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Volume I

STUDY OF AN ADVANCED CREW ESCAPE AND RESCUE CAPABILITY (AERCAB)

Volume I

R. HARLEY WALKER, JR.
STEPHEN R. MEHAFFIE

TECHNICAL REPORT AFFDL-TR-74-22, VOLUME I

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A study was conducted to assess the potential operational practicality of an Advanced Crew Escape and Rescue Capability, AERCAB. The AERCAB concept offers the advantage of a fly-away escape/rescue capability for a crewmember following conventional ejection from a fighter-type combat aircraft. Five primary questions are addressed: Is an AERCAB system operationally effective? operationally practicable? technically feasible? technically practicable? cost effective?

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A methodology for evaluating the AERCAB as an escape/rescue concept was established and formulated into a computer program, and effectiveness evaluations were conducted in selected combat scenarios. It was determined that the most important AERCAB design parameter and its greatest asset is range capability. Analysis of an SEA scenario indicated that use of the AERCAB system in conjunction with the Combat Search and Rescue forces would have resulted in more ejected air crewmembers being rescued and therefore fewer POW's and lower crewmember replacement costs. Other combat scenarios are developed and analyzed.

Analyses were conducted to determine AIRCRAFT/AERCAB integration compatibility and configuration design information necessary for evaluating system effectiveness, performance, and costs. The AERCAB appears more practicable for new aircraft where retrofit design problems and aircraft modification costs are not a factor.

AFFDL-TR-74-22
Volume I

FOREWORD

This report was prepared by the Recovery and Crew Station Branch of the Air Force Flight Dynamics Laboratory under Project 1961, "Advanced Crew Escape and Rescue Capability (AERCAB)." This study was accomplished at the direction of the Secretary of the Air Force for Research and Development. Funds were provided by Hq USAF. The study was begun in September 1972 and completed in October 1973.

Project management and technical and administrative responsibility were in the Vehicle Equipment Division, Air Force Flight Dynamics Laboratory, with Mr. R. Harley Walker, Jr. (AFFDL/FER) as Program Manager.

This report is a compilation of the accomplishments and findings of four work efforts conducted separately by three contractors and an AFFDL technical team. An evaluation methodology, a computer program, and an effectiveness evaluation of the AERCAB concept were performed by the Caywood-Schiller Division of A. T. Kearney, Inc., 100 South Wacker Drive, Chicago, Illinois 60606, under Contract F33615-72-C-1668, P00002. A Rigid Wing AERCAB configuration design effort was conducted by the Parsons Corporation of California, A HITCO Company, 3437 South Airport Way, Stockton, California under Contract F33615-73-C-3120. An investigation to determine guidance, navigation, and control subsystem feasibility for the AERCAB was conducted by The Analytic Sciences Corporation (TASC), 6 Jacob Way, Reading, Massachusetts 01867, under Air Force Avionics Laboratory Contract F33615-72-C-1787. A technical and preliminary cost analysis of AERCAB configurations was conducted by engineers from the Prototype Division (AFFDL/PT). Technical reports were prepared giving the details of the work conducted under each of these contracts, and these reports are referenced herein. Special thanks are due to Ray E. Fredette and Nathan L. Sternberger (AFFDL/PT) for their participation in the in-house analyses and Capt S. Schwam, AFAL, for his assistance with the Avionics study.

Mr. Stephen R. Mehaffie, AFFDL/FER, assisted in all technical aspects of the program and personally organized SEA aircraft combat damage data into a meaningful rescue scenario.

The authors wish to acknowledge the attention and interest given this study by LTC W. Baird, AFSC/DLFF; LTC V. Dander, AFSC/XRLA; LTC H. Webb, ASD/XRL; LTC J. Vallone and Major D. Adamson, MAC; Mr. T. Thomasson, NASC: and Mr. W. Bollinger, NADC.

This report is published in two volumes. Volume I entitled, "Study of an Advanced Crew Escape and Rescue Capability (AERCAB)" is unclassified. Volume II (same title) is classified SECRET.

This report was submitted by the authors in November 1973.

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INTRODUCTION AND SUMMARY

1. PROGRAM OBJECTIVE

This report documents the results of an extensive analytical investigation conducted with the primary objective being to assess the potential operational practicality of an Advanced Crew Escape and Rescue Capability, AERCAB. The AERCAB concept offers the advantage of a fly-away, escape/self-rescue capability for the crewmember following conventional ejection from a fighter-type combat aircraft.

2. PROGRAM ACCOMPLISHMENTS

The AERCAB concept was analyzed in various combat environments and the results were compared to conventional escape and rescue capabilities. The advantages of using the AERCAB system for pilot recovery were defined.

The rescue environment and functional requirements for the AERCAB were defined through selection of specific combat scenarios and operational criteria established for the defined rescue environment. Capabilities of the AERCAB system when operating in selected scenarios were determined. Tradeoffs were performed to select optimum operational conditions and show the effects on probability of rescue. AERCAB configuration performance tradeoffs were defined, and integration and performance analysis with respect to the F-4 and A-7 aircraft were included.

Configuration design for a deployable rigid wing AERCAB vehicle was developed and analyzed. A methodology and associated procedures and techniques for accomplishing AERCAB effectiveness evaluations were developed, and a preliminary cost analysis is presented.

Detailed guidance, navigation, and control techniques applicable to an AERCAB system were defined. Relative costs are developed and compared with projected G, N, and C subsystem accuracies Previous AERCAB developments were catagorized and are presented where relevancy exists.

3. BACKGROUND

As a result of rescue deficiencies evident from the SEA conflict, new methods were sought which would increase the probability of rescuing aircrewmen forced to abandon their aircraft over enemy territory. To a major extent, potential methods are based on the hypothesis that if the descent of the escaping aircrewman can be delayed, or better, if he can be suspended out of small arms fire range, mid-air retrieval and evacuation may be possible. This hypothesis was reached from analyzing rescue statistics derived from operations in SEA. These statistics (classified) were used in the analysis presented in Appendix I of Volume II of this report. Statistical data for rescue operations in hostile environments indicates aircrewmen recovery rates increase with time between aircraft hit and crewman ejection, and after a certain time increment, all possible rescues are successfully accomplished. Since time can be related to distance (through aircraft velocity) the distance from aircraft hit to ejection appears to be the significant factor. The significance of distance is related to reaching a less populated and defended inland area or the coastal region or sea where the likelihood of rescue is greater. Thus, the "self rescue" or "fly away" escape concept evolved.

In 1967, the US Air Force and Navy showed considerable interest in the potential of the self-rescue AERCAB. A number of programs were initiated to demonstrate concept feasibility, directed specifically at the evaluation of various approaches to AERCAB. Close Air Force and Navy coordination at the working level was maintained to ensure the programs complemented each other. The feasibility evaluation was based upon successful deployment, performance, and stability of the AERCAB lifting surface subsystem. Consequently, initial test efforts were directed at acquiring the technical data needed to select the most promising configuration for advanced development. All subsystems were considered analytically and, where applicable, laboratory, wind tunnel, and flight tests of full-scale experimental models were conducted. A synopsis of the test programs is presented in Section V. The exploratory efforts to demonstrate technical feasibility of the concept have now been concluded within the Air Force.

While the exploratory analytical and experimental investigations demonstrate that the flyaway rescue concept is technically feasible, two major unknowns remained: (1) Is the AERCAB technically practicable?; and (2) Is the AERCAB operationally practicable? The question regarding operational practicability requires basically a cost-effectiveness assessment, and technical practicability requires hardware development and experimental tests of prototype systems. In September 1972, the Air Force Flight Dynamics Laboratory was assigned the responsibility of assessing the potential operational practicality of a deployed AERCAB escape and rescue system.

4. GUIDANCE

Hq USAF issued Program Management Directive, PMD, (P-2P032(2)/63205F), dated 17 June 1972, requesting several independent studies be conducted to assess the potential operational practicality of the AERCAB concept. In addition, it requested the analysis address itself to current Air Force rescue capabilities and tactics, projected changes to these tactics, threats for various theaters of operation, probability of rescue/survival with current equipment, definition of improved rescue capabilities, and effective cost of current and improved rescue capabilities.

Hq AFSC Program Direction (AFSC Form 56, dated 30 August 1972) modified the guidance to pursue only that portion of the PMD which relates to the practicability of the AERCAB concept, since the Air

Staff was initiating a mission analysis of the combat air rescue posture. Accordingly, this study was prepared to answer five questions:

(1) Is an AERCAB operationally effective?

(2) Is an AERCAB operationally practicable?

(3) Is an AERCAB technically feasible?

(4) Is an AERCAB technically practicable?

(5) Is an AERCAB cost effective?

5. ORGANIZATION OF THE STUDY

The question of operational effectiveness is summarized in Section III; detailed documentation is presented in Reference 1. This work was accomplished under Contract F33615-72-C-1668, P00002 by the Caywood-Schiller Division of A. T. Kearney, Inc. Operational practicability was assessed by the Vehicle Equipment Division of the Air Force Flight Dynamics Laboratory by analyzing AERCAB data generated either prior to or during this investigation.

Technical feasibility was addressed by considering complete exploratory development programs and two additional efforts accomplished during this investigation. The area of avionics subsystem feasibility was evaluated by The Analytical Sciences Corporation under contract to the Air Force Avionics Laboratory, and is documented in Reference 4. Additional feasibility effort on the Rigid Wing AERCAB design was conducted by The Parsons Company of California under Contract F33615-73-C-3120 to AFFDL and is documented in Reference 3.

The question of technical practicability was partially addressed by the Prototype Division in AFFDL and is being separately documented in detail in Reference 5. It is concluded that a complete technical or engineering practicability assessment requires accomplishment of a "hardware oriented effort" on the level of an Advanced Development Program.

The cost analysis was accomplished in-house, primarily by the Prototype Division. These costs are considered very preliminary; a more-in depth analysis would increase the creditability.

All other contributors are referenced as they appear.

6. SUMMARY

The purpose of this analysis is to provide additional information pertinent to the assessment of the "flyaway" concept as an operationally feasible capability. The objective in this analysis is to assess the advantages of the concept for improving the current escape/rescue capability and to determine the impact of the concept on the mission aircraft. The scope of this analysis is limited to a study of the "flyaway" concept as an improved escape/rescue concept and how it could perform under combat operations. It does not include a tradeoff analysis of other concepts for providing improved search and rescue capabilities. The approach taken in this study included: (1) establish a methodology for evaluating the AERCAB: (2) determine the crew station compatibility of AERCAB configurations with selected fighter aircraft configurations; (3) conduct a weights and costs tradeoff analysis to evaluate penalties versus AERCAB performance; and (4) evaluate the AERCAB in various scenarios using the developed methodology, aircraft compatibility, and tradeoff analysis results.

One of the initial tasks undertaken was the development of a methodology for assessing the effectiveness of the AERCAB. This task involved the formulation and programming of a computer effectiveness model to evaluate alternative AERCAB configurations integrated in specified fighter aircraft and exposed to selected combat scenarios. Background information on four AERCAB configurations and selected fighter aircraft was used as a technical base for formulating concept effectiveness assessment criteria. The operational effectiveness of the AERCAB was evaluated as to its ability to provide more crewmember candidates for rescue. "Safe" areas were identified within the scenario which, by

definition, would provide a given probability of rescue of the crewman if he successfully reached this area, regardless of how he got there (i.e., AERCAB, flying mission aircraft, ejecting into area directly). Consideration of the environment in which the aircraft is operating when a crewmember ejects, the flight of the AERCAB to a "safe" area, and subsequent probability of location and pick-up by Search and Rescue (SAR) forces was included.

Simultaneous with the development of an evaluation methodology, a technical analysis of the AERCAB configurations was undertaken. Industry had originally designed four configurations against a specified set of performance criteria, most of which was oriented toward a system which would perform adequately in Southeast Asia. This study addresses the operational characteristics of the AERCAB concept in other geographical locations. Thus, without having prior knowledge of what performance would be required of AERCAB in the different scenarios, a technical analysis was undertaken which would provide inputs to a cost effectiveness model. The approach taken investigated the concept in two phases. Phase I consisted of: (1) evaluating the existing configurations with respect to aircraft installation, weights, aerodynamic characteristics, and performance; (2) resizing the configurations as necessary to achieve realistic designs and thereafter determine the degree of aircraft modification needed for installation; and (3) resizing the configurations to achieve various ranges and check the stability characteristics of each. Phase II involved considering AERCAB designs which are devoid of the dimensional constraints of current aircraft cockpits. These designs seek maximum achievable performance and flying qualities for AERCAB vehicles and provide volume and weight allowances that should be considered in future aircraft designs. This phase concentrates on system point designs for a "best" capability based on results from the effectiveness evaluation.

Prior to evaluation of the operational feasibility of the AERCAB in a combat scenario, a parametric sensitivity analysis of the effectiveness computer model was conducted to determine the importance of various parameters in relation to each other or to the expected results. Very simple scenarios were used to avoid unnecessary complexity in analysis of the results.

Subsequently, the effectiveness of the AERCAB concept was evaluated in three different scenarios. The geographical areas selected are identified, and the particulars of each scenario are discussed in Volume II. In general, the effectiveness evaluation showed that with the AERCAB system the probability is significantly greater that an ejected crewmember can be recovered from enemy territory. The range capability provided by the flyaway system offers a greater overall advantage than any other factor in the effectiveness model.

A supplemental effort was conducted to provide design and performance information on the Rigid Wing AERCAB configuration. This information was used in assessing the potential of this particular configuration as compared to other AERCAB designs.

Successful aircrew recovery in a hostile environment requires more than the ability to remain airborne; it requires guidance, navigation, and control (GN&C). The GN&C functions are a vital element in the AERCAB safe area concept. An effort was conducted to evaluate various GN&C approaches against selected performance guidelines. The results of this analysis indicate the expected accuracies and costs associated with the various GN&C approaches. An automatic guidance, navigation, and control system for the AERCAB vehicle is not only feasible, but will improve the probability of successful crew retrieval over a strictly manual control system.

A cost analysis was conducted to permit a cost-effectiveness assessment of the concept. A cost model was developed and computerized to support this analysis. The cost model was kept separate from the effectiveness model because many of the parametric variations of interest in the effectiveness model have little or no effect on cost.

SECTION II

ADVANCED CREW ESCAPE AND RESCUE CAPABILITY (AERCAB)

1. GENERAL

Ejection seats have been used successfully over the past 25 years as a positive means for flight crewmembers to escape their mission vehicle as irreversible emergencies arise. Technology advancement in the escape area is expected to provide for ejection under previously deemed "unrecoverable" conditions, i.e., higher speeds, lower altitudes, adverse attitudes, etc. While advancements are being made in the crew escape area, the escape/rescue concept for air crewmen has remained unchanged for many years, i.e., following a successful ejection the crewman descends to earth on his parachute and is eventually picked up by a rescue team. Most of the time, the rescue team uses a helicopter. If the ejection has occurred in a combat situation over enemy-controlled territory, the crewman is usually captured. Under escape conditions such as adverse weather, severe terrain, or nighttime, a long wait prior to rescue may severely tax the crewman's mental and physical faculties.

Within the boundaries of the free world, on the high seas as well as on land, the probability of speedy rescue is very high by virtue of mutual international agreements and the highly efficient and effective organizational net of the Air Rescue and Recovery Services. In combat zones, particularly deep in enemy territory, this probability drastically decreases as a function of distance and population density. Rescue techniques with helicopter aircraft are greatly impaired in severe terrain environments, become increasingly hazardous when exposed to enemy ground resistance, and are hopelessly inadequate in an environment of enemy air superiority. Failure in such rescue missions invariably results in the capture or death of highly trained personnel and/or loss of critical combat equipment.

2. CONCEPT DESCRIPTION

What is an AERCAB?	A secondary flight vehicle contained in a primary aircraft.
Who uses it?	Crews of fighter aircraft.
When is it used?	When the primary aircraft is no longer capable of flying.
Where is it used?	Primarily in hostile environments.
Why is it used?	To save training dollars, lives, and prevent imprisonment.
How?	By removing crews from a high threat environment to a lower threat environment.

The "flyaway" escape concept provides the aircrewman with a secondary flight vehicle capable of gaining or maintaining altitude and permits him to assist in his own rescue by navigating over a limited range and at a specified cruise speed out of a hostile area toward predetermined "safe" sites where he can be rescued with the least jeopardy to all personnel involved. Thus, the AERCAB is a new dimension in airborne escape. It represents the next generation escape system by providing an "aircraft within an aircraft".

Any advanced escape/rescue concept must increase the time available to the ejectee to be rescued and minimize the time required to perform the rescue mission. The AERCAB provides increased time for rescue by allowing the ejectee to remain airborne and providing him with sufficient maneuverability to fly to a more secure and accessible area for landing and pickup. In addition, flying toward the rescue forces reduces the time required for rendezvous with the rescue forces.

Since the AERCAB system, for all practical purposes, is a small aircraft, it must contain the various subsystems associated with the major aircraft functions: Lifting Surface, Propulsion, Flight Controls, Avionics, Aircraft Escape, and Airframe. Although some degree of commonality exists in any vehicle comprised of these subsystems, there can be considerable variation in configuration. In the case of the

AERCAB, the basic and more pronounced variation occurs in the lifting surface. From the initial evolution of the flyaway concept, a degree of uncertainty has existed within the technical community as to which of the proposed lifting surface configurations offers the best overall solution: the Parawing, Rotor, Sailwing, and a deployable Rigid Wing. Investigations have been conducted on each to obtain sufficient data on each as an integrated configuration to evaluate its technical feasibility. The feasibility would be mostly dependent upon successful deployment, performance, and stability of the particular lifting surface subsystem (see Figure 1).

