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A MULTIPLE ATTRIBUTE DECISION ANALYSIS OF MANNED AIRLOCK SYSTEMS

THESIS

Dennis P. Jeanes
Captain, USAF

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OF MANNED AIRLOCK SYSTEMS

THESIS

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of the Air Force Institute of Technology
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19. expendable gas usage, and number of EVA periods per mission. Compromise programming was used to indentify the airlock system closest to the "ideal solution" using the AHP-derived weights.

The results indicate that the one Crewlock with void fillers was the closest to the ideal and the present shuttle airlock system augmented with consumable gases to be the farthest. The main observation shows a Crewlock system to be a possible airlock system for the space station. The report also provides and illustrates a well-structured decision support mechansim that is easy to use and responsive to changes in space issues and technology.

Preface

This study evaluated five manned airlock systems for use on the space shuttle. The need to find the best system stems from the requirement to increase the number of extravehicular activity during construction of the space station and from new airlock design proposals.

This report is limited in scope to evaluating only physical characteristics and performance parameters of the five alternatives. Cost data was not considered in this report. The work also provides a well structured approach to decision making that is responsive to changes in space issues and technology.

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— Paul Jeanes

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Abstract

This study is a multiple attribute decision analysis involving five manned airlock alternatives. The five alternatives are the present shuttle airlock system augmented with additional consumable gas tanks and four variations of the Crewlock, a new airlock design concept proposed by Mr. William Haynes of the Aerospace Corporation. The purpose was to identify which airlock system can best support both the normal shuttle mission extravehicular activity (EVA) and the shuttle's EVA requirements during construction of the space station. Only physical characteristics and performance parameters are included in the analysis. Cost factors are not addressed.

The analytic hierarchy process (AHP) was used to structure the problem and helped identify and rate ten airlock attributes, safety, reliability, weight, size, volume, transit time, depressurization time, repressurization time, expendable gas usage, and number of EVA periods per mission. Compromise programming was used to identify the airlock system closest to the "ideal solution" using the AHP-derived weights.

Keywords: theses; void fillers; decision making; operations research

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gases to be the farthest. The main observation shows a Crewlock system to be a possible airlock system for the space station. The report also provides and illustrates a well-structured decision support mechanism that is easy to use and responsive to changes in space issues and technology.

A MULTIPLE ATTRIBUTE DECISION ANALYSIS OF MANNED AIRLOCK SYSTEMS

I. Introduction

Historical Background

An airlock is a device used to permit passage between regions of differing atmospheric pressures. The Soviets were the first to use an airlock in space in 1965, even though the technology was first patented in 1830 when airlocks were used in harbor works and tunneling operations.

As the United States embarked into the space age, one of the critical questions facing American space designers in the 1960s was how an astronaut would exit from his spacecraft (1:169). The first solution to this question was to depressurize the entire cabin and open the hatch. This concept required all cabin instruments, equipment and supplies be able to survive and operate in the vacuum of space. Furthermore, it required all other crewmen to be in space suits and wait in vacuum conditions during the extravehicular activity (EVA). The depressurization of the space cabin required the expenditure of a large amount of oxygen to repressurize the entire Gemini cabin instead of a small closet sized airlock, but then again the whole Gemini capsule was not much bigger than a closet anyway (1:169). On

Gemini 10, for example, the cabin hatch was opened four times and each time required a complete repressurization of the cabin.

The concept of cabin depressurization continued into the Apollo missions. During Apollo missions 11, 12, 14, 15, 16, and 17, astronauts, donned with autonomous life support system, made more than two dozen cabin depressurizations and repressurizations (1:174).

The Skylab program used planned routine EVAs to accomplish operational tasks such as changing film canisters. The real value of an EVA crewmember was demonstrated on the first Skylab mission, when a contingency EVA was used to free a jammed solar panel. This demonstration was a critical factor in the decision to incorporate EVA operations into the space shuttle program.

Although the U.S. did not need an extra airlock module until Skylab,

> . . . the capability to operate outside a spaceship was a crucial intermediate step between the first simple space shots and the ultimate mastery of space operations which reached initial maturity during the Apollo moon walks and the Skylab voyages. (1:175)

There is no doubt that the experiences gained during the Gemini, Apollo and Skylab missions have made the U.S. success with the space transportation system (STS) EVAs possible.

Today, U.S. Space Policy identifies the STS as the primary U.S. Government space launch vehicle (2:15-10). As such, the STS must fulfill numerous functions; one such function is the performance of extravehicular activities by the STS astronauts. Extravehicular activities range from on-orbit repair of satellites and payload experiments to large space station construction. It is this last function which will help realize President Reagan's goal of an operational space station by 1994. STS flights will be required for space station element delivery, payload delivery, material processing resupply needs, crew rotation and replenishment of life support systems. This goal and the increased requirements on STS to help construct the space station will also increase the number of EVA periods performed by the shuttle astronauts on each STS mission.

Currently, the number of EVA periods available on an STS mission is limited to three; two planned and one contingency period. The limiting factor is the amount of nitrogen gas used by the STS airlock system. The most current estimates on the number of EVAs required to build the space station is between five and eleven per mission, in addition to the regularly scheduled shuttle EVAs (3). To support this requirement, NASA will need to find a more efficient way to perform EVAs. Studies are now being conducted by NASA on airlock chamber design for the space station, but formal study on improving the shuttle's EVA capabilities has not yet begun (4). Five alternatives that can increase the shuttle's EVA capabilities are the present airlock system augmented with additional consumable gases and four variations of the Aerospace Crewlock concept.

Problem Statement

The five alternatives need to be evaluated in terms of their physical characteristics and performance capabilities to determine which system best satisfies the increased EVA requirements during construction of the space station.

Research Question

How well do the five alternatives meet NASA's airlock performance requirements? Which of the five alternatives provide the best means to conduct EVAs on the space shuttle?

Scope

This research project will address only the questions concerning quantitative performance parameters and physical characteristics of the manned airlock system. Monetary cost will not be included in the study. Accurate cost estimates for the Aerospace Crewlock system are unavailable at this time and the cost data from the Rockwell Corporation is very limited.

The STS will serve as the test platform for the five airlock systems. The evaluation will be based on how well each system is able to support the construction and service of the space station.

The ensuing literature review will be limited to those decision analysis tools that are relevant to completing this research project. The literature review will cover the following methodologies used in multiple criteria decision making: multiple attribute utility theory (MAUT), multiple objective optimization theory (MOOT), multiple attribute value theory (MAVT), analytic hierarchy process (AHP) and compromise programming.

Literature Review

Introduction. Selecting a multicriteria decision methodology is not a prescribed selection process. The wide variety of problems and the multitudinous means for a decision maker (DM) to articulate preferences make it unlikely that any one methodology can be labeled as most preferred. Nevertheless, some multicriteria methodologies are more appropriate than others for a given decision and decision maker. For this study several methodologies were considered but only two were chosen, analytic hierarchy process and compromise programming.

MAUT. Multiple attribute problems can be divided into two categories, those with certain outcomes and those where the outcome contains an element of uncertainty. Markland points out that multiple attribute utility theory (MAUT) is especially applicable for decisions involving alternatives with uncertain outcomes and unclear cause and effects (5:815). It is also extremely helpful where the decision is not made purely on monetary terms and where the DM is asked to select and rank the N most preferred alternatives from a set of X alternatives.

The process of MAUT starts with the assessing of a real valued (utility) function U, for the entire alternative set X. This function must satisfy the property that the expected "utility of alternative x is greater than the utility of alternative x' if and only if alternative x is preferred to alternative x'" (6:15). The utility function is computed for all X alternatives and used as a scale to rank order all alternatives. Finally, the DM chooses the alternative with the greatest expected utility value. This result not only indicates the DM's preferences for alternatives in a specific instance but also indicates how the DM feels about these alternatives in a specific instance.

Von Neumann and Morgenstern contend that the assignment of utilities is such that if the DM's choice is based solely on the expected utility, then he is acting based on his true preferences. Of course, all this hinges on the fact that there is some degree of consistency in the DM's preferences (7:44).

The major drawback to this approach is the extensive time required to solicit a DM's utility function. This problem compounds itself if the number of attributes under consideration is large. However, White and Sage point out that there are conditions, mutual independence for example, that imply a special functional form for the utility function that will adequately model a DM's preferences, additive and multiplicative for example (6). Modeling a DM's preference structure as one of these functional forms reduces the time needed to determine a DM's utility function. However, verification of this functional form can be a burdensome procedure (6:315). Furthermore, a DM's preference can change with time and the utility function must be re-evaluated.

MOOT. Where MAUT solicits the decision maker's preferences, multiple objective optimization theory (MOOT) identifies optimal solution sets. In linear programming, a single optimal solution is sought; in MOOT the goal is to identify the non-dominated solution set (NDSS). The NDSS is also known by "the efficiency frontier," "Pareto-Optimal solution" and the "admissible set" (8:70).

The NDSS is the set of alternatives that cannot be bettered by any other feasible alternatives. The scales used to gauge dominance are called measures of effectiveness (MOE). Each attribute is assigned a MOE and each alternative has a vector set of MOEs. Determination of the NDSS is accomplished by a direct comparison between MOE vectors. In order to dominate, each element in one MOE vector must be equal to or better than its corresponding element in another alternative's MOE vector and strictly better in at least one element (8:72). For example, if the MOE vector sets for two alternatives are defined as $\bar{X}^1 = (X_1^1, X_2^1, \ldots, X_N^1)$ and $\bar{X}^2 = (X_1^2, X_2^2, \ldots, X_N^2)$, then in order for $\bar{X}^1$ to dominate $\bar{X}^2$, $X_1^1 \geq X_1^2$, $X_2^1 \geq X_2^2$, ..., $X_N^1 \geq X_N^2$ and at least one of the elements of $\bar{X}^1$ has to be strictly greater than its corresponding element in $\bar{X}^2$.

The methods of generating the NDSS use only the vector of objective functions to generate and identify the NDSS in the feasible region. By doing this, only the physical realities (namely the constraints) are considered. At no time in the process are the DM's preferences considered. The outcome of generating the NDSS is to help a DM gain insight to the physical realities of the problem and to screen out the clearly unacceptable alternatives. The most widely used methods of generating the NDSS are the graphical method, the weighted method and the constraint method (9:40).

Zeleny points out numerous advantages to using the NDSS; the biggest advantage is in complex problems and decisions where the utility function of the DM may be too complex or unrealistic or impractical to use MAUT or multiple attribute value theory. Generating the NDSS provides meaningful insight to problems despite this complexity (8:315).

Another useful division of multiple attribute problems can be those problems that are continuous and those problems that are discrete. Continuous problems are those in which the solution space is continuous and defined by constaints (10:7). This means there are an infinite number of alternatives, such as those found in the feasible region of linear programming problems. In discrete problems, the DM is faced with a choice between a number of discrete alternatives. Discrete problems can be broken down further into problems involving a few or many alternatives and few or many criteria (10:7). Numerous approaches do nothing more than narrow down a long list of alternatives. What is needed in this study, a shortlist multiple attribute decision, is an approach which aids the DM in the analysis and synthesis of detailed information in a manner consistent with the DM's value judgement about the relative importance of the DM's objectives (10:8). Two methodologies that elicit and utilize a weighted value function to represent the DM's preference structure are multiple attribute value theory (MAVT) and the analytic hierarchy process (AHP).

MAVT. MAVT is very similar to MAUT. Where MAUT was applicable to multi-attribute problems with uncertainty, MAVT is applicable to multiple attribute problems with the element of certainty in the outcome. In many of these types of decision problems, there is no single solution that dominates all the other alternatives in terms of all objectives. The DM must decide how much of one objective he or she is willing to give up to gain more of another objective (11:66). The issue becomes one of value tradeoffs.

MAVT provides a systematic structure to make these tradeoffs. Paralleling MAUT, the strategy of MAVT is to solicit the DM's value function for the range of possible outcomes, combine these single values into an overall value function and select the alternative that maximizes the value function with respect to all the objectives.

Since MAVT is similar to MAUT, it presents similar problems. Access to a DM to solicit his or her value function to determine if he or she is of the additive or multiplicative form is still a time-consuming operation. Once again a form can be assumed, but the number of forms the DM can take is limited, i.e. additive or multiplicative. Verification of the assumed functional form is still a burdensome process. Additionally, MAVT has certain conditions that must be met for the existence of a measurable value function. These conditions are: the DM must be able to make a preference statement given any two consequences, transitivity among preferences must hold, as well as, the property of reflexivity (12). The greatest weakness of MAVT, according to Belton, is "its failure to incorporate systematic checks on consistency of judgements" (10:18).

AHP. According to Thomas L. Saaty, the developer of the AHP, there are three underlying principles recognizable in problem solving. The three principles are the principle of decomposition, comparative judgements and the principle of logical consistency (13:17).

The decomposition principle requires the breakdown of the complex system into a hierarchical structure. This decomposition of complex problems is in line with the human ability to perceive ideas, identify concepts and communicate to others these ideas and concepts. In order to understand complex problems in detail, the human mind breaks complex reality into constituent parts and then breaks these parts into their constituent parts and so on hierarchically, with the best number of parts being between five and nine. For this reason, Saaty claims the hierarchy is the "single most powerful mental construct for studying complex systems" (14:141). Vargas and Dougherty also emphasize the decomposition principle:

> Hierarchical structuring of any decision problem deals efficiently with complexity and identifies the major components of the problem through a consensus among the manager confronted with the problem. (15:61)

The ability to perceive relationships among different things, to compare similar objects and to discriminate between two members of a pair and express a preference for one or the other forms the basis of the second principle, comparative judgements. This principle calls for the setting up a matrix to carry out pairwise comparisons "to assess the dominance of each element over the others with respect to each element of the immediately higher level of the hierarchy" (16:63). This priority setting helps identify which criteria is most preferred in relation to the other criteria.

Completing the analytical thought process is the principle of logical consistency. Consistency is the ability to establish coherent relationships between ideas and objects. When speaking of consistency, we mean, first, that similar ideas and objects are grouped according to homogeneity and relevance and, secondly, "that the intensities of relations among ideas or objects based on a particular criterion justify each other in some logical way" (13:18). Most multiple criteria decision-making methodologies employ these three principles of analytic thought in some form or another. The analytic hierarchy process is based on these three principles.

The analytic hierarchy process is a systematic procedure to solve complex problems. It combines all three principles of analytical thought and incorporates both the quantitative and qualitative aspects of the decision process. The hierarchical decomposition of the problem and the problem definition handle the quantitative while pairwise comparisons and expression of judgements incorporate the qualitative. A detailed summary of the steps involved in the AHP is found in Figure 1-1. A more detailed and problem

1. Define the problem and specify the solution desired.

2. Structure the hierarchy from the overall managerial purposes (the highest levels) through relevant intermediate levels to the level where control would alleviate or solve the problem.

3. Construct a pairwise comparison matrix of the relative contribution or impact of each element on each governing objective or criterion in the adjacent upper level. In such a matrix of the elements by the elements are compared in a pairwise manner with respect to a criterion in the next level. In comparing the i,j elements, people prefer to given a judgement which indicates the dominance as an integer. Thus, if the dominance does not occur in the i,j position while comparing the ith element then it is given the j,i position as a_{ji} and its reciprocal is automatically assigned to a_{ij}.

4. Obtain all n(n-1)/2 judgements--specified by the set of matrices developed in Step 3.

5. Having collected the pairwise comparison data and entering the reciprocals together with n unit entries down the main diagonal, the eigenvalue problem $Aw = (\lambda \max)(w)$ is solved and consistency is tested.

6. Steps 3, 4, and 5 are repeated for all levels and clusters in the hierarchy.

7. Hierarchical composition is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to each element to obtain the composite priority of the element in a level. These are then used to weight the eigenvectors corresponding to those in the next lower level and so on, resulting in a composite priority vector for the lowest level of the hierarchy.

8. Consistency is then evaluated for the entire hierarchy by simply multiplying each consistency index by the priority of the corresponding criterion and adding over all such products. The result is divided by the same type of expression using the random consistency index corresponding to the dimensions of each matrix weighted by the priorities as before. The ratio should be about 10 percent or less for acceptable overall consistency. Otherwise, the quality of the judgemental data should be improved.

Fig. 1-1. Summary Steps of the Analytic Hierarchy Process (15:68) specific explanation of each step is provided in the following chapters prior to the application of each step.

Some of the criticism of AHP focuses on the use of a simple additive weighted value function as the underlying model of the DM's preference structure (10:18). Also, Belton specifies

> . . . the greatest weaknesses of AHP are the ambiguous questioning procedure about criteria weights and the strong assumption of a ratio scale for the measurement of scores. (10:18)

Despite these criticisms, the AHP has been successfully applied to many multicriteria problems in various fields. These include designing a transport system for the Sudan, oil price prediction, a plan to allocate energy to industries, and design of future scenarios of higher education in the U.S. (14:155).

AHP applied in its entirety could provide a solution to the airlock problem. However, for this study, the AHP will be used to decompose the problem, survey system managers for pairwise comparisons and apply a consistency check on these comparisons. The criteria weights generated by the AHP will be inputs to the compromise programming evaluation of the alternatives.

Compromise Programming. Compromise programming, like the AHP, is a relatively new methodology based on the idea of distance from an ideal point. This ideal point, chosen by the decision maker, is a compilation of the best values of each attribute or a set of arbitrary values. Zeleny describes the goal of this methodology as "an effort to approach or emulate the ideal solution as closely as possible" (8:135). This goal is supported by the Axiom of Choice which states:

> Alternatives that are closer to the ideal are preferred to those that are farther away. To be as close as possible to the perceived ideal is the rational of human thought. (8:156)

The measure of an alternative's goodness is how close (distance) the alternative comes to the ideal set of attributes (ideal point). This distance measurement is given by the expression:

$$\min \left\{ dp = \sum_{i=1}^{n} \lambda_i^p \left(\frac{X_i^* - X_i^k}{X_i^* - X_i^{**}} \right)^p \right\}^{1/p} \quad 1 = 1, 2, \ldots, n \qquad (1-1)$$

where

X_i^* is the best value of the ith attribute

X_i^{**} is the worst value of the ith attribute

X_i^k is the value of the alternative's ith attribute

λ_i is the weight associated with the ith attribute

N is the number of attributes

Though this distance metric is derived from the Pythagorean distance theorem used in geometry, the "distance" referred to in compromise programming is used as "a proxy measure for human preference and not a purely geometric concept" (8:317). Distance represents "a measure of resemblance, similarity, or proximity with respect to individual coordinates, dimensions, and attributes" (8:318). To find this distance requires the attributes of each alternative to be quantifiable.

