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Underwater Search and Rescue for Non-Military Submersibles

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UNITED STATES NAVAL WAR COLLEGE

COLLEGE OF NAVAL COMMAND AND STAFF

RESEARCH PAPER

UNDERWATER SEARCH AND RESCUE
FOR NON-MILITARY SUBMERSIBLES

BY

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UNDERWATER SEARCH AND RESCUE FOR NON-MILITARY SUBMERSIBLES

by

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Date: 6 April 1982

Abstract of

UNDERWATER SEARCH AND RESCUE FOR NON-MILITARY SUBMERSIBLES

A system of underwater search and rescue for non-military submersibles utilizing a helicopter delivered rescue submersible is proposed. In the last 10 years there has been a substantial increase in manned underwater endeavors. This expansion is expected to continue with increasingly greater emphasis in the recreational field. The necessity to overcome the relatively short life support of the small recreation submersible dictates a rapid response. This system should be capable of providing the lift necessary to rescue the entrapped personnel by bringing the submersible to the surface. At the present time the Coast Guard must rely on other submersible operators to provide search services while relying on a ship to provide the lift necessary to bring the distressed submersible to the surface. The paper finds that the present plan is incapable of carrying out the underwater search and rescue mission. It is concluded that using a helicopter to overcome many of the inherent problems of delivering and launching a rescue submersible while using the heavy lift capability of the most recent helicopters to bring the distressed submersible to the surface, provides a viable solution to the most complex

marine search and rescue problem envisioned today. The paper also concludes that, in order to simplify the search and location problem, safety legislation will be required which will allow the distressed submersible to be detected much more efficiently.

TABLE OF CONTENTS

CHAPTER PAGE

ABSTRACT. ii

LIST OF TABLES. vi

LIST OF ILLUSTRATIONS vii

I INTRODUCTION. 1

II THE PROBLEM EMERGES 3
  The Growth of Non-Military Submersibles . 3
  Existing Situation. 6
  Present Requirements. 9

III SYSTEM COMPONENTS 11
  Discussion. 11
  SARS Design Criterion 13
    Descent 13
    Endurance 13
    Speed 14
    Navigation. 15
    Visibility. 16
    Manipulator Arms. 16
  Helicopter Design Criterion 17
    Speed 18
    Payload vs. Range 18
    Lift. 19
    Scenario. 20
  Helicopter/SARS Location. 23

IV SEARCH AND LOCATION 24
  Discussion. 24
    Cooperative Search. 24
      Transmitter Buoy. 25
      Emergency Pinger. 26
    Non-Cooperative Search. 27
    Elements of Search Planning 28
      Probability of Detection. 28
      Sweep Width 28
      Track Spacing 29
      Coverage Factor 29
    Search Area 31
    Delimiting the Search Area. 31
    Active Search Patterns. 32

CHAPTER PAGE

Expanding Spiral. 33
Expanding Square. 34
Sector Search 35
Contour Search. 36
Search Requirements 37

V RESCUE OF PERSONNEL 39
Discussion. 39
Mating. 39
Universal Escape Hatch. 40
Flat Surface. 40
Thrusters 40
SARS Configuration. 41
Disadvantage of the Escape Hatch. . . . 41
Emergency Ascent. 41
Types of Distress Cases 42
Rescue by Salvage 43
Surface Lift. 44
Buoyancy Lift 45
Helicopter Lift 46
Breakout Force. 47
Time Factor 48

VI SUMMARY AND CONCLUSIONS 50
Summary 50
Conclusions 51

NOTES 53

BIBLIOGRAPHY. 56

APPENDIX I--CH 53E PAYLOAD VS. RADIUS 58

II--LEVEL FLIGHT PERFORMANCE. 59

III--U.S. SUBMERSIBLE SAR CHARACTERISTICS. . . . 60

IV-- 61

LIST OF TABLES

TABLE PAGE

I. SARS Design Criteria Comparison 12

II. Location of Coast Guard Air Stations. 23

III. Search Radius Safety Factor 31

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1.	Mission Analysis	22
2.	Probability of Detection	30
3.	Expanding Spiral Search	34
4.	Expanding Square	35
5.	Sector Search	36
6.	Contour Search	37
7.	Parallel Sweep	37
8.	Lift Vectors	48

