aircraft Fixed Sighting System	Should 2	2	3	4
Helmet Mounted Sighting System	Should 1	3	5	10
Hell-Fire Anti-Tank Missiles	Should 1	3	5	10
Stinger Air-To-Air Missiles	Should 1	3	5	10
Penguin Anti-Ship Missiles	Should 1	3	5	10
2.75 inch Unguided Rockets	Should 1	3	5	10

Table A-8
Iteration 1
Helicopter Configuration Optimization Summary

MAXIMUM ALLOWABLE HELICOPTER PRICE ($)	14,000,000	**HELICOPTER PRICE**	13,975,000	**TOTAL UTILITY POINTS AWARDED**	78
MAXIMUM ALLOWABLE WEIGHT (Lb)	16,108	**HELICOPTER WEIGHT**	13,756		
MAXIMUM ALLOWABLE DRAG (SQ FT)	205	**HELICOPTER DRAG**	175		

Table A-8 continued

Microsoft Excel 8.0a Answer Report
Worksheet: [Iteration1.xls]Tableau

Target Cell (Max)

Adjustable Cells

Name	Final Value
TOTAL UTILITY POINTS AWARDED	78

Name	Final Value
Digital Cockpit	0
Flight Director	1
4-axis Coupled	0
VHF/AM Radio	0
VHF/FM Radio	0
VHF/FM Radio Encryption	1
UHF/AM Radio	1
HF Radio	1
Cell Phone	1
Microwave Data Link	0
Transponder	0
Transponder w/Mode S	1
Emergency Locator Transmitter	1
VOR/ILS Navigation System	1
LF/ADF Navigation System	0
GPS Navigation System	1
Inertial Navigation System	1
Doppler Navigation System	1
Distance Measuring Equipment	1
Digital Moving Map	0
Search and Rescue Direction Finder	0
Weather radar	0
Weather Radar w/Ground Mapping	1
360 Degree Search Radar	0
Forward Looking Infra-red Optronics	1

Forward Looking Infra-red Optronics w/Range-finder and Laser Designator	0
Low Light TV	1
Cargo Hook	1
Rescue Hoist	1
Flotation System	1
Medical Evacuation Kit	1
Cargo Loading Kit	1
Extreme Temperature Operations Kit	1
High Power Searchlight	1
Loud Speaker System	1
External Mirrors	1
Storm-Scope Lightening Detector	0
Radar Altimeter	1
Air Conditioning	1
Cockpit Voice Recorder and Flight Data Recorder	0
Rotor Brake	1
Fast Rope System for Deploying Troops	1
Rappelling System for Deploying Troops	1
Underwater Sonic Locator	1
Emergency Egress Lighting System	1
Auxiliary Fuel System	1
Engine Inlet Particle Separator	1
Automatic Blade Fold	0
Snow Ski Kit	1
Fire-Fighting Kit	0
VIP Interior	0
VIP KIT	0
Bubble Windows in Cabin	1
Chaff/Flare Dispensers	1
Infra-red Countermeasures	1
Directed Infra-red Countermeasures	0
Laser Warning System	1
Missile Warning System	1
Radar Warning System	0
7.62 mm Machine Guns	0

.50 Caliber Machine Guns	1
Fixed Sighting System	1
Helmet Mounted Sighting System	0
HellFire Anti-tank missiles	0
Stinger Air to Air Missiles	0
Penguin Anti-ship Missiles	0
2.75 inch Unguided Rockets	1

Constraints

Name	Cell Value	Status	Slack
PRICE	13,975,000	Not Binding	25000
HELICOPTER WEIGHT	13,756	Not Binding	2352
HELICOPTER DRAG	175	Not Binding	30
MUST CHOOSE EITHER ANALOG OR DIGITAL COCKPIT	1	Not Binding	0
CAN CHOOSE AT MOST 1 RADAR	1	Binding	0
MUST CHOOSE EITHER VHF/FM WITH OR WITHOUT ENCRYPTION	1	Not Binding	0
CAN ONLY CHOOSE DME IF VOR/ILS IS CHOSEN	0	Binding	0
CAN ONLY CHOOSE DIGITAL MAP IF DIGITAL COCKPIT IS CHOSEN	0	Binding	0
CAN CHOOSE AT MOST 1FLIR	1	Binding	0
CAN ONLY CHOOSE LOW LIGHT TV IF A FLIR IS CHOSEN	0	Binding	0
CAN CHOOSE AT MOST 1 VIP INTERIOR	0	Not Binding	1
CAN CHOOSE AT MOST 1 TYPE OF INFRA-RED COUNTERMEASURE	1	Binding	0
CAN CHOOSE AT MOST 1 TYPE OF WEAPONS SIGHT	1	Binding	0
MUST CHOOSE EITHER TRANSPONDER WITH OR WITHOUT MODE S	1	Not Binding	0