Of course, the choice of the units of measurements of a given attribute definitely affects the preference for an alternative. This issue of commensurability of individual attributes is taken care of in compromise programming. By using "relative distance," instead of absolute distance, attributes with different units of measurements can be used in the algorithm. This "relative distance" is obtained by using $(X_i^* - X_i^{**})$ in the denominator of expression 1-1.

The compromise programming metric, 1-1, incorporates a double weighting scheme. The parameter p reflects the DM's concern with the maximum deviation and λ indicates the DM's preference for a particular attribute. The higher the value of p, the more conservative the DM, that is, the more concerned he or she is with the attribute with the largest deviation from the ideal.

Compromise programming has been used in a multiple linear objective context and in the analysis of discrete objective problems such as the Central Tisza River Basin development project (9:240).

Conclusion. By using the weights supplied by the AHP and the compromise programming distance metric, the best alternative can be identified. Compromise programming allows the variation of weights to determine how the increase in preference or decrease in preference for a particular attribute changes the "distance" of a system from the ideal point and how much change in a decision maker's preference can occur before the best alternative is no longer considered the best. What makes compromise programming a powerful tool in multicriteria decisions is that it uses several attributes of the system not just one to obtain the relative distance.

The two multicriteria problem-solving methodologies, AHP and compromise programming, collectively combine the three elements of analytical thought, blend the quantitative and qualitative aspects of problem solving and supply the solution as a relative distance to an ideal solution. Additionally, sensitivity analysis of the weights of each attribute provides insight into how much a decision maker's preference for an attribute can change before the ranking of alternatives changes. Finally, no assumption about the DM's underlying preference structure is made.

Overview

Chapter II continues, in more detail, the discussion of the two methodologies used in this study, AHP and compromise programming. The explanation of these methodologies is accompanied by an illustrative example, the selection of an automobile from a shortlist of three alternatives. Each major step of the AHP is discussed and demonstrated, starting with hierarchy construction and covering the focus and judgement criteria. The comparative judgement phase of the AHP is also discussed, including the rating scale suggested by Saaty. Determining the consistency of the DM's judgement is demonstrated and discussed. This chapter also discusses and develops the distance metric used in compromise programming. The illustrative example started in the AHP section is concluded and the compromise programming results interpreted. The decision process used in the automobile example is similar to the process used in the manned airlock decision problem.

Chapter III defines the five alternative airlock systems being evaluated in this study, the present airlock system augmented with additional nitrogen gas and four variations of the Crewlock system. The present system is covered in detail in the first part of this chapter, followed by descriptions of the Crewlock alternatives.

Chapter IV describes the application of the AHP and compromise programming to the airlock decision problem. Each element of the hierarchy is discussed and serves as a lead into the comparative judgement phase of the AHP. The rating scale is reviewed and the survey used to solicit the

DM's preferences is presented and explained. The results of the survey are tabulated and a consistency check performed. From here, compromise programming is applied for the p values of one, two and infinity, and the results summarized. Chapter IV's format follows the methodology format used in the illustrative example problem presented in Chapter II.

A summary of the findings, recommendations for future action and general observations concerning the space station airlocks are presented in Chapter V.

II. The Methodologies

Introduction

This chapter will discuss in detail the methodologies used in this research project, analytic hierarchy process and compromise programming. Each step in the methodologies will be discussed and then used in an illustrative example. The example involves the selection of an automobile from a shortlist of three alternatives. Only those portions of the AHP methodology relevant to this study will be illustrated. As for compromise programming, the distance metric will be explained and a discrete objective example illustrated.

AHP and Its Application

As mentioned in Chapter I, AHP is a systematic procedure for problem solving based on the three principles of decomposition, comparative judgements and the principle of logical consistency. The AHP reflects the way DMs naturally behave and think, but accelerates this natural process through a systematic, consistent and reproducible methodology.

Principle of Decomposition. The principle of decomposition is based on the belief that the hierarchy is the most powerful mental construct in complex systems.

Hierarchies are the tools of the human mind. With these tools, complex systems can be better understood. Greater understanding is gained by breaking the complex system into their constituent elements, structuring these elements hierarchically and then by synthesizing, or composing, "judgements on the relative importance of the elements at each level of the hierarchy into a set of overall priorities" (13:28). There are certain advantages to using hierarchies when dealing with complex systems. The list of advantages include:

1. Hierarchical representation of a complex system can be used to show how changes in priority at upper levels affect the priority of elements in lower levels.

2. Hierarchies are stable and flexible; stable in that small changes have a small effect and flexible in that additions to a well-structured hierarchy do not disrupt the performance of the hierarchy.

3. Hierarchies give a great deal of information on the structure and function of a complex system and provide an overview of the elements and their purposes (16:14).

Saaty talks about two types of hierarchies, structural and functional. For structural hierarchies, Saaty explains: "complex systems are structured into their constituent parts in descending order according to structural properties such as size, shape, color, or age" (13:28). Functional hierarchies, on the other hand, "decompose complex systems into their constituent parts according to their essential relationship" (13:28). The hierarchies in this study are functional types.

In functional hierarchies, each set of elements occupies a level in the hierarchy. The overall objective occupies the top level of the hierarchy and is called the focus. There can be only one element in this level. Subsequent levels of the hierarchy, the intermediate criteria, can have more than one element, but usually the number of elements is small, between five and nine. All subsequent levels support the focus of the hierarchy. Each element in subsequent levels represents the criteria of highest concern to the DMs.

Though there are no inviolable rules in constructing hierarchies, Saaty points out that

> . . . the elements of the last or bottom level of the hierarchy be meaningfully pairwise comparable according to elements in the next higher level, these in turn according to elements in the next level and so on up to the focus of the hierarchy. (14:141)

It is important to remember that elements in each level must be of the same order of magnitude. This means large boulders cannot be compared to small stones nor atoms with stars; in these cases, several levels of objects of slightly different magnitudes must be used to make the transition and comparison possible (13:29). Failure to abide by this fundamental concept will subject our judgement to significant error.

One method of construction, suggested by Saaty, when choosing among alternatives as in this study, is to start at the bottom level by listing the alternatives. The next level consists of the judgement criteria for the alternatives. Finally, the top level consists of a single element, the overall objective or focus, in terms of which the criteria can be compared according to the importance of their contribution (13:30).

Hierarchy for Selecting an Automobile. The hierarchy for choosing an automobile from several alternatives is shown in Figure 2-1. The parts of the hierarchy are readily apparent, the overall objective is to select an automobile; it is the only element in Level One. Level Two consists of the judgement criteria the DM considers important to the decision and Level Three contains the alternatives. Not only is this a functional-type hierarchy, but it is a complete hierarchy "because all factors at any level relate to all the factors in the next higher level" (13:47).

Comparative Judgements. Now that a complete hierarchy of the problem exists, a measurement methodology establishes the relative weights among the elements within each level of the hierarchy. It is in this phase of the AHP that the DM makes his or her preferences known. In the context of the example, this measurement methodology not only indicates whether cost, fuel economy or trunk size is

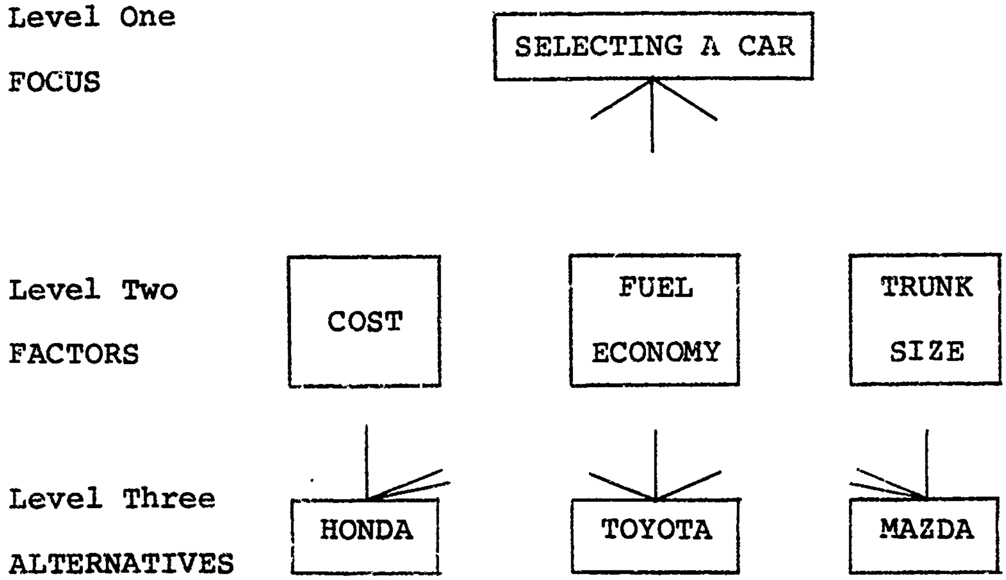

Fig. 2-1. Hierarchy for Selecting an Automobile

of more concern to the DM, but indicates by how much the DM prefers a certain attribute. These relative weights carry over to the compromise programming methodology later in this chapter. The establishment of priorities is accomplished by making pairwise comparisons, that is "to compare the elements in pairs against a given criterion" (13:76). These pairwise comparisons constitute the heart of the AHP.

A matrix is the preferred form of making pairwise comparisons. The matrix is a simple well-established tool that reflects the dual aspects of priorities, namely dominating and dominated. Furthermore, the use of a matrix allows for consistency testing which is covered later in this chapter.

Setting up the matrix is accomplished by listing the criteria of comparison on the left side of the matrix and the elements to be compared along the top. For the car example, the matrix form is shown in Figure 2-2.

SELECT A CAR	SIZE	ECONOMY	COST
SIZE			
ECONOMY			
COST			

Fig. 2-2. Matrix Structure

Pairwise comparisons are accomplished by taking an element on the left side of the matrix and comparing it with the elements along the top row. The question to ask for each pairwise comparison is:

> How much more strongly does this element possess or contribute to, dominate, influence, satisfy, or benefit- the property than does the elements with which it is being compared? (13:77)

It should be pointed out that the phrasing of the question is crucial to the AHP. The question needs to reflect the relationship between the elements in one level with the property in the next higher level.

Numbers are used to fill the pairwise comparison matrix. These numbers reflect the relative importance of one element over another with respect to a certain property. Saaty provides a numeric rating scale to use with the AHP. (See Table 2-1.) This scale allows the DM to express his or her preference between two elements as equally preferred, weakly preferred, strongly preferred or absolutely preferred. It also bounds the input values between one and nine.

Saaty contends that based on past experiences a scale with nine units is "reasonable and reflects the degree to which we can discriminate the intensities of relationships between elements" (13:77).

When comparing elements in the pairwise matrix always compare the element on the left hand side (first element of the pair) to the element in the top row (second element of the pair) and estimate, using the rating scale (Table 2-1), the relative importance of this element. The reciprocal of the value will be entered into the transpose position of the matrix when the second element is compared to the first. A comparison of an element with itself results in unity. Therefore, all elements of the diagonal of the matrix will have the value of one.

Since AHP uses the reciprocals of the numeric values in the transpose positions of the matrix only $n(n-1)/2$ judgements need to be made. Here n is the number of elements in a row or a column of the matrix.

TABLE 2-1

SCALE OF RELATIVE IMPORTANCE (14:145)

Intensity	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favor one criterion over the other
5	Essential or strong importance	Experience and judgement strongly favor one criterion over the other
7	Very strong or demonstrated importance	A criterion is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one criterion over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

Using the illustrative example, the complete pair-wise comparison matrix for the three decision factors is shown in Figure 2-3.

	SIZE	ECONOMY	COST
SIZE	1	1/2	1/5
ECONOMY	2	1	1/2
COST	5	2	1

Fig. 2-3. Simple Matrix Comparing Three Decision Factors

The numeric values answer the question of how much more important to the DM is the cost of the car than fuel economy and trunk size. Using both the matrix values and the scale from Table 2-1 to interpret Figure 2-3, it is seen that the cost of the car is strongly more important than trunk size and slightly more important than fuel economy, and fuel economy is slightly favored over trunk size.

Geometric Mean. Two methods are presented by Saaty to complete the AHP. One is the dominant eigenvector method and the other is the geometric mean. This study uses the geometric mean method. Reasons for using the geometric mean are when compared to the dominant eigenvector method the geometric mean vector is statistically better and much easier to calculate. The geometric mean method gives rise to a more meaningful measure of consistency with known statistical properties. Consistency checking when using the geometric mean can also be accomplished in a similar manner to that used in the eigenvector approach (16:21; 14). The geometric mean allows tests of hypotheses and confidence interval estimation. Finally, as pointed out in the Rand study, the geometric mean vector is "rooted in a mathematical approach to estimation" providing an intuitive understanding to the problem as well as a means to assess the method's suitability (17:6).

The geometric mean of the judgement matrix is defined as:

$$V_i = \prod_{j=1}^{n} a_{ij}^{1/n} \qquad \text{for } i = 1, 2, \ldots, n$$

where a_{ij} is the numeric scale value in the ith row jth column of the nxn judgement matrix.

For the car example, the judgement matrix is

	SIZE	ECONOMY	COST	
SIZE	1	1/2	1/5	
ECONOMY	2	1	1/2	= A
COST	5	2	1	

Applying the above definition results in the geometric mean vector

$$V = \begin{bmatrix} ((1) & (1/2) & (1/5))^{1/3} \\ ((2) & (1) & (1/2))^{1/3} \\ ((5) & (2) & (1))^{1/3} \end{bmatrix} = \begin{bmatrix} 0.50 \\ 1.00 \\ 1.99 \end{bmatrix}$$

The normalized geometric mean is computed by dividing each element of the geometric mean vector by the sum of all the elements in the geometric mean vector. The sum of the normalized geometric mean vector is one. Applying this, results in the following:

$$\begin{bmatrix} .5/3.49 \\ 1/3.49 \\ 1.99/3.49 \end{bmatrix} = \begin{bmatrix} .143 \\ .286 \\ .570 \end{bmatrix}$$

These results indicate that the car buyer considers cost to be considerably more important than fuel economy and trunk size, and fuel economy to be more important than trunk size.

Logical Consistency. Though consistency is not required from the DM when making pairwise comparisons, we must concern ourselves with knowing how good is his or her consistency. Consistency

> . . . informs the judges about the adequacy of their knowledge and whether they need to study the matter further in order to obtain greater coherence in their understanding of the problem. (18:647)

What we do not want is the decision to be based on judgements with low consistency and appear to be random (13:82). This implies a certain degree of consistency is needed to obtain valid results. A consistency ratio (CR) measures the overall consistency of judgements and provides an indication that the DM's values did not change dramatically during the rating process. This consistency ratio is defined as the confidence index/random consistency. According to Saaty, a consistency ratio of 10 percent or less is desired; a consistency ratio greater than 10 percent makes the judgements appear random and the process should be repeated (13:83). The goal is not to minimize the CR but to make good sound judgements and decisions.

The consistency index, CI, used to find the CR, is defined as $\left(\frac{\lambda max - n}{n-1}\right)$.

Where n is the number of rows or columns in the judgement matrix and λmax is equal to the sum of the product of the judgement matrix and the normalized geometric mean vector (16:21; 14).

$$\begin{bmatrix} 1 & 1/2 & 1/5 \\ 2 & 1 & 1/2 \\ 5 & 2 & 1 \end{bmatrix} \text{ X } \begin{bmatrix} .143 \\ .286 \\ .570 \end{bmatrix} \begin{bmatrix} .40 \\ .857 \\ 1.714 \end{bmatrix}$$

$\lambda max = .4 + .857 + 1.714 = 3.114.$

Therefore CI = (3.114 - 3)/2 = .057.

The denominator of the consistency ratio is the random consistency. Saaty uses Table 2-2 to determine the random consistency. Enter Table 2-2 with the appropriate value of N, the number of rows or columns in the judgement matrix, to find the random consistency value. The CR, CI/random consistency, for the car selection problem is .057/.58 or .0982, which is less than the 10 percent Saaty uses to rate consistency in the judgement matrix and indicates the DM's values did not dramatically change during the pairwise rating process.

TABLE 2-2

RANDOM CONSISTENCY VALUES (14:147)

N	Random Consistency
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Compromise Programming

The second part of this decision analysis involves the compromise programming methodology introduced in Chapter II. According to Goicoechea, et al., "compromise programming is an interactive method appropriately used in a multiple linear objective context" (9:235). The methodology has, however, been used in the analysis of discrete objective problems (9). It is the application in the latter case that will be discussed here.

The principal premise of compromise programming is to emulate or approach an ideal solution as closely as possible and the "measure of goodness of any compromise is its closeness to the ideal solution or its remoteness to the anti-ideal" (8:315). The terms closeness and remoteness imply a distance of some sort. The best known concept of distance is the Pythagorean Theorem. This theorem states the distance between two points with known coordinates is given by the expression:

$$d = \sqrt{(X_1^1 - X_1^2) + (X_2^1 - X_2^2)} \qquad (2\text{-}1)$$

where X_1^1 and X_2^1 are the first and second coordinate values of point 1 and X_1^2 and X_2^2 are the first and second coordinate values of point 2.

In compromise programming, we are not only interested in the distance between two points, but we are interested "in comparing the distance of various points from one point of reference, the ideal point" (8:316). The formula to accomplish this distance calculation in two-dimensional space is:

$$d = \sqrt{(X_1^* - X_1^k)^2 + (X_2^* - X_2^k)^2} \qquad (2-2)$$

where X_1^k and X_2^k are the various points and X_1^* and X_2^* are the reference or ideal points. Here the underlying geometric concept is very simple; the differences between coordinates of the ideal point and those of a given point are raised to the second power. The squared differences are then added and the square root is taken. Generalizing this concept to a higher dimension yields the equation

$$d = \left(\sum_{i=1}^{n} (X_i^* - X_i^k) \right)^{1/p} \qquad \begin{array}{l} k = 1,2,\ldots,n \\ i = 1,2,\ldots,n \end{array} \qquad (2-3)$$

where n is the number of attributes,

i refers to a specific attribute and

k represents the number of alternatives or points.