UNDERWATER SEARCH AND RESCUE
FOR NON-MILITARY SUBMERSIBLES

CHAPTER I

INTRODUCTION

No environment has proven to be more extreme in its hostility than the deep ocean. Tremendous pressures, intense cold, and the total absence of light combine to make the deep ocean the most difficult and unforgiving region in which man has chosen to work.[1] The rescue of personnel trapped in a distressed submersible will impose a number of very difficult tasks upon the Coast Guard. These tasks will have to be accomplished within the relatively short life support endurance of non-military submersibles. The Coast Guard will have to decrease time in which they have performed many of these same or similar tasks on the surface. The two most critical phases of this operation will be the delivery of the rescue submersible to the distress scene in time, and the location of the DISUB. In addition, the Coast Guard must adopt a completely new concept of rescue by salvage to consummate the rescue of personnel successfully.

Just as no two submersibles are alike today, it is also hard to find two definitions of submersibles that are alike. For the purpose of this paper a submersible is defined as a small manned submarine capable of operating with or without a surface support ship and able to withstand external pressures at various depths while maintaining an internal pressure of one atmosphere. The nature of this definition poses an even greater degree of difficulty on the underwater search and rescue problem because a surface support vessel will not necessarily be present at the scene of the dive. With a surface support vessel in attendance, there is always two-way communications, and the location of the submersible is accurately known. In view of the absence of a surface support vessel in many cases, an accurate search and location system should be developed by the Coast Guard. This paper will develop a system for underwater search and rescue predicated upon the helicopter-SARS team. The study will necessarily address itself to operational procedures, safety legislation, hardware and rescue methods.

To limit the scope of this paper, the writer has selected a 2,000 foot depth for an initial Coast Guard rescue capability. As in many other papers relating to military operations, there are a number of abbreviations used throughout the text which should be defined here for ease in reading.

SARS	Search and Rescue Submersible
DISUB	Distressed Submersible
RCC	Rescue Coordination Center
NSARM	National Search and Rescue Manual
MARSAP	Mutual Assistance Rescue and Salvage Plan

CHAPTER II

THE PROBLEM EMERGES

The Growth of Non-Military Submersibles

The research submersible has enabled man to study the ocean environment from within. The present number of research submersibles is expected to grow from 37 to over 80 by 1975.[1] As the cost of submersibles becomes competitive with other forms of marine recreation, more and more recreation submersibles may traverse our coastal waters. Dr. John Knauss, Dean of the University of Rhode Island's Graduate School of Oceanography, has stated that he believes the United States will see more submarines and underwater habitats widely used for recreation in another 20 years.[2] Dr. John P. Craven, former chief scientist of the Navy's deep submergence project and a prominent authority in the field, suggested in 1967 that the United States will witness a large number of research-exploration submarines in the very near future.

> It has been suggested by some that the problem of deep ocean mining is remote and that exploiters will be relatively few. The presumptions here is the projected high cost of vehicles and equipment designed to operate on the ocean bottom. On the contrary, although they do not exist at present, it is contended that low cost vehicles capable of exploitation are technologically feasible and will be realized in the next two decades. . . . It has come as a surprise to the uninitiated, and

> even to some professional naval architects, that at present the major investment cost of deep submersibles is in the surface ship and surface support systems now required for their operation.
>
> In summary, the projection of deep ocean technology is such that, in the period beyond 1980, we may expect a significant proliferation of non-military submersibles and low cost equipment capable of operating throughout the water column at or on the bottom and capable of exploiting the sea bed or the resources of the sea bed.[3]

Piccard wrote in the Compass magazine:

> Today the future of the submarine belongs as much to industry as it does to science. For both, this working tool soon will be used like the automobile, the railway train, the plane, the motorcycle, the bulldozer, the truck or even the crane--wherever there is a need to travel or move something under water.[4]

In the same article, the renowned Swiss scientist cited tourism as a lucrative civilian submarine use.