MUST HAVE UHF/AM RADIO	1	Not Binding	0
MUST HAVE HF RADIO	1	Not Binding	0
MUST HAVE EMERGENCY LOCATOR TRANSMITTER	1	Not Binding	0
MUST HAVE VOR/ILS	1	Not Binding	0
MUST HAVE RESCUE HOIST	1	Not Binding	0
MUST HAVE AIR CONDITIONING	1	Not Binding	0
MUST HAVE SNOW SKIS	1	Not Binding	0
Analog Cockpit	1	Binding	0
Digital Cockpit	0	Binding	0
Flight Director	1	Binding	0
4-axis Coupled	0	Binding	0
VHF/AM Radio	0	Binding	0
VHF/FM Radio	0	Binding	0
VHF/FM Radio Encryption	1	Binding	0
UHF/AM Radio	1	Binding	0
HF Radio	1	Binding	0
Cell Phone	1	Binding	0
Microwave Data Link	0	Binding	0
Transponder	0	Binding	0
Transponder w/Mode S	1	Binding	0
Emergency Locator Transmitter	1	Binding	0
VOR/ILS Navigation System	1	Binding	0
LF/ADF Navigation System	0	Binding	0
GPS Navigation System	1	Binding	0
Inertial Navigation System	1	Binding	0
Doppler Navigation System	1	Binding	0
Distance Measuring Equipment	1	Binding	0
Digital Moving Map	0	Binding	0
Search and Rescue Direction Finder	0	Binding	0
Weather radar	0	Binding	0
Weather Radar w/Ground Mapping	1	Binding	0
360 Degree Search Radar	0	Binding	0
Forward Looking Infra-red Optronics	1	Binding	0
Forward Looking Infra-red Optronics w/Range-finder	0	Binding	0

and Laser Designator			
Low Light TV	1	Binding	0
Cargo Hook	1	Binding	0
Rescue Hoist	1	Binding	0
Flotation System	1	Binding	0
Medical Evacuation Kit	1	Binding	0
Cargo Loading Kit	1	Binding	0
Extreme Temperature Operations Kit	1	Binding	0
High Power Searchlight	1	Binding	0
Loud Speaker System	1	Binding	0
External Mirrors	1	Binding	0
Storm-Scope Lightening Detector	0	Binding	0
Radar Altimeter	1	Binding	0
Air Conditioning	1	Binding	0
Cockpit Voice Recorder and Flight Data Recorder	0	Binding	0
Rotor Brake	1	Binding	0
Fast Rope System for Deploying Troops	1	Binding	0
Rappelling System for Deploying Troops	1	Binding	0
Underwater Sonic Locator	1	Binding	0
Emergency Egress Lighting System	1	Binding	0
Auxiliary Fuel System	1	Binding	0
Engine Inlet Particle Separator	1	Binding	0
Automatic Blade Fold	0	Binding	0
Snow Ski Kit	1	Binding	0
Fire-Fighting Kit	0	Binding	0
VIP Interior	0	Binding	0
VIP KIT	0	Binding	0
Bubble Windows in Cabin	1	Binding	0
Chaff/Flare Dispensers	1	Binding	0
Infra-red Countermeasures	1	Binding	0
Directed Infra-red Countermeasures	0	Binding	0
Laser Warning System	1	Binding	0
Missile Warning System	1	Binding	0
Radar Warning System	0	Binding	0
7.62 mm Machine Guns	0	Binding	0
.50 Caliber Machine Guns	1	Binding	0

Fixed Sighting System	1	Binding	0
Helmet Mounted Sighting System	0	Binding	0
HellFire Anti-tank missiles	0	Binding	0
Stinger Air to Air Missiles	0	Binding	0

Table A-9
Iteration 2
Helicopter Configuration Optimization Summary

MAXIMUM ALLOWABLE HELICOPTER PRICE ($)	14,000,000	**HELICOPTER PRICE**	13,975,000	**TOTAL UTILITY POINTS AWARDED**	121
MAXIMUM ALLOWABLE WEIGHT (Lb)	16,108	**HELICOPTER WEIGHT**	13,756		
MAXIMUM ALLOWABLE DRAG (SQ FT)	205	**HELICOPTER DRAG**	175		