In the Pythagorean Theorem, the deviations are raised to the second power. The deviations can in fact be raised to any real power before being summed. The parameter p can take on values of one up to infinity. Moreover, the different deviations corresponding to different attributes i, can be weighted by differential levels of their relative contribution to the total sum (8:317). The generalized formula incorporating these relative weights is

$$dp = \left(\sum_{i=1}^{n} \lambda_i^p \, (X_i^* - X_i^k)^p \right)^{1/p} \qquad i = 1,2,\ldots,n \qquad (2\text{-}4)$$

With λ_i representing the weight differential or the relative importance of the ith objective or attribute. This weight allows the DM to express his or her feelings of concern for the relative importance of the various attributes. The parameter p indicates the DM's concern with respect to the weighted maximum deviation. The larger the value of p the greater the concern for that deviation (9:237). Together λ and p form a double weighting scheme.

With the attribute values defined and the parameter λ determined through the AHP and for all p between one and infinity, the compromise solution is determined by calculating the distance of each alternative from the ideal and identifying the alternatives with the minimum distance to the ideal as the compromise set.

In practice, only three points are usually calculated, p = 1, 2, and p = infinity. Having p = 1 implies "the longest deviation between the two points in a geometric sense--one has to transverse the full extent of all deviations" (8:317). This measurement is referred to as a "city block" or "manhattan block" measurement of distance. Having p = 2 represents the shortest distance between any two points, a straight line. Finally, having $p = \infty$ implies the largest of the deviations completely dominates the distance determination. The higher the value of p, the more conservative the DM, that is, the more concerned he is with the attribute with the largest weighted deviation from the ideal.

The distance discussed here is employed in compromise programming as a "proxy measurement for human preferences and not as a purely geometric concept" (8:317). Distance is used as a measure of "resemblance, similarity or proximity with respect to individual coordinates, dimensions and attributes" (8:317).

Commensurability. There are situations where distances are influenced by the unit of measure of a given attribute. In the modeling of preferences, the influence of the units of measurements is undesirable and must be eliminated. It is true, there is no difference between 5 kilograms and 5000 grams of sugar and there is no difference between a foot and 12 inches, "but clearly units of measurements do affect our preferences" (8:320). For instance, one would not be fully indifferent about receiving \$100 versus receiving 10,000 pennies (8:320). Most people, given the choice, would prefer to receive the $100 and not the 10,000 pennies.

Zeleny demonstrates this problem of measurement scale. Plotted in Figure 2-4(a) are three alternatives; from this figure, A is closer to the ideal point X^* than C. However, by re-scaling the plots from kilogram to dekagram, Figure 2-4(b), C now becomes closer to X^*, and A is farther away. It is erroneous to conclude that A, because it is now farther away, became less desirable than C because the measurement scale changed from kilograms to dekagrams. The issue to confront is one of commensurability; it is not necessary, however, to change all apples to oranges or make all oranges apples. To avoid this issue of non-commensurability the compromise programming methodology utilizes relative distances rather than absolute distances.

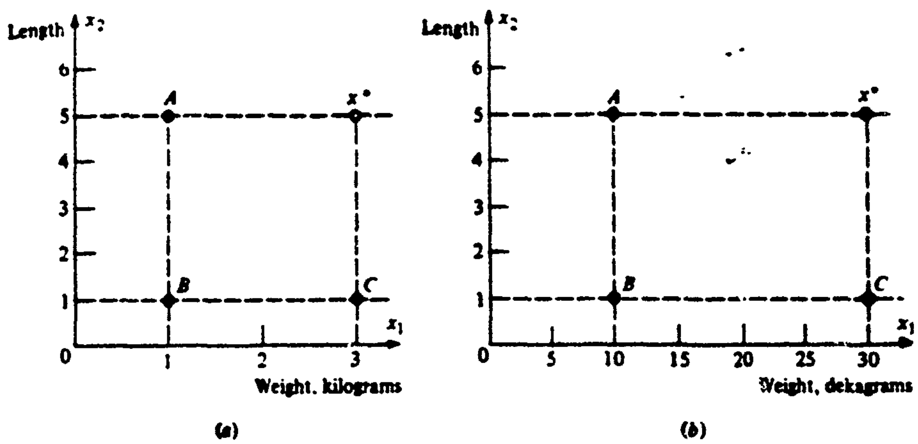

Fig. 2.4. Effect of Scale on Distance Measurement (8:321)

By using a scaling factor a relative distance is achieved. This scaling factor is

$$\left(\frac{X_i^* - X_i^k}{X_i^* - X_i^{**}}\right) \qquad (2\text{-}5)$$

where

X_i^* is the best value of the ith attribute

X_i^{**} is the worst value of the ith attribute

X_i^k is the value of the alternatives ith attribute for the kth alternative

Combining this scaling factor with the distance formula and remembering that our interest is in finding the minimum distance, the distance formula becomes:

$$\text{Min}\left\{dp = \sum_{i=1}^{n} \lambda_i^p \left(\frac{X_i^* - X_i^k}{X_i^* - X_i^{**}}\right)^p\right\}^{1/p} \qquad (2\text{-}6)$$

This expression is the operational definition of a compromise solution.

<u>Example Problem</u>

Compromise programming will be used to complete the car selection problem introduced in the AHP section. Sample data on the car's attributes are found in Table 2-3.

TABLE 2-3

SAMPLE DATA

	Honda	Mazda	Toyota
Base Price	\$10,000	\$7,800	\$6,600
Fuel Econ	43 MPG	34 MPG	33 MPG
Trunk Size	45 Ft^3	50 Ft^3	43 Ft^3

The normalized geometric mean vector elements calculated in the AHP portion of the problem are the weight values, λ, for expression 2-6. The relative weights for the automobile attributes are:

Cost = .570

Econ = .286

Size = .143

The ideal point for this problem consists of the best value of each attribute and is represented by the vector X^*. The vector X^{**} consists of the worst values of each attribute. For this example, $X^* = (6600, 43, 50)$ and $X^{**} = (10000, 33, 43)$.

The results from the compromise programming metric are summarized in Table 2-4. The results in Table 2-4 show that the Toyota is the closest alternative to the ideal point, unless the DM desires to minimize the maximum deviation, then the Mazda is the preferred alternative.

TABLE 2-4

DISTANCE VALUES FOR SELECTING AN AUTOMOBILE

Alternative	p=1	p=2	p=Infinity
Honda	.672	.335	1
Mazda	.458	.106	.9*
Toyota	.429*	.101*	1

* indicates minimum values (compromise solution).

Conclusion

This chapter explained the steps and the thoughts behind the two methodologies used in this study, AHP and compromise programming. AHP broke down the system into a complete and functional hierarchy through which the DM made his or her preferences known by pairwise comparisons. By using the geometric mean method, the consistency of these judgements was evaluated. The normalized geometric mean provided the weights used in the compromise programming methodology.

Compromise programming used the concept of distance to an ideal point to identify the preferred solution. The alternative(s) with the minimum distance to the ideal solution are the preferred solution(s). With the approach now firmly established, the next chapter will define the alternatives and present the relevant data in the airlock decision.

III. The Alternatives

Introduction

This chapter describes the five alternatives considered in this multiple attribute decision problem. The five alternatives are the present airlock system augmented with additional consumable gases, the Crewlock with void fillers, the Crewlock without void fillers, one Crewlock with void fillers and one Crewlock without void fillers. Each system's physical characteristics and performance parameters are described and a summary of these features is found at the end of the chapter. The attribute values to be used in the AHP and compromise programming methodologies will be highlighted. Also included in the descriptions will be discussion on some of the issues involved in EVA and use of the airlock system.

STS Orbiter Airlock System

The orbiter's airlock system provides the means for suited crewmembers to exit the mid-deck of the space shuttle to the vacuum of outer space without depressurizing the entire crew compartment. Three two-man EVA periods of six-hour durations are capable on the shuttle with no weight or volume cost to the payload. Two EVA periods are planned excursions while the third is reserved for contingency missions such as manually closing the payload doors prior to re-entry. Any additional EVA periods will be "considered with consumables charged to payloads"; in other words, the more EVAs, the more gases, specifically nitrogen gas, needed to be loaded and carried into space and the less payload the shuttle can carry (19:295).

The present airlock is basically a modular cylindrical structure composed of machined and welded aluminum. The walls of the cylinder and the bulkheads are of a honey combed construction and the inner walls are machined aluminum plate (see Figure 3-1). The orbiter's airlock is large enough to accommodate three crewmen. The two EVA astronauts require a third party to don and doff their suits, called Extravehicular Mobility Units or EMUs.

The actual physical measurements of the airlock are as follows. The inner diameter is 63 inches and the length is 83 inches; this makes the airlock volume 150 cubic feet or 4.25 cubic meters. The effective airlock volume is 130 cubic feet; this is based on two EMU suited crewmen occupancy (19:284; 20:3).

The airlock is equipped with two hatches mounted on opposite sides of the module. The inner hatch is mounted on the orbiter crew cabin mid-deck side and opens toward the mid-deck. This hatch isolates the airlock from the rest of the crew cabin. The outer hatch, mounted in the interior of the airlock, opens into the airlock. This

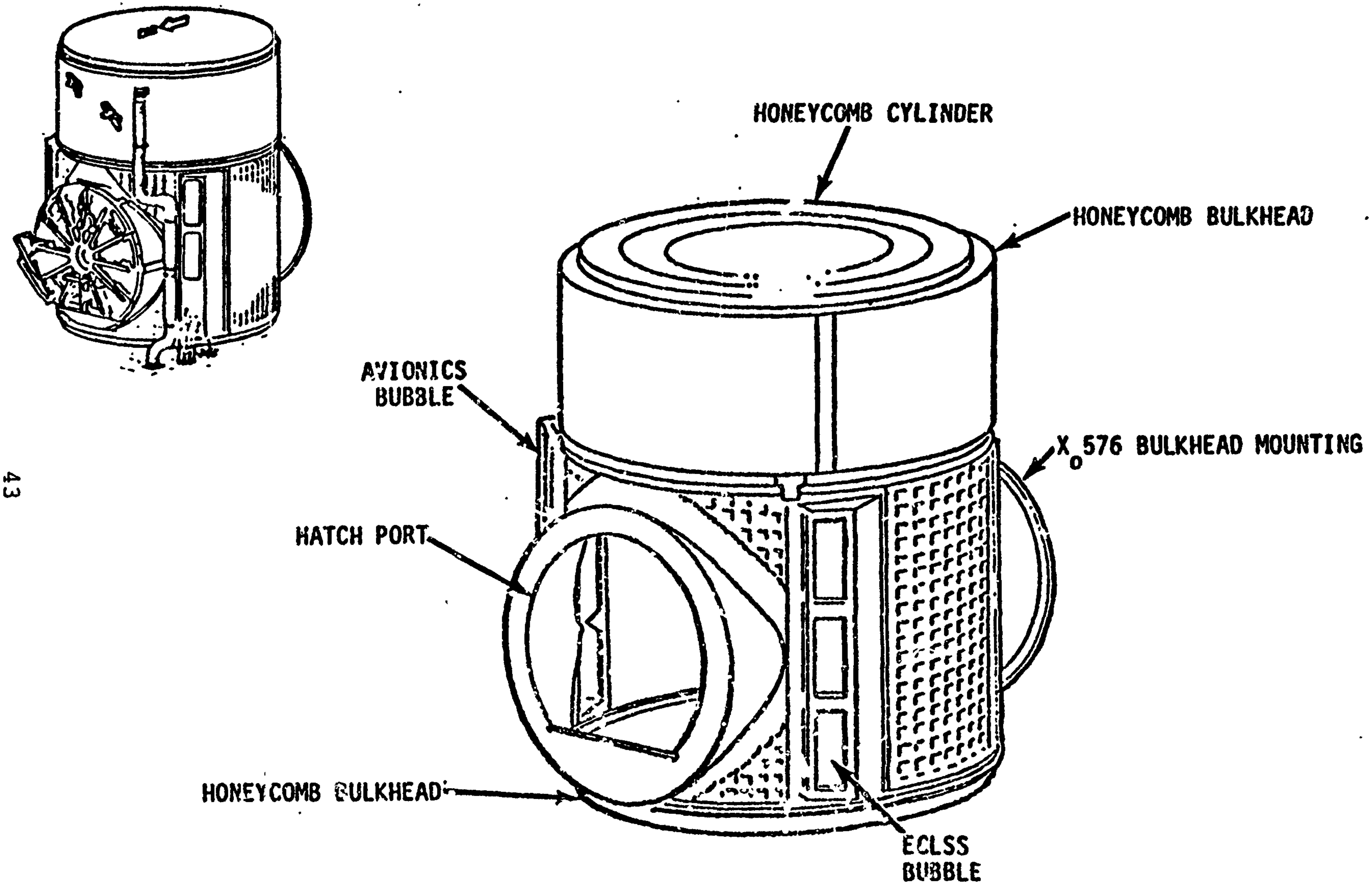

Fig. 3-1. Airlock Structure (21:2-2)

hatch separates the airlock from the unpressurized payload bay (19:284). These D-shaped hatches measure 39.3 inches in diameter. The fact that these hatches open toward the primary pressure source not only satisfies the NASA design requirement, but provides pressure assist sealing in the closed position (19:288). Total weight of the airlock and its support and auxiliary equipment is approximately 1800 pounds, and it occupies one-fourth of the shuttle's mid-deck void volume.

The airlock module can be installed in any one of four configurations (see Figure 3-2). The baseline location is upright inside the mid-deck compartment. In this configuration, maximum use of the payload bay volume is possible. Another configuration is to rotate the module 180 degrees and install it in the cargo bay. This configuration optimizes the seating capacity in the orbiter's mid-deck. The third configuration is placing the airlock on top of the pressurized tunnel adapter when habitable payloads such as Space Lab are flown in the payload bay. The final configuration uses the airlock chamber in series with the tunnel adapter (21:2-1).

Prior to EVA periods, crewmembers must don the EMU space suit. The two crewmembers going EVA must pre-breathe pure oxygen in the EMU for three and a half hours prior to leaving the orbiter. This pre-breathe is necessary to remove nitrogen from their blood stream before working in

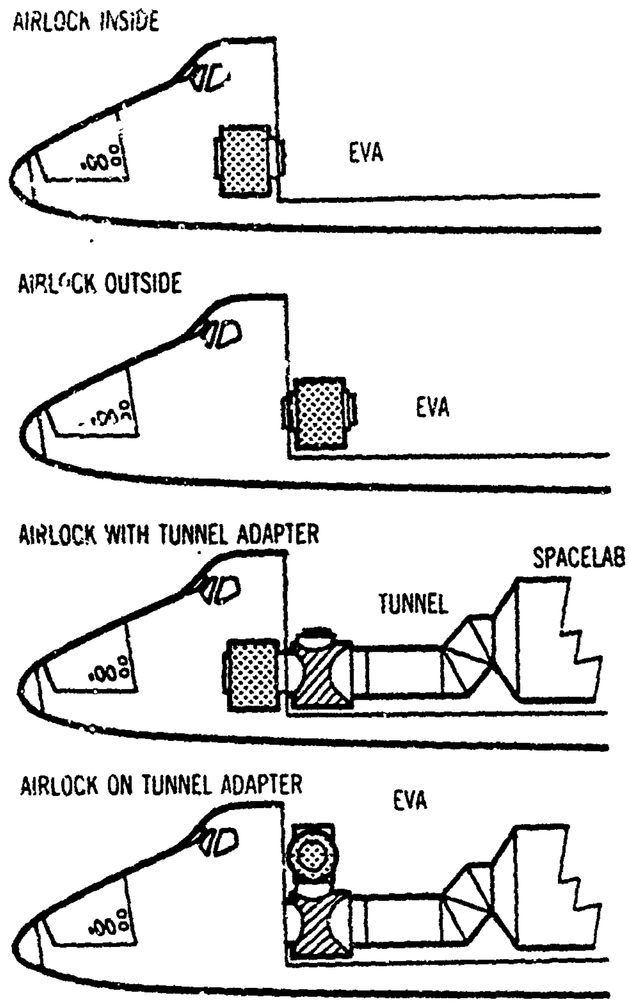

Fig. 3-2. Possible Airlock Locations (23:84)

the pure oxygen environment of the EMU and due to the orbiter's pressurized crew cabin atmosphere of 20 percent oxygen and 80 percent nitrogen. The pressure of the orbiter is maintained at 14.7 $\pm$ .2 psia. Bends will occur when an individual fails to reduce the nitrogen level in the blood prior to working in a pressure condition where nitrogen bubbles come out of solution. This condition can result in pain in body joints, spinal cord, and lungs, unconsciousness, deafness, choking and ultimately death (22:108).

The amount of oxygen used for two crewmen during pre-breathe is approximately 5.4 pounds per mission and the shuttle currently allows for six pre-breathe cycles per mission.

Following the pre-breathe period and EMU check out, EVA is initiated by opening the airlock depressurization valve to the first of three discharge positions. This three-position valve, located in the airlock, controls the rate of depressurization by varying the orifice diameter size of the waste management vacuum vent lines.

Depressurization of the airlock is accomplished in two stages. With the valve in the closed position, no air-flow escapes through the overboard vent system. Moving the valve to position five initiates phase one of the depressurization sequence. In position five, the vent line orifice is open to a diameter of .5925 inches. During this phase, the airlock pressure is dropped from 14.7 psia (the orbiter's normal operating atmosphere) to 5 psia in just under 180 seconds. At this time, the EVA crewmembers perform communication checks as well as EMU pressure and integrity checks. Phase two, moving the depressurization valve to position zero, increases the vent valve diameter to 1.0164 inches and allows the pressure in the airlock to decrease from five psia to 0 psia in another 180 seconds (19:3-13). The airlock is depressurized within eight minutes at a depressurization rate of no more than .1 psia per second (see Figure 3-3). During the depressurization of the airlock, eleven pounds of nitrogen gas is dumped overboard through the two-inch stainless steel waste management vacuum vent line (20:4). This eleven pounds of nitrogen gas is irretrievable.

The depressurization of the airlock also has provisions for contingency operations. Of the two contingency profiles, the fastest airlock depressurization is three minutes (see Figure 3-4). This is accomplished by placing one valve in the emergency position.