3. AERCAB CONFIGURATIONS

During earlier exploratory efforts, feasibility studies were conducted on AERCAB configurations incorporating the Parawing, Rotor, Sailwing, and Rigid Wing lifting surfaces. In these studies each AERCAB configuration had been designed and analyzed in sufficient detail to analytically assess feasibility. Each was considered to merit further investigation. The particulars of each configuration are discussed in Appendix I of this report and in Reference 6.

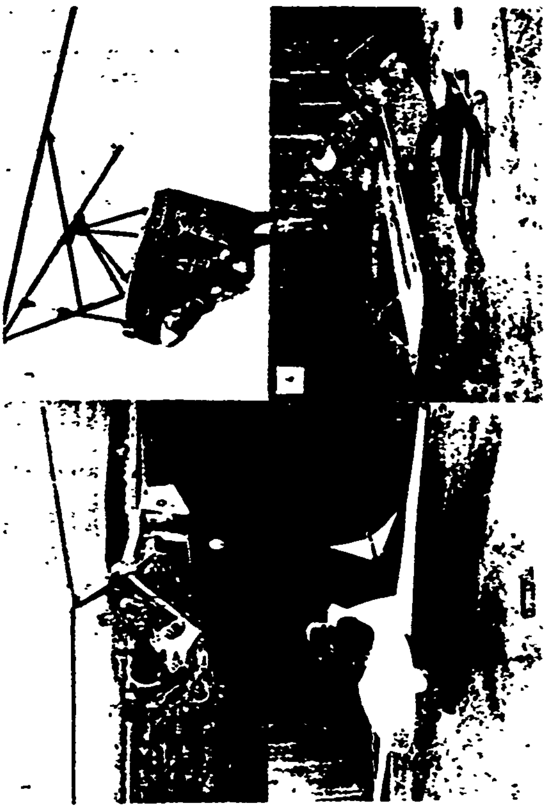


Figure 1. AERCAB Configurations

SECTION III

AERCAB EFFECTIVENESS

1. GENERAL

Is the AERCAB operationally effective? To properly address this question, we must understand the Combat SAR role and the conventional rescue operations, establish some gauge for measuring AERCAB effectiveness, and evaluate the AERCAB system in combat scenarios.

2. SEARCH AND RESCUE ROLE

a. Origin of the SAR Mission

Let us assume an F-4E aircraft with pilot and weapon systems operator takes off from home base on an interdiction mission. As it crosses the forward edge of the battle area (FEBA), the aircraft is fired upon by outlying defenses, and the fire becomes more determined as the aircraft approaches the target. The F-4E delivers its ordnance but is lethally hit by defensive fire. The instant the aircraft is lethally hit marks the beginning of the Combat Search and Rescue mission: The safe return of aircrews from hostile environments.

b. The SAR Problems

The SAR forces, knowing that an aircraft is down, are tasked with:

(1) Locating the crewmembers.

(2) Protecting them from future injury.

(3) Treating them for any injury already sustained.

(4) Returning them to friendly control.

The solution of this problem ranges from simple to complex, depending on the location of the downed crewman. If he is downed on the friendly side of the FEBA, the SAR mission may consist of sending a jeep to pick him up. But if he is deep in hostile territory, as many as 300 combat sorties may be required to recover him, if it is at all possible! The impact of the AERCAB system on the SAR problem will determine its operational effectiveness.

c. Locating Downed Crewmembers

At present a plethora of locating, signalling, etc., devices exists, but the effectiveness of these devices is reduced in that the crewman may be anywhere in the area of operations. Additional information from radio transmission prior to egress from the aircraft, wingman reports, radar fixes, etc., is required to roughly locate the downed man. A decision must be made early as to how to locate the man precisely and establish linkup with the rescue forces. Is he in friendly, moderately hostile, or extremely hostile territory? What tactics must be used to pinpoint the location? Do we have air superiority in that area? If not, can we establish it either permanently or temporarily? Do we have ground superiority? Can ground fire suppression operations be laid on? The location of the man determines the tactics needed to rescue him.

d. Protection of the Man

The crewman must be protected from ground threats to be rescued. Again, depending on location, protection may be a life raft or a major combat suppression operation. The man must be protected from capture, either by enemy regulars or civilian populace.

e. Medical Treatment

The man must be treated for injuries; for this, the SAR operation requires speed to minimize the time between when he is injured and when he is treated. This time is again directly dependent on the man's location: if the location dictates a complex, multifaceted rescue operation, the time could be quite lengthy; if it allows a relatively simple straightforward operation, the time should be short.

f. Safe Return to Friendly Control

The crewman must be safely returned to friendly control. This dictates that the SAR operations be secure so that the SAR helicopter is not shot down, starting the problem all over again. Air superiority must be maintained. Again, location of the crewmember is of utmost importance. It is extremely hazardous to take a low-performance highly vulnerable helicopter into the same environment where a high-performance, low-vulnerability fighter aircraft was just shot down.

g. SAR Driving Force

Again and again, the location of the downed crewman is seen to control all aspects of the SAR operation. The threat level where the man is and the threats that the rescue forces must cross to reach him determine all tactics and decisions, even whether or not an attempt will be made to rescue the aircrew.

h. Safe Area Concept

Prior to a combat mission, an aircrew is told, "If you get hit, try to get to such-and-such coordinates, it's a safe area." What is a safe area? How is it chosen? How is it used?

A safe area is an area loosely defined as possessing some or all of the following properties:

(1) Low density enemy troop concentrations.

(2) Low density hostile civilian population.

(3) Possible local partisan support.

(4) Ease of access for SAR flight.

(5) Favorable escape and evasion terrain.

(6) Friendly air superiority.

(7) Shelter and food.

(8) Medical facilities.

Obviously, home base is a very safe area, but so is a mountain meadow, or "feet wet," depending on the scenario; in short, it is any area where a crewman can survive and SAR forces can operate with a minimized risk. [redacted]. Safe areas may be permanent (e.g., home base) or temporary (an Air Cavalry assault may establish a safe area for 6 hours).

The safe area is used when an aircraft receives a lethal hit. The pilot attempts to guide the crippled aircraft so as to maximize his chances of rescue. If he is deep in enemy territory, he will attempt to go to a designated safe area to increase his probability of rescue.

3. EFFECTIVENESS ANALYSIS

a. Methodology

One of the initial tasks was to develop a methodology for assessing the effectiveness of the AERCAB. This task involved the formulation and programming of a computer effectiveness model to evaluate alternative AERCAB configurations integrated in specified fighter aircraft and exposed to selected combat scenarios. Background information on the AERCAB configurations and selected fighter aircraft was used as a technical base for formulating concept effectiveness assessment criteria. The operational effectiveness of the AERCAB was evaluated as to its ability to provide more crewmember candidates for rescue. "Safe" areas were identified within the scenario, which by definition would provide a given probability of rescue of the crewman if he successfully reached this area, regardless of the manner in which he got there (i.e. AERCAB, flying mission aircraft, ejecting into area directly). Consideration of the environment in which the aircraft is operating when a crew member ejects, the flight of the AERCAB to a "safe" area, and subsequent probability of location and pick up by Search and Rescue (SAR) forces was included.

b. Effectiveness Model

A computerized combat evaluation model was developed to assess the impact of an AERCAB system in the operational environment. The model had to be responsive to those inputs which were available at the early stages of an AERCAB development. The model was developed based on extensive knowledge of Southeast Asian aircraft damage and loss experience, vulnerability/survivability studies, and on the HAVE LIME study, (Reference 8).

The computer model, Evaluating the Survival of Crew and Aircraft Penetrating Enemy Environments (ESCAPEE) calculates the probability of a pilot surviving a sortie. The survival may be via the safe return of his aircraft or, if the aircraft is lethally hit by enemy defenses, then via an escape mode and subsequent extraction by SAR forces. In the model the aircraft flies along an input flight path consisting of several doglegs. Various enemy defenses may shoot at the aircraft and at the AERCAB when the pilot uses such to escape from the lethally hit aircraft to fly to a safe area. The enemy defenses are scaled by the model such that the attrition of the nominal aircraft is equal to an input value. All calculations are probabilistic.

The flight path is broken into increments for purposes of numerical integration. At each increment the probability the aircraft is lethally hit is calculated. Given a lethal hit, the probability the pilot could successfully reach each safe area via each possible escape mode is calculated. The probabilities are combined with the input (assumed) extraction probabilities from the safe areas, and the best escape mode and area are used as the optimum (Reference 2). By integrating the probabilities over the total flight path the probability the pilot returns to home base is obtained.

The penetration of enemy defenses begins at the FEBA (see Figure 2). The aircraft traverses three defense regions: the inbound area, the target area, and the outbound area. In each such region a different mix of defenses may be deployed at random. The flight path of the aircraft

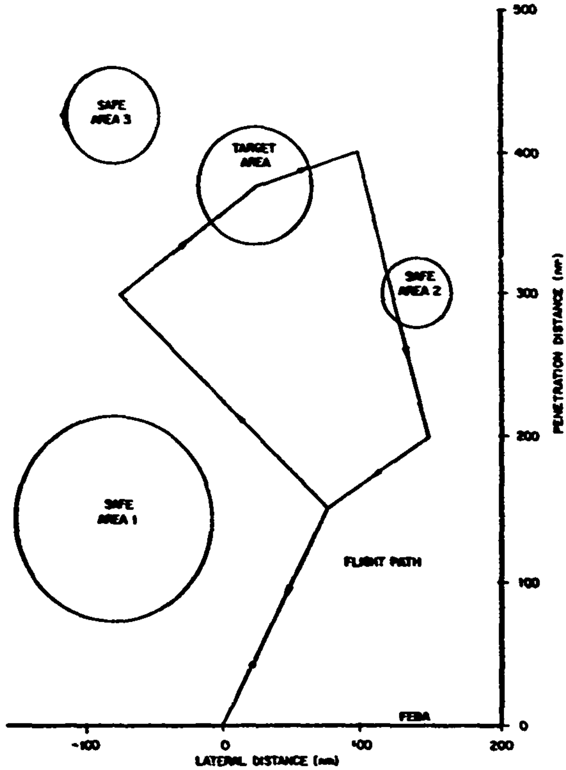


Figure 2. Sample ESCAPEE Scenario Geometry

consists of legs (straight line segments) between way-points, which may be thought of as navigation check points. Between defense regions the aircraft flight profile may change. Thus, inbound, for instance, the aircraft may fly at 35,000 feet and 400 kts, descend to 1,000 feet and 600 kts in the target area, and climb to 40,000 feet and 450 kts outbound. The legs of the flight path may avoid known concentrations of defenses. The outbound path may differ from the inbound route. A single aircraft penetrates the enemy defenses.

The aircraft entry point at the FEBA (X-axis) is the origin of the coordinate system with the positive Y-axis in the direction of the enemy. The target area is described by a circle with the target at the center.

On the enemy side of the FEBA are several safe areas where a pilot (or crew member) may land after his aircraft is shot down, and where SAR forces may be expected to extract him with an assumed probability. Each safe area is a circle and its center and radius are specified.

The computer model was used to evaluate the AERCAB on both a conceptual and a real world basis. Conceptually, the AERCAB is perfectly reliable. It can be damaged by enemy defenses, but it cannot fail through inherent reliabilities. The real world AERCAB has been modeled to reflect conservative hardware associated reliabilities. The method of determining the effectiveness of an AERCAB was to answer the question, "If 100 aircraft were lost in a scenario, how many crews are rescued with and without an AERCAB system?" Of secondary importance are:

-What are the important design parameters for an AERCAB system?

-What is the status, and why, of the remaining (nonrescued) aircrews?

c. Scenario Evaluations

Three scenarios were selected for evaluating the AERCAB system. The details of these scenarios and their derivations are classified and are contained in Volume II. A general description and results of the evaluation are presented here. The three scenarios represent past, present, and future combat operations.

(1) Historical Southeast Asia

A scenario based on a statistical derivation of U.S. Air Force experience in SEA (see Volume II) was included as past combat operations. The statistical analysis was computer modeled as shown in Figure 3. In the target area, the probability of rescue was zero and in a large area of up to 50 miles off target center, the probability was very low (0.08). Beyond 50 miles, the probability of rescue rose to 0.80, where it remained out to 110 miles off target center. The scenario was analyzed to determine the impact of an AERCAB system had it been available. Figure 4 shows the percentages of crewman in each category as the result of actual combat, the computer modeling without AERCAB, and the impact of an AERCAB system of increasing range. According to this analysis, if an AERCAB system had been available for use in conjunction with the SAR forces, 47% more crewmen could have been rescued. The AERCAB range was found to be the most powerful design parameter. This comparison is for the real-world reliability AERCAB system; an AERCAB mechanism with zero range capability would reduce the rescue percentage because it would be substituting a more complex mechanism (the AERCAB) for an ejection seat. The percentage rescued rises sharply with AERCAB range until a plateau is reached at about 50 miles. If the AERCAB range is increased so that it is possible to fly from the target all the way to the FEBA (see Figure 3), the percentage rescued will again increase sharply, but additional AERCAB range has no payoff.

(2) U. S. Navy Scenario

The Naval Air Development Center, Warmister, Pa., provided a scenario representative of present day combat operations. This scenario is shown in computerized format in Figure 5 (for details see Volume II).

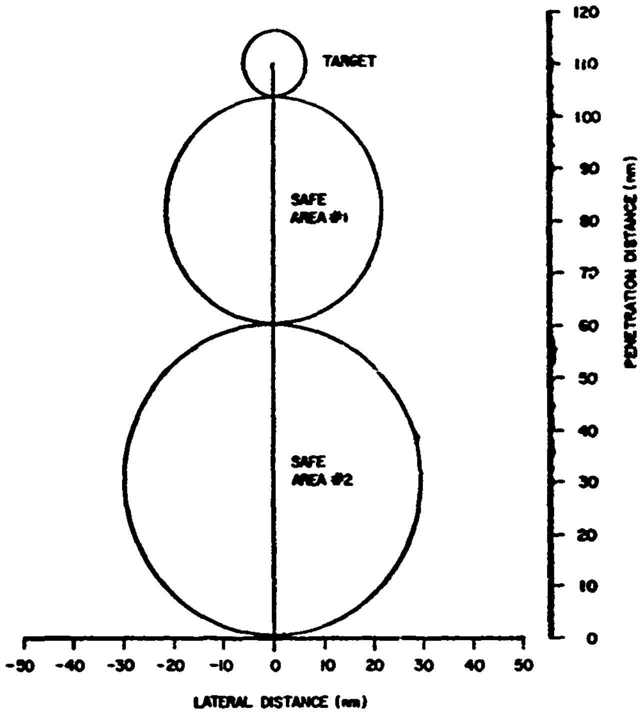


Figure 3. Southeast Asia Scenario Geometry

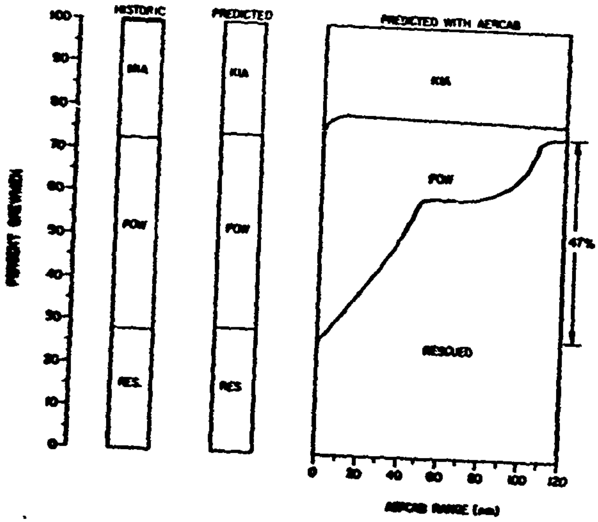


Figure 4. Southeast Asia Scenario Evaluation and Comparison

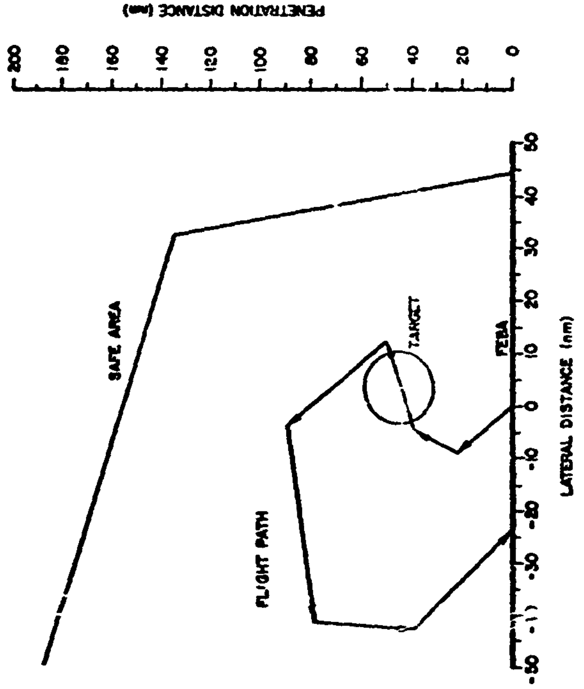


Figure 5. USN Scenario Geometry

In this scenario, 38 combinations of altitude and speed for a variety of AERCAB ranges were analyzed. Without an AERCAB system, the percentage of aircrew rescued is predicted to be 26%; with an AERCAB system, this prediction rises to 63%. At ranges beyond about 45 nm, a larger AERCAB would be required, which makes it more vulnerable to this particular defensive weapon mix and decreases the percent rescued slightly (see Figure 6). The spread in probability of rescue for a given AERCAB range (represented by the narrow band of cross hatched area) reflects a slight difference in capability due to a particular combination of speed and altitude. The higher speed and lower altitude combinations tend to be near the upper portions of the band and the lower speed, higher altitude configurations near the lower part of the band.