> He stated that in 1964 a mesoscaph, a vessel used for medium depth diving, made more than 13,000 dives into Lake Geneva as part of a national exposition at Lausanne, Switzerland.
>
> The vessel carried 33,000 passengers paying $10 for adults and $5 for children. The passengers purchased their tickets, stepped on a scale and went on board. Every 90 minutes the mesoscaph left port, sailed on the surface for a few minutes and then dove to about 300 feet. It remained at the bottom for fifteen minutes, surfaced and returned to port to exchange its cargo of passengers.
>
> At the end of the exhibition, revenues from the craft came to $250,000 which indicated that such an apparatus well promoted in a good tourist region, could be profitable within a short time.[5]

In conclusion he emphasized that the civilian submarine had come into its own, "Whether it be designed for tourism, research, salvage or transportation; wherever it has been tested, it has proved itself."[6]

The recent Report of the Commission on Marine Science, Engineering and Resources predicted that the average American will be spending twice the present amount of money he is now spending on marine recreation by 1980.[7] As mass production lowers the cost of the small acrylic submersible together with more leisure time and money, the increase in the number of recreational submersibles is just a question of time. Designs of self-propelled submersibles for recreational use are beginning to appear, and for shallow water operation the cost may be low enough to create a substantial market.[8] Today a German firm manufactures a fiberglass submersible priced to sell at $2,500, although no depth capability has been reported.[9]

It should be obvious that there will be a significant number of submersibles, with their attendent problems, off the coast of the United States by 1980. Although present activity is inadequate for projecting future growth, if the growth rate of the snowmobile is any indication of what to expect, then the total number of submersibles will be much higher than even the optimists have predicted. Indeed Samuel A. Jordan, General Manager of Westinghouse's

Underseas Division, forecast that by the year 2000 "There might be as many as 100,000 working submersibles in the sea."[10]

Existing Situation

The problem confronting the Coast Guard today is how to rescue personnel from submersibles unable to surface without external help. Recently the laws affecting the mission of the Coast Guard have been amended to include the safety of life beneath the surface of the sea as well as on and above it.[11] Therefore, the Coast Guard is statutorily responsible for underwater safety, and specifically, underwater search and rescue. However, it has to date no viable means to accomplish this mission with any probability of success.

At the present time MARSAP relegates the Coast Guard to a coordinating activity. Under this system a volunteer civilian submersible would undertake the rescue operation, relying on the Coast Guard for reimbursement and immunity from liability. There are three major shortcomings to this plan which make it of little value. First, ~~less~~ than 50% of all submersibles are capable of conducting search and rescue as part of this system because they lack scanning sonar, manipulator arms and depth capability.[12] For example, if the Alvin became entrapped by oozes on the ocean bottom at a depth of 1,500 feet, only 15 of the 37 U.S. submersibles, or 40.5% have the depth capability to effect a rescue which reduces the probability of finding a qualified volunteer. In addition, this percentage would be further reduced because some of the qualified subs would be engaged in work in distant parts of the oceans. Harry Suzuki calculated in a paper prepared for the University of Rhode Island's ocean engineering program that the probability of rescuing any of the 12 research submersibles operating on the East Coast as of 1969, utilizing the present MARSAP, would be 33%. He assumed that no time would be lost in dispatching a volunteer rescue submersible or in locating the distressed submersible.[13] In view of these highly unrealistic assumptions, the actual probability would be much closer to zero.

The Coast Guard would be unable to reimburse the volunteer submersible owner for his cost in the operation under the existing laws. Special legislation would have to be passed before a submersible owner could be reimbursed for his expenses. Historically, Congress has refused to fund civilian participation in marine rescue operations, relying on the Coast Guard to carry out this mission.