Once the airlock is depressurized, the time schedule allocates forty minutes for the astronauts to exit the airlock into the cargo bay and begin EVA operations. Upon completion of the six to eight hour EVA period, the astronauts are allocated twenty to thirty minutes to re-enter the airlock (24).

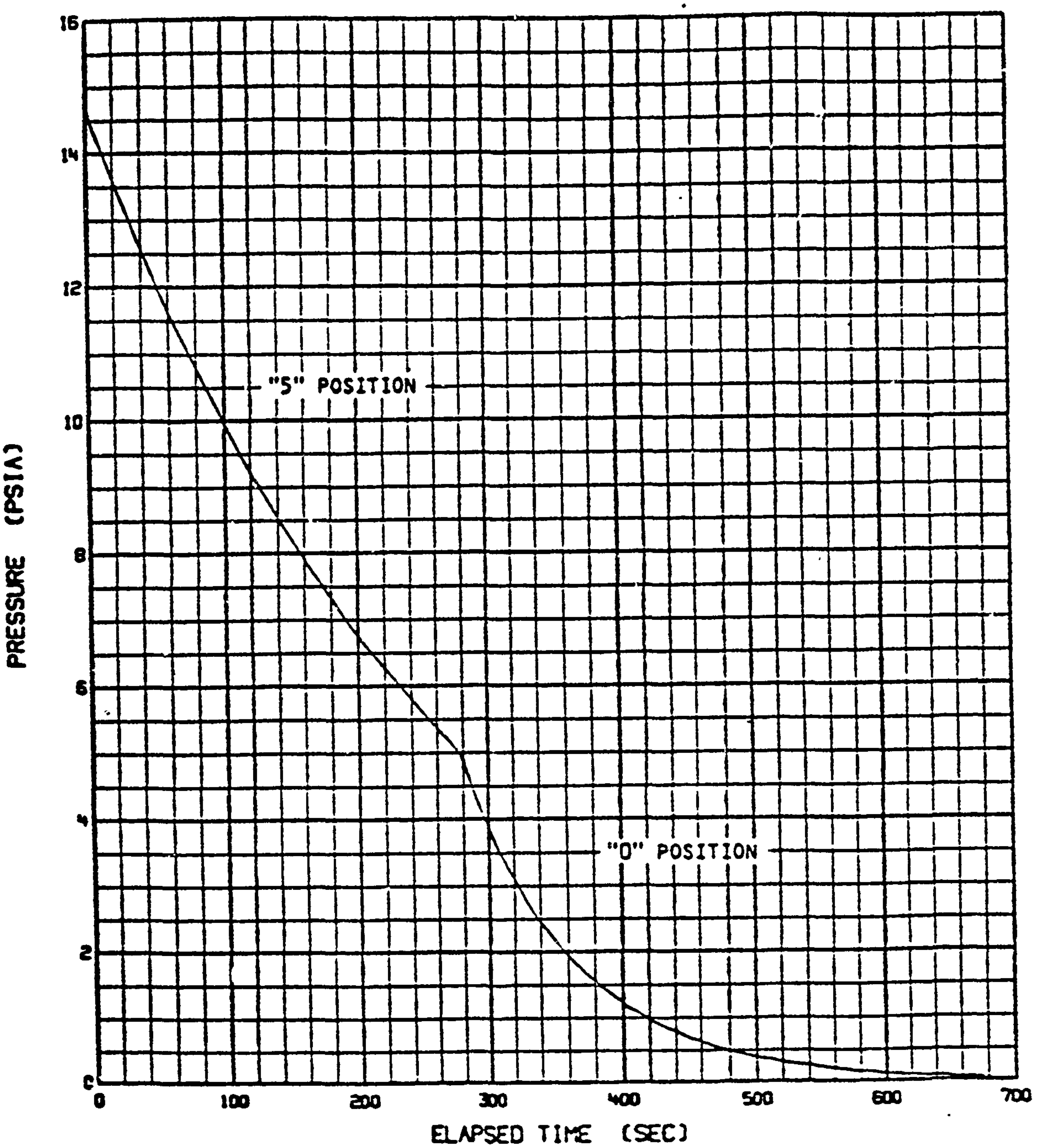

Fig. 3-3. Airlock Depressurization Profile
Normal Mode (21:4.6.4-11)

Repressurization is accomplished by equalizing the airlock and cabin pressure with the inner equilization valves mounted on the airlock's inner hatch. The airlock has two pressure equalization valves which can be operated from both sides of the hatch. Each pressure equalization valve has three positions, closed, normal and emergency. By using the equalization valve in various positions, the astronauts can control the repressurization profiles (see Table 3-1).

TABLE 3-1

REPRESSURIZATION PROFILE SETTINGS AND TIME

Mode	# Valves/Setting	Time
Normal	1/Norm	160 secs
1st Emergency	2/Norm	82 secs
2nd Emergency	1/Emer	33 secs
3rd Emergency	2/Emer	16 secs

Normal repressurization, accomplished by placing one of the two equalization valves in the normal position, restores the airlock chamber to 13.98 psia in approximately 160 seconds or about 3 minutes (based on a pressurization rate of .1 psia/sec) (see Figure 3-5). The orbiter environmental control life support system's, ECLSS, cabin pressure regulator continues the flow of oxygen and nitrogen until

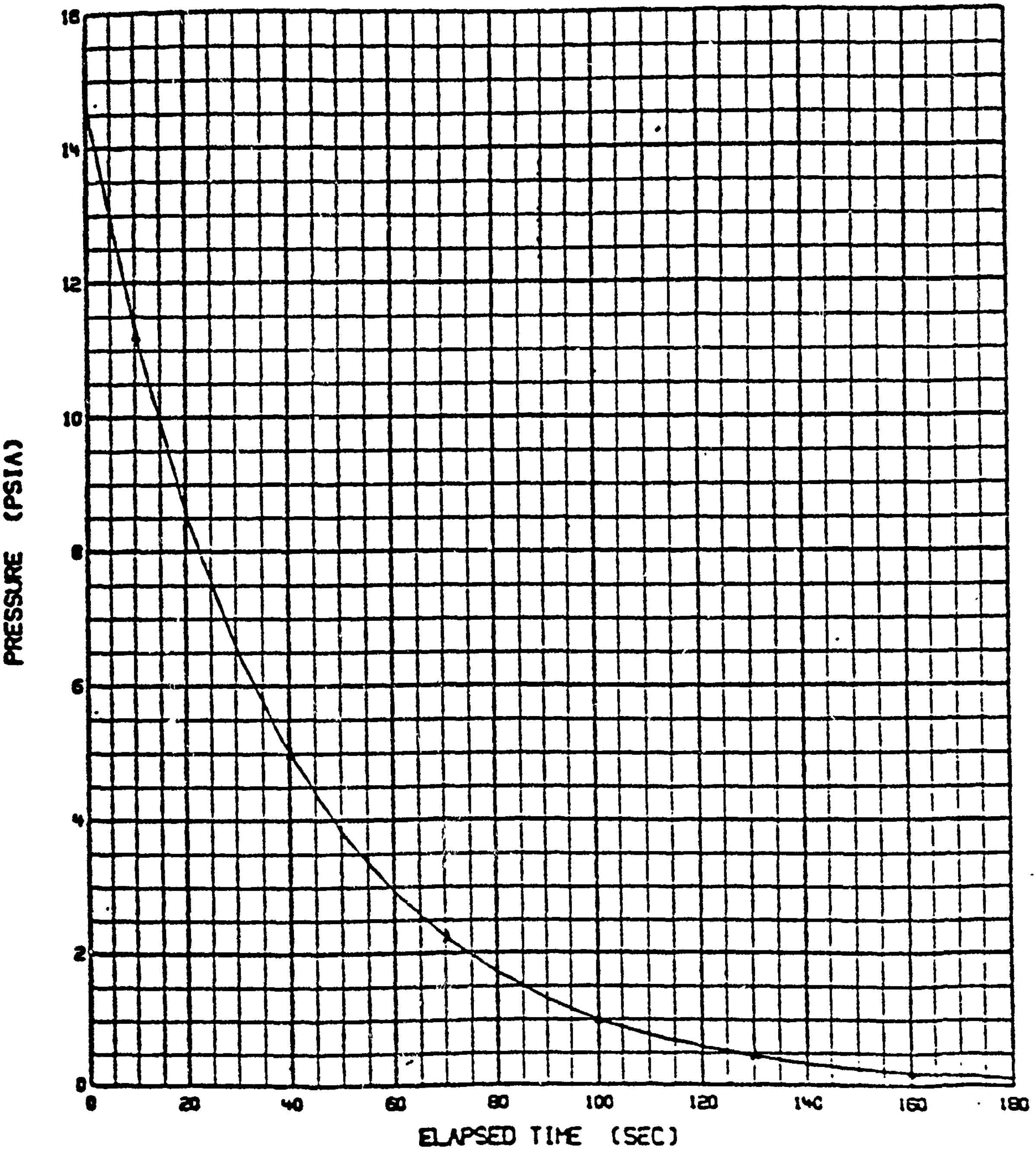

Fig. 3-4. Contingency Depressurization Profile (21:4.6.4-13)

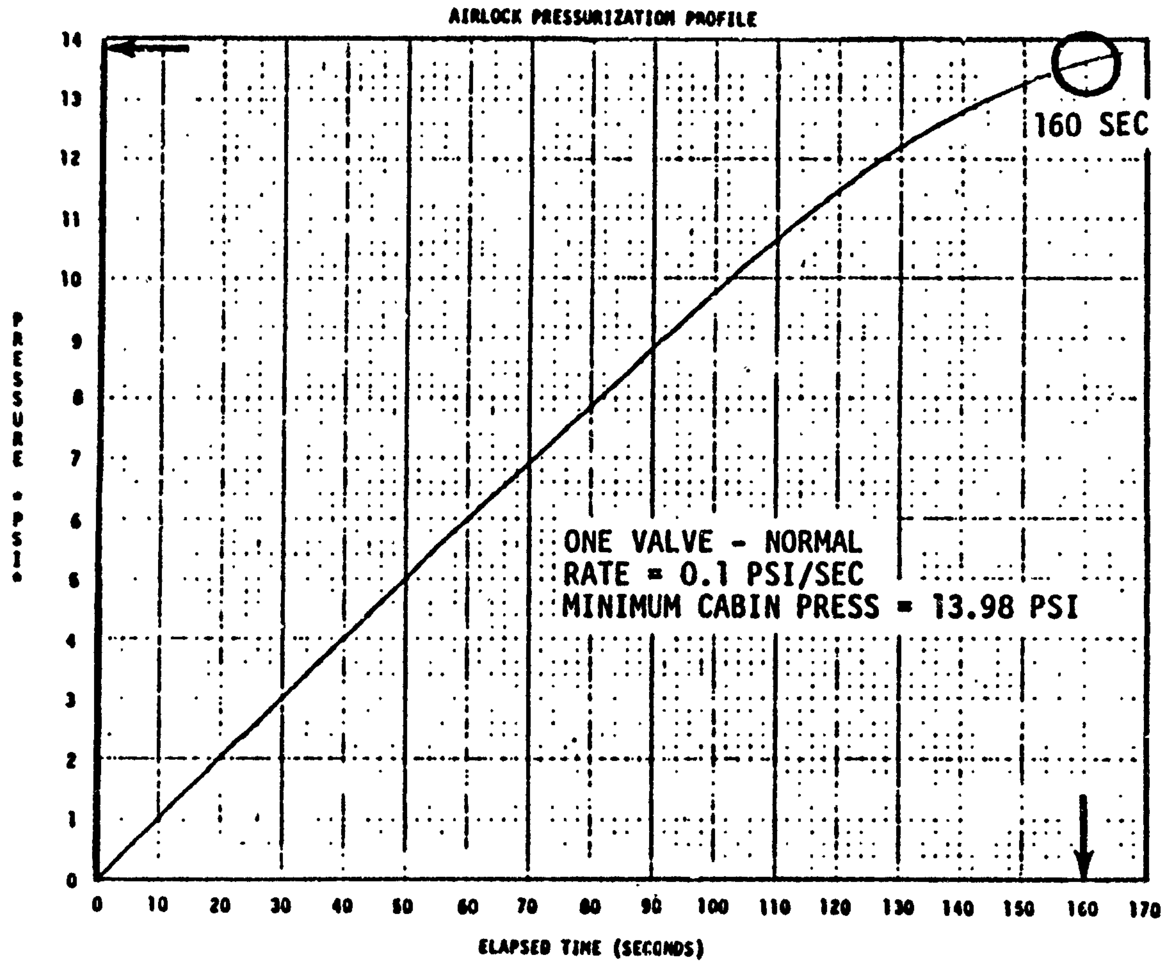

Fig. 3-5. Airlock Repressurization Profile Normal Mode (21:3-15)

the airlock pressure returns to 14.7 psia. The three so-called emergency repressurization rates, achieved by varying the number and setting of the equalization valves, reduce the time to reach 14.7 psia cabin pressure with the shortest repressurization time being 16.3 seconds (see Figures 3-6, 3-7, and 3-8). This time is achieved by opening both valves to the emergency position and using a maximum rate of repressurization of 1 psia/sec. The emergency rates are used if time constraint situations, such as a leak in an EMU or imminent depletion of the portable life support system comsumables, are placed on the EVA crewmember (21:3-13). During repressurization, approximately 8 pounds of oxygen gas and just over 8 pounds of nitrogen gas are used to restore the airlock's pressure from 0 psia to 14.7 psia. For the three EVA operations, the repressurization totals are 24 pounds of oxygen and 27 pounds of nitrogen (25:35).

The nitrogen gas used to repressurize the airlock and to maintain the cabin pressure at 14.7 psia is stored in titanium storage tanks located in the lower forward portion of the shuttle's mid fuselage (see Figure 3-9). The nitrogen system consists of four tanks each weighing 57.5 pounds. Maximum capacity of a nitrogen tank is 56 pounds and the minimum capacity is 49 pounds (26:84).

Using the present system, three EVA periods are possible without penalty to the payload. One NASA-suggested

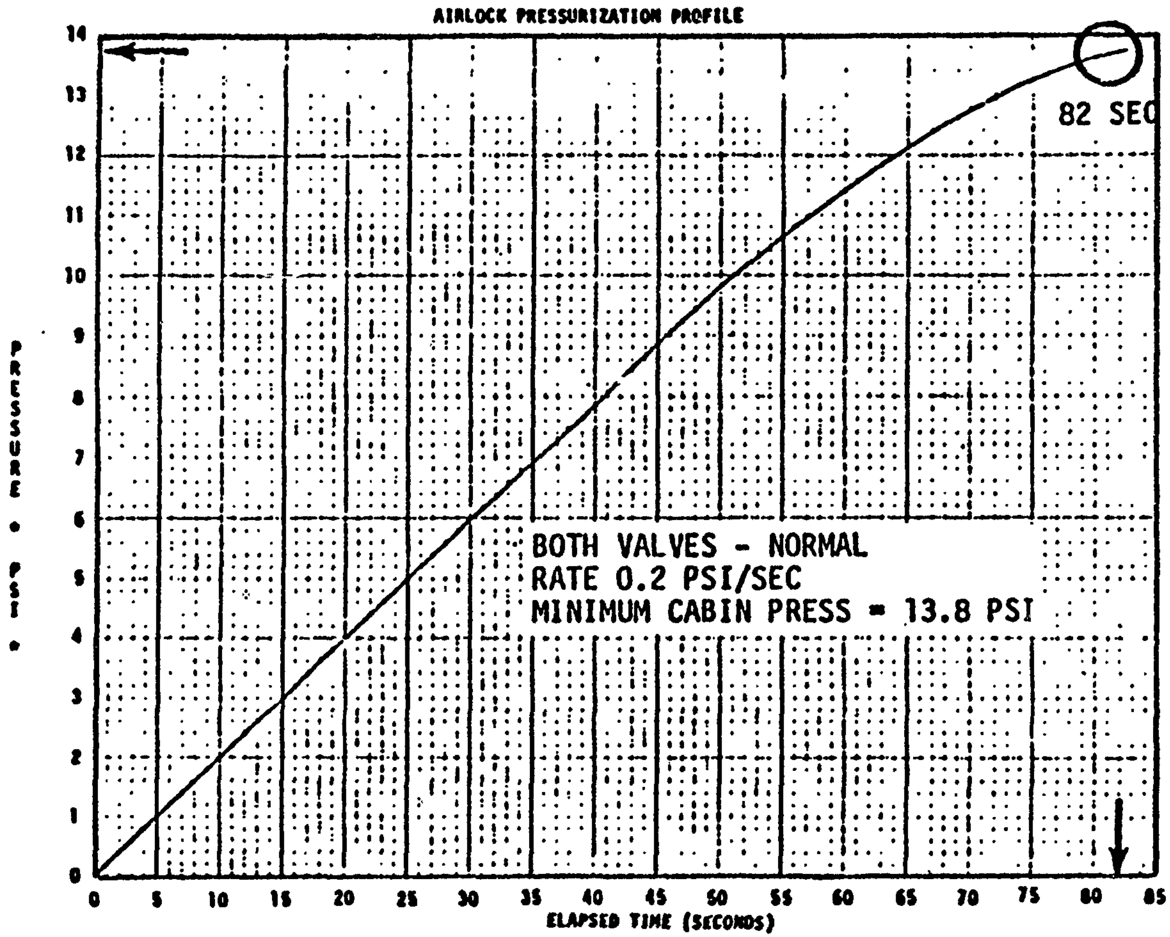

Fig. 3-6. Airlock Repressurization Profile First Emergency Mode (21:3-16)