Table A-9 continued

Microsoft Excel 8.0a Answer Report
Worksheet: [Iteration2.xls]Tableau

Target Cell (Max)

Adjustable Cells

Name	Final Value
TOTAL UTILITY POINTS AWARDED	121

Name	Final Value
Digital Cockpit	0
Flight Director	1
4-axis Coupled	0
VHF/AM Radio	0
VHF/FM Radio	0
VHF/FM Radio Encryption	1
UHF/AM Radio	1
HF Radio	1
Cell Phone	1
Microwave Data Link	0
Transponder	0
Transponder w/Mode S	1
Emergency Locator Transmitter	1
VOR/ILS Navigation System	1
LF/ADF Navigation System	0
GPS Navigation System	1
Inertial Navigation System	1
Doppler Navigation System	1
Distance Measuring Equipment	1
Digital Moving Map	0
Search and Rescue Direction Finder	0
Weather radar	0
Weather Radar w/Ground Mapping	1
360 Degree Search Radar	0
Forward Looking Infra-red Optronics	1

Forward Looking Infra-red Optronics w/Range-finder and Laser Designator	0
Low Light TV	1
Cargo Hook	1
Rescue Hoist	1
Flotation System	1
Medical Evacuation Kit	1
Cargo Loading Kit	1
Extreme Temperature Operations Kit	1
High Power Searchlight	1
Loud Speaker System	1
External Mirrors	1
Storm-Scope Lightening Detector	0
Radar Altimeter	1
Air Conditioning	1
Cockpit Voice Recorder and Flight Data Recorder	0
Rotor Brake	1
Fast Rope System for Deploying Troops	1
Rappelling System for Deploying Troops	1
Underwater Sonic Locator	1
Emergency Egress Lighting System	1
Auxiliary Fuel System	1
Engine Inlet Particle Separator	1
Automatic Blade Fold	0
Snow Ski Kit	1
Fire-Fighting Kit	0
VIP Interior	0
VIP KIT	0
Bubble Windows in Cabin	1
Chaff/Flare Dispensers	1
Infra-red Countermeasures	1
Directed Infra-red Countermeasures	0
Laser Warning System	1
Missile Warning System	1
Radar Warning System	0
7.62 mm Machine Guns	0

.50 Caliber Machine Guns	1
Fixed Sighting System	1
Helmet Mounted Sighting System	0
HellFire Anti-tank missiles	0
Stinger Air to Air Missiles	0
Penguin Anti-ship Missiles	0
2.75 inch Unguided Rockets	1

Constraints

Name	Cell Value	Status	Slack
PRICE	13,975,000	Not Binding	25000
HELICOPTER WEIGHT	13,756	Not Binding	2352
HELICOPTER DRAG	175	Not Binding	30
MUST CHOOSE EITHER ANALOG OR DIGITAL COCKPIT	1	Not Binding	0
CAN CHOOSE AT MOST 1 RADAR	1	Binding	0
MUST CHOOSE EITHER VHF/FM WITH OR WITHOUT ENCRYPTION	1	Not Binding	0
CAN ONLY CHOOSE DME IF VOR/ILS IS CHOSEN	0	Binding	0
CAN ONLY CHOOSE DIGITAL MAP IF DIGITAL COCKPIT IS CHOSEN	0	Binding	0
CAN CHOOSE AT MOST 1FLIR	1	Binding	0
CAN ONLY CHOOSE LOW LIGHT TV IF A FLIR IS CHOSEN	0	Binding	0
CAN CHOOSE AT MOST 1 VIP INTERIOR	0	Not Binding	1
CAN CHOOSE AT MOST 1 TYPE OF INFRA-RED COUNTERMEASURE	1	Binding	0
CAN CHOOSE AT MOST 1 TYPE OF WEAPONS SIGHT	1	Binding	0
MUST CHOOSE EITHER TRANSPONDER WITH OR WITHOUT MODE S	1	Not Binding	0
MUST HAVE UHF/AM	1	Not Binding	0