(3) Air Force Scenario

A scenario representative of future combat operations was generated by the Air Force Flight Dynamics Laboratory in conjunction with several other Air Force organizations. The details of this scenario are shown in Volume II. The computerized format of this scenario is shown in Figure 7.

The same 38 combinations of altitude and speed for a variety of AERCAB ranges as were analyzed in the USN scenario were run in the Air Force scenario; the results are shown in Figure 8. The predicted percentage of aircrews rescued without an AERCAB system is about 10%. With an AERCAB system, this prediction rises significantly. With an AERCAB having a range of 220 nm, the predicted percentage is 67%, and for a range of 100 nm, is 50%.

d. <u>Fate of the Crews</u>

The AERCAB system has been shown to increase the percentage of aircrews rescued. The question remains what happened to the aircrews that were not rescued and why? For the case where the mission aircraft is lethally hit at the target and the aircrew has a 95 nm range AERCAB,

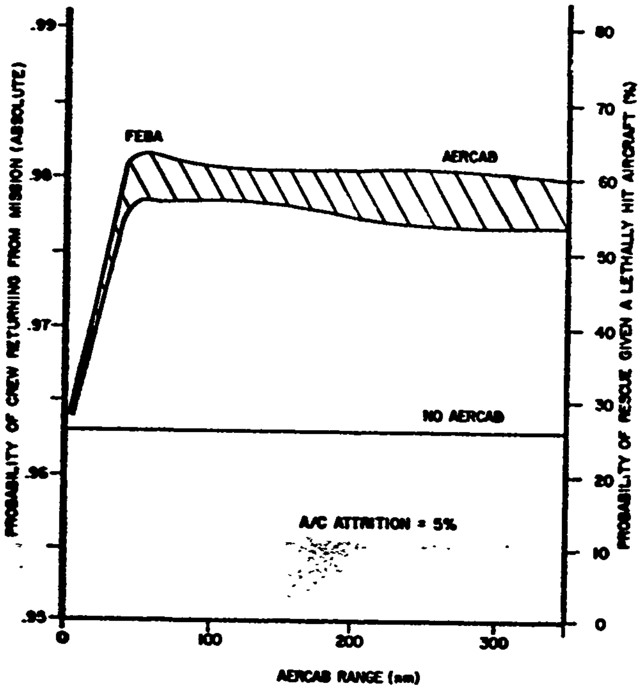


Figure 6. Effectiveness of AERCAB in USN Scenario

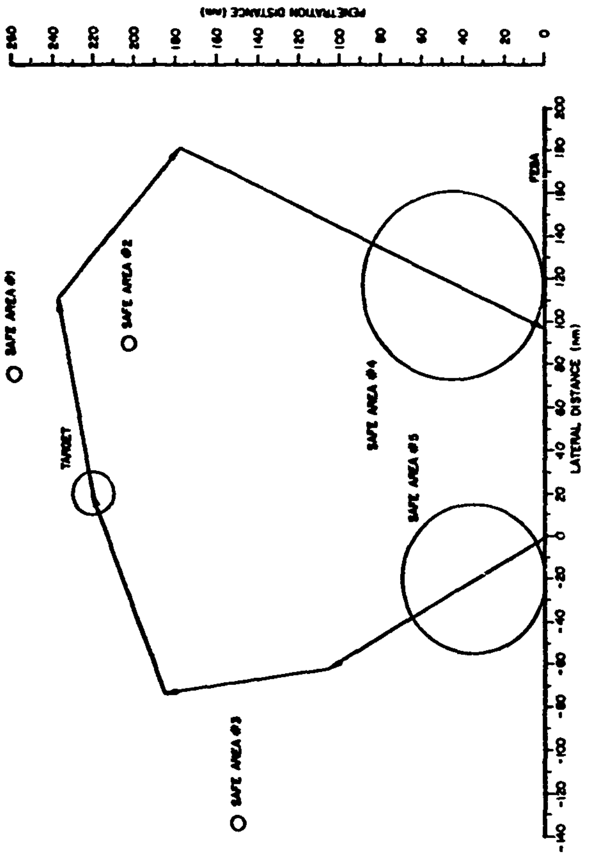


Figure 7. USAF Scenario Geometry

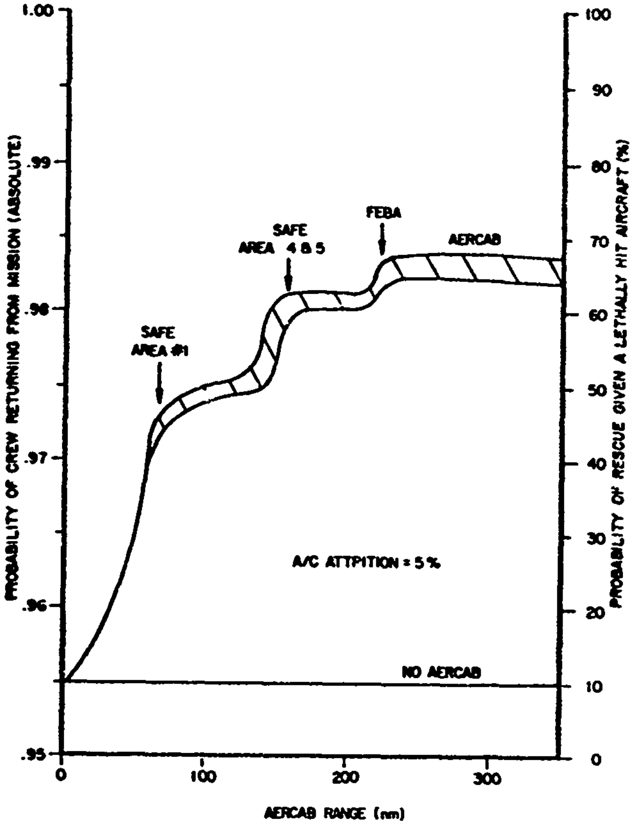


Figure 8. Effectiveness of AERCAB in USAF Scenario

the status for the Navy and Air Force scenarios is shown in Figure 9. This cannot be compared directly to the previous scenario evaluation because of differences in the distribution of attrition along the flight path.

The category of Misc is shown as less than 1% and is the result of more convoluted logic paths than shown here (e.g. the AERCAB was shot down but the crewman was still rescued). The AERCAB was not necessary in those cases where the mission aircraft could fly to a safe area with a high probability. The AERCAB was necessary if the mission aircraft could not reach any safe area. The status of "Crew not rescued from safe area" is caused by the assumed SAR probability of rescue of 0.7 for some safe areas. Thirty percent of the aircrews reaching the safe area were assumed as not being able to link up with the rescue force and so were not rescued. Note that the Navy scenario does not have this status because a 95 nm AERCAB has sufficient range to reach the FEBA where the probability is 1.0.

The category of personnel chute failure is considered a reliability factor of the overall sequence of parachuting to earth. The extremely high reliability of canopy opening is degraded because of historic losses occurring at ground contact. Unfavorable terrain, inadequate training/proficiency, and previous personnel injuries contribute to the degradation of this reliability. An AERCAB system will allow the crewmember some choice of when to parachute to earth, allowing him to avoid lakes, rivers, karst, cliffs, etc., but this improved reliability cannot be quantitatively analyzed. For conservatism the improvement in this reliability has been ignored.

The status of "AERCAB Unreliable" includes the product of two reliability factors: (1) the reliability of ejection from the aircraft (similar to the ejection seat specification reliability/confidence levels); and (2) the reliability of the AERCAB mechanism deploying. Both of these reliabilities have been considered to be 95% for conservatism.

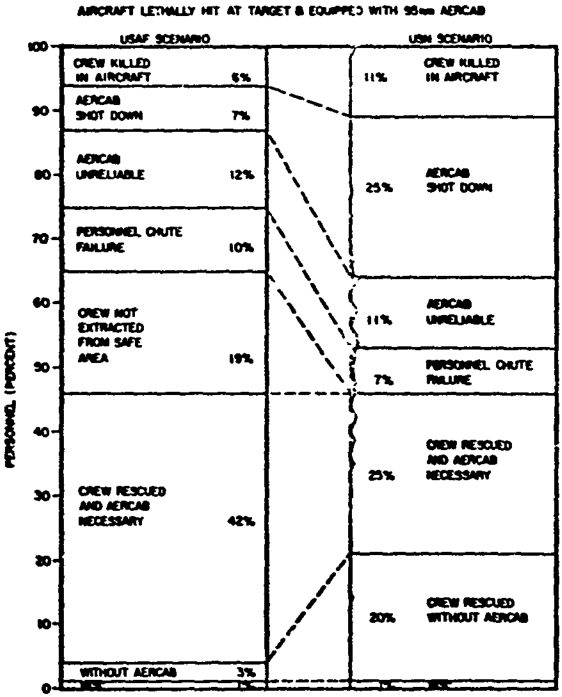


Figure 9. Fate of the Aircrew, USN and USAF Scenarios

The status "AERCAB Shot Down" demonstrates the effect of different scenario weapon mixes. The Navy scenario weapon mix was especially effective against AERCAB's; note that these AERCAB's have to fly through the target area.

The mechanisms that killed crews in the aircraft were considered to be the same that lethally damaged the aircraft (e.g., they were not trapped by a faulty ejection seat).

To evaluate the AERCAB conceptually (perfectly reliable), the expected percentage of crews saved becomes 58% for a 95 nm AERCAB in the Air Force scenario and 57% in the Navy scenario.

The respective figures for a real world AERCAB (not perfectly reliable) are 46% for both scenarios (by coincidence).

The effect of AERCAB altitude and velocity on AERCAB attrition was investigated. Increasing velocity was found to always decrease attrition. At altitudes above 3000 feet, increasing altitude decreases attrition. Both of these effects, however, are secondary to range. The effects are directly related to the weapon mix involved in the scenarios. The analysis in the Navy scenario is shown in Figure 10 and Figure 11.

4. REMARKS ON EFFECTIVENESS

The AERCAB system has been shown to be operationally effective:

a. In conjunction with SAR forces, aircrews using AERCAB can be saved which would otherwise be lost.

b. It reduces the SAR force losses because the SAR operations can be conducted in lower threat level areas.

c. The effectiveness analysis and scenario evaluations are documented in detail in Reference 1.

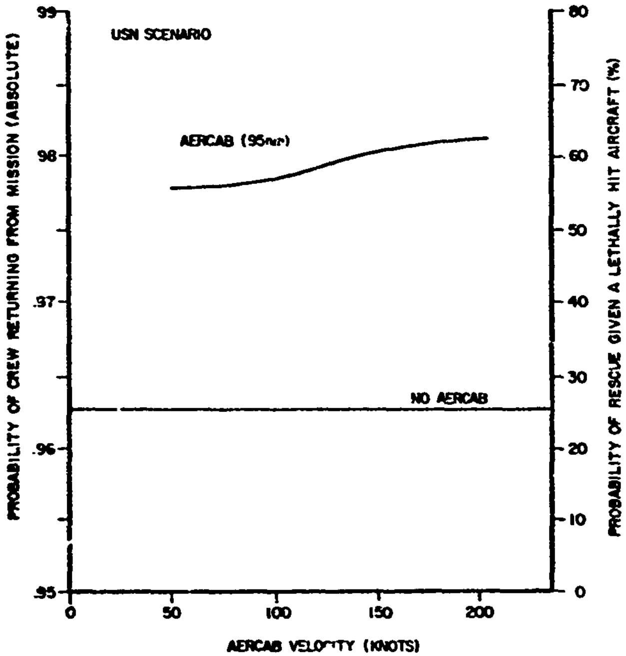


Figure 10. Parametric Variation of AERCAB Velocity

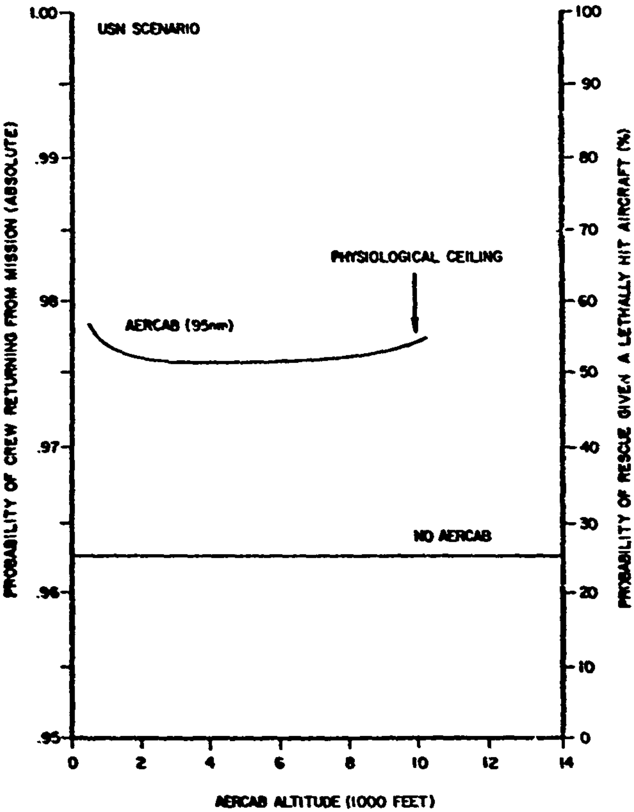


Figure 11. Parametric Variation of AERCAB Altitude

SECTION IV

OPERATIONAL PRACTICABILITY

1. GENERAL

Is an AERCAB operationally practicable? To answer this question, we must consider factors important to the using command, namely, could the using command's mission accommodate the system, and could it be operated and maintained by the resources either currently or potentially available to the command?

2. MISSION IMPACT

One effect of an AERCAB system on a fighter aircraft is that it increases the weight of the ejection seat subsystem. This increase in subsystem weight may be expressed in terms of effect on aircraft mission as increased gross takeoff weight, reduced range, reduced maneuverability, reduced ordnance load, etc. A more detailed treatment of this effect is presented in Volume II.

The addition of fuel in the cockpit for the AERCAB does not make a significant change in the vulnerable area of the F-4 aircraft; this is supported by the rationale that the area required for the 100 pounds or less of fuel for the AERCAB is negligible compared to the area required for the 12,954 pounds of JP-4 currently carried internally in the F-4. The fact that fuel is in the cockpit, however, does require special attention to minimize the danger of fires or explosions. Some protection is provided by the mission aircraft since the AERCAB is stowed so that many of its components, including the fuel tanks are shielded by the aircraft components. Safety in stowing and handling, and protection against fire or explosion due to small arms fire can be maximized by using self-sealing foam-filled tanks and fuel "scrubbing." A cockpit fire-suppression system sensitive to "hits" should be considered to prevent flash fires in the event of fuel seepage during the few seconds required for the sealant to act.

Rocket catapults and pyrotechnic ejection seat stabilization systems are presently incorporated in baseline aircraft. Thus, vulnerability is not changed by these items being required as AERCAB components.

3. PILOT TRAINING

The analytical flying qualities of an AERCAB vary between lifting surface configurations. The feasibility hardware work completed to date (Section V) indicates that an AERCAB should be reasonably simple to fly manually. The normal mode of operation is automatic, but a manual override capability is desirable. Ground trainers or simulators will be required to familiarize pilots and nonpilot rated back seat aircrewmembers with controls, instruments, switches, etc. Flight training procedures should be similar to checkout in a single engine light plane. The absence of takeoffs, landings, and high performance maneuvers should greatly simplify training requirements. Nonpilot rated personnel may require slightly more training than rated personnel. Undergraduate pilot training, together with simulator or ground trainer time and an understanding of the purpose, capabilities, and limitations of an AERCAB, are expected to be sufficient for manual operation of the vehicle.

4. MAINTENANCE

Maintenance for a deployed AERCAB system will be greater than for existing ejection seats, primarily because of the propulsion and avionics subsystems and their assoicated components and interfacing equipment. Maintenance is required for not only the basic engine and GN&C equipment, but for the electrical equipment, instrumentation, fuel cells, etc. Although these subsystems have not yet reached the breadboard stage, we anticipate that they would become straightforward applications of existing technology in the timeframe of an operationally deployed system. These subsystems are not subject to continuous use and are designed for one-time, high-reliability, short-service-life, long-shelf-life applications. Periodic checking of circuitry, displays, and lubrication levels, in addition to normal pyrotechnic system checking, should be satisfactory for continued operational readiness. The maintenance requirements should be well within the provisions of MIL-S-9479B, "General Specification for Seat System, Upward Ejection, Aircraft."

If the mission scenario requires GN&C and other functions to be performed following the ejection without pilot assistance, then two important conclusions may be reached: (1) The increased scope of logical functions is best handled by general purpose digital logic (in addition to any primary GN&C requirement for digital computation). Simple and low-cost analog autopilots are available for low-speed general-purpose aircraft, and some may believe that such systems are sufficient for a fully automatic AERCAB system; however, the capabilities of these autopilots are extremely limited, and manual intervention is necessary for their use. (2) The entire AERCAB GN&C system must be turned on, warmed up, and initialized prior to ejection from the aircraft. At least some portion of the system, e.g., navigational logic elements, as certain information (present coordinates, wind speed, azimuth to the safe area, etc.) must be continually updated. For fully automatic operation, gyroscopes must be spun up and erected, crystal oscillators be temperature-stabilized, and so on. Reliability, performance, and operational lifetime of the system are affected by the accumulated on-time and the number of power switching transients, with each components responding to the resulting electrical, thermal, and mechanical stresses in a different way.

Fully automatic GN&C allows a significant reduction or simplification in pilot display requirements and "bare airframe" handling qualities. The pilot is relieved of tracking and control tasks with the automatic system.