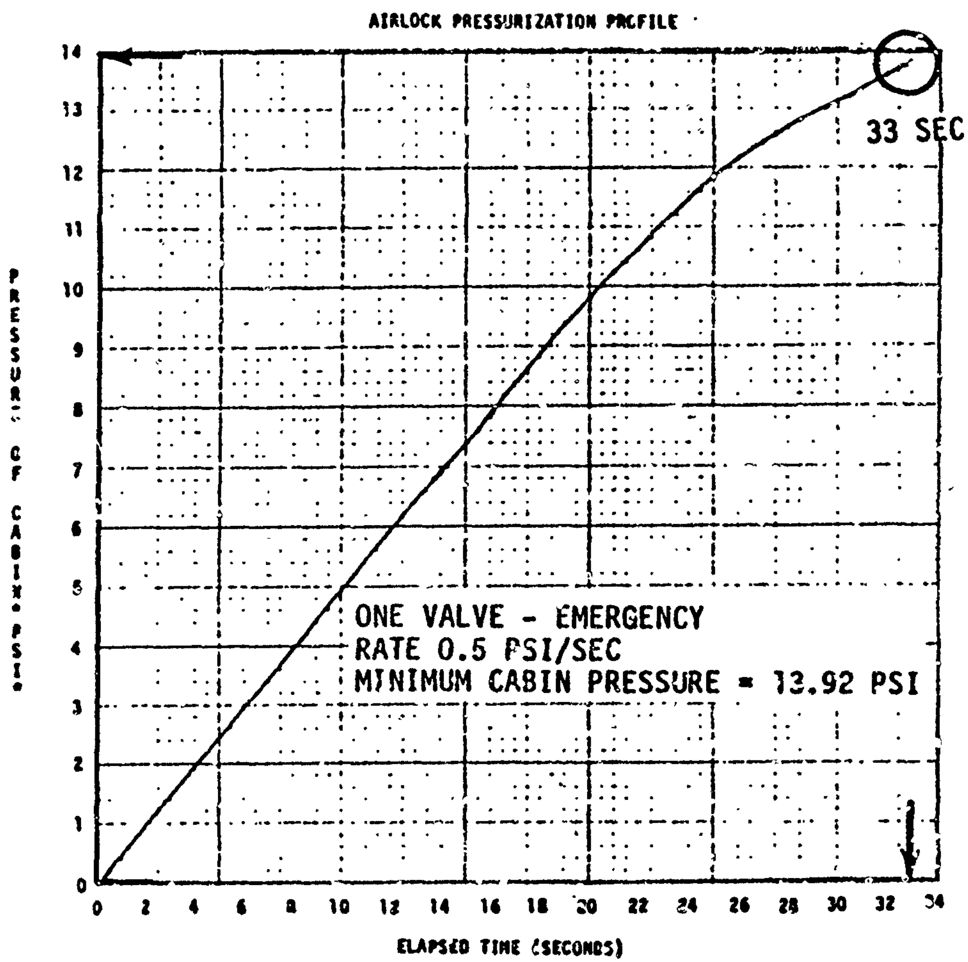

Fig. 3-7. Airlock Repressurization Profile Second Emergency Mode (21:3-17)

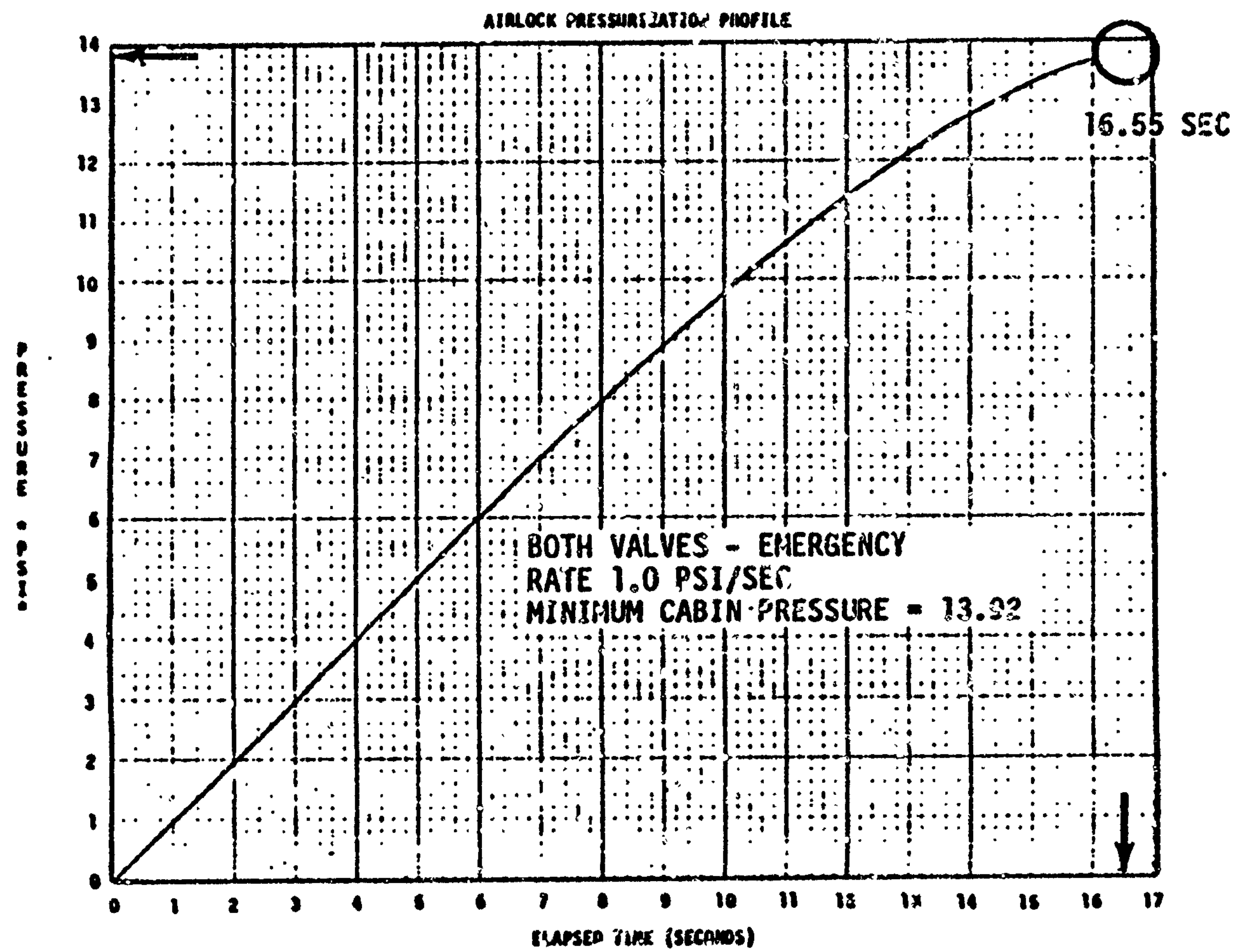

Fig. 3-8. Airlock Repressurization Profile Third Emergency Mode (21:3-18)

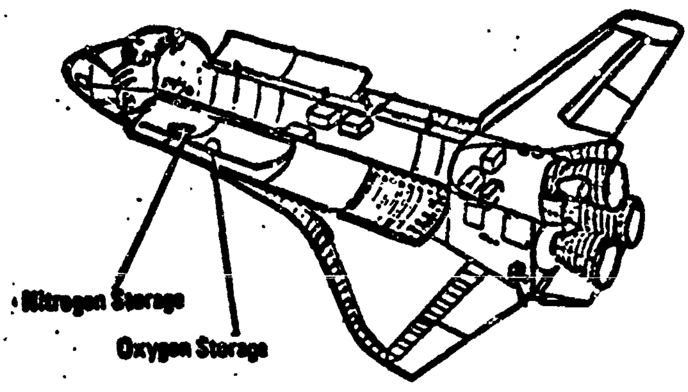

Fig. 3-9. Nitrogen and Oxygen Storage Tank Locations

means to increase the number of EVA periods during space station construction is to augment the nitrogen gas system. To increase the number of EVA periods from 3/mission to 8/mission with 11 pounds of nitrogen expended for each airlock depressurization and 8 pounds expended during repressurization requires 95 additional pounds of nitrogen gas. For the purpose of this study, 95 pounds of nitrogen requires two extra nitrogen tanks for a total additional weight of 115 pounds. With the two additional nitrogen tanks, the airlock's total weight is now approximately 1915 pounds.

In addition to providing depressurization and pressurization, the airlock system also provides various support functions. Among these are emergency breathing support, stowage of EVA equipment, assistance in EVA equipment donning and doffing, portable life support system

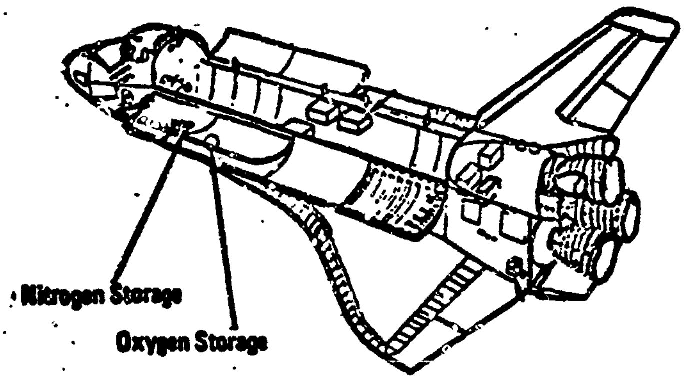

Fig. 3-9. Nitrogen and Oxygen Storage Tank Locations

means to increase the number of EVA periods during space station construction is to augment the nitrogen gas system. To increase the number of EVA periods from 3/mission to 8/mission with 11 pounds of nitrogen expended for each airlock depressurization and 8 pounds expended during repressurization requires 95 additional pounds of nitrogen gas. For the purpose of this study, 95 pounds of nitrogen requires two extra nitrogen tanks for a total additional weight of 115 pounds. With the two additional nitrogen tanks, the airlock's total weight is now approximately 1915 pounds.

In addition to providing depressurization and pressurization, the airlock system also provides various support functions. Among these are emergency breathing support, stowage of EVA equipment, assistance in EVA equipment donning and doffing, portable life support system recharge provision and cooling loops for space suit cooling during pre- and post-EVA periods.

Crewlock with Void Fillers

The Crewlock is an alternative concept in airlock chamber design proposed by William E. Haynes. Currently, the Crewlock is being evaluated by McDonald Douglas under contract from Air Force Space Division.

Crewlock's final shape has not yet been completely determined, but for the purpose of this study and for comparison purposes, Crewlock will be described as "a cylindrical chamber, split longitudinally and sized to accept a fully suited 95th percentile man" (27:2). The physical dimensions of this chamber are 200 centimeters for the interior length and 100 centimeters for the interior diameter or approximately 6½ feet by 3½ feet.

What differentiates Crewlock from the present airlock system is that "the void volume present around the crewmember will be occupied by solid low mass material transparent on the crewmember's front side" (27:2). With the use of these void fillers the residual void volume is on the order of .03 cubic meters or roughly 1 cubic foot. This is compared to the 150 cubic foot volume of the present airlock system. Figures 3-10a, 3-10b, and 3-11 illustrate the Crewlock void filler concept.

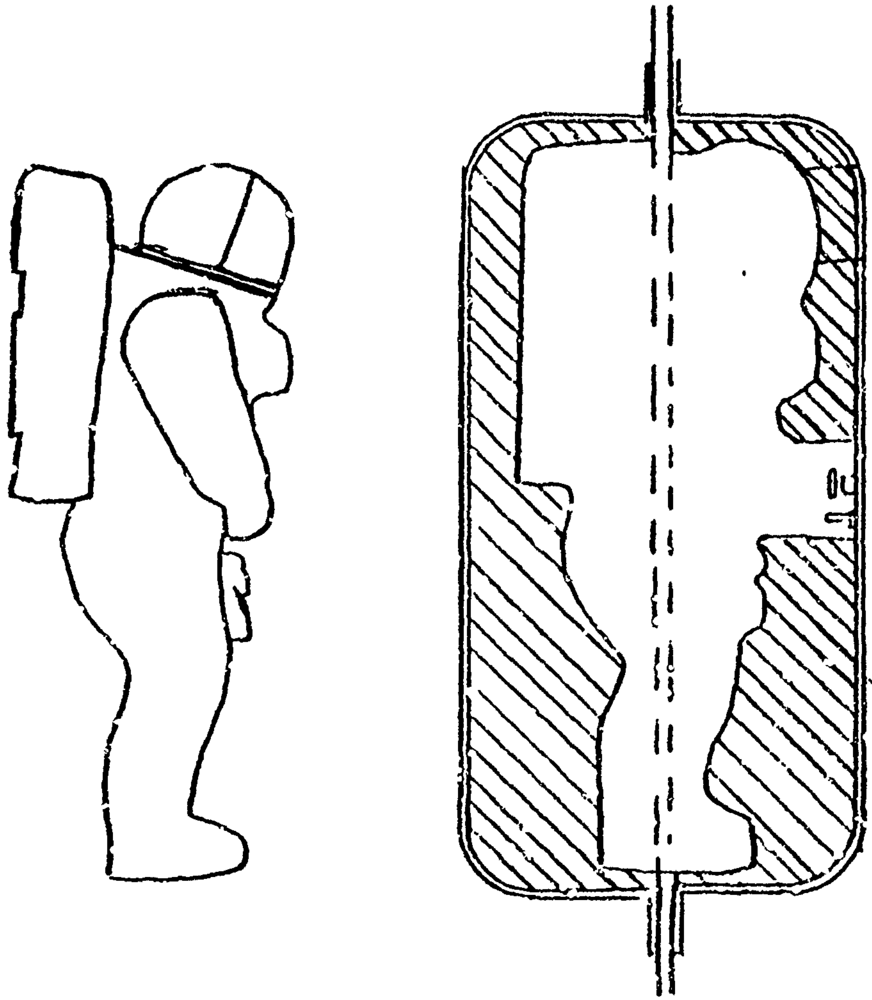

Fig. 3-10a. Crewlock with Void Fillers (27:2)

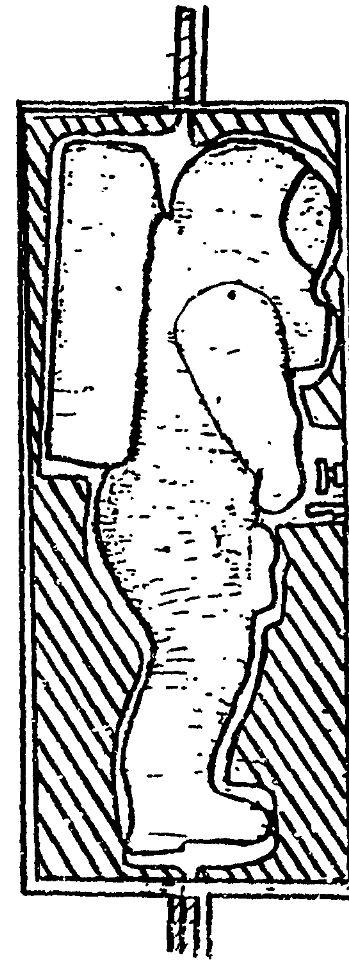

Fig. 3-10b. Occupied Crewlock with Void Fillers (27:2)

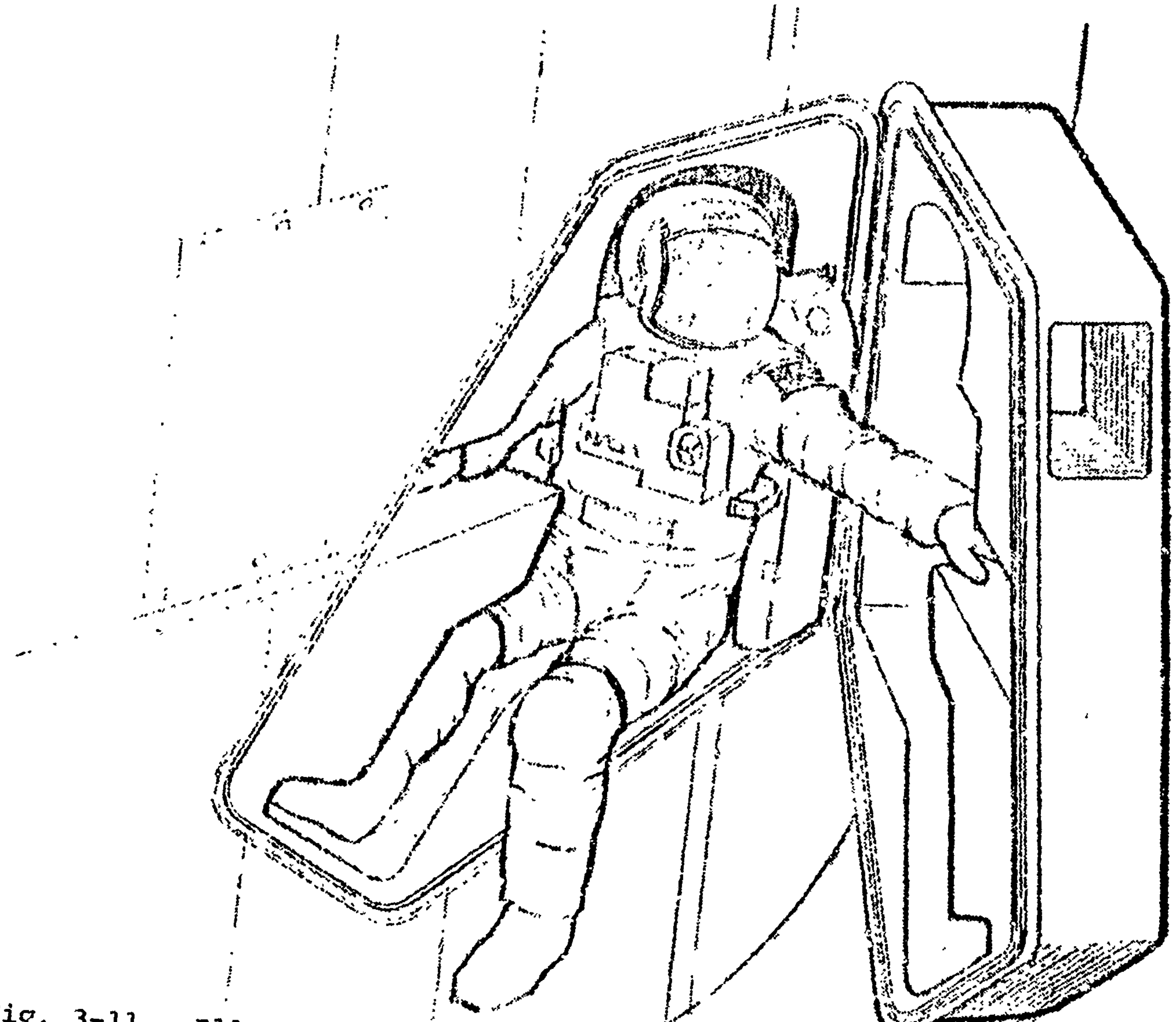

Fig. 3-11. Illustration of Crewlock's Void Filler Concept (27:2)

The estimated weight of the Crewlock chamber is approximately 300 pounds. The Crewlock's weight saving is attributed to its construction material, graphite epoxy. In order to meet the NASA requirement of two man EVAs, two Crewlock chambers, mounted on the right and left side of the mid-deck aft bulkhead, will be required on each shuttle. The combined weight is approximately 600 pounds and the combined residual void volume is 2 cubic feet or .06 cubic meters (27:2).