RADIO			
MUST HAVE HF RADIO	1	Not Binding	0
MUST HAVE EMERGENCY LOCATOR TRANSMITTER	1	Not Binding	0
MUST HAVE VOR/ILS	1	Not Binding	0
MUST HAVE RESCUE HOIST	1	Not Binding	0
MUST HAVE AIR CONDITIONING	1	Not Binding	0
MUST HAVE SNOW SKIS	1	Not Binding	0
Analog Cockpit	1	Binding	0
Digital Cockpit	0	Binding	0
Flight Director	1	Binding	0
4-axis Coupled	0	Binding	0
VHF/AM Radio	0	Binding	0
VHF/FM Radio	0	Binding	0
VHF/FM Radio Encryption	1	Binding	0
UHF/AM Radio	1	Binding	0
HF Radio	1	Binding	0
Cell Phone	1	Binding	0
Microwave Data Link	0	Binding	0
Transponder	0	Binding	0
Transponder w/Mode S	1	Binding	0
Emergency Locator Transmitter	1	Binding	0
VOR/ILS Navigation System	1	Binding	0
LF/ADF Navigation System	0	Binding	0
GPS Navigation System	1	Binding	0
Inertial Navigation System	1	Binding	0
Doppler Navigation System	1	Binding	0
Distance Measuring Equipment	1	Binding	0
Digital Moving Map	0	Binding	0
Search and Rescue Direction Finder	0	Binding	0
Weather radar	0	Binding	0
Weather Radar w/Ground Mapping	1	Binding	0
360 Degree Search Radar	0	Binding	0
Forward Looking Infra-red Optronics	1	Binding	0
Forward Looking Infra-red Optronics w/Range-finder and Laser Designator	0	Binding	0

Low Light TV	1	Binding	0
Cargo Hook	1	Binding	0
Rescue Hoist	1	Binding	0
Flotation System	1	Binding	0
Medical Evacuation Kit	1	Binding	0
Cargo Loading Kit	1	Binding	0
Extreme Temperature Operations Kit	1	Binding	0
High Power Searchlight	1	Binding	0
Loud Speaker System	1	Binding	0
External Mirrors	1	Binding	0
Storm-Scope Lightening Detector	0	Binding	0
Radar Altimeter	1	Binding	0
Air Conditioning	1	Binding	0
Cockpit Voice Recorder and Flight Data Recorder	0	Binding	0
Rotor Brake	1	Binding	0
Fast Rope System for Deploying Troops	1	Binding	0
Rappelling System for Deploying Troops	1	Binding	0
Underwater Sonic Locator	1	Binding	0
Emergency Egress Lighting System	1	Binding	0
Auxiliary Fuel System	1	Binding	0
Engine Inlet Particle Separator	1	Binding	0
Automatic Blade Fold	0	Binding	0
Snow Ski Kit	1	Binding	0
Fire-Fighting Kit	0	Binding	0
VIP Interior	0	Binding	0
VIP KIT	0	Binding	0
Bubble Windows in Cabin	1	Binding	0
Chaff/Flare Dispensers	1	Binding	0
Infra-red Countermeasures	1	Binding	0
Directed Infra-red Countermeasures	0	Binding	0
Laser Warning System	1	Binding	0
Missile Warning System	1	Binding	0
Radar Warning System	0	Binding	0
7.62 mm Machine Guns	0	Binding	0
.50 Caliber Machine Guns	1	Binding	0
Fixed Sighting System	1	Binding	0

Helmet Mounted Sighting System	0	Binding	0
HellFire Anti-tank missiles	0	Binding	0
Stinger Air to Air Missiles	0	Binding	0

Table A-10
Iteration 3
Helicopter Configuration Optimization Summary

MAXIMUM ALLOWABLE HELICOPTER PRICE ($)	14,000,000	**HELICOPTER PRICE**	13,955,000	**TOTAL UTILITY POINTS AWARDED**	218
MAXIMUM ALLOWABLE WEIGHT (Lb)	16,108	**HELICOPTER WEIGHT**	13,415		
MAXIMUM ALLOWABLE DRAG (SQ FT)	205	**HELICOPTER DRAG**	158		

Table A-10 continued

Microsoft Excel 8.0a Answer Report
Worksheet: [ITERATION3.xls]Tableau
Target Cell (Max)