5. REMARKS ON OPERATIONAL PRACTICABILITY

An operationally deployed AERCAB system appears to be a practicable system in view of:

(a) Impact on the mission aircraft

(b) Personnel training and proficiency required

(c) Projected maintenance requirements

Further, it appears that no insurmountable problems exist to prevent a deployed AERCAB system from being practical for using commands.

SECTION V

TECHNICAL FEASIBILITY

1. GENERAL

Is an AERCAB technically feasible? This question was originally addressed in late 1967, when the first investigation of the flyaway, self-rescue, escape concept was initiated. Subsequent to the completion of that first feasibility study, numerous exploratory development programs have been conducted by the Air Force and Navy not only to substantiate the initial conclusion that the AERCAB concept is technically feasible, but to establish a good technical base from which an equitable comparison of proposed configurations can be made

2. AERCAB EXPLORATORY DEVELOPMENT EFFORTS

As indicated by the outline presented in this section, sufficient data has been obtained during the exploratory development to assure the feasibility of each of the four concepts (Parawing, Rotor, Sailwing, Rigid Wing). However, not all of the concepts have reached the same stage of development so that an equitable comparison can be made. Consequently, in-flight deployment and transition to steady state flight has been selected as the milestone to be achieved by each concept prior to any elimination. The following completed exploratory development efforts sponsored by the Air Force Flight Dynamics Laboratory (AFFDL) or the Naval Air Development Center (NAVAIRDEVCEN) form a solid technical foundation for this feasibility assessment. These programs are discussed below.

a. Parawing

(1) Integrated Aircrew Escape/Rescue System Capability (AFFDL). This study effort has been completed and resulted in the generation of specific operational and design criteria for an integrated aircrew escape/rescue system capability; operational and performance limits were defined and it was analytically shown that the AERCAB concept using a parawing/jet engine/ejection seat is feasible and merits continued

study, experimental testing, and development. The study used a new ejection seat and assumed the development of a new high bypass ratio, twin turbofan engine to package the system in the available aircraft space. A modular design was evaluated which permits the system to operate as an independent escape/recovery system or as an integrated escape rescue system. This program was started in April 1968 and was completed in October 1968 (Reference 9).

(2) Half-Scale Parawing Wind Tunnel Program (AFFDL). This effort was completed to determine the aerodynamic and static stability characteristics of a 1/2-scale model of a Parawing AERCAB configuration. The data was used to compare with free flight data of a similar full-scale AERCAB configuration. The data compared extremely well with the free flight data and proved invaluable in predicting the stability characteristics of the full-scale vehicle. This program started in September 1969 and was completed in April 1970 (Reference 10).

(3) AERCAB Experimental and Feasibility Testing (AFFDL). This effort has been completed and resulted in the experimental demonstration of a powered, rigidly coupled Parawing ejection seat/engine configuration. Aerodynamic performance data, longitudinal and lateral stability data over a range of cg variation, and the in-flight control and turning capabilities of a rigid nonarticulated Parawing system were obtained under both powered and unpowered flight conditions. The practicability of crewmember bailout from a flying seat was demonstrated under this program as an anthropomorphic dummy with a personnel parachute was released from an AERCAB vehicle in a stable gliding descent mode. The dummy and AERCAB carrier vehicle were both recovered separately and intact. This program started in March 1969 and was completed in December 1970 (Reference 11).

(4) Jet-Car Testing (AFFDL). This experimental effort has been completed. An articulated test Parawing model was deployed on the jet car at the Naval Air Test Facility, Lakehurst, New Jersey. Preliminary deployment characteristics of the deployable/erectable

full-scale Parawing were obtained. This effort was completed in January 1971.

(5) Articulated Parawing AERCAB Wind Tunnel Program (AFFDL). This effort was conducted to determine the aerodynamic, stability, and deployment characteristics of a deployable/erectable AERCAB full-scale model. The wind tunnel aerodynamic and stability results were compared to available free-flight performance characteristics to validate the flight performance. The Parawing articulation characteristics were determined from dynamic deployment/erection tests, which demonstrated the feasibility of deploying and erecting the Parawing from a stowed configuration into an AERCAB flight configuration. This program started in September 1970 and was completed in February 1971.

(6) Articulated Parawing AERCAB Air Drop Tests (AFFDL). This program evaluated deployment and erection of an articulated Parawing from its stowed position and determined the transition dynamics from the postejection mode to the unpowered gliding mode in a free flight environment. This program started in January 1971 and was completed in April 1971 (Reference 12).

b. Rotor

(1) Rotor Discretionary Descent System (AFFDL). This in-house effort has been completed and resulted in the preliminary design of a rotary-wing self-rescue system and the establishment of a performance envelope. It was concluded from this effort that a teetering type rotor system employing the telescoping blade technique, when combined with a small engine propulsion system, provided a high degree of potential as an escape/rescue flyaway concept. This program was started in July 1968 and was completed in December 1968.

(2) Rigid Rotor Experimental Test Program (AFFDL). This effort is completed. Investigated under this program was the feasibility of using a rigid rotor system to provide a glide and maneuver capability during descent from altitude. Flight tests were conducted to evaluate

a gliding, descending, unpowered type rotor capability with that of a powered, "flyaway" system. The "flyaway" system proved to be the more promising approach for satisfying the overall AERCAB objective. This program was started in January 1968 and completed in April 1969.

(3) Catholic University AERCAB Conceptual Study (NAVAIRDEVCEN). This study effort is completed. The results of the study indicated the feasibility of a packageable, deployable autogyro powered by a small turbofan engine for accomplishing the AERCAB objectives. Results of this study have been used in follow-on autogyro development efforts. This program was started in November 1968 and was completed in June 1969 (Reference 13).

(4) Rotary Wing AERCAB Feasibility Study (NAVAIRDEVCEN). This study effort by Kaman Aerospace Corporation has been completed. The purpose of the study was to evaluate the feasibility of using an autogyro as an AERCAB vehicle. Rotor selection was based upon performance analysis. Design and integration studies indicated that the autogyro AERCAB can be stowed in the cockpits of the A-7 and F-4 aircraft with only minor modifications. It was concluded that this concept is feasible, that it should be studied more extensively, and that an experimental model should be fabricated and tested. This program was started in December 1968 and completed in June 1969 (Reference 14).

(5) Rotary Wing AERCAB Feasibility Testing (NAVAIRDEVCEN). The purpose of this program is to verify the conclusions of the feasibility study by demonstrating the flight performance with a full-scale experimental vehicle. More extensive testing of this model will be conducted during Phase I to advance the state-of-the-art and to ascertain that the optimum lifting surface is selected for final development. The following paragraphs discuss the various phases of the Feasibility Testing.

(a) Jet-Car Testing (NAVAIRDEVCEN). This experimental effort has been completed. The rotor was tested on the jet car at the Naval Air Test Facility at Lakehurst, New Jersey. Rotor performance was demonstrated and tentatively optimum values were selected for blade pitch and blade coning angles. Extension of the telescoped blades and rotor spin up and deployment from a trailing, coned position were demonstrated. It was concluded that the autogyro AERCAB was ready for full-scale wind tunnel testing. This program was started in May 1970 and was completed in September 1970 (Reference 15).

(b) NASA Ames Wind Tunnel Tests (NAVAIRDEVCEN). This effort has been completed. The rotary-wing AERCAB was tested in the 40 x 80-foot wind tunnel at the NASA Ames Research Center. More extensive rotor performance tests were completed and it was concluded that the rotor thrust is more than adequate for the prescribed mission. Vehicle aerodynamic data was gathered, and staged deployment of the complete vehicle was demonstrated. The remaining effort during feasibility testing will be directed toward actual flight demonstration. This program was started in June 1969 and completed in October 1970 (Reference 15).

(c) Wind Tunnel Testing (NAVAIRDEVCEN). This effort has been completed. The rotary-wing AERCAB vehicle model was tested in the Naval Ships Research and Development Center's 8 x 10-foot wind tunnel for a total of 50 data runs. Aerodynamic characteristics were initially obtained for the seat plus man less rotor configuration. Comparative data was then collected by varying tail fin size, boom length, or both. The influence of various nose fairings on the drag and stability of the basic rotorless vehicle was also evaluated. The resultant aerodynamic data when coupled with empirical rotor data was used to predict lateral, longitudinal, and directional stability characteristics of the rotary-wing AERCAB manned flight test vehicle. This program was started in October 1970 and completed in February 1971 (Reference 16).

(d) Flight Testing. Manned flight tests of the AERCAB vehicle equipped with a 16-foot diameter rotor were conducted in January 1972 to assess the influence of a relatively high disc loading. Following satisfactory demonstration of flight capability under these conditions, the 14-foot diameter telescoping blades were substituted to successfully demonstrate flight performance of the configuration which would ultimately be integrated in operational aircraft. These tests were completed in January 1972 (Reference 17).

(e) Laboratory Testing. Static and dynamic laboratory tests and rotor overspeed tests were conducted to demonstrate the structural adequacy of the experimental vehicle previous to entering the wind tunnel. These tests were started in April 1970 and were completed in June 1970.

c. Sailwing

(1) Sailwing AERCAB Feasibility Investigation (NAVAIRDEVCEN). This study effort conducted by Fairchild Industries has been completed. The Sailwing concept, which is similar to a light conventional aircraft, was investigated for its feasibility and practicality as a highly efficient configuration potentially applicable to the AERCAB escape/rescue operational environment. Each wing is formed by a rigid leading edge spar and a trailing edge cable with fabric stretched between them. The leading edge spar is designed to fold in two sections to permit the vehicle to be stowed in the cockpits of the A-7 and F-4 aircraft without major modification. Performance analysis and trade-off studies were also performed. The results of the analytical study indicated that the Sailwing AERCAB is feasible and merits further investigation. These tests were started in December 1968 and completed in July 1969 (Reference 18).

(2) Sailwing AERCAB Feasibility Testing (NAVAIRDEVCEN). The purpose of this program was to verify the conclusions of the feasibility study by demonstrating flight performance with a full-scale model. More extensive testing of this model will be conducted in Phase I to advance the state-of-the-art and ascertain that the optimum lifting surface is selected for final development. The following paragraphs discuss the various phases of the feasibility testing (Reference 19).

(a) <u>Quarter-Scale Sailwing Wind Tunnel Program (NAVAIRDEVCEN)</u>. This program has been completed. A quarter-scale model of the Sailwing AERCAB was evaluated in the wind tunnels at the NASA Langley Research Center and at Wright-Patterson Air Force Base. The tests were conducted to verify the predicted values of aerodynamic loads and moments acting on the AERCAB. From the tests we concluded that the full-scale vehicle should be longitudinally and directionally stable and that spoilers located on the upper surface of the wings at the leading edges could provide sufficient lateral control. This program was started in September 1969 and was completed in November 1969.

(b) <u>Semispan, Wind Tunnel Tests (NAVAIRDEVCEN)</u>. This phase of the program has been completed. A single wing and the semispan vehicle were tested in the 8' x 10' tunnel at the Naval Ships Research and Development Center. The objectives of these tests were to investigate vehicle deployment in an airstream, to investigate wing performance characteristics, to determine the optimum trailing edge cable tension, and to evaluate wing spoiler effectiveness. The testing indicated that the spoiler provided adequate control forces and that the wing is an efficient aerodynamic surface. Some difficulties, however, were encountered during deployment. The wing mechanism had to be revised prior to further testing. This program was started in February 1970 and was completed in May 1970.

(c) <u>NASA Langley Wind Tunnel Tests (NAVAIRDEVCEN)</u>. This phase of the program has been completed. The complete full-scale model was tested in the wind tunnel at the NASA Langley Research Center at velocities up to 80 knots. The purpose of the test was to further evaluate the performance characteristics of the Sailwing and the deployment capability of the AERCAB. Results of the aerodynamic test were generally good, but investigation of wing and fuselage flow patterns in future wind tunnel tests was recommended to assist in fairing optimization. Deployment was improved, but we encountered difficulties again, which required additional design changes. This program was started in April 1970 and completed in August 1970.

(d) NASA Ames Wind Tunnel Tests (NAVAIRDEVCEN). This phase of the program has been completed. Wind tunnel tests were performed with the full-scale model at the NASA Ames Research Center. Maximum velocities for the aerodynamic and deployment portions of the tests were 150 and 70 knots, respectively. The vehicle was tufted for some of the aerodynamic tests to determine the flow pattern around the wing and fuselage. Camber reversal of the lower wing surface was experienced at approximately 120 knots. The deployment test was suspended due to the failure of the wing deployment cable. Demonstration of deployment by truck will be required before any additional wind tunnel test is scheduled. Vehicle aerodynamic data was recorded on the fully deployed vehicle. This program was started in June 1969 and was completed in October 1970.

(e) Gliding Flight Tests (NAVAERORECFAC). These tests at the Naval Aerospace Recovery Facility have been suspended following structural failure experienced during the initial free flight. A full-scale model of the Sailwing vehicle was lifted in its deployed configuration by a helicopter and transitioned to stable tow at the release speed. Upon its release from tow, the vehicle exhibited short duration stable flight prior to entering a dive and exceeding design speed. Structural failure occurred before the vehicle recovery system could be actuated. The instability was attributed to vehicle cg shift and lack of control. This program was started in October 1970 and was completed in February 1971.

(f) Laboratory Tests. Static and dynamic laboratory tests were conducted to demonstrate the structural adequacy of the experimental model. Initial deployment tests of the vehicle when not subjected to dynamic pressure were also conducted previous to entering the wind tunnel. These tests were started in December 1969 and were completed in April 1970.

d. Rigid Wing

(1) Laboratory Tests (AFFDL). Static and dynamic laboratory tests were conducted to demonstrate the structural adequacy of the experimental wing semispan. Repetitive deployment tests of the semispan when not subjected to dynamic pressure were conducted previous to entering the wind tunnel. These tests started in December 1970 and were completed in April 1971 (Reference 20).

(2) Wind Tunnel Tests (AFFDL). Testing of a deployable rigid wing semispan at the Naval Ships Research and Development Center 7 x 10-foot tunnel has been completed. The objectives of these tests were to investigate wing deployment under dynamic pressure, to record wing aerodynamic data, and to evaluate aileron effectiveness. The testing revealed that the aileron provides adequate control forces and that the deployed wing is an efficient aerodynamic surface. Difficulties were encountered in consistently locking the semispan during deployments at angles of attack above 9 degrees. This program was started in May 1971 and completed in June 1971 (Reference 20).

(3) NASA Ames Wind Tunnel Tests (AFFDL). Testing of a full-scale deployable rigid wing in the NASA Ames 40' x 80' wind tunnel have been completed. Wing deployment at velocities up to 135 knots was successfully demonstrated. Aerodynamic data on a full-scale AERCAB configuration was recorded. This program was started in February 1972 and completed in June 1973.

(4) Rigid Wing AERCAB Design (AFFDL). A preliminary and a detail design phase was initiated and completed in FY 73. The primary purpose was to substantiate the viability of the rigid wing AERCAB configuration. The AERCAB configuration resulting from this analytical effort represents the most compact stowed arrangement and lightweight system yet achieved using a rigid wing as the lifting surface. AFFDL-TR 73-134 (Reference 3) documents this work.

e. Lifting Surface Subsystem Remarks

The most critical subsystem for this concept, from a technical risk standpoint, is the lifting surface. We need a lifting surface that is as efficient as possible while still being stowable within the confines of the seat, and which can be deployed at AERCAB velocities. The thrust required to attain the performance goals of the AERCAB concept is directly related to the efficiency of the lifting surface subsystem. The propulsion subsystem requirements cannot be defined until the lifting surface has been selected. At this point, none of the candidates being studied for the AERCAB lifting surface have demonstrated either superiority or inferiority to the other devices. Table I is presented to reflect the progress achieved.

TABLE I

DEVELOPMENT MILESTONES

	PARAWING	SAILWING	ROTOR	RIGID WING
SPECIFICATION	X	X	X	X
FEASIBILITY STUDY	X	X	X	X
DESIGN	X	X	X	X
MODEL FABRICATION	X	X	X	X
LABORATORY TESTS	X	X	X	X
WIND TUNNEL TESTS	X	X	X	X
SLED TESTS	X		X	
FLIGHT TESTS	X		X	
TRANSITIONAL DEPLOYMENT	X			
AERCAB EGRESS	X			

3. AVIONICS AND FLIGHT CONTROL SUBSYSTEMS INVESTIGATION

Successful aircrew recovery in a hostile environment requires more than just the ability to remain airborne; it requires guidance, navigation, and control (GN&C). The GN&C functions are a vital element in the AERCAB safe-area concept. An emergency situation in a hostile environment is neither the time nor place for a recreation of the legendary "wrong-way Corrigan."

a. Guidance, Navigation, and Control. Performance guidelines necessary for the operational functioning of the GN&C system are:

(1) Automatic Functioning. For the extreme case of an incapacitated crewman, the AERCAB system should perform all necessary functions required to reach the safe area "hands off." Additionally, manual overide control must be available at all times.

(2) Secure Safe Areas. The GN&C system should operate with a safe area that has no signature detectable to hostile forces (e.g., no homing beacon).

(3) Secure Navigation. The navigation technique employed should be autonomous and resistant to electronic countermeasures.

(4) Accuracy Requirements. The accuracy required of the GN&C system is directly related to the size and ranges of the safe areas. Conversely, in future operations, the size and ranges of the safe areas will be directly related to the accuracy achievable by the AERCAB.