Use of the Crewlock still necessitates the 3½ hour pre-breathing to de-nitrogenate the body and reduce the chances of suffering from the bends. This pre-breathe period is a function of the EMU and not the airlock system. Preparation operations for EVAs remain the same as previously described, but whereas the donning and doffing of the EMUs and EMU checkout was performed in the airlock, all preparations of the EMUs when using the Crewlock take place in the orbiter's mid-deck in the space now occupied by the current airlock chamber. The assistance of a third crewmember is still required to don and doff the EMU. Once inside the Crewlock, the crewmember actuates the depressurization valves and partially evacuates the chamber. Actuation of the depressurization cycle can be controlled either from the orbiter's mid-deck or inside the Crewlock chamber. The remaining pressure in the Crewlock is vented overboard after the EMU is checked for proper operation and pressure integrity.

During the egress operations, approximately .1 pound of air is vented overboard compared to the 11 pounds of nitrogen dumped overboard with the current system (27:4). This figure is derived from the volume of the cylinder being 1 cubic foot and the EVA Crewmember with EMU donned occupying 2/3 of the void volume.

$$\text{mass} = 1/3\ (1\ \text{ft}^3)\ (32.2)\ (.0022926) = .1\ \text{lb of air} \quad (3\text{-}1)$$

Therefore, the amount of gas used to operate two Crewlocks is approximately two tenths of a pound. For these calculations, the air mixture is 80 percent nitrogen and 20 percent oxygen giving the air a combined weight of 28.8 grams/mole and an average cabin temperature of 23°C. See Appendix A for more detailed calculations.

The transit time for the Crewlock, determined from tests conducted by the McDonald Douglas Corporation, is less than four minutes. It is feasible to reduce this time down to one minute as crewmembers become more experienced with Crewlock operations (24).

Upon completion of the EVA period, repressurization of the Crewlock is accomplished in approximately 10 seconds (24). One tenth of a pound of air is assumed to be consumed during repressurization of the Crewlock. Doffing of the suit takes place outside the Crewlock in the orbiter's mid-deck. EMUs can be dried by returning them to the Crewlock and venting Crewlock to a vacuum. Although this does require the use of more gases, the amount is small. This procedure is optional and not a necessity.

The Crewlock can utilize much of the same hardware as the present system and performs the same EMU support functions as the present system.

Crewlock without Void Fillers

Alternative three is a variation of the second alternative described above. The one exception being the low mass void fillers that surround the suited crewmember are removed. One benefit from this is added mobility of the crewmember during transit. The removal of the void fillers increases the Crewlock volume to approximately 50 cubic feet, but decreases the weight of each Crewlock chamber by 5-10 pounds (28:5). Increasing the volume of the Crewlock will undoubtedly mean a greater expenditure of gases during operations. Using the same assumptions, a suited crewmember occupies 2/3 of the volume, the 80 percent nitrogen and 20 percent oxygen air mixture and a weight of 28.8 grams/mole, equation 3-1 yields

$$\text{mass} = 1/3\ (50\ \text{ft}^3)\ (32.2)\ (.0022926) = 1.4\ \text{lbs of air}$$

Therefore, the amount of gas used to operate two Crewlock system with no void fillers is three pounds. Again, refer to Appendix A for more detailed calculations. Aside from the decreased weight and additional consumables used, all other Crewlock features and performance characteristics remain the same.

<u>One Crewlock with Void Fillers</u>

This alternative is the same as the Crewlock with void fillers alternative except, instead of two Crewlock chambers, only one is used. Having only one chamber means the chamber has to be recycled after the first EVA astronaut exits into the cargo bay or re-enters the orbiter's mid-deck. This extra cycle adds to the total transit time and increases the amount of consumables used. By using only one chamber, the system's total weight is approximately 300 pounds.

<u>One Crewlock without Void Fillers</u>

This is the last alternative to be evaluated. It is identical to the alternative just described except, the low mass void fillers are removed. Without void fillers, the total weight of the system is reduced, but the volume (for expendable gas considerations) increases. This increased volume means more consumable gas expended per cycle. Just as before, having only one chamber requires recycling of the chamber after the first EVA astronaut exits into the cargo bay or re-enters the orbiter's mid-deck. This extra cycle adds to the total transit time and increases the amount of consumable gas used. The system's total weight, including an additional gas tank, is approximately 350 pounds.

A summary of the quantitative performance parameters and physical characteristics is provided in Table 3-2. Chapter IV uses this data along with the methodologies developed and described in Chapter II to identify the alternative closest to the ideal airlock system.

TABLE 3-2

ALTERNATIVE SOLUTIONS PERFORMANCE PARAMETERS

	Airlock	2 Crewlocks w/void fillers	2 Crewlocks w/o void fillers	1 Crewlock w/void fillers	1 Crewlock w/o void fillers
Weight (lbs)	1914	600	590	300	350
Size					
Height (in)	84	78	78	78	78
Width (in)	63	80	80	40	40
Volume (effective) Ft^3	130	2	38	1	19
Total Transit Time (Secs)	60	<8	<8	<16.3	<16.3
Depress Time (Secs)	360	10	10	30	30
Repress Time (Secs)	160	10	10	30	30
Expandables / Cycle (lbs)	19	.4	6	1	14
# Transits / Mission (EVAs)	8	142	9	57	8

IV. Application of the AHP and Compromise Programming

Introduction

In this chapter, the AHP and compromise programming methodologies will be applied to the airlock decision problem. The format of this chapter parallels that of Chapter II. AHP starts off with the principle of decomposition and the construction of the hierarchy to include the focus, intermediate levels and the alternatives. The comparative judgements section describes the judgement matrix and the method used to solicit the n(n-1)/2 pairwise comparisons. This is followed by the determination of a group consensus and the final matrix inputs. The AHP ends with the determination of weights of each attribute. The compromise programming section leads off with definitions of the ideal solution and the worst case attributes. Finally, the compromise programming metric will be applied using the weights generated by the AHP and the performance and physical characteristic data presented at the end of Chapter III.

AHP

Principle of Decomposition. The principle of decomposition is concerned with the breaking down of a problem or system into separate parts or elements. For the airlock decision, a functional hierarchy is used. Functional hierarchies "decompose complex systems into their constituent parts according to their essential relationships" (13:28).

Construction of the airlock selection hierarchy followed Saaty's suggested method. Saaty suggested starting at the bottom by listing the alternatives. The next level is composed of the judgement criteria used to evaluate the alternatives and, finally, the top level or focus is the overall objective or purpose of the study. Starting at the bottom, level three, the alternatives, described in Chapter III, are the present system augmented with additional consumables, the Crewlock with void fillers, the Crewlock without void fillers, one Crewlock with void fillers and one Crewlock without void fillers. Comprising the second level of the hierarchy are the judgement criteria. Through telephone interviews with civilian and military decision makers, technicians and system managers, ten attributes were identified to judge the competing airlock systems. The ten attributes are listed and defined in Table 4-1.

The top level of the hierarchy, or focus, is the selection of the best airlock system to use during construction of the space station. All attributes will be compared and subjective judgements made on the importance of their relative contribution to meeting this objective. The complete airlock selection hierarchy is found in Figure 4-1.

TABLE 4-1

ATTRIBUTES AND DEFINITIONS

Attribute	Definition
Safety	Freedom from danger, risk or injury.
Reliability	The dependability of the airlock system.
Weight	The total weight of the airlock chamber, auxiliary equipment, including hand holds and foot restraints and support equipment additional consumable gas tanks measured in pounds.
Size	Size includes the height and width of the airlock chamber measured in inches.
Volume	Effective volume or the volume of the airlock with two crewmen suited with EMUs inside measured in cubic feet.
Transit Time	The time to pass from one pressure differential to another measured in seconds.
Expendables Used	The amount of nitrogen gas used per cycle of the airlock measured in pounds. A cycle is a depressurization and a repressurization of the airlock.
Depressurization Time	The time for the airlock to go from 14.7 psia to approximately 0 psia measured in seconds.
Repressurization Time	The time of the airlock to go from 0 psia to approximately 14.7 psia measured in seconds.
# Transits/Mission	The number of EVA periods during a normal shuttle mission.

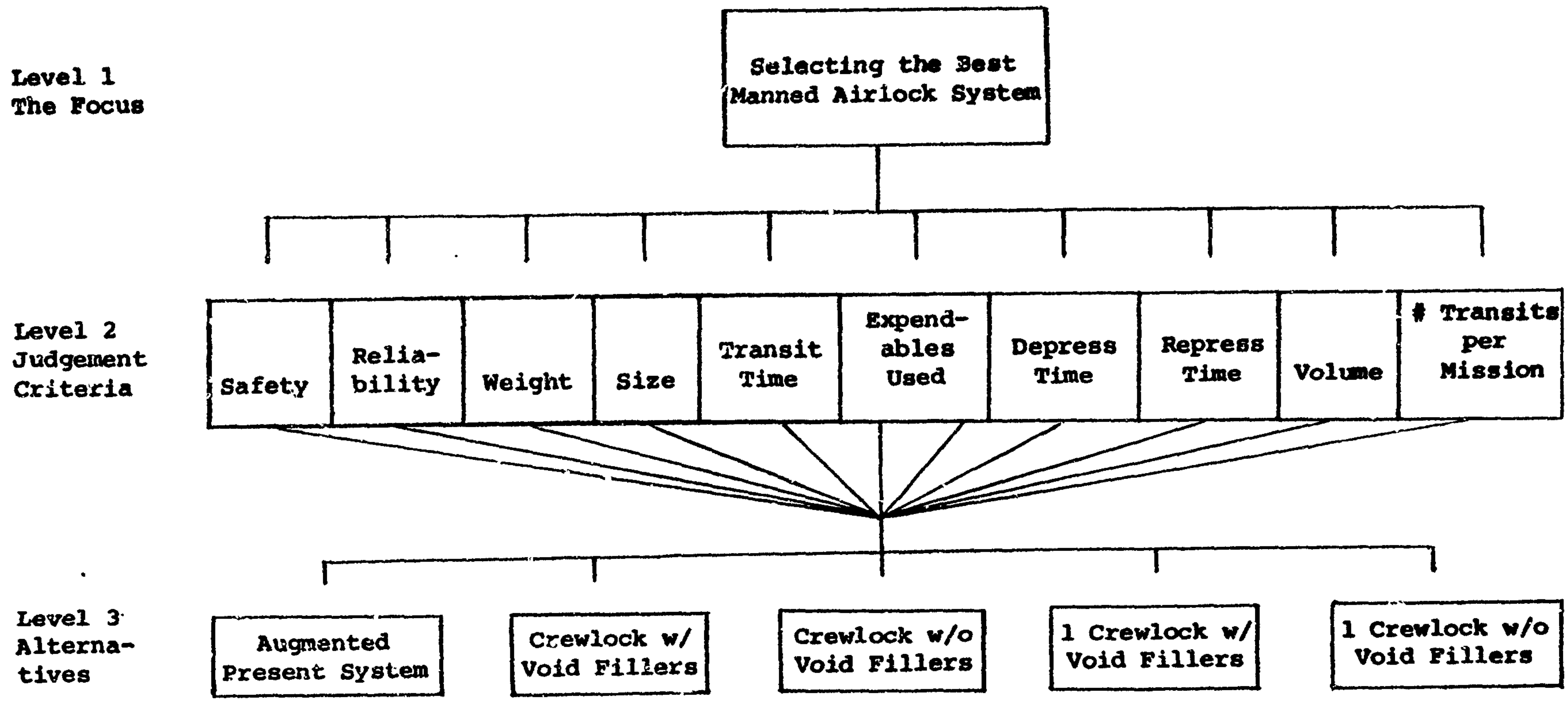

Fig. 4-1. Airlock Selection Hierarchy

Comparative Judgements. With a complete hierarchy established, the second principle of the AHP, comparative judgements, is applied. The principle of comparative judgements involves the ranking of each element according to its relative importance to the overall objective. These subjective judgements require the comparison of all elements, or judgement criteria, in pairs against a given criterion.

For the airlock selection, the solicitation of judgements was accomplished by means of a mail survey. The survey participants, many of whom participated in the hierarchy construction, covered a broad range of occupations, all related to space systems. This wide variety of participants insured that the required expertise for all airlock/EVA issues was available.

In accordance with Saaty's AHP, the survey participants were asked to make pairwise comparisons involving the judgement criteria, found in level two of the hierarchy (see Figure 4-1). The number of judgement criteria, n, is 10; therefore, 45 pairwise comparisons were required. The group utilized Saaty's one to nine rating scale to indicate their preferences on the relative importance of one attribute over another (see Table 2-1). The subjective judgements made by the participating DMs will fill the top half of the judgement matrix. The diagonal of the matrix is composed of ones and the lower portion is filled by invoking the law of transitivity. A copy of the survey is in Appendix B.

Group Consensus. Saaty points out one advantage or benefit gained by using the AHP is it provides a new way to "incorporate judgements of several people and resolve conflicts among them" (16:68). What prevents this from being a very simple step in most group decisions is

> How to represent group judgement in a satisfactory way when people's experiences and judgement differ, and whose opinions should be taken more seriously and why. . . ? (8:69)

Answering these questions results in the formation of a consensus. A consensus is different from a compromise:

> A compromise is a solution, or a settlement of differences, in which each side makes some concessions. A consensus is a collective opinion or accord. There can be many compromise solutions but only one consensus. A group can define different compromise solutions; one of them will emerge as a consensus. (8:69)

Saaty defines a consensus as "improving confidence in the priority values by using several judges to bring the results in line with majority preferences" and the process of obtaining a consensus is a means to persuade people that their interests were considered (16:66).

Ideally in group decision problems, the entire group is present and a consensus is formed through group interaction and feedback or the Delphi or similar processes. Unfortunately, trying to obtain a consensus for a large matrix via the survey process is nearly impossible due to the intractability of the participants and, in this case, the anonymity promised to the participants. Compounding this problem is the enormous amount of feedback required for the n(n-1)/2 pairwise comparisons. A more direct approach to consensus formulation is needed in this case.

Even though a direct method is required here, the goal remains the same. The goal is to find a method that molds several group inputs into a true group priority vector. The method of aggregation suggested by Saaty is to take the geometric mean of the group input values. The geometric mean is needed since these subjective judgements are actually ratio values between two attributes. The geometric mean formula is

$$\text{Geometric Mean} = \left(\prod_{i=1}^{n} a_i \right)^{1/n} \qquad i = 1,2,\ldots,n \qquad (4\text{-}1)$$

where a_i is the input value for the ith criteria and n is the number of values for a_i.

For example, for the pairwise comparison between safety and weight, the six survey participants gave the following ratings: 7, 5, 5, 5, 9, 9. The geometric mean is therefore

$$\{(7)(5)(5)(5)(9)(9)\}^{1/6} = 6.43$$

The same procedure is followed for all 45 pairwise comparisons. The actual survey results and the calculated geometric means are found in Appendix C. The geometric mean weighs all the DM's survey inputs equally and satisfies the questions presented earlier on how to represent the group's judgement.

Consistency Check. To check the consistency of the group's input, a consistency check on the judgement matrix was performed (see Appendix D). For λmax equal to 10.75 and a random consistency of 1.49, for n equal to 10 (see Table 2-2), the confidence interval, CI, for this matrix is .08, and the consistency ratio, CR, is .053. This is well below the .1 CR considered acceptable to Saaty. It also indicates the judgements used in the group consensus were consistent.

Weights. From the input values found in Appendix C, the weighted preferences for the ten judgement criteria were calculated in accordance with the procedure illustrated in Chapter II. Table 4-2 illustrates the results of these calculations.

Together safety and reliability account for over 50 percent of the weighted values. These two attributes are followed by, in order of decreasing importance, expendables used, weight, the number of transits per mission, size, depress time, transit time, repress time, and volume.

TABLE 4-2

JUDGEMENT CRITERIA WEIGHTS

Attribute	Weight
Safety	.3214
Reliability	.2594
Weight	.0716
Size	.0481
Transit Time	.0396
Expendables Used	.0976
Depress Time	.0403
Repress Time	.0352
# Transit/Mission	.0579
Volume	.0282

Although safety and reliability carry over 50 percent of the weight, there is no clear-cut measure of effectiveness for either; furthermore, as pointed out in some of the surveys, an unsafe or unreliable system would never become operational. For these reasons, both safety and reliability were dropped from the hierarchy.

Another adjustment to the hierarchy involves the two attributes, effective volume and expendable gases used per cycle of the airlock. The two attributes are closely related because the larger the effective volume of the chamber the more consumable gases expended per cycle. This makes the expendable gases a function of the airlock chamber's volume. Thus, the volume attribute is dropped from the hierarchy in favor of the expendable gases attribute. Since the alternatives and their parameters are defined to meet the minimum [illegible] requirements during the space station construction missions, the number of transits per mission is dropped from the hierarchy. To incorporate these changes either normalize the remaining attribute weights or remove the values from the judgement matrix and recompute the weights. Table 4-3 contains the normalized judgement criteria weights and Appendix E contains data resulting from recomputing the survey results. Now, the amount of expendables used and system weight carry the most weight, and the remaining 50 percent is almost equally distributed among the 4 remaining criteria.

TABLE 4-3

NORMALIZED JUDGEMENT CRITERIA WEIGHTS

Attribute	Weight
Weight	.2149
Size	.1444
Transit Time	.1188
Expendables Used	.2930
Depress Time	.1204
Repress Time	.1056

The weights listed in Table 4-3 were determined by the rating method, i.e., the DMs rated, on a scale of one to nine, the relative "importance" of each attribute. According to Benjamin Hobbs, "some psychologists and decision scientists assert that people often perceive things (such as attribute 'importance') logarithmically rather than linearly" (29:728). For this reason, attributes rated "1, 2, and 3 by a rating method should actually be assigned weights of e^1, e^2, and e^3" (29:728). In light of the possible logarithmical thinking on the part of the DM, the compromise programming methodology uses two sets of weights, the normalized weights found in Table 4-3 and the exponentially determined weights suggested by Hobbs (see Table 4-4).