Name	Final Value
TOTAL UTILITY POINTS AWARDED	218

NAME	
Analog Cockpit	1
Digital Cockpit	0
Flight Director	0
4-axis Coupled	0
VHF/AM Radio	0
VHF/FM Radio	0
VHF/FM Radio Encryption	1
UHF/AM Radio	1
HF Radio	1
Cell Phone	1
Microwave Data Link	0
Transponder	0
Transponder w/Mode S	1
Emergency Locator Transmitter	1
VOR/ILS Navigation System	1
LF/ADF Navigation System	0
GPS Navigation System	1
Inertial Navigation System	1
Doppler Navigation System	1
Distance Measuring Equipment	1
Digital Moving Map	0
Search and Rescue Direction Finder	0
Weather radar	0
Weather Radar w/Ground Mapping	1
360 Degree Search Radar	0
Forward Looking Infra-red Optronics	0
Forward Looking Infra-red Optronics w/Rangefinder and Laser Designator	1
Low Light TV	1
Cargo Hook	1
Rescue Hoist	1
Flotation System	0
Medical Evacuation Kit	1
Cargo Loading Kit	1

Extreme Temperature Operations Kit	1
High Power Searchlight	1
Loud Speaker System	1
External Mirrors	1
Storm-Scope Lightening Detector	0
Radar Altimeter	1
Air Conditioning	1
Cockpit Voice Recorder and Flight Data Recorder	0
Rotor Brake	1
Fast Rope System for Deploying Troops	1
Rappelling System for Deploying Troops	1
Underwater Sonic Locator	1
Emergency Egress Lighting System	1
Auxiliary Fuel System	1
Engine Inlet Particle Separator	1
Automatic Blade Fold	0
Snow Ski Kit	1
Fire-Fighting Kit	0
VIP Interior	0
VIP KIT	0
Bubble Windows in Cabin	1
Chaff/Flare Dispensers	1
Infra-red Countermeasures	0
Directed Infra-red Countermeasures	1
Laser Warning System	1
Missile Warning System	0
Radar Warning System	0
7.62 mm Machine Guns	0
.50 Caliber Machine Guns	1
Fixed Sighting System	0
Helmet Mounted Sighting System	1
HellFire Anti-tank missiles	0
Stinger Air to Air Missiles	0
Penguin Anti-ship Missiles	0
2.75 inch Unguided Rockets	1

Constraints

Name	Cell Value	Status	Slack
HELICOPTER PRICE	13,955,000	Not Binding	45000
HELICOPTER WEIGHT	13,415	Not Binding	2693
HELICOPTER DRAG	158	Not Binding	47

MUST CHOOSE EITHER ANALOG OR DIGITAL COCKPIT	1	Not Binding	0
CAN CHOOSE AT MOST 1 RADAR	1	Binding	0
MUST CHOOSE EITHER VHF/FM WITH OR WITHOUT ENCRYPTION	1	Not Binding	0
CAN ONLY CHOOSE DME IF VOR/ILS IS CHOSEN	0	Binding	0
CAN ONLY CHOOSE DIGITAL MAP IF DIGITAL COCKPIT IS CHOSEN	0	Binding	0
CAN CHOOSE AT MOST 1FLIR	1	Binding	0
CAN ONLY CHOOSE LOW LIGHT TV IF A FLIR IS CHOSEN	0	Binding	0
CAN CHOOSE AT MOST 1 VIP INTERIOR	0	Not Binding	1
CAN CHOOSE AT MOST 1 TYPE OF INFRA-RED COUNTERMEASURE	1	Binding	0
CAN CHOOSE AT MOST 1 TYPE OF WEAPONS SIGHT	1	Binding	0
MUST CHOOSE EITHER TRANSPONDER WITH OR WITHOUT MODE S	1	Not Binding	0
MUST HAVE UHF/AM RADIO	1	Not Binding	0
MUST HAVE HF RADIO	1	Not Binding	0
MUST HAVE EMERGENCY LOCATOR TRANSMITTER	1	Not Binding	0
MUST HAVE VOR/ILS	1	Not Binding	0
MUST HAVE RESCUE HOIST	1	Not Binding	0
MUST HAVE AIR CONDITIONING	1	Not Binding	0
MUST HAVE SNOW SKIS	1	Not Binding	0
Analog Cockpit	1	Binding	0
Digital Cockpit	0	Binding	0
Flight Director	0	Binding	0
4-axis Coupled	0	Binding	0
VHF/AM Radio	0	Binding	0
VHF/FM Radio	0	Binding	0
VHF/FM Radio Encryption	1	Binding	0
UHF/AM Radio	1	Binding	0
HF Radio	1	Binding	0
Cell Phone	1	Binding	0
Microwave Data Link	0	Binding	0
Transponder	0	Binding	0
Transponder w/Mode S	1	Binding	0
Emergency Locator Transmitter	1	Binding	0