A study was conducted by The Analytic Sciences Corporation under contract to the Air Force Avionics Laboratory investigating "Guidance, Navigation, and Control Concepts for a Flyable Ejection Seat," AFAL-TR-73-396. A wide spectrum of GN&C approaches was investigated, including the following navigation techniques:

Unaided Dead Reckoning Ground

Ground Based Direction Finding

Airborne Direction Finding

VOR

DME

TACAN

OMEGA

LORAN (Hyperbolic)

Direct Ranging LORAN

Short Range Hyperbolic Systems

Doppler

Satellite

Star/Sun Tracker

Optical Correlator

Radar Correlator

Ground Based Radar Tracking with Data Link

b. Feasible Approach

(1) Flight Control Subsystems. Automatic control suggests that AERCAB manual modes be Fly-by-Wire for the spectrum of lifting surface configurations. In addition to lowering overall system weight and cost, potential conflict between the automatic (electrical) and manual (mechanical) control elements is eliminated. Handling qualities could be improved through the electronic "shaping" of pilot commands and the decoupling of hand controller forces from aerodynamic loads and actuaction mechanisms. The fly-by-wire requires a source of electrical power for control under engine off conditions. A small, high amperage, short-life battery is included.

(2) Autopilot & Guidance Subsystems. A general purpose digital computer is proposed for the logic function of this subsystem. The autopilot requirements and any stability augmentation requirements are dependent on the aerodynamic characteristics of a particular AERCAB configuration. The guidance system requirements, which can best be performed by digital logic, are:

(a) Monitor and assess navigation data,

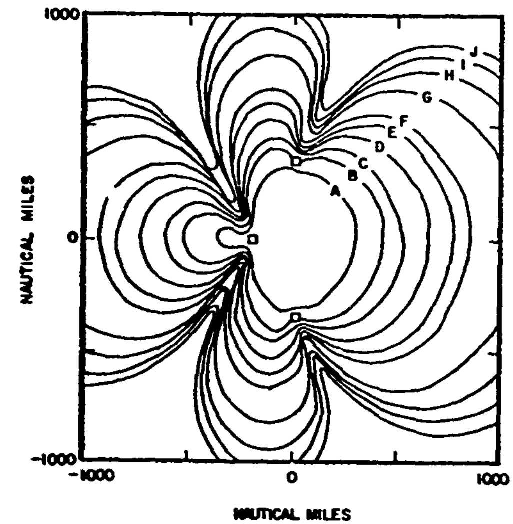
(b) Generate autopilot commands,

(c) Management of minimum time/maximum range cruise policies.

(3) Navigation Subsystem. The most feasible state-of-the-art navigation technique was determined to be hyperbolic LORAN. An additional concept using Direct Ranging LORAN also appears feasible and may be desirable for its higher accuracy. For example, if a hyperbolic LORAN navigation system were used and if a safe area were to be located at coordinates (+500, +500) in Figures 12 and 13, then the minimum safe area radius (corresponding to the radial error) would be approximately 10,000 feet. If a Direct Ranging LORAN navigation system were used, however, this radius would be approximately 1200 feet. Thus, greater system accuracy has reduced the safe area needed from 11.3 square miles to 0.162 square mile. Differences in terrain alone (e.g., desert vs. jungle) may require or negate this increased accuracy.

4. REMARKS ON TECHNICAL FEASIBILITY

The exploratory programs conducted to date have indicated the technical feasibility of the AERCAB concept and substantiated the attainment of its capability. A void exists in the technical data base for comparatively evaluating the assets of the individual AERCAB configurations in that achievement of all preestablished technical milestones has not been accomplished for each configuration. The parawing configuration successfully completed all phases of initial feasibility testing while the rotor, sailwing, and rigid wing



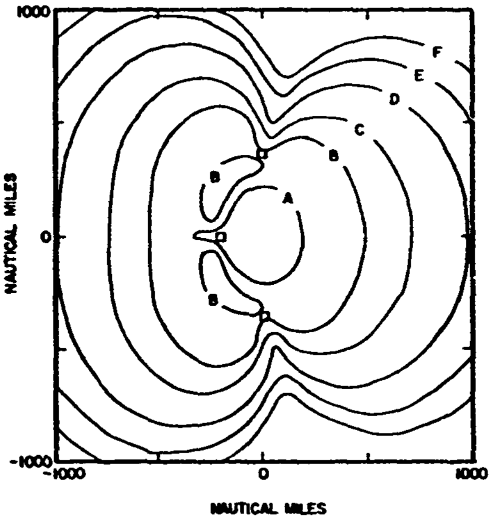
□ TRANSMITTER

PROPAGATION ANOMALY SCALE FACTOR = 10^{-4}
RANGE DEPENDENT RECEIVER NOISE

RADIAL ERROR
CONTOUR LEVEL VALUES

A = 1000 ft	F = 10,000 ft
B = 2000 ft	G = 20,000 ft
C = 3000 ft	H = 30,000 ft
D = 5000 ft	I = 40,000 ft
E = 7500 ft	J = 50,000 ft

Figure 12. Radial Error for LORAN Navigation



□ TRANSMITTER

USER CLOCK PHASE ERROR = 500 nsec
PROPAGATION ANOMALY SCALE FACTOR= 10^{-4}
RANGE DEPENDENT RECEIVER NOISE

RADIAL ERROR
CONTOUR LEVEL VALUES

A = 500 ft   D = 1500 ft
B = 750 ft   E = 2000 ft
C = 1000 ft   F = 2500 ft

Figure 13. Radial Error for Direct Ranging LORAN Navigation

configurations have limited testing remaining. The fact that not all of the concepts have reached the same stage of development is not a reflection on the capability of a particular configuration but is more indicative of the level of effort applied to each.

We concluded that an automatic Guidance, Navigation, and Control system for the AERCAB vehicle is not only feasible, but that it would be highly desirable since it improves the probability of successful crew retrieval, particularly in cases where the pilot is injured, by optimizing the flight performance of the vehicle and providing navigation to a safe area.

Reference 3 contains the detailed documentation of a feasible Rigid Wing AERCAB design conducted during this study. Reference 4 contains detailed accuracy and cost analyses of feasible GN&C approaches.

SECTION VI

TECHNICAL PRACTICABILITY

1. GENERAL

Is an AERCAB technically practicable? The ultimate answer to this question could best be determined by conducting an Advanced Development Program. Without the benefit of prototype experimental results, a complete assessment of the engineering practicability of the AERCAB concept is not possible. However, some useful information can be gained through analyses.

2. APPROACH

An investigation was conducted within the AFFDL to provide AERCAB vehicle configuration inputs for a system effectiveness analysis. The approach employed involved:

(1) An analysis and evaluation of available AERCAB data to establish a data base for formulation of vehicle configurations and to examine the state-of-the-technology in this area;

(2) A parametric development of configurations subsequently used in the effectiveness analysis; and

(3) A point design definition of an AERCAB vehicle that offers solutions to any performance and/or aircraft integration problems uncovered in previous analyses.

3. ANALYSIS OF PREVIOUS DESIGNS

Previous feasibility and design study results of various AERCAB configurations were reviewed. Evaluation procedures were employed which involved detailed checking of the available engineering drawings. Particular attention was directed to structural assemblies in terms of weights and drag estimates.

a. Weights. In each configuration analyzed (Parawing, Rotor, and Sailwing), larger gross weights were calculated than quoted in previous analyses. Much of the discrepancy between the calculated configuration weights of this study and those developed previously was in the weights of crewman, seat assembly, and survival kit. Component weight estimates are shown in Tables II, III, and IV. These estimates are compared with those previously quoted in Reference 5.

Escalating component weights requires that propulsion, lifting, stabilization, and control subsystems be scaled upward. Resultant vehicle designs will be heavier and larger, and thus add additional complexity to the already difficult task of retrofitting the AERCAB system into existing aircraft without major structural modification. The integration of AERCAB configurations into new aircraft where cockpit volume is not already constrained is considered very practicable.

b. Aerodynamics Evaluation. Drag and lift analyses were accomplished for the Parawing and Sailwing using the aerodynamic prediction methods documented in Reference 5. Aerodynamic characteristics appear in Figures 14 and 15. Maximum system lift and drag ratios (L/D) are approximately 3.7 and 2.7 for the Sailwing and Parawing AERCABs, respectively. These L/D values are lower than earlier analytical studies predicted, although improvements may be possible if packageability constraints are removed (i.e., not designing to retrofit). The largest contributor to the L/D differences were found in the estimates of nonlifting system drags.

c. Performance Evaluation. A performance analysis of the Parawing and Sailwing configurations was accomplished. The Sailwing weight and aerodynamic revisions were considered, and a range performance of 30 nautical miles was calculated for flight at a 500 foot altitude and 100 knots. Flying gross weight for this revised design is 685 lbs with the original 45 lbs of fuel. To achieve the design condition of 50 nautical miles, a flying gross weight of 715 lbs was found to be necessary. This vehicle would require an engine of 318 lbs SLS thrust and 75 lbs of fuel.

TABLE II

PARAWING AERCAB WEIGHTS (LBS.)

PARAWING	33.9
PROPULSION	87.0
CONTROLS	15.6
FURNISHINGS	138.3
INSTRUMENTS	21.6
FUEL	83.0
PILOT	225.0
FLYING GROSS WT.	604.4

TABLE III

ROTOR AERCAB WEIGHTS (LBS.)

ROTOR GROUP	82.7
TAIL GROUP	19.9
PROPULSION	93.5
CONTROLS	31.9
FURNISHINGS	180.6
INSTRUMENTS	13.4
MISC. HARDWARE	1.5
FUEL	100.0
PILOT	225.0
FLYING GROSS WT.	748.5

TABLE IV

SAILWING AERCAB WEIGHTS (LBS.)

SAILWING GROUP	62.6
TAIL GROUP, FAIRINGS, MISC.	57.1
PROPULSION	56.8
CONTROLS	21.5
FURNISHINGS	182.8
FUEL	47.0
PILOT	225.0
FLYING GROSS WEIGHT	652.8

Simultaneous application of recalculated weights and aerodynamics estimates to the Parawing AERCAB also resulted in lower performance. For the flying gross weight of 623 lbs, the cruise range is estimated at 40 nautical miles. To cruise the design goal of 50 nautical miles, the flying gross weight would have to be increased to approximately 675 lbs.

These existing designs are judged to be marginal with respect to performance achievable versus performance desired. Greater engine size, fuel volume, and wing area appear necessary to achieve established performance goals; however, the effectiveness analysis, as discussed in Section III, demonstrates that any range capability is always better than a no-range capability.

To upgrade the existing designs to meet the established performance goals implies an increase in stowed volume which is already critical for F-4 and A-7 installations. For AERCAB flight range exceeding 50 nautical miles, major cockpit modifications would have to be made to the F-4 and A-7 aircraft.

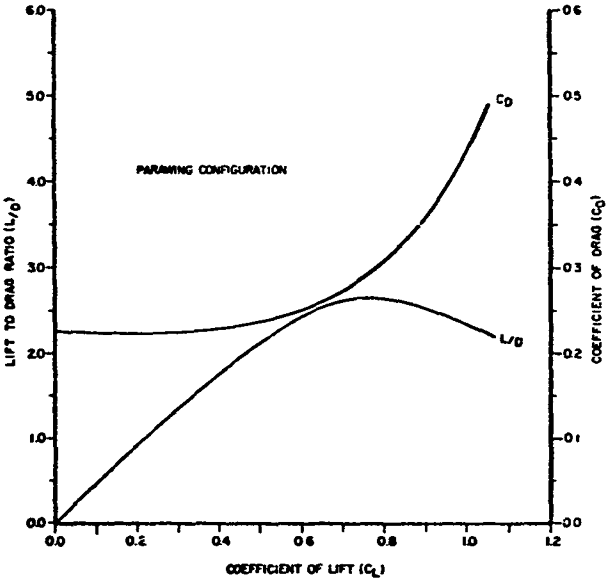


Figure 14. Parawing Aerodynamics

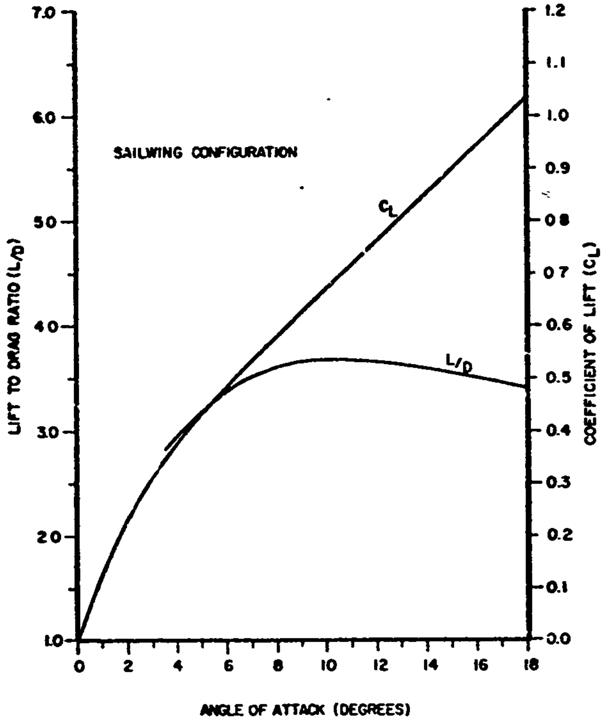


Figure 15. Sailwing Aerodynamics

4. PARAMETRIC SYNTHESIS

Synthesis of Parawing and Sailwing configurations were completed and included in the effectiveness evaluation of the AERCAB as described in Section III of this report. Aerodynamic analysis techniques, weights scaling equations, and engine size/performance data described in Reference 5 were used in the parametric synthesis of these designs. Some of the results are presented in Figures 16 through 22.

5. POINT-DESIGN SOLUTION

The prevailing general design philosophy employed for AERCAB has been a sizeable wing area collapsed into a greatly reduced volume for stowage. This approach was found to have several major shortcomings: (1) the types of lifting systems that are superior from a stowage point of view, are inferior from an aerodynamic efficiency standpoint; (2) the resulting low wing loading is unnecessary inasmuch as drag due to lift is a small fraction of total system drag and low speed flight can be obtained with development of high lift coefficient, C_L; and (3) the aerodynamic inefficiencies accrue to produce higher thrust and fuel flows that induce still larger stowed volumes.

An alternate design philosophy emerged from the study in which smaller amounts of more efficient wing area can be used. Wing design objectives would be to attain high L/D at high C_L. We determined that these objectives can be met with efficient airfoil sections as applied to a "rigid" wing.* A wing weight penalty results, but weights comparable to those for the Parawing and Sailwing designs are achievable. The best technological approach to rigid wings has not been determined, but several candidate systems are available which offer considerable freedom in airfoil shaping.

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*A "Rigid" AERCAB wing is one that retains a constant aerodynamic shape regardless of flight attitude and dynamic pressure. A "Rigid" wing may be in a collapsed condition when stowed but attains and retains its aerodynamic shape and efficiency after deployment into its flight configuration.