With the weights established and the hierarchy refined, the objective behind each of the remaining

TABLE 4-4

EXPONENTIALLY DETERMINED WEIGHTS

Attribute	Weight
Weight	1.23
Size	1.15
Transit Time	1.12
Expendables Used	1.34
Depress Rate	1.12
Repress Rate	1.11

attribute needs addressing. The overall objective behind the six attributes is to minimize their value. Minimizing weight is tied directly to payload; the lighter the airlock system the more pounds of payload the shuttle can lift into space. Minimizing size frees valuable space in the orbiter's mid-deck, space used for either more equipment or personnel. Saving time in transits between pressure differentials provides more time for EVA activity, more EVA periods per mission and EMU refurbishment. The less expendable gases used by the airlock system equates to more cycles of the airlock and more payload if smaller consumable gas tanks are used. Reducing the depress rate and repress rate has advantages in many situations. For instance, if an EVA crewmember encountered EMU integrity problems a minimal depress or repress time could mean the difference between life and death. If assistance is needed for whatever reason during EVA, the response time by other crewmembers is reduced with minimal depress and repress times.

Compromise Programming

The weights established through the AHP will now be used in the compromise programming portion of this study. To utilize compromise programming, two items need defining, the ideal solution and the worse case attributes.

Ideal Solution. Part one of the mail survey asked the participants to give the ideal solution values for each of the eight quantifiable attributes. The ideal solution was then defined as the composite of the best values of the attributes. This definition varied from Zeleny's definition of the ideal in that the survey stipulated that the inputs should reflect what the participants thought was technically feasible. Initial compromise programming calculations revealed that some of the alternative's attribute values exceeded the ideal values determined by the survey. Therefore, this definition of the ideal solution was abandoned and replaced by Zeleny's definition. The ideal solution is now comprised of the best attribute values from all five alternatives and this "ideal" system does not have to be feasible. The best attribute values of all five alternatives are listed in Table 4-5. The values in Table 4-5 are the X^* values in expression 2-6.

TABLE 4-5

IDEAL VALUES FOR AIRLOCK SYSTEM ATTRIBUTES

Attribute		Ideal Value
Weight		300 pounds
Size	Height	78 inches
	Width	40 inches
Total Transit Time		8 minutes
Expendables Used		.4 pounds
Depress Rate		10 seconds
Repress Rate		10 seconds

Worse Case. Determination of the worse case values also used Zeleny's definition, taking the worst value of each attribute from all five of the alternatives. Not surprisingly, all but one of the worst values belong to the present airlock system. The values of the worse case alternative are listed in Table 4-6. The values in Table 4-6 are the X^{**} values in the compromise programming metric.

TABLE 4-6

WORSE CASE VALUES FOR AIRLOCK SYSTEM ATTRIBUTES

Attribute		Worst Case
Weight		1857 pounds
Size	Height	84 inches
	Width	80 inches
Total Transit Time		60 minutes
Expendables Used		19 pounds
Depress Time		360 seconds
Repress time		160 seconds

Results of Compromise Programming. With X^{*} and X^{**} defined and the weights, λ, determined, the compromise programming metric is applied to each alternative for the p values of 1, 2, and infinity. The results of these calculations are shown in Table 4-7. For calculation purposes,

TABLE 4-7

COMPROMISE PROGRAMMING RESULTS

Alternative	p=1	p=2	p=Infinity
For Normalized Weights			
Augmented System	.966	.179	6.52
Crewlock with Void Fillers	.111	.005	1.18
Crewlock without Fillers	.188	.013	1.48
One Crewlock with Fillers	.049*	.0007*	.37*
One Crewlock without Fillers	.431	.046	1.11
For Exponential Weights			
Augmented System	6.65	8.09	6.52
Crewlock with Void Fillers	.78	.36	1.18
Crewlock without Void Fillers	1.17	.51	1.48
One Crewlock with Fillers	.41*	.05*	.37*
One Crewlock without Fillers	1.35	.92	1.11

* indicates minimum value.

size is considered to be composed of two measures, height and width. It is assumed that each contributes equally to the overall size. Therefore, the overall weight for size is divided equally between height and width.

Summary of Results. This study evaluated five alternatives based on physical and performance parameters of manned airlock systems. Within this scope, the compromise programming results clearly show that for p equal to one, two and infinity, the one Crewlock with void fillers alternative is the closest to the ideal system The second closest alternative is dependent on the value of p. For p equal to one and two, the next best alternative is the two Crewlock with void fillers alternative. However, if the DM was strongly concerned with just minimizing the maximum deviation, then the one Crewlock without void fillers is the second closest alternative to the ideal. This result holds for increasing the number of shuttle EVAs from three to a minimum of eight to a maximum of eleven, the estimated number of EVAs required during space station construction. (See Appendix F.)

If, on the other hand, the EVA objective was not limited to a range of eight to eleven EVA periods, but was changed to maximize the number of EVA periods, then the two Crewlock with void fillers alternative prevails for the values of p equal to one and two. If, however, the DM remains strongly concerned with minimizing the maximum deviation, the one Crewlock alternative is again closest to the ideal. The one Crewlock system remains the closest to the ideal even if all judgement criteria except weight and expendable gas use were eliminated and the remaining two criteria were equally weighted. If the DM's sole objective is to maximize the efficient use of expendable gas, then the two Crewlock with void fillers is once again the correct choice. Furthermore, the width criteria prevents the two Crewlock with void fillers alternative from being the best choice for p equal to one and infinity, but for p equaling two, the one Crewlock with void fillers alternative still prevails. Although the one Crewlock with void fillers alternative is closer in the geometric sense, a DM not concerned with width would be better off selecting the two Crewlock with void fillers alternative. The augmented present system remains the least preferred, farthest from the ideal, in all cases. This remains true even with the present system operating in the depress contingency mode, the fastest depressurization time, and in the third emergency repressurization mode, the fastest repressurization time. These results hold regardless of the weighting scheme, normalized and exponentially determined. The same results were obtained when the AHP methodology was used for the entire selection process (see Appendix G).

Conclusion

Chapter IV applied the AHP and compromise programming methodologies to the alternative systems data. The AHP process used in this study was explained and insight into the iterative thought process was given. Through this iterative process, the hierarchy was revised by eliminating and combining judgement criteria. To compensate for this revision, the weights derived from the survey inputs were normalized. These normalized weights and the exponentially determined weights, used to account for the possible logarithmical perception of the DM, were applied in the compromise programming methodology. The results of compromise programming show the one Crewlock with void fillers to be the closest system to the ideal.

V. Summary and Recommendations

Introduction

This chapter summarizes the results from the compromise programming analysis and draws parallels between the shuttle's use of the airlock system and airlock issues on the space station. Recommendations concerning future action related to this study are also presented.

Summary of Results

This study evaluated five alternatives based on physical and performance parameters of manned airlock systems. Within this scope, the results clearly show that the one Crewlock with void fillers alternative is the closest to the ideal system. The second best alternative is the two Crewlock with void fillers. The augmented present system was the farthest alternative from the ideal even when operating in its fastest depressurization and repressurization modes. These results are not that surprising considering the definition of the ideal system and the worse case attributes and the fact that cost data was not included as one of the judgement criteria.

Space Station Parallels

This study allows certain general observations concerning the space station airlock system. The airlock system onboard the space station can be judged by the same criteria and selected using the same methodologies. The issues surrounding weight, size, expendables, transit time, depress and repress times are also valid concerns for space station airlock design. Additionally, designers of the space station airlock would also seek to maximize the number of transits in order to fully exploit the capabilities of a manned space station. Thus, some form of the Crewlock alternative is a possible front-running candidate for the space station, possible because airlock use, requirements, specifications and structure on the shuttle are slightly different from those being planned for the space station.

Recommendations for Future Research

One key attribute missing from this analysis is cost. Costs of any type were purposely ignored because no cost data was available on any of the systems. To complete the analysis, cost data must be included. Even though Crewlocks possess better performance and physical characteristics, their costs may negate the other attributes. The first recommendation is to fold in the cost attribute into the second level of the hierarchy and repeat the entire process presented with complete cost data.

Two other issues concerning the Crewlock still need to be discussed. The issues concern redundancy and the Crewlock hatch system. The best performing system was the one Crewlock system. A major disadvantage inherent in this system is that if the chamber becomes inoperable, the EVA portion of the shuttle or space station missions is lost and could jeopardize the entire mission. Of course, using the two Crewlock alternative provides some degree of redundancy but moves the DM farther away from the ideal. The performance/redundancy issues and related tradeoffs need addressing.

The second issue needing attention is the hatch system of the Crewlocks. NASA specifies all hatches must open to the side of primary pressure (30:36). The current airlock system satisfies this requirement but none of the Crewlock alternatives does. Electronic and mechnical schemes designed to insure inadvertent hatch openings with the Crewlock alternatives will need evaluation and the results of this study would definitely affect the airlock selection decision. Failure to meet this specification would eliminate all Crewlock alternatives despite their potential performance gains.

NASA is currently studying new Extravehicular Mobility Unit, EMU, designs. Once the design is finalized any changes to the airlock system must be folded into the airlock selection process.

This work has provided a comprehensive structure and methodology for the airlock selection problem. Any of the above issues can easily be incorporated into this structure once the data becomes available.

Appendix A: Expendable Gas Calculations

The amount of air expended during operation of the Crewlock system is found by applying the perfect gas law.

$$PV = NRT$$

where

P is pressure (atm)

V is volume (liters)

N is number of moles

T is temperature (°K)

R is Avagodro's number (liter-atm)/(moles-°K)

The volume of the Crewlock with void fillers is 3 Ft^3. Assuming a suited astronaut occupies 2/3 of the volume:

$$(3\ Ft^3)(1/3)\left(\frac{1\ liter}{.0353\ Ft^3}\right) = 28.3\ liters$$

Pressure = 1 atm

Temperature = 23 °C or 296 °K

The number of moles $N = PV/RT = \dfrac{(1\ atm)(28.3\ liters)}{\left(\frac{.08205\ liter\text{-}atm}{mole - °K}\right)(296\ °K)}$

N = 1.16 moles of air.

The air mixture is

Oxygen: 20 percent weight 32 grams/mole

Nitrogen: 80 percent weight 28 grams/mole

Air = .2 (32grams/mole) + .8 (28 grams/mole) = 28.8 grams/mole.

To convert moles to pounds:

$$(1.16 \text{ moles}) \left(\frac{28.8\text{g}}{\text{mole}}\right) \left(\frac{1 \text{ oz}}{28.3\text{g}}\right) \left(\frac{1 \text{ lbs}}{16 \text{ oz}}\right) = .1 \text{ lbs of air}$$

For the Crewlock without void fillers:

Pressure = 1 atm

Temperature = 296 °K

Volume = 57 Ft^3 = 538.2 liters
(based on a suited astronaut occupying 2/3 of the volume).

The number of moles, N, equals PV/RT.

$$N = \frac{(1\text{atm})(538.2 \text{ liters})}{\left(\frac{.08205 \text{ liter-atm}}{\text{mole °K}}\right)(296 \text{ °K})} = 22.16 \text{ moles of air.}$$

The air mixture is the same; therefore, N = 28.8 grams/mole.

To convert moles to pounds:

$$(22.16 \text{ moles})\left(\frac{28.8\text{g}}{\text{mole}}\right)\left(\frac{1 \text{ oz}}{28.35\text{g}}\right)\left(\frac{1 \text{ lb}}{16 \text{ oz}}\right) = 1.4 \text{ lbs of air.}$$

Appendix B: AHP Survey

TO: Survey Participants

I would like to request your assistance in completing the attached airlock system survey. This survey is part of a master's degree thesis for the Air Force Institute of Technology School of Engineering's Department of Operational Sciences.

Your experience with space systems and familiarity with space issues make your inputs to this survey highly relevant. The insight you provide as decision makers, managers and technicians will make an invaluable contribution to not only demonstrating decision methodologies but assessing the value of new concepts in manned airlock systems.

I want to emphasize, I will apply the principle of non-attribution. The identity of the individuals completing the survey will not be revealed. Your name will not be associated with the information you provide. Additionally, the inputs provided will not be considered as official statements from the companies and organizations you represent.

Please take a few minutes to read the brief instructions and complete the survey. If questions arise while filling out the survey, I am available to answer these questions at the numbers listed below.

I will provide you with a copy of my completed thesis which will summarize the survey results. Please indicate if you desire a copy of my thesis by checking the block at the end of the survey.

Thank you for your participation. In order for me to complete my thesis on time, please return the survey within 10 days after receipt.

DENNIS P. JEANES, Capt, USAF
Graduate Student for Space Operations
Autovon: 785-5533
Home: 513-233-7118

MANNED AIRLOCK SYSTEM SURVEY

PURPOSE

The purpose of this survey is to obtain feedback on selected airlock system attributes for assessing and prioritizing manned airlock system attributes and to determine the "ideal" system performance characteristics and physical attributes.

DESCRIPTION OF THE SURVEY

This survey is composed of two parts. The first part of the survey asks you to help define the "ideal" airlock system. The second part of the survey will require you to rate system attributes. This part of the survey will utilize the Analytical Hierarchy Process (AHP) developed by Thomas L. Saaty, in his book entitled Decision Making for Leaders.

ASSESSMENT PROCESSS

The first part of the survey requests you to define the "ideal" manned airlock system. To do this a list of nine system attributes will be given along with the units of measurement used in this exercise. PLEASE DO NOT CHANGE THE MEASUREMENT UNITS OF THE ATTRIBUTES.

A key point to remember is that the values you give to this "ideal" system's attributes should be feasible. The "ideal" system you define should be composed of the desired performance parameter you would like to see in an airlock system based on your knowledge of available and state-of-the-art technology.

The second part of this survey utilizes the AHP. AHP is a multiple criteria decision-making methodology I have chosen to use in my thesis. One of the goals of the AHP is to solicit subjective preferences between a set of paired attributes from decision makers and managers.

In this survey, you will be given a pair of attributes, in which you will be asked to rate, according to the provided scale (see Table 1), the importance of the first element in the pair to the second element relative to the overall objective.

If the first element in the pair is more important than the second, then a positive number from the scale is used. If the first element is less important than the second, then a negative number from the scale is used. Remember, the pairwise comparisons are done in terms of which element dominates another. Each pairwise comparison is independent of each other. Your rating in one pairwise comparison does not carry over to the next pairwise comparison.

TABLE 1

AHP COMPARISON SCALE

Intensity	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one criterion over the other
5	Essential or strong importance	Experience and judgment strongly favor one criterion over the other
7	Very strong or demonstrated importance	A criterion is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one criterion over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

An example is provided below:

Given the pair of attributes (A,B) and attribute "A" is slightly more important than attribute "B" then the rating that should be given is "+3". On the other hand, if attribute "B" is strongly more important than attribute "A" then a value of "-5" should be given for the pairwise comparison.

The question to ask when doing these pairwise comparisons is: Given the objective of finding the best way to support both the normal space shuttle mission EVA requirements and the shuttle's EVA requirements during the space station construction, HOW MUCH MORE STRONGLY DOES ATTRIBUTE "A" INFLUENCE THE SELECTION OF AN AIRLOCK SYSTEM THAN DOES ATTRIBUTE "B"?

ATTRIBUTE DEFINITIONS

WEIGHT: weight considerations include the airlock chamber, auxiliary equipment (hand hold and foot restraints) and support equipment (consumable gases tank).

SIZE: size is broken down into two measures: height of the airlock chamber and the width or diameter of the chamber.

VOLUME: this is the effective volume or the volume of the airlock system with two crewmen suited with EMUs inside.

TRANSIT TIME: this time is the time to pass from one pressure differential to another.

EXPENDABLES USED: this is the amount of Nitrogen gas used per cycle of the airlock.

DEPRESSURIZATION TIME: this is the time for the airlock to go from 14.7 psia to approximately 0 psia.

PRESSURIZATION TIME: this is the time to restore the airlock from a pressure of 0 psia to approximately 14.7 psia.

TRANSITS/MISSION: this is the number of EVA periods (maximum duration of eight hours) possible during one normal STS mission.

PART 1 THE IDEAL SYSTEM

Please indicate the value you would consider ideal for the following attributes.

ATTRIBUTE		IDEAL VALUE
Weight		______pounds
Size	height	______inches
	width/diameter	______inches
Volume		______cubic feet
Transit Time		______seconds
Expandables Used		______pounds
Depress Time		______secs
Repress Time		______secs
# Transits/mission		______EVA periods/mission

END OF PART ONE

PART 2 PAIRWISE COMPARISONS

Using the provided rating scale (See Table 1), please indicate your rating for each pair of attributes.

REMEMBER: THE OBJECTIVE IS TO FIND THE BEST WAY TO SUPPORT BOTH THE NORMAL MISSION EVA REQUIREMENTS OF THE SPACE SHUTTLE AND THE EVA REQUIREMENTS OF THE SPACE SHUTTLE DURING SPACE STATION CONSTRUCTION.

AND...

THE QUESTION TO CONSIDER IS: HOW MUCH MORE STRONGLY DOES ATTRIBUTE "A" INFLUENCE THE SELECTION OF A MANNED AIRLOCK SYSTEM THAN DOES ATTRIBUTE "B"?