VOR/ILS Navigation System	1	Binding	0
LF/ADF Navigation System	0	Binding	0
GPS Navigation System	1	Binding	0
Inertial Navigation System	1	Binding	0
Doppler Navigation System	1	Binding	0
Distance Measuring Equipment	1	Binding	0
Digital Moving Map	0	Binding	0
Search and Rescue Direction Finder	0	Binding	0
Weather radar	0	Binding	0
Weather Radar w/Ground Mapping	1	Binding	0
360 Degree Search Radar	0	Binding	0
Forward Looking Infra-red Optronics	0	Binding	0
Forward Looking Infra-red Optronics w/Rangefinder and Laser Designator	1	Binding	0
Low Light TV	1	Binding	0
Cargo Hook	1	Binding	0
Rescue Hoist	1	Binding	0
Flotation System	0	Binding	0
Medical Evacuation Kit	1	Binding	0
Cargo Loading Kit	1	Binding	0
Extreme Temperature Operations Kit	1	Binding	0
High Power Searchlight	1	Binding	0
Loud Speaker System	1	Binding	0
External Mirrors	1	Binding	0
Storm-Scope Lightening Detector	0	Binding	0
Radar Altimeter	1	Binding	0
Air Conditioning	1	Binding	0
Cockpit Voice Recorder and Flight Data Recorder	0	Binding	0
Rotor Brake	1	Binding	0
Fast Rope System for Deploying Troops	1	Binding	0
Rappelling System for Deploying Troops	1	Binding	0
Underwater Sonic Locator	1	Binding	0
Emergency Egress Lighting System	1	Binding	0
Auxiliary Fuel System	1	Binding	0
Engine Inlet Particle Separator	1	Binding	0
Automatic Blade Fold	0	Binding	0
Snow Ski Kit	1	Binding	0
Fire-Fighting Kit	0	Binding	0
VIP Interior	0	Binding	0
VIP KIT	0	Binding	0
Bubble Windows in Cabin	1	Binding	0
Chaff/Flare Dispensers	1	Binding	0
Infra-red Countermeasures	0	Binding	0
Directed Infra-red Countermeasures	1	Binding	0

Laser Warning System	1	Binding	0
Missile Warning System	0	Binding	0
Radar Warning System	0	Binding	0
7.62 mm Machine Guns	0	Binding	0
.50 Caliber Machine Guns	1	Binding	0
Fixed Sighting System	0	Binding	0
Helmet Mounted Sighting System	1	Binding	0
HellFire Anti-tank missiles	0	Binding	0
Stinger Air to Air Missiles	0	Binding	0

Table A-11 Optimization Tableau

UTILITY POINTS AWARDED FOR OPTION			1	2	3	5	6	2	8	6	0	8	5
TOTAL UTILITY POINTS AWARDED		328											
			OPTIONS (1 IS IN CONFIGURATION, 0 IS NOT IN CONFIGURATION)										
			Analog Cockpit	Digital Cockpit	Flight Director	4-axis Coupled	VHF/AM Radio	VHF/FM Radio	VHF/FM Radio Encryption	UHF/AM Radio	HF Radio	Cell Phone	Microwave Data Link
			1	0	0	0	1	0	1	1	0	1	0
	BASE AIRCRAFT												
CONSTRAINTS:													
COST CONSTRAINT ($)	10,250,000		100,000	600,000	210,000	700,000	50,000	40,000	70,000	70,000	70,000	25,000	310,000
WEIGHT CONSTRAINT (lb)	11,000		200	100	50	150	20	20	10	20	25	10	80
EQUIVALENT FLAT PLATE DRAG CONSTRAINT (FT SQUARED)	105		0	0	0	0	0	0	0	0	0	0	5
MUST CHOOSE EITHER ANALOG OR DIGITAL COCKPIT			1	1									
MUST CHOOSE EITHER VHF/FM WITH OR WITHOUT ENCRYPTION								1	1				
MUST CHOOSE EITHER TRANSPONDER WITH OR WITHOUT MODE S													
CAN ONLY CHOOSE DME IF VOR/ILS IS CHOSEN													
CAN ONLY CHOOSE DIGITAL MAP IF DIGITAL COCKPIT IS CHOSEN				-1									
CAN CHOOSE AT MOST 1 RADAR													
CAN CHOOSE AT MOST 1FLIR													
CAN ONLY CHOOSE LOW LIGHT TV IF A FLIR IS CHOSEN													
CAN CHOOSE AT MOST 1 VIP INTERIOR													
CAN CHOOSE AT MOST 1 TYPE OF INFRA-RED COUNTERMEASURE													
CAN CHOOSE AT MOST 1 TYPE OF WEAPONS SIGHT													