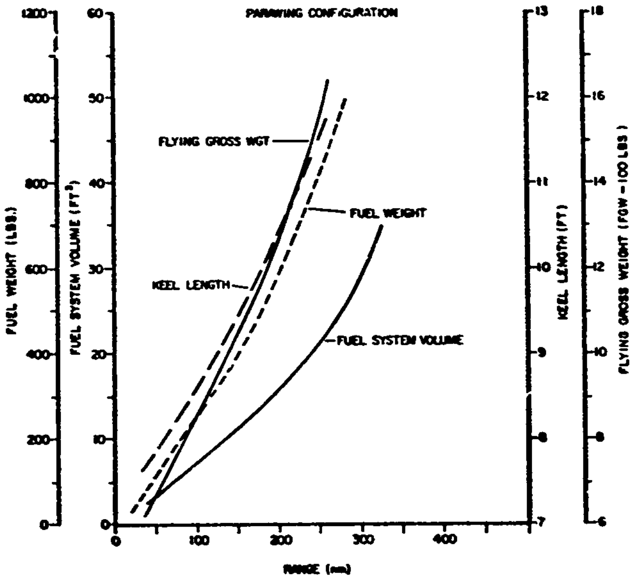

Figure 16. Parawing Parametrics

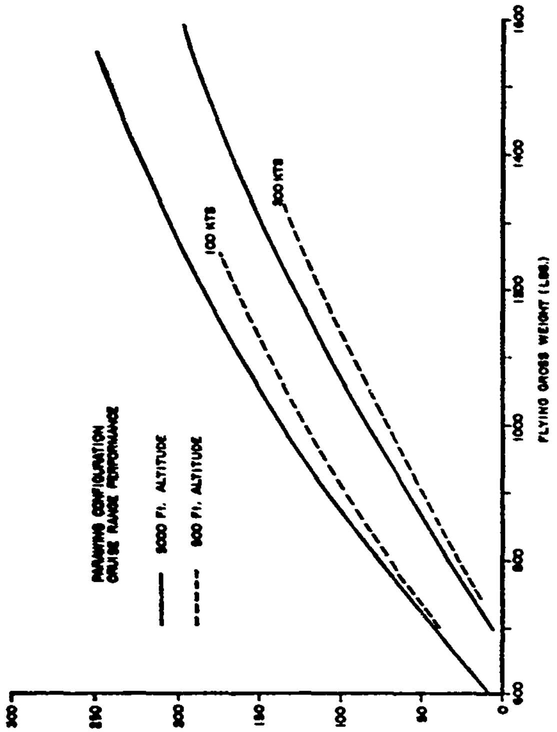

Figure 17. Effect of Altitude on Parawing Cruise Range

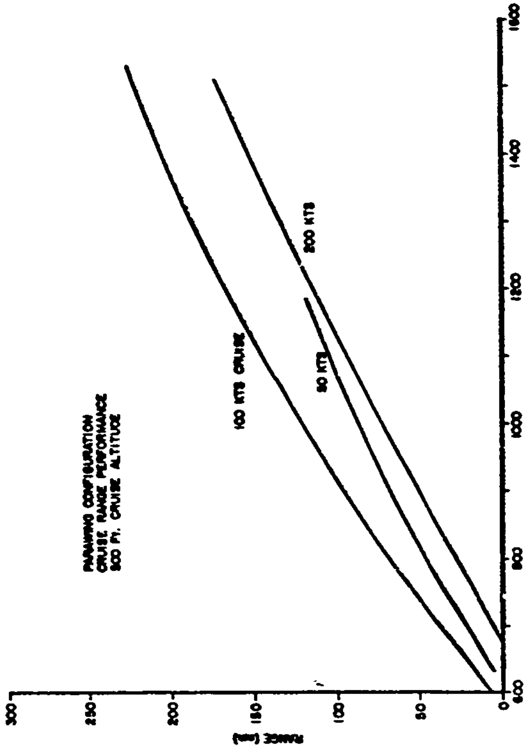

Figure 18. Effect of Velocity on Parawing Cruise Range

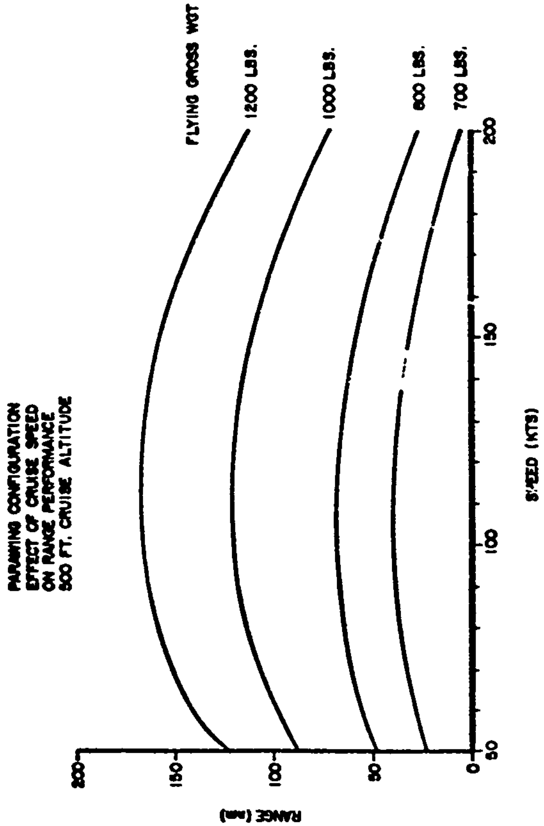

Figure 19. Effect of Cruise Speed on Parawing Cruise Range

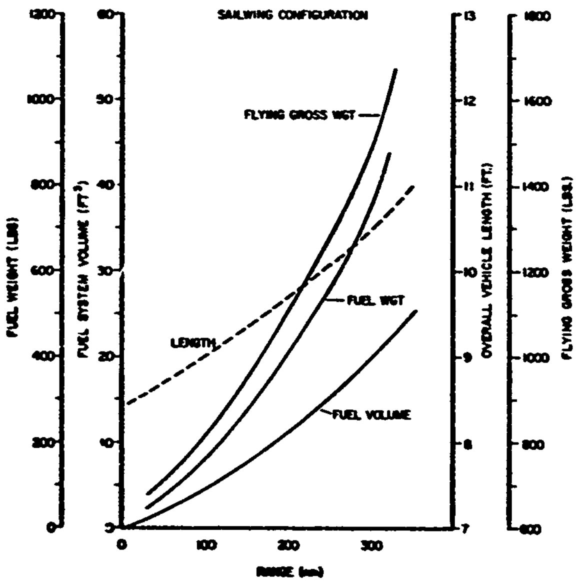

Figure 20. Sailwing Parametrics

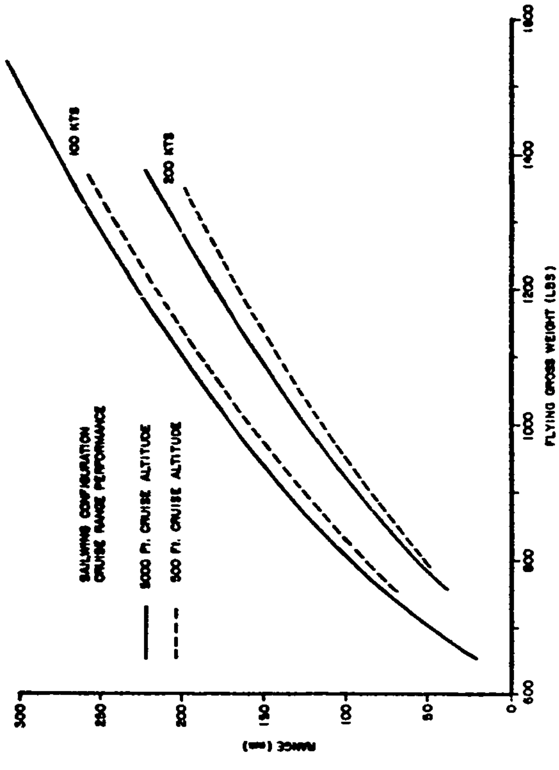

Figure 21. Effect of Altitude on Sailwing Cruise Range

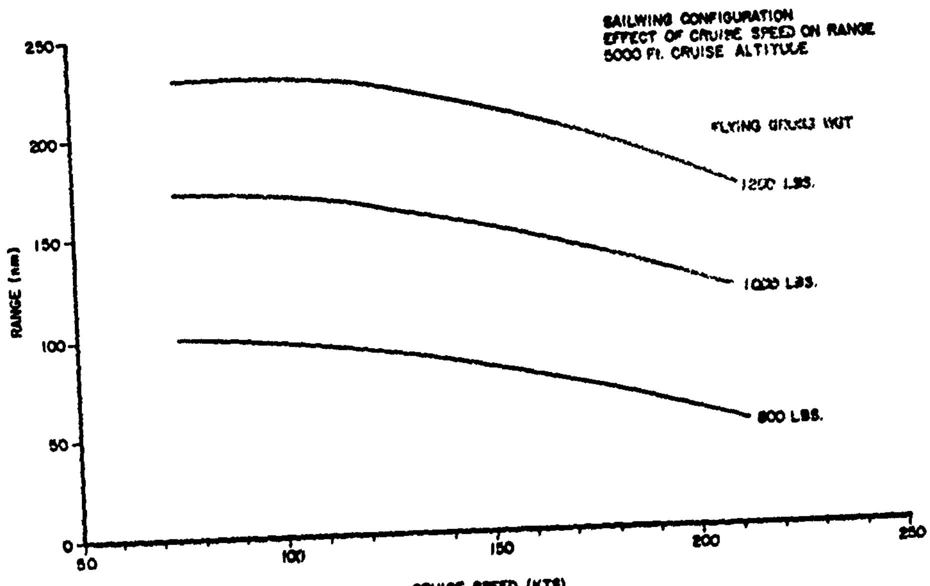

Figure 22. Effect of Cruise Speed on Sailwing Cruise Range

By changing console configurations in the F-4 and A-7 cockpits, they can accommodate an AERCAB stowed width of up to 26 inches. The changes will affect only such components as nonload-bearing structure, plumbing, electrical wiring, and controls placement. There is a possibility of attaching the AERCAB wings to the sides of the seat; by allowing 18 inches for the pilot's seat pan, we could use approximately 4 inches of width per side for the stowed wings. In addition, up to 10 inches of wing chord can be used without interfering with the rear bulkheads in the cockpits.

Four feet of stowed wing span (per side) can be obtained if the upper regions of the seat structure are utilized. In this design, space has been used to the best advantage by employing an "Alverez-Caledron" wing concept in which outer wing panels are hinged and tucked under bigger, inner wing panels. The inner panels are, in turn, hinged to an 18-inch span section fixed to the top of the seat. With this arrangement, a deployed wing span of 17.1 feet can be realized.

For a design flying gross weight of 700 lbs, a stall speed of 67 kts at sea level (equivalent to the Stratos-Western basic sailwing design) requires

$$C_L S = \frac{W_{FG}}{q} = \frac{700}{15.4} = 45.5 \text{ sq. ft.}$$

where

W_{FG} = flying gross wt. (lbs)

q = dynamic pressure (psf)

By designing the basic wing with a Fowler type wing chord extension (which may also be used an an aileron and flap by providing a double hinge action) a ratio of flap area to wing area of 0.35 can be achieved; this, in turn, is worth an incremental maximum lift coefficient increase ($C_{L_{max}}$) of approximately 1.8. Starting with a flat-bottomed airfoil (to facilitate the Alverez approach) with a $C_{L_{max}}$ of 1.25, at the low Reynolds Numbers involved here, a total $C_{L_{max}}$ of over 3.0 is possible. This is the $C_{L_{max}}$ required to achieve a stall speed of 70 knots at sea level. The flap extended for cruise flight merely acts as additional wing area and brings the total platform area to 22 sq. ft.

Using an airfoil thickness ratio of 19% results in a maximum wing thickness of 1.9 inches. If the wing deployment mechanism serves as a wing strut brace when the wing is unfolded and locked in place, then a large wing span to thickness ratio (b/t) can be tolerated; in this case, b/t = 108. Such a large b/t value will necessitate a certain level of stiffness, which might be achieved with composites or thick aluminum skins.

Of the 48.5 lbs of total fuel, 40 lbs is available for cruise. Cruise lift coefficients between 1.02 and 1.06 are required at 100 knots and 5000 ft altitude, which lead to lift-to-drag ratios of 9.5 to 9.9. Very small powerplants can be used with resultant low fuel flows. A cruise range of 78 nautical miles is estimated.

6. REMARKS ON TECHNICAL PRACTICABILITY

Although the current AERCAB configuration designs, based on analysis only, are marginal with respect to performance achievable versus performance desired, performance can be improved if higher L/D ratios can be achieved. This may be impractical with some or all of the existing designs, particularly when retrofitting into existing aircraft. More efficient airfoils could be selected as the lifting surface, and fairings could be used more effectively to reduce the high system drags.

The most critical dimensional constraints imposed by the F-4 and A-7 aircraft are those between the rear extremities of the AERCAB and the aircraft cockpit aft bulkhead. A forward displacement of only 3 inches of the design eye position will enable a 50-nautical-mile AERCAB to be installed. Any fore or aft displacement of the seat, however, would affect the pilot's relationship to control stick, throttle, instrument panel, rudder pedals, etc.

Feasibility and operational analyses and exploratory hardware programs have progressed to the point where the military potential and functional characteristics of the AERCAB concept as an integrated system must be demonstrated to further assess its technical practicability. An advanced development program to demonstrate engineering practicability through flight evaluation of an AERCAB prototype is considered the next logical step. Details of the AFFDL in-house vehicle design analysis are presented in Reference 5.

SECTION VII

COST EFFECTIVENESS

1. GENERAL

Is the AERCAB a cost-effective system? This is a most difficult question to answer because many aspects involved (morale, humanitarian, etc.) cannot be quantified, and were not included in the analysis; thus, these results reflect only partially the true value of an escape/rescue concept. Nevertheless, there is a dollar value which is measurable -- the costs involved in training replacement personnel. If the training replacement costs are known, or can be reasonably estimated, then it is possible to determine a dollar value for achieving a specified recovery rate. Savings of these costs can then be compared with cost estimates for developing, acquiring, operating, and maintaining the AERCAB system. In this section we will not attempt to make an absolute judgement about AERCAB cost effectiveness, but rather to provide cost analysis information (preliminary at best) which may be used to formulate subjective judgements about the relative merits of the AERCAB system.

2. CREW REPLACEMENT TRAINING COSTS

The following information was used in arriving at a representative value for replacement training costs for Air Force crew members (Source - AFM 172-3, Chapter 22, 27 Oct 1970):

<u>BASIC</u>

Undergraduate Pilot Training - $85,970
Undergraduate Nav-training - $38,750

<u>SPECIALIZED</u> (additive to basic costs)

	Aircraft Commander	Weapon Systems Officer
RF-101	$213,140	-
F-105	$440,780-468,190	-
F-100	$241,480-244,280	-
F-4	$102,460-147,060	$82,470-139,500

Naval Air Development Center information concerning Naval crew replacement costs was provided in a classified memorandum identifying specific Navy costs. Desired information is presented in Appendix II. Only the Air Force training costs were used in this analysis. Total cost to the government when a highly trained crewmember is lost, however, would include cost considerations in addition to crew training replacement.

The actual computer model inputs used per F-4 crew were $411,300 for the Navy and $439,150 for the Air Force. These values are based on Air Force training cost information and on the assumption that all Navy F-4 crews consist of a pilot and a navigator, and that half of the Air Force crews consist of two pilots and half of one pilot and one navigator.

3. ESCAPEE COST MODEL

The cost parameters and related estimates for the AERCAB system were developed by AFFDL personnel. The cost parameters were used as a basis for development of the ESCAPEE cost model.

RDTE cost estimates were assumed to be the same for both weight classes of AERCAB configuration. Analysis indicated the difference in total RDTE cost was less than 2%; thus, the model was written to assume that RDTE cost was constant with respect to the weight of the AERCAB.

Acquisition cost estimates were generated for four procurement quantities. The actual production costs of the AERCAB were such that they could be closely approximated by a curve of the form aN^b, where N is the procurement quantity, and a and b are constants. Figure 23 demonstrates how a graph of the production cost estimates was used to develop the constants a and b. The fit shown resulted from values of 88.4 and 0.9 for a and b, respectively. Other components of the acquisition cost (production support, AGE, spares) also varied with the number of AERCABs procured. Values for these inputs were determined by linear interpolation from the available data, including the cost of initial AERCAB training in the acquisition cost, in terms of the training cost per aircrew member.

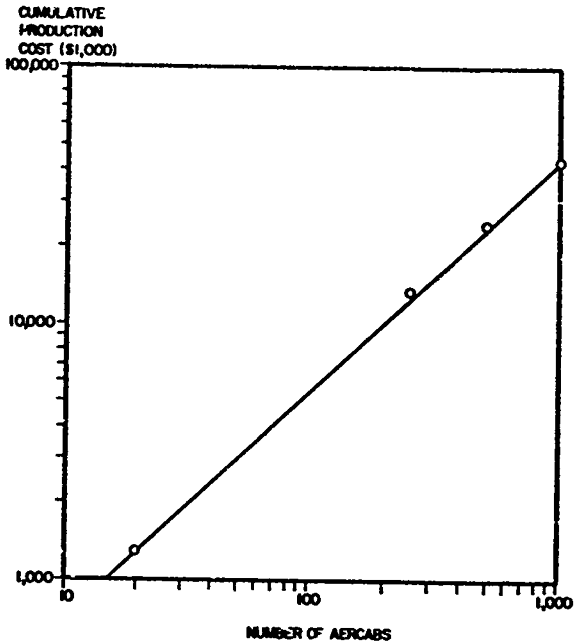

Figure 23. Cumulative Production Cost

The cost estimates for aircraft modification were generated in the form of kit costs, required manhours, and cost per manhour. From these estimates, the total modifications cost can be computed on the basis of the number of AERCABs to be procured.

The annual peacetime operating and maintenance costs were estimated on the basis of hours of maintenance required per year and cost per manhour. No attempt was made to estimate wartime costs.

The estimates of AERCAB replacement and crew replacement costs were made on the basis of one thousand sorties flown. The number of AERCABs to be replaced is then readily calculated given the aircraft attrition rate. The cost of replacing this number of AERCABs is considered to be the production cost taken between appropriate points on the cumulative production cost curve. The crew replacement cost is calculated as a negative number which represents the savings from the return of crews who would have been lost without the AERCAB. The number of crews saved is generated by the effectiveness model for a particular scenario. The amount saved per crew is considered to be the cost of training a new crew. This is an input and may represent the cost of training two pilots or one pilot and one navigator.

4. COST ANALYSIS

A listing of actual input data and output results for one run of the cost model appears in Reference 1. By combining the results of cost model runs for various procurement sizes, it was possible to produce graphs such as Figures 24 and 25 which show, respectively, the cumulative cost and average cost per AERCAB plotted against the buy size.