PAIRWISE RATING

ATTRIBUTE "A"	ATTRIBUTE "B"	RATING
SAFETY	RELIABILITY	______
SAFETY	WEIGHT	______
SAFETY	SIZE	______
SAFETY	TRANSIT TIME	______

ATTRIBUTE "A"	ATTRIBUTE "B"	RATING
SAFETY	EXPENDABLES USED	______
SAFETY	DEPRESS TIME	______
SAFETY	PRESS TIME	______
SAFETY	# TRANSITS/MISSION	______
SAFETY	VOLUME	______
RELIABILITY	WEIGHT	______
RELIABILITY	SIZE	______
RELIABILITY	TRANSIT TIME	______
RELIABILITY	EXPENDABLES USED	______
RELIABILITY	DEPRESS TIME	______
RELIABILITY	PRESS TIME	______
RELIABILITY	# TRANSITS/MISSION	______
RELIABILITY	VOLUME	______
WEIGHT	SIZE	______
WEIGHT	TRANSIT TIME	______
WEIGHT	EXPENDABLES USED	______
WEIGHT	DEPRESS TIME	______
WEIGHT	PRESS TIME	______
WEIGHT	# TRANSIT/MISSIONS	______
WEIGHT	VOLUME	______
SIZE	TRANSIT TIME	______
SIZE	EXPENDABLES USED	______
SIZE	DEPRESS TIME	______
SIZE	PRESS TIME	______
SIZE	# TRANSITS/MISSION	______

ATTRIBUTE "A"	ATTRIBUTE "B"	RATING
SIZE	VOLUME	______
TRANSIT TIME	EXPENDABLES USED	______
TRANSIT TIME	DEPRESS TIME	______
TRANSIT TIME	PRESS TIME	______
TRANSIT TIME	# TRANSITS/MISSION	______
TRANSIT TIME	VOLUME	______
EXPENDABLES USED	DEPRESS TIME	______
EXPENDABLES USED	PRESS TIME	______
EXPENDABLES USED	# TRANSITS/MISSION	______
EXPENDABLES USED	VOLUME	______
DEPRESS TIME	PRESS TIME	______
DEPRESS TIME	# TRANSITS/MISSION	______
DEPRESS TIME	VOLUME	______
PRESS TIME	# TRANSITS/MISSION	______
PRESS TIME	VOLUME	______
TRANSITS/MISSION	VOLUME	______

END OF SURVEY

☐ CHECK HERE IF YOU WOULD LIKE A COPY OF THIS THESIS SENT TO YOU. It will be available in late December 1986 or early January 1987.

Appendix C: Survey Results

The following is a listing of the actual survey results and the calculated geometric mean. The negative values correspond to reciprocal values mentioned in Chapter II. For example, the value of -5 is actually interpreted as 1/5. Survey values correspond to the pairwise comparisons asked for in the AHP survey found in Appendix B. The Value Used column shows the geometric mean value rounded to the nearest whole integer.

Survey Values						Geometric Mean	Value Used
3	1	3	3	3	3	1.57	2
7	5	5	9	9	5	6.43	6
9	5	3	9	9	3	5.65	6
9	5	6	9	5	5	6.26	6
9	5	4	9	7	3	5.69	6
9	7	7	9	5	7	7.19	7
9	7	7	9	5	7	7.19	7
9	7	4	9	7	4	6.31	6
9	7	6	9	8	6	7.39	7
6	5	4	5	9	4	5.27	5
7	5	6	5	9	6	6.19	6
9	7	5	5	5	5	5.83	6
7	7	4	5	7	4	5.49	5
9	7	7	5	5	5	6.16	6
9	7	7	5	5	5	6.16	6
9	7	7	5	7	3	5.99	6
9	7	6	5	8	6	6.70	7
5	7	3	5	3	1	3.41	3
9	-5	2	5	-8	2	1.28	1
3	-7	1	-2	-6	1	.57	1
9	5	7	3	-8	7	3.06	3
9	7	7	3	-8	7	3.24	3
3	-7	1	-5	-6	1	.49	-2
3	7	3	3	-4	3	1.66	2
9	5	1	3	-8	1	1.60	2
-3	-7	1	-5	-7	1	.33	-3

Survey Values						Geometric Mean	Value Used
9	7	1	3	-9	1	1.66	2
9	7	1	3	-9	1	1.66	2
7	-7	-3	-3	-7	-3	.50	1
5	1	1	5	-5	1	1.30	1
-9	-7	-2	-5	4	-2	.38	-3
-9	1	3	1	2	3	1.05	1
-9	1	1	1	2	1	.77	1
-3	-7	-1	-5	3	-1	.55	1
-9	-5	7	-3	5	7	1.10	1
9	7	3	5	-4	3	2.98	3
9	7	3	5	-4	2	2.79	3
9	1	1	3	3	1	2.08	2
7	7	7	3	5	7	5.74	6
1	1	-3	1	-3	-3	1.73	2
9	-7	-2	3	4	-3	1.17	1
5	-7	3	-3	6	3	1.53	2
9	-7	-2	-3	4	-2	.86	1
5	-7	7	-3	6	7	2.06	2
-9	7	9	9	4	9	3.62	4

Appendix D: Completed Judgement Matrix

	Safety	Relia-bility	Weight	Size	Transit Time	Expend-ables Used	Depress Time	Press Time	#Transits per Mission	Volume
Safety	1	2	6	6	6	6	7	7	6	7
Relia-bility	1/2	1	5	6	6	5	6	6	6	7
Weight	1/6	1/5	1	3	1	1	3	3	1/2	2
Size	1/6	1/6	1/3	1	2	1/3	2	2	1	1
Transit Time	1/6	1/6	1	1/2	1	1/3	1	1	1	1
Expend-ables Used	1/6	1/5	1	3	3	1	3	3	2	6
Depress Time	1/7	1/6	1/3	1/2	1	1/3	1	2	1	2
Press Time	1/7	1/6	1/3	1/2	1	1/3	1/2	1	1	2
#Transits per Mission	1/6	1/6	2	1	1	1/2	1	1	1	4
Volume	1/7	1/7	1/2	1	1	1/6	1/2	1/2	1/4	1

$\lambda max = 10.75$; C.I. = .08; C.R. = .053

Appendix E: Recomputed Weight Data and Results

This appendix contains the recomputed AHP weights and summarizes the compromise programming results obtained when these weights were used.

TABLE E-1

RECOMPUTED WEIGHTS

Attribute	AHP Weights	Exponential Weights
Weight	.33	1.39
Size	.075	1.17
Total Transit Time	.080	1.08
Expendables	.030	1.34
Depress Time	.05	1.05
Repress Time	.07	1.07

The results in Table E-2 are the same results as those obtained when the normalized weights were used. The one Crewlock with void fillers alternative is the closest system to the ideal and the augmented system is the farthest from the ideal.

TABLE E-2

COMPROMISE PROGRAMMING RESULTS

Alternative	p=1	p=2	p=Infinity
For AHP Weights			
Augmented System	.946	.218	6.52
Crewlock with Void Fillers	.136	.009	1.18
Crewlock without Void Fillers	.154	.017	1.48
One Crewlock with fillers	.034*	.011*	.73*
One Crewlock without Fillers	.250	.048	1.11
For Exponential Weights			
Augmented System	6.33	7.68	6.52
Crewlock with Void Fillers	.84	.39	1.18
Crewlock without Void Fillers	.83	.56	1.48
One Crewlock with Fillers	.24*	.05*	.37*
One Crewlock without Fillers	1.39	1.01	1.11

* indicates minimum value.

Appendix F: Compromise Programming Results for 11 EVA Periods/Mission

TABLE F-1

COMPROMISE PROGRAMMING RESULTS FOR 11 EVA SCENARIO

Alternative	p=1	p=2	p=Infinity
For Normalized Weights			
Augmented System	.966	.179	6.52
Crewlock with Void Fillers	.111	.005	1.18
Crewlock without Fillers	.195	.011	1.48
One Crewlock with Fillers	.049*	.0007*	.37*
One Crewlock without Fillers	.437	.047	1.11
For Exponential Weights			
Augmented System	7.81	8.43	6.52
Crewlock with Void Fillers	.78	.36	1.18
Crewlock without Fillers	1.18	.52	1.49
One Crewlock with Fillers	.415*	.056*	.38*
One Crewlock without Fillers	1.39	.924	1.14

* indicates lowest value.

Increasing the requirement for 8 EVA periods per mission to 11 EVA periods per mission changes the weight data for three alternatives, the augmented system, the two Crewlock without void fillers and the one Crewlock without void fillers systems. Table F-1 shows the results after the weight adjustment to the three alternatives. Once again, the one Crewlock with void fillers is the closest to the ideal and the Crewlock with void filler is the second closest for p=1 and p-2, and the augmented system is the farthest from the ideal.

Appendix G: AHP Basic Program and Results

This Basic computer program supplied by Saaty was used to compute the AHP results mentioned at the end of Chapter IV. The results from using AHP for the entire selection process are found at the end of the appendix.

```
1000  REM ANALYTIC HIERARCHY PROCESSES:  PRIORITY HIERARCHY PROGRAM
1010  DIM A(99), B(30,30), N(99),Y(99),R(20),C(30,30),W(99),W2(99),C7(99),Z(99)
1020  FOR I=1 TO 15
1030  READ R(I)
1040 NEXT
1050 DATA 00.0,0.0,0.58,0.9,1.12,1.24,1.32,1.41,1.45
1060  DATA 1.49,1.51,1.48,1.56,1.57,1.59
1070 REM 2ND LEVEL
1080 L=2
1090 PRINT "ENTER THE NUMBER OF FACTORS IN SECOND HIERARCHY LEVEL:
1100 INPUT N1
1110 PRINT "THE HIERARCHY HAS " N1 " FACTORS IN LEVEL 2."
1120 PRINT "IS THIS CORECT? IF YES TYPE 0, ELSE TYPE 9."
1130 INPUT Y9
1140 IF Y9>5 GOTO 1100
1150 S1=N1
1160 GOSUB 2140
1170 FOR I=1 TO 60: A(I)=W(I): NEXT I
1180 REM T9 = TOTAL RANDOM CONSISTENCY FOR THIS HIERARCHY.
1190 REM T3 = TOTAL CONSISTENCY FOR THIS HIERARCHY.
1200 REM R() = RANDOM CONSISTENCY TABLE.
1210 L=L+1
1220 FOR I=1 TO 20: FOR J=1 TO 20: B(I,J)=0
1230 NEXT J: NEXT I
1240 PRINT: PRINT "HIT AND KEY TO CONTINUE. ";
1250 INPUT G7$
1260 PRINT: PRINT "ENTER THE NUMBER OF FACTORS IN LEVEL " L
1270 PRINT: PRINT "IF YOU WANT TO STOP HERE, TYPE A 0.  ";
1280 INPUT N2
1290 PRINT: PRINT N2 "?";
1300 PRINT: PRINT "IF WRONG TYPE A 9, ELSE TYPE 0.;
1310 INPUT Y9
1320 IF Y9 > 5 GOTO 1280
1330 IF N2 < 1 GOTO 2110
1340 REM
```

```
1350 FOR N6=1 TO N1
1360 PRINT: PRINT "HIT ANY KEY TO CONTINUE.  ";
1370 INPUT G6$: PRINT
1380 PRINT "ENTER # OF FACTORS IN LEVEL "L" RELATED TO ELEMENT "N6" ";
1390 PRINT "OF LEVEL "L-1".";
1400 INPUT N3
1410 PRINT "THIS PROGRAM IDENTIFIES THE ELEMENTS IN LEVEL "L
1420 PRINT "BY NUMBERING THEM FROM LEFT TO RIGHT."
1430 PRINT "ENTER THE NUMBER OF EACH ELEMENT IN LEVEL "L
1440 PRINT "RELATED TO ELEMENT "N6" OF LEVEL " L-1"."
1450 PRINT
1460 FOR I=1 TO 60: N(I)=0: NEXT I
1470 FOR I=1 TO N3: INPUT; N(I): NEXT I: PRINT
1480 FOR X=1 TO N3
1490 PRINT N(X) "   ";
1500 NEXT X
1510 PRINT
1520 PRINT "IF WRONG TYPE A 9, ELSE TYPE A 0.  ";
1530 INPUT Y9
1540 IF Y9>5 THEN 1470
1550 IF N3>1 GOTO 1590
1560 REM ONLY ONE ELEMENT RELATED
1570 B(N(1), N6)=1
1580 GOTO 1700
1590 S1=N3
1600 GOSUB 2140
1610 FOR I=1 TO 60: Y(I) = W(I)
1620 NEXT I
1630 T3 = T3 + A(N6)*C8
1640 T9 = T9 + A(N6)*R(N3)
1650 PRINT T3,T9
1660 REM ONLY RELATED ELEMENTS HAVE WEIGHTED VALUES
1670 FOR I = 1 TO N3
1680 B(N(I),N6) = Y(I)
1690 NEXT I
```

```
1700 NEXT N6
1710 PRINT: PRINT "HIT ANY KEY TO CONTINUE. ";
1720 INPUT G6$: PRINT
1730 PRINT "*** LEVEL "L" WITH RESPECT TO LEVEL "L-1"."
1740 PRINT
1750 PRINT "WEIGHT: ": PRINT
1760 PRINT "       ";
1770 FOR X = 1 TO N1
1780 PRINT USING "##.####"; INT(10000*A(X))/10000;
1790 NEXT X
1800 PRINT: PRINT
1810 FOR I = 1 TO N2
1820 PRINT I "   ";
1830 FOR J = 1 TO N1
1840 PRINT USING "##.####";INT(10000*B(I,J))/10000;
1850 NEXT J
1860 PRINT
1870 NEXT I
1880 REM COMPOSITE
1890 FOR I = 1 TO N1
1900 FOR J = 1 TO N2
1910 B(J,I) = B(J,I) * A(I)
1920 NEXT J
1930 NEXT I
1940 FOR I = 1 TO N2
1950 S9 = 0
1960 FOR J = 1 TO N1
1970 S9 = S9 + B(I,J)
1980 NEXT J
1990 A(I) = S9
2000 NEXT I
2010 PRINT
2020 PRINT "***COMPOSITE PRIORITIES FOR LEVEL "L" ***"
2030 PRINT
2040 FOR X = 1 TO N2
```

```
2050 PRINT X;
2060 PRINT USING "###.####";INT(A(X)*10000)/10000
2070 NEXT X
2080 N1 = N2
2090 GOTO 1210
2100 REM CONSISTENCY OF HIERARCHY
2110 PRINT
2120 PRINT "THE CONSISTENCY OF THIS HIERARCHY = "INT(100*T3/T9)/100
2130 GOTO 3120
2140 PRINT: PRINT "ENTER THE UPPER TRIANGULAR PART OF THE MATRIX."
2150 PRINT "DO NOT ENTER THE ELEMENTS ALONG THE MAIN DIAGONAL."
2160 PRINT "AFTER EACH QUESTION MARK, ENTER ONE ELEMENT OF THE ROW."
2170 PRINT "ELEMENTS LIKE 1/3 SHOULD BE ENTERED AS -3."
2180 PRINT
2190 FOR I = 1 TO S1 - 1
2200 PRINT
2210 PRINT "ROW "I":"
2220 FOR J = I + 1 TO S1
2230 INPUT;C(I,J)
2240 NEXT J
2250 PRINT
2260 FOR J = I=1 TO S1
2270 PRINT " "
2280 PRINT " "
2290 NEXT J
2300 PRINT
2310 PRINT "IF WRONG TYPE A 9 ELSE TYPE A 0. ";
2320 INPUT Y9
2330 IF Y9 > 5 GOTO 2210
2340 FOR J = I + 1 TO S1
2350 IF C(I,J) > = 0 GOTO 2370
2360 C(I,J) = -(1/C(I,J))
2370 C(J,I) = 1/C(I,J)
2380 NEXT J
2390 NEXT I
```

```
2400 FOR I = 1 TO S1
2410 C(I,I) = 1
2420 NEXT I
2430 REM FIND INITIAL WEIGHT
2440 T4 = 0
2450 FOR I = 1 TO S1
2460 S = 0
2470 FOR J = 1 TO S1
2480 S = S + C(I,J)
2490 NEXT J
2500 W2(I) = S
2510 T4 = T4 +S
2520 NEXT I
2530 FOR I = 1 TO S1
2540 W2(I) = W2(I)/T4
2550 NEXT I
2560 REM
2570 K = 0
2580 T4 = 0
2590 K = K + 1
2600 FOR I = 1 TO S1
2610 S = 0
2620 FOR J = 1 TO S1
2630 S = S + C(I,J) * W2(J)
2640 NEXT J
2650 W(I) = S
2660 T4 = T4 + S
2670 NEXT I
2680 D = 0
2690 FOR I = 1 TO S1
2700 W(I) = W(I)/T4
2710 D = D + ABS(W(I) - W2(I))
2720 NEXT I
2730 IF K > 10000 GOTO 2770
2740 IF K <.0001 GOTO 2770
```

```
2750 FOR I = 1 TO 60:W2(I) = W(I): NEXT I
2760 GOTO 2580
2770 PRINT
2780 PRINT "LEVEL  ";L;" ELEMENT "N6: PRINT
2790 PRINT "INPUT MATRIX": PRINT
2800 FOR I = 1 TO S1
2810 C(I,I) =1
2820 FOR J = 1 TO S1
2830 PRINT USING "###.####";INT(C(I,J)*1000)/1000;
2840 NEXT J
2850 PRINT
2860 NEXT I
2870 REM
2880 FOR I = 1 TO S1
2890 S = 0
2900 FOR J = 1 TO S1
2910 S = S + C(I,J) * W(J)
2920 NEXT J
2930 C7(I) = S
2940 NEXT I
2950 S =0
2960 FOR I = 1 TO S1
2970 S =S + C7(I) / W(I)
2980 NEXT I
2990 Y5 = S/S1
3000 C8 = (Y5 - S1) / (S1-1)
3010 PRINT: PRINT "WEIGHTS"
3020 PRINT
3030 FOR I = 1 TO S1
3040 PRINT USING "###.####";INT(W(I) * 10000) / 10000
3050 NEXT I
3060 PRINT
3070 PRINT  "LAMBDA(MAX) = " INT(Y5*100)/100
```

```
3080 PRINT
3090 PRINT "C.I. = " INT(C8*100)/100
3100 PRINT
3110 RETURN
3120 END
```

AHP Computations

Relative Weights		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5		
.3421		.509	.159	.151	.078	.093		
.0823		.212	.196	.196	.196	.196		.478
.0823		.207	.264	.264	.132	.132		.104
.0800	X	.552	.073	.073	.150	.150	=	.142
.2914		.470	.009	.148	.024	.346		.084*
.0526		.818	.022	.022	.068	.068		.183
.0689		.666	.041	.041	.125	.125		

Relative Weights — Normalized Performance Parameters
* indicates smallest value.

The numbers on the far left represent the relative weights for the seven attributes. The matrix to the right of these weights contains the normalized performance and physical characteristics parameters. These normalized parameters can be used in the AHP because all the measures of effectiveness for each alternative system were quantifiable. The numbers on the far right are the results of multiplying these two matrices together.

Since all the attributes were minimizations, the alternative with the smallest value is the preferred choice. The alternative with the smallest value is the one Crewlock with void fillers followed by the two Crewlock with void filler alternative. The alternative with the largest value and therefore the least preferred is the augmented system.

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Vita

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