5	5	2	9	4	6	6	6	2	1	8	8	5	4	6
Transponder	Transponder w/Mode S	Emergency Locator Transmitter	VOR/ILS Navigation System	LF/ADF NavigationSystem	GPS Navigation System	Inertial NavigationSystem	Doppler Navigation System	Distance Measuring Equipment	Digital Moving Map	Search and Rescue Direction Finder	Weather radar	Weather Radar w/Ground Mapping	360 Degree Search Radar	Forward Looking Infra-red Optronics
1	0	1	1	1	1	1	1	1	0	1	1	0	0	1
15,000	25,000	7,000	110,000	40,000	55,000	47,000	58,000	40,000	80,000	130,000	120,000	160,000	500,000	210,000
15	15	5	28	22	23	32	59	30	45	56	60	60	150	140
0	0	0	0	0	0	0	0	0	0	0	4	4	10	5
1	1													
			-1					1						
									1					
											1	1	1	
														1
														-1

8	7	4	1	2	6	4	7	10	6	7	5	4	4
Forward Looking Infra-red Optronics w/Rangefinder and Laser Designator	Low Light TV	Cargo Hook	Rescue Hoist	Flotation System	Medical Evacuation Kit	Cargo Loading Kit	Extreme Temperature Operations Kit	High Power Searchlight	Loud Speaker System	External Mirrors	Storm-Scope Lightening Detector	Radar Altimeter	Air Conditioning
0	1	1	0	0	1	1	1	1	1	1	1	1	0
410,000	50,000	20,000	80,000	200,000	60,000	40,000	20,000	66,000	17,000	9,000	44,000	57,000	240,000
189	30	20	120	400	65	25	15	45	26	11	22	18	170
5	0	0	3	20	0	0	0	3	6	1	0	0	0
1													
-1	1												

5	5	5	7	8	8	4	5	4	6	7	6	65	10	2
Cockpit Voice Recorder and Flight Data Recorder	Rotor Brake	Fast Rope System for Deploying Troops	Rappelling System for Deploying Troops	Underwater Sonic Locator	Emergency Egress Lighting System	Auxiliary Fuel System	Engine Inlet Particle Seperator	Automatic Blade Fold	Snow Ski Kit	Fire-Fighting Kit	VIP Interior	2	Bubble Windows in Cabin	Chaff/Flare Dispensers
0	1	1	1	1	1	0	1	0	1	1	0	1	1	1
470,000	100,000	22,000	5,000	7,000	87,000	350,000	247,000	756,000	11,000	12,000	568,000	345,000	8,000	2,000
27	102	29	13	3	49	450	46	202	69	102	578	604	12	22
0	0	0	0	0	0	7	2	2	3	12	0	0	2	2
											1	1		

3	7	9	5	5	5	5	3	3
Infra-red Countermeasures	Directed Infra-red Countermeasures	Laser Warning System	Missile Warning System	Radar Warning System	7.62 mm Machine Guns	.50 Caliber Machine Guns	Fixed Sighting System	Helmet Mounted Sighting System
0	1	1	1	1	1	1	1	0
30,000	270,000	170,000	200,000	300,000	18,000	60,000	40,000	190,000
8	102	29	33	33	36	102	10	9
1	6	2	2	1	0	2	0	0
1	1							
							1	1

7	9	0	10
HellFire Anti-tank missiles	Stinger Air to Air Missiles	Penguin Anti-ship Missiles	2.75 inch Unguided Rockets

0	0	0	1					
1,000,000	800,000	1,200,000	270,000	HELICOPTER PRICE	13,954,000	<=	14,000,000	MAXIMUM ALLOWABLE
207	124	231	127	HELICOPTER WEIGHT	13,530	<=	15,000	MAXIMUM ALLOWABLE
5	4	5	5	HELICOPTER DRAG	163	<=	205	MAXIMUM ALLOWABLE DRAG
					1	=	1	
					1	=	1	
					1	=	1	
					0	<=	0	
					0	<=	0	
					1	<=	1	
					1	<=	1	
					0	<=	0	
					1	<=	1	
					1	<=	1	
					1	<=	1	