In particular, the upper curve of Figure 25 is obtained by plotting the total of RDT&E, acquisition, operating and maintenance, and aircraft modification costs. Thus, for 1000 AERCABs the average cost is $182,000.00 over a ten-year period (see Figure 25). The lower curve is obtained by subtracting the aircraft structural modification cost from the upper curve. Thus, for 1000 AERCABs the average cost is $91,000 00

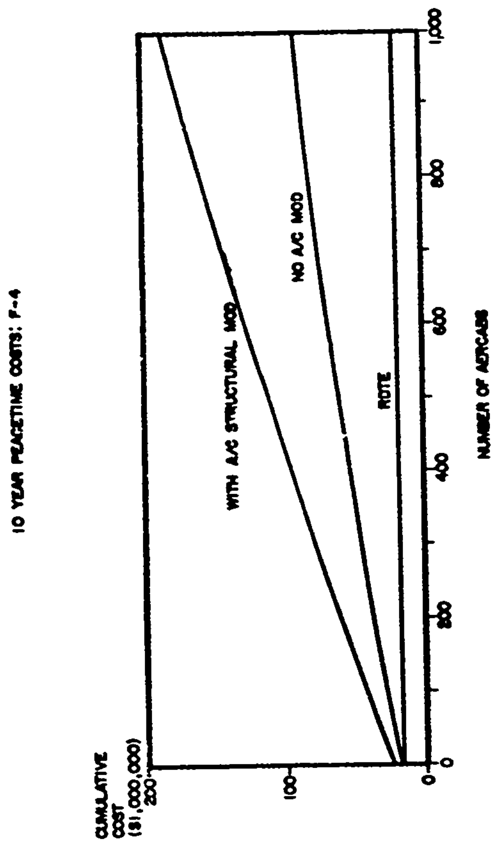

Figure 24. Cumulative 10-Year AERCAB Costs

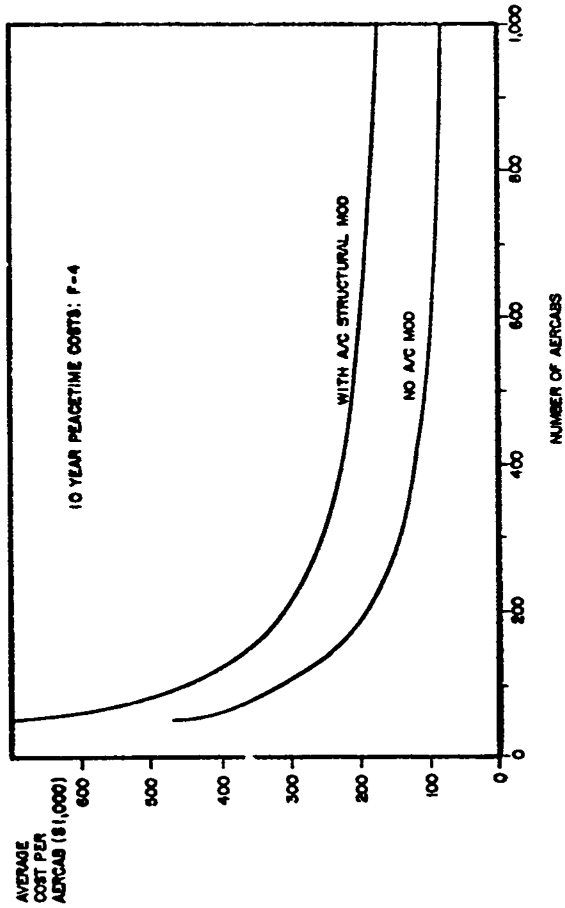

Figure 25. Average Cost per AERCAB

over a 10-year period. It should be noted that the curves of Figure 25 are not straight lines; the second derivatives of these curves are negative due to learning curve effects on several components of the cost.

5. REMARKS ON COST EFFECTIVENESS

The cost analysis conducted under this study does not provide a true and absolute answer to the question; Is AERCAB a cost-effective system? This study was limited to the development and analysis of AERCAB system costs traded-off against crew replacement training costs. Some indication for the relative merits of the system may be gained through this approach; however, a more conclusive judgement could best be formulated by conducting an economic analysis which would identify the most efficient means of securing a particular objective from among several alternate uses of resources.

This analysis does show that for new aircraft the AERCAB may be considered cost-effective in a narrow sense, the 10-year-life-cycle cost (including prorated RDT&E, production, and 10-year peacetime operation costs) of an AERCAB is $91,000.00. In long-range operations (penetration on the order of 200 nm) AERCABs could save 57% of the crews of aircraft shot down and who would otherwise be lost. Relating this to the cost per man used in this study (approximately $220,000.00) means a $129,000.00 savings per man saved. This more than offsets the total cost of the AERCAB equipment expended, including those units which do not contribute to a successful recovery of a crewmember. A rescue and return of at least 42% in any scenario under these cost conditions will result in a straight dollar for dollar tradeoff (i.e., dollars saved equals dollars spent). Rescue and return of a higher percentage would result in more dollars saved than spent.

For the case where the AERCAB is to be retrofitted into an existing aircraft and the module cannot be installed without a major structural modification, then the dollar tradeoff becomes a different story. Even though the cost of structurally modifying an existing aircraft and installing AERCAB's and operating such for 10 years is less than the cost of replacement crew training ($182,000.00 versus $220,000 per man), the AERCAB must begin to show a return of better than 80% of the crews shot down before the total cost expended equals the dollars saved in crew re, acement training. An 80% rescue rate is not beyond reason if the SAR forces are capable of recovering close to 100% of all crewmembers who reach designated safe areas. In this study the SAR force successful rescue capability was assumed to be 70%.

Possible SAR cost savings were not considered in this study nor was the cost savings which may be realized due to fewer crews missing in action or becoming prisoners of war.

The details of the cost model and sample results of the AERCAB cost analysis are presented in Reference 1. Reference 4 contains AERCAB GN&C cost estimates.

SECTION VIII

OVERVIEW AND CONCLUDING REMARKS

1. OVERVIEW

This study has been conducted to provide additional information which is pertinent to the assessment of the "fly-away" escape/rescue concept as an operationally practical approach. The scope of the study was limited to an analysis of the AERCAB concept and did not include a trade-off with other methods or concepts for providing improved Search and Rescue capabilities. The approach taken was to provide useful information by specifically addressing the five primary questions listed and discussed below:

a. Is the AERCAB Operationally Effective?

The AERCAB is shown to be an effective escape/rescue concept in operational environments. An analysis of SEA statistics indicates that if an AERCAB system had been available for use in conjunction with the SAR forces, an increase of 47% rescued could have been realized. Future combat rescue operations are predicted to be less successful than experienced in SEA if improved capabilities are not available; losses on the order of 90% of ejected crewmembers could be expected in some scenarios with the current escape, search, and rescue capability. The AERCAB in conjunction with SAR forces would save some of these. It would also reduce the SAR force losses by permitting the SAR force to operate in lower threat level areas.

b. Is the AERCAB Operationally Practicable?

An operationally deployed AERCAB system appears to be a practicable system in view of: (a) impact on the mission aircraft, (b) personnel training and proficiency required, and (c) projected maintenance requirements. The impact of the AERCAB on the mission aircraft is primarily to increase the weight of the ejection seat subsystem. Several alternatives for absorbing this additional weight are available (the weight increment will vary with the desired AERCAB range), but each will result in some compromise in aircraft capability. The lesser penalty, depending on the mission, appears to be in off-loading fuel; this will reduce the aircraft's combat radius somewhat, but most missions either do not require maximum design range or do provide for midair refueling.

Having fuel in the cockpit for the AERCAB system does not significantly change the vulnerable area of the F-4 aircraft. It does require that special attention be given to minimizing the potential of fires and explosions in the cockpit. Self-sealing foam-filled tanks, fuel scrubbing, and a cockpit fire suppression system are potential solutions.

Other important items to the using command, such as maintenance and pilot training requirements, are not considered prohibitive. More maintenance will be required due to the propulsion and avionics subsystems and associated components and equipment. The increased maintenance requirements would be primarily in the categories of specialized training and more time. The pilots and non-pilot rated backseat crewmembers may need some additional training over and above that now received. Undergraduate pilot training together with simulator or ground trainer time and an understanding of the purpose, capabilities, and limitations of an AERCAB is expected to be sufficient.

c. Is the AERCAB Technically Feasible?

The AERCAB concept has been shown to be technically feasible through successful exploratory programs. Individual AERCAB configurations have achieved various levels of demonstrated capability; the extent of development has been determined more by the amount of funding alloted rather than to any great differences in technical complexity or configuration limitations. A void exists in the technical data base in that all preestablished milestones have not been accomplished for each AERCAB configuration, but the experimental results of the exploratory programs indicate the "fly-away" concept is technically feasible.

An automatic guidance, navigation, and control approach for AERCAB was analyzed and determined to be within the current state-of-technology and producible at a reasonable cost. We expect that including an automatic GN&C system in AERCAB will improve the probability of successful crew retrieval by easing the workload of injured pilots, optimizing flight performance, and providing navigation to a safe area.

d. Is the AERCAB Technically Practicable?

The technical practicability of the AERCAB has not been completely determined. Feasibility and operational analyses and exploratory hardware programs have progressed to the point where the military potential and functional characteristics of the AERCAB concept as an integrated system must be demonstrated to further assess its technical practicability. An Advanced Development Program to demonstrate engineering practicability through flight evaluation of an integrated AERCAB vehicle is considered the logical way to fully address this question.

Although assessing technical practicability would normally be concluded by hardware evaluation, some indication can be gained through analysis. Crew station compatibility and AERCAB system performance were re-analyzed during this study. The shortcomings of the current AERCAB designs are mainly in the area of poor lift-to-drag (L/D) ratios, which lead to higher fuel consumption. Higher L/D is desirable and is determined to be achievable with more efficient "hardwing" designs.

Critical dimensional constraints imposed on the AERCAB by the F-4 and A-7 aircraft suggest that if AERCAB flight ranges are to exceed 50 nautical miles, costly major cockpit modifications to these aircraft must be accomplished. Accomodation of AERCAB's with flight range in excess of 50 nautical miles can be accomplished if AERCAB system L/D ratios of 10:1 are achieved.

e. Is the AERCAB Cost Effective?

The cost analysis conducted under this study does not permit a complete and unquestionable determination of the cost effectiveness of the AERCAB concept. It does, however, provide a limited tradeoff analysis of the AERCAB system costs against crew replacement training costs.

The cost analysis shows that the AERCAB may be cost effective for a new aircraft. The 10-year life cycle cost (including prorated RDT&E, production, and 10-year peacetime operation costs) of an AERCAB is $91,000.00. In the scenarios described in the effectiveness analysis of this study, the AERCAB increased the percentages of crews saved by approximately 25% to 60%, depending on the conditions of the scenario. Relating the cost of the AERCAB to the cost per man, $220,000, means a $129,000 saving per man saved. Using these costs, for any combat condition from which the AERCAB increases the rescue and return percentage by at least 42% would provide a straight dollar saved for dollar spent tradeoff.

The case where an AERCAB retrofit program would require major structural modification of existing aircraft, the breakeven point would be increased to better than 80% because the cost has doubled due to aircraft modification. This success rate was not achieved by AERCAB in the scenarios evaluated in this study. One factor is that the SAR force extraction capability was assumed to be less than perfect (only 70% of those crews getting to a safe area were assumed to be picked up by the SAR force).

Possible cost savings for the SAR operations when interfaced with the AERCAB were not evaluated in this study. A more conclusive judgement as to the cost effectiveness of the AERCAB concept could be reached through conducting an economic analysis, which would identify the most efficient means of securing a particular objective from among several alternatives.

2. CONCLUDING REMARKS

The AERCAB concept represents a radical departure from conventional ejection, escape, and rescue tactics. It is unique in that it provides a means for both escaping from a lethally damaged aircraft and escaping (flying) from the particular locale where the ejection took place. This capability by itself is desirable; however, the vehicle to accomplish it involves complex engineering and the implementation of the concept into the inventory requires significant changes to the established methods of performing rescue. Operational tradeoffs should be conducted to provide a better evaluation of the advantages and disadvantages of the AERCAB as compared to other approaches for achieving the same or similar capability.

APPENDIX I

AERCAB CONFIGURATIONS

Feasibility studies have been conducted on proposed AERCAB configurations incorporating the Parawing, Rotor, Sailwing, and Rigid Wing lifting surfaces. AERCAB/aircraft integration studies were accomplished which indicated that installation from a volume and weight standpoint was potentially feasible for an AERCAB with performance capabilities of 50 nautical-mile range and 100-knot airspeed. In addition, any proposed AERCAB configuration must be capable of automatically controlled flight to rescue incapacitated pilots.

Following the feasibility studies, models were fabricated and experimental tests of the four configurations were conducted.

1. PARAWING CONFIGURATION

Based on an extensive parametric design/performance analysis, we decided a conical parawing AERCAB configuration as shown in Figure 26, a feasible approach. The wing is formed by a telescoping center keel and two telescoping leading edge booms covered with a nylon fabric lifting surface. The parawing is rigidly coupled to the ejection seat, with an articulated linkage for stowage and deployment. A face-down flight attitude was selected for the pilot because it offered the advantages of reduced system drag and minimum engine thrust, simplified parawing deployment, and safe separation of the crewman from the seat at anytime during the flight. Due to the flight attitude, the engine can be rigidly attached to the seat back in its flight position, thus eliminating the need for engine deployment. The fuel cells are mounted on the outboard sides of the seat structure. The retracted and folded parawing structure is stowed behind the seat. Figure 27 is a cross section of the stowed parawing system. When the parawing AERCAB is ejected from the aircraft, a drogue parachute deploys to provide stabilization and deceleration. A drogue bridle is then released and the drogue force rotates the seat into its face-down flight attitude.

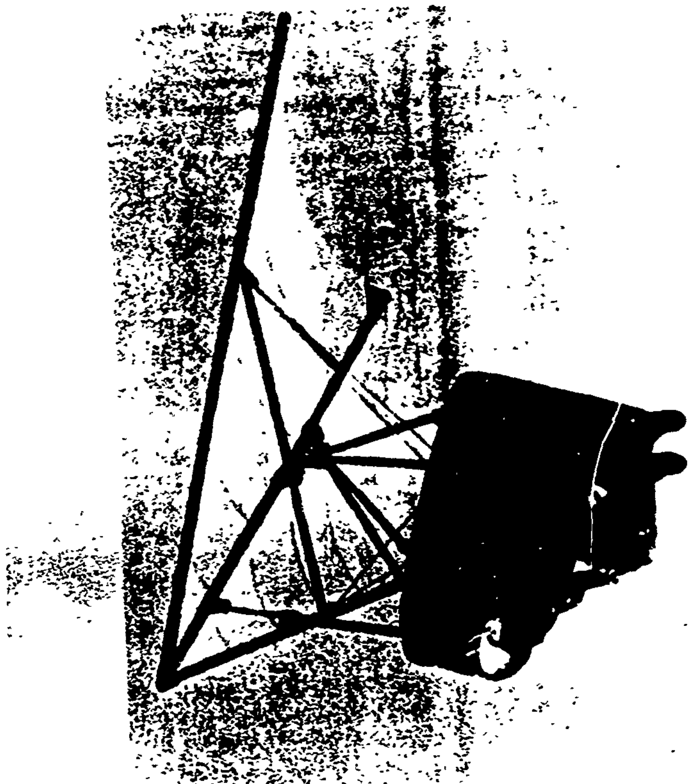

Figure 26. Parawing Deployed

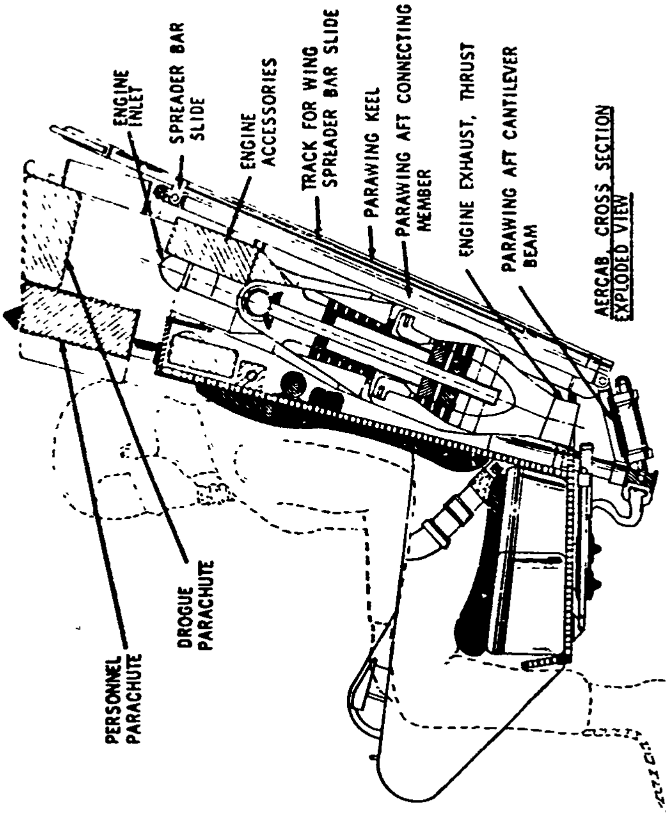

Figure 27. Parawing Stowed

After a preset time, the parawing is ejected above the back of the seat and the telescoping keel and leading edge booms are extended via compressed air and pneumatic actuators. Flight control is achieved by regulating the wing angle in pitch and roll to control altitude and direction. Speed can be controlled by throttling of the engine.

The experimental tests conducted on the Parawing configuration have included one-half-scale wind-tunnel aerodynamics, full-scale powered flights, Jet-car deployments, full-scale wind-tunnel deployments, and air drop deployments. The combined results of these test programs have proven the technical feasibility of the parawing AERCAB configuration. The complete sequence of events for an operational parawing AERCAB has been demonstrated with the exception of the aircraft ejection phase. This was not attempted due to lack of a sufficiently sized, readily available rocket-catapult system. This phase of the AERCAB sequence is not considered critical to the feasibility evaluation of a particular configuration.

2. ROTARY WING CONFIGURATION

The rotary wing approach to the AERCAB concept is a compact, deployable autogyro (see Figure 28). The rotor is a two-bladed, two-section telescoping system which stows behind the seat. The propulsion system (turbo fan) stows behind the seat headrest, between the rotor blades and the seat. A self-sealing fuel tank is under the seat pan. A catapult thruster and a sustainer rocket are installed in a continuous tube which is mounted to the seat back and serves as the primary structure. The two vertical tail surfaces stow at the sides of the seat bucket. The stowed rotary wing configuration is shown in Figure 29.

After the AERCAB is ejected and rocket-boosted to clear the aircraft, a drogue parachute deploys and pulls the rotor blades and rotor support arm aft and upward to a trail position, while the seat is rotated aft to a horizontal attitude. After the deployment latch bolt explodes, the drogue parachute activates a linkage which cones the teetering/flapping hinges outward and gives the trailing blades sweep and pitch.

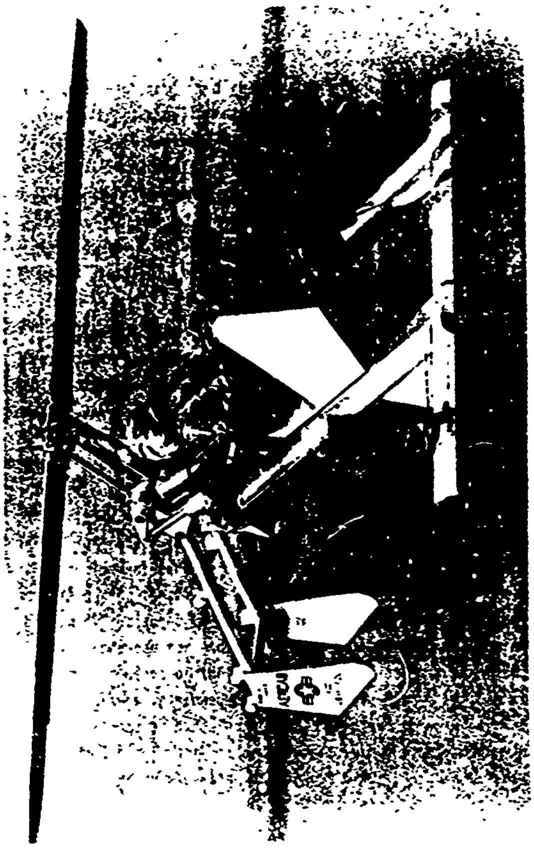

Figure 28. Autogyro Deployed

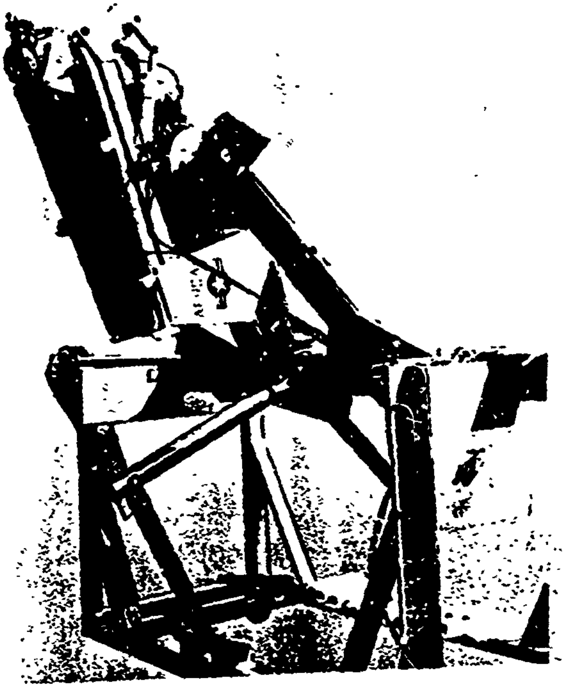

Figure 29. Autogyro Stowed

As aerodynamic force spins up the rotor, centrifugal action extends the two-section blades to their full length. The system decelerates to a lower velocity, the coning restraint is released, and the rotor is allowed to cone at a lower equilibrium angle. Further deceleration occurs and the vehicle pitches into vertical descent. The stowed engine, the tail surfaces, and the rotor support arm are then deployed to their flight positions with a pyrotechnic device, completing the transition to an autogyro flight vehicle. Figure 30 illustrates the deployment sequence, which is similar for all configurations.

The rotor is a direct tilt, two-bladed rotor with coinciding teetering/flapping hinges and secondary delta-3 flapping hinges which are used for deployment and for initial governing in the coned configuration. The two-section telescoping blades are aluminum alloy bonded with epoxy resin. The rotor diameter is determined by the space available behind the ejection seat for stowage. A tradeoff exists between the advantages of a larger diameter and the complexity of telescoping the blades. For nontelescoping blades, the largest diameter possible is 8 feet, which results in a disc loading even higher than that normally used for helicopters. High descent rate and critical handling make this diameter unacceptable for AERCAB. The 14-foot-diameter rotor selected for AERCAB is the largest that could be stowed within the cockpit when using two-section blades. The maximum chord size is 8 inches, which is used for the inboard blade. The outboard blade is 7 inches. The rotor is designed for a normal operating speed of 920 RPM, which gives a tip speed of 675 feet per second. Basic control is provided through pitch and lateral direct tilt of the rotor and weathercocking of the vertical tail surfaces.

The experimental tests conducted on the rotor AERCAB include full-scale wind tunnel, and jet-powered manned free flight. The experimental tests have demonstrated:

(a) Decelerator mode rotor operation at speeds up to 180 knots.

(b) Rotor deployment and operation on the seat at 160 knots.

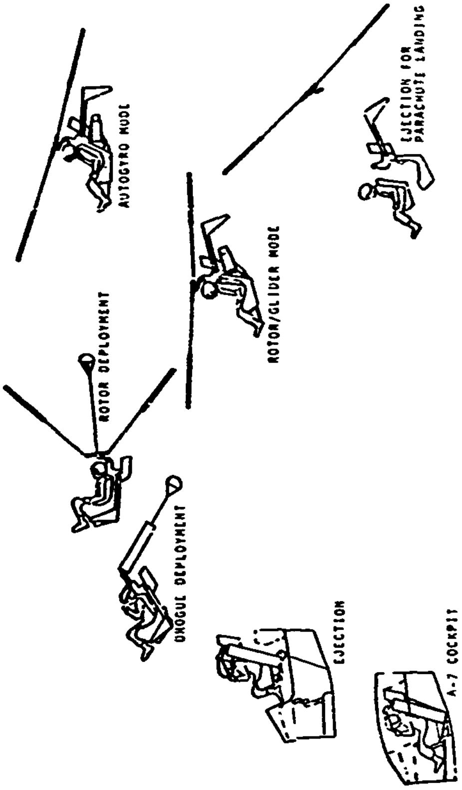

Figure 30. Deployment Sequence

(c) Conversion from decelerator to flight vehicle configurations.

(d) Autogyro mode rotor operation at speeds up to 110 knots.

(e) Predicted preliminary design performance.

(f) Manned flight of the rotor lift system.

(g) Stable controllable rotor and vehicle behavior.

(h) Rotor lift capability of 700 pounds - 14% over design need

(i) Flight at above normal autogyro disc loading - 4.6 vs. 2.0

(j) Flight of trainer prototype

With these flights, this AERCAB vehicle became the world's first manned turbine-powered autogyro and the first autogyro to fly with telescoping rotor blades.

Demonstration of full-flight deployment and transition is being prepared, which is the final experimental feasibility demonstration phase.

3. SAILWING CONFIGURATION

The Sailwing configuration consists basically of a seat, tail booms, wing, jet engine, and an inflatable nose fairing. The seat forms the basic structure for the entire vehicle. Figure 31 illustrates the deployed Sailwing and Figure 32 shows the same system stowed.

The nose fairing is a double-walled inflatable structure that stows when deflated under the pilot's legs against the front of the seat. The seat is of conventional design, including catapult thrusters and sustainer rockets. A high-bypass fan-jet engine, which stows under the seat, is used for propulsion. The wing folds once at the midpoint of the semispan and then hinges at the wing root to fold against the tail boom assembly. The tail boom assembly consists of three telescopic tubes, of which the inner tube is the empennage assembly. The tail boom is attached by a hinge to the lower rear portion of the seat and is supported by a folding diagonal brace attached to the upper rear portion of the seat. The

Figure 31. Sailwing Deployed

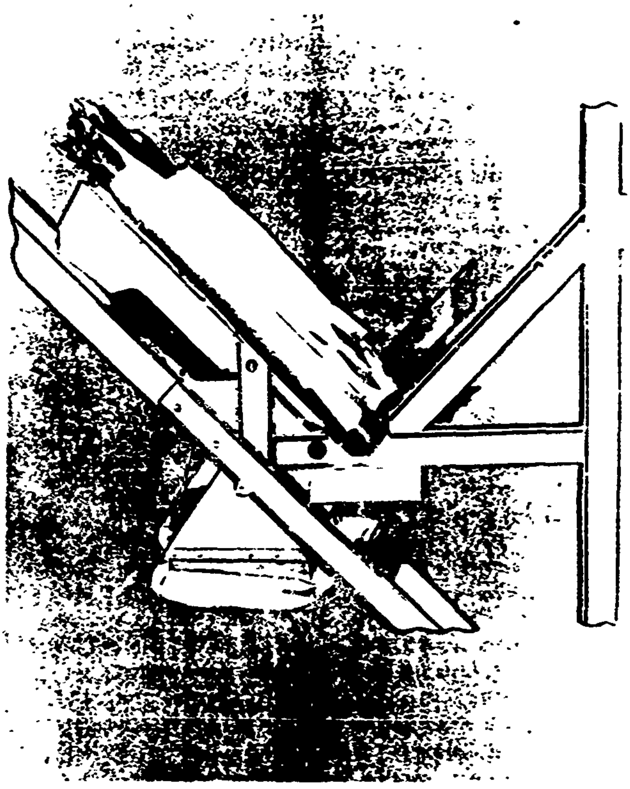

Figure 32. Sailwing Stowed

assembly stows by telescoping to a 4-foot height and folds against the back of the seat.

The nose fairing protects the occupant from the airstream and provides a low drag profile for the vehicle. The fairing forms a closed egg-shaped nose for the fuselage and is supported by a tubular framework that extends forward from the seat. The closed air space in the fabric is inflated with pressurized air from a tank in the seat to provide shape and rigidity.

The seat structure is of conventional ejection seat construction and forms the basic structure for the vehicle. Attachment points are provided for the catapult tubes, the pivot points for the engine frame and torque bar that drives the nose fairing structure and the attachment points for the tail boom assembly. The space between the side members is open on the front side and will be filled by the pilot's parachute. The space above the upper cross member forms the headrest into which the drogue chute is stowed.

The tail boom consists of three tubular telescoping sections that allow the boom to fit within the confines of the aircraft cockpit when retracted and position the tail surfaces far enough aft for aerodynamic stability when extended. The tail structure is of conventional configuration, but uses the Princeton sailwing concept.

The wing is designed after the Princeton sailwing principle. The structure is supported on the leading edge and tip by a rigid spar and along the trailing edge by a tensioned wire; it is covered over on the top and bottom with a dacron sailcloth fabric. Wing lift is gained from the predictable deformation of the fabric between the leading edge and the tensioned trailing edge catenary. The main supporting structure of the wing is the spar which forms the contour of the leading edge. This spar folds in the middle and is hinged at the root, which allows it to fold inward and backward, parallel to the fuselage centerline. The internal volume of the leading edge spar and tip is used for fuel storage.

The experimental tests conducted on the Sailwing configuration have included structural and functional testing in the laboratory, sailwing semispan wind tunnel testing, full-scale vehicle wind tunnel testing (aerodynamic and deployment) and full-scale deployments from a moving truck. Powered manned flight tests and air-drop deployment tests are planned.

4. DEPLOYABLE RIGID WING CONFIGURATION

The deployable Rigid Wing AERCAB configuration (see Figure 33) employs a unique technique for folding and stowing the all-metal lifting surface. The complete vehicle consists of the same basic subsystems as are found on the other configurations; the primary differences appear in the lifting surface and propulsion system. The wing is formed by three sections of approximately equal length, the root, center, and tip. Each section consists of two segments, a leading edge D-spar and a hinged trailing edge. This unique design allows the deployed spanwise dimension of 84 inches to be reduced to 49 inches when stowed, and the deployed chordwise dimension of 30 inches to be reduced to 14 inches when stowed, which are reductions of approximately 42 and 53 percent, respectively. These reductions are accomplished by folding the trailing edge segments outboard to a position adjacent to the rear edge of the D-spar. The tip section and its trailing edge segments then slide into the D-spar of the center section. Both of these sections then slide into the D-spar of the root section.

The wing is deployed by means of pneumatic actuators. Detent lock pins are employed at the two spanwise wing joints in each semispan to lock the wing in full deployment position once that condition is achieved.

Another unique feature of this wing is that an aileron is included as part of the telescoping tip sections. The aileron is mechanically and structurally capable of plus or minus 25-degrees deflection.

Figure 33. Rigid Wing Deployed

The propulsion system is composed of the engine installation, pusher propeller unit, and drive train assembly. A rotating combustion engine is employed in this design. It is a two-bank liquid-cooled, gasoline-fueled engine, and rotates at 10,000 RPM. The pusher propeller is a three-bladed folding unit. A brake is activated to stop the propeller prior to man/seat separation at the completion of the AERCAB flight.

The tail assembly of the Rigid Wing AERCAB is comprised of the tail boom unit, propeller hub and transmission, seat-to-boom fairings, inverted V-tail surfaces, drogue chute, and the tail unit deployment cable assembly. A fabric tail boom fairing is provided to improve propeller efficiency as well as reduce seat drag. The two tail surfaces, which comprise the empennage, employ the same folding trailing edge structure as does the wing. These tail surfaces are movable and capable of differential and/or collective control input for the rudder and elevator functions, respectively. A drogue chute is connected to the deployment cable assembly and is used to deploy the tail unit and actuate wing deployment.

Limited experimental testing of this configuration has been accomplished. A wing semispan was tested in a low speed wind tunnel subsequent to extensive functional and structural testing in the Laboratory. A full-scale Rigid Wing AERCAB was tested in a wind tunnel for acquisition of flight configuration aerodynamics. Successful deployments have been achieved under wind tunnel test conditions up to 150 knots airspeed. Plans are formulated to continue investigation of this configuration through completion of free flight and air drop deployment testing.

APPENDIX II

NAVAL PILOT REPLACEMENT COSTS

This appendix is a shortened version of a memorandum from the Naval Air Development Center, Air Vehicle Technology Department, in response to a request for information concerning pilot replacement costs.

The cost to the government of losing the pilot from an attack or fighter aircraft is the sum of the costs for replacing him with another equally qualified pilot, for attempting to rescue him, and associated with his death or interment. The amounts and description of Naval Pilot and Flight Officer training costs are readily available in "Officer Personnel Costs." Naval Personnel Research and Development Laboratory, WOS 71-4, J. N. Clary and J. T. Creaturo, March 1971. This data represents the total cost through 4-1/2 years after a pilot is designated as Naval Aviator, or 3-1/2 years after Naval Flight Officer. At this point, a pilot will have completed Primary Flight, Basic Jet, Advanced Jet, and Combat Readiness Air Wing (CRAW) training plus training in operational squadrons. The cost given for an A-7 pilot updated to 1973 dollars is $651,870. Table V gives the cost breakdown for an NROTC-R pilot for an A-7 aircraft, and Table VI for pilots of other aircraft.

The annual cost of manning an established operational Navy pilot billet is obtainable from "Navy Military Manpower Billet Cost Data for Life Cycle Planning Purposes." NAVPERS 15163, Personnel Systems Research Branch, Personnel Research Division, April 1972. Manpower costs are computed from initial procurement to the end of retirement and charged to an active duty base of 25 operational billet years. "Down" costs of prisoners, who are in a nonoperational status, are included but are difficult to separate due to the method in which they are charged to the active billet duration. Certainly the salaries for prisoners of war must be included in overall costs, in addition, future costs such as retirement, rehabilitation, and medical treatment should be included. They were not included in this study, so the costs cited

TABLE V

NROTC-R A-7 PILOT REPLACEMENT COSTS

Precommissioning Costs	
Procurement	$ 62
Travel	812
Subs, Training Pay, Clothing, FICA	5135
College	9162
Total Precommissioning Costs	$15,171
Postcommissioning Costs	
Training	
Primary Flight & Flight Sys	$ 4,157
Basic Jet	45,633
Advanced Jet	77,317
CRAW	426,625
Total Training	$553,732
Pay & Allowances	
Pay, BAS, BAQ, FICA, Flight Pay	
Primary Flight & Flight Sys	$ 1,702
Basic Jet	5,451
Advanced Jet	4,091
CRAW	5,641
Other than Training	62,107
Total Pay	78,992
Clothing Allowance	370
Total Pay & Allowances	$ 79,362
Transportation	
Training to 1st Opsqn	$1,277
1st to 2nd Opsqn	1,593
Total Transportation	$2,870

TABLE V (contd)

Medical	$735
Total Postcommissioning Costs	$636,699
Total Cost through 4-1/2 yr period after designation as Naval Aviator	$651,870

TABLE VI

USN PILOT REPLACEMENT COSTS

Total cost through 4-1/2 years after designation as Naval Aviator for NROTC-R pilots.

A/C	TOTAL COST (1973$)
A-3	$421,034
A-4	441,345
RASC	638,762
A6	603,280
E2	355,156
F4	575,310
F8	485,975
P3	235,549
S2	244,197
SH3A	250,094

here will be on the low side. Assuming that the pilot is a Lieutenant (USN) with over four years of service, and that he remains a POW for three years, his salary will total $52,230 (in 1973 dollars).

Costs of search and rescue attempts should also be included. These costs were assessed in "Cost Effectiveness of the Combat SAR System" study conducted by USAF/ARRS. This effort quartitized the average cost per save as $57,140 (1969$) which updates to $70,510 (1973$). Some of the lost pilots will be down in locations from which no rescue is attempted. Many will be down in contested areas, resulting in large numbers of rescue forces being committed to the rescue attempt and costs far in excess of the average. Therefore, the average cost for unsuccessful rescues is assumed to be the same as for successful rescues.

This rationale indicates that the cost of a pilot becoming a prisoner of war is on the order of $775,000. These costs are real, tangible, and can be approximated. In Southeast Asia, however, the intangible, but real, costs of POW pilots dwarfed these, since the prisoners of war became a political issue. If a rescue system had existed which could have prevented our aircrewmen from becoming prisoners, the war might have terminated much earlier. From this point of view, the cost of lost aircrewmen would be staggering.

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