Table A-12 Optimum Configuration for each of Three Iterations			
(1 is in configuration, 0 is not in configuration)			
OPTION			
	ITERATION 1	ITERATION 2	ITERATION 3
Analog Cockpit	1	1	1
Digital Cockpit	0	0	0
Flight Director	1	1	0
4-Axis Coupled Navigation	0	0	0
Communications:			
Very High Frequency/Amplitude Modulation	0	0	0
(VHF/AM) Radio			
Very High Frequency/Frequency Modulation	0	0	0
(VHF/FM) Radio			
VHF/FM Radio Encryption	1	1	1
Ultra High Frequency/Amplitude Modulation	1	1	1
(UHF/AM) Radio			
High Frequency (HF) Radio	1	1	1
Cellular Telephone	1	1	1
Microwave Data Link System	0	0	0
Transponder	0	0	0
Transponder with Mode S	1	1	1
Emergency Locator Beacon	1	1	1

Navigation Equipment :			
VHF Omni Range/ Instrument Landing	1	1	1
(VOR/ILS)			
Low Frequency Automatic Direction Finder (LF/ADF)	0	0	0
Global Positioning System (GPS)	1	1	1
Inertial Navigation System (INS)	1	1	1
Doppler Navigation	1	1	1
Distance Measuring Equipment (DME)	1	1	1
Digital Moving Map	0	0	0
Search And Rescue Direction Finder (SAR/DF)	0	0	0
Mission Equipment :			
Weather Radar	0	0	0
Weather Radar with Ground Mapping	1	1	1
360 Degree Search Radar	0	0	0
Forward Looking Infra-Red Optronics	1	1	0
Forward Looking Infra-Red	0	0	1
w/laser Range-finder and Designator			
Low-Light Television	1	1	1
Cargo Hook	1	1	1
Rescue Hoist	1	1	1
Flotation System	1	1	0
Medical Evacuation Kit	1	1	1
Cargo Loading Kit	1	1	1

Kit for Operation at Extreme	1	1	1
Temperatures			
High Power Searchlight	1	1	1
Loud-speaker System	1	1	1
External Mirrors	1	1	1
Storm-scope Lightening Detector	0	0	0
Radar Altimeter	1	1	1
Air conditioning	1	1	1
Cockpit Voice Recorder	0	0	0
and Flight Data Recorder (CVR/FDR)			
Rotor Brake	1	1	1
Fast Rope System for Deploying Troops	1	1	1
Rappelling System for Deploying Troops	1	1	1
Underwater Sonic Locator	1	1	1
Helicopter Emergency Egress Lighting System (HEELS)	1	1	1
Auxiliary Fuel System	1	1	1
Engine Inlet Particle Separator (IPS)	1	1	1
Automatic Blade Fold	0	0	0
Snow Ski Kit	1	1	1
Fire-Fighting Kit	0	0	0
VIP Interior	0	0	0
VIP Removable Interior Kit	0	0	0
Bubble Windows in Cabin	1	1	0

Aircraft Survivability Equipment :			
Chaff/Flare Dispensers	1	1	0
Infra-red Countermeasures	1	1	0
Directed Infra-red Countermeasures	0	0	1
Laser Warning System	1	1	1
Missile Warning System	1	1	0
Radar Warning System	0	0	0
Weapons Systems:			
7.62 mm Guns	0	0	0
.50 Caliber Machine Guns	1	1	1
Aircraft Fixed Sighting System	1	1	0
Helmet Mounted Sighting System	0	0	1
Hell-Fire Anti-Tank Missiles	0	0	0
Stinger Air-To-Air Missiles	0	0	0
Penguin Anti-Ship Missiles	0	0	0
2.75 inch Unguided Rockets	1	1	1

ACRONYMS

BOM – Bill Of Material

BTO – Build To Order

CVR/FDR – Cockpit Voice Recorder/Flight Data Recorder

DME – Distance Measuring Equipment

DTC – Design To Cost

FAA – Federal Aviation Authority

FLIR – Forward Looking Infra-Red

GPS – Global Positioning System

HEELS – Helicopter Emergency Egress Lighting System

INS – Inertial Navigation System

IPS – Inlet Particle Separator

LF/ADF – Low Frequency/Automatic Direction Finder

QFD – Quality Function Deployment

RFQ – Request For Quotation

SAR/DF – Search And Rescue Direction Finder

UHF/AM – Ultra High Frequency/Amplitude Modulation

VHF/AM – Very High Frequency/Amplitude Modulation

VHF/FM – Very High Frequency/Frequency Modulation

VIP – Very Important Person

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