Lastly, no immunity from liability could be granted because under existing laws, the Coast Guard cannot hire a civilian craft as a search and rescue vehicle and it can be presumed that the term craft includes submersibles as well. Title 14, United States Codes, paragraph 2, as amended by public law 91-278, is quite specific as to the Coast Guard's responsibilities.

> . . . shall develop, establish, maintain and operate, with due regard to the requirements of national defense, aids to maritime navigation, icebreaking facilities and rescue facilities for the promotion of safety on, under and over the high seas and water subject to the jurisdiction of the United States; . . .
>
> . . . and perform any and all acts necessary to rescue any persons and protect and save property; . . .[14]

In recent rulings applicable to this same subject, and in light of the above, it was held that the Coast Guard does not have the authority to contract for search and rescue services.

> . . . If Congress intended the Coast Guard to hire vessels as in a bare boat charter, it would have so provided; therefore, in the absence of statutory authority to hire vessels as discussed, it is concluded the Coast Guard is without authority to hire private vessels to perform Coast Guard functions, manned by Coast Guard personnel. . . .[15]

In view of the existing law, and the legal opinions, no immunity from liability may be granted, and therefore it is doubtful whether any submersible owner would offer assistance unless he were operating in the immediate area of the distress, and were motivated by the humanitarian principles of the sea.

Present Requirements

Historically the public has been aroused by catastrophes where life was sustained during a prolonged but eventually unsuccessful rescue effort. Anyone who reads a newspaper can recall examples such as mine cave-ins, people lost in caves and children trapped in wells.[16] In spite of the fact that life could not be sustained at the depths that the Thresher and Scorpion were lost, the American public could not accept the fact that there were no means available to rescue the crews of military submarines.[17] Shortly thereafter Congress appropriated funds for the Navy's Deep Submergence Rescue Project. Dr. Edward Wenk, Jr., of the National Council on Marine Resources and Engineering Development has stated:

> I take the view that a slow creeping crisis is dangerous because it is likely to go unnoticed until it is too late. By contrast, a sudden crisis tends to attract attention and to trigger attention.[18]

For instance, the Andria Doria-Stockholm collision off the coast of New England in 1956 precipitated the 1960 Safety of Life at Sea Convention, which resulted in long overdue changes to the antiquated International Rules of the Nautical Road. The public outcry as a result of the Coast Guard's present inability would only be exceeded by the Coast Guard's own embarrassment. Nevertheless, Congress has failed to appropriate a commensurate amount of money for the additional task.

The Coast Guard must develop a complete and adequate underwater rescue system at the earliest possible date in order to avoid a reaction crisis as a result of a submersible disaster. A program of this immensity and uniqueness would take a minimum of six years.[19]

CHAPTER III

SYSTEM COMPONENTS

Discussion

The helicopter-SARS concept reduces the number of types of hardware which are necessary to place this plan in operation. The only component of the overall system yet to be developed is the SARS, and because this will bear a similarity to other proven submersibles, the prototype of a configured search and rescue submersible is practically available as a commercial item.

A manned submersible is practical for search and rescue for two reasons. First, in the helicopter-SARS concept, the unmanned tethered submersible cannot be considered because even though the unmanned tethered vehicle is much lighter, it would still require surface support for guidance, thus slowing down the delivery and reducing the search time. Second, the free manned submersible has good maneuverability, low chance of entanglement due to nonexistence of a tether, and gives the rescuer a good feel for the situation. Although scuba teams should not be ruled out, they will be used in a suplementary role to provide inshore hook-ups at depths of less than 130 feet. For the foreseeable future, search and rescue at greater depths will require a deep diving submersible. Either the Star III or the Deepstar 2000 could be the prototype for the Coast Guard version. A comparison of the Lockheed proposed SARS for the Coast Guard with these vehicles is shown below.

TABLE I

SARS DESIGN CRITERIA COMPARISON

Name Operational Depth Owner	Wt. tons	Crew endurance	Speed cruise max	Length
DEEPSTAR 2000 2000' Westinghouse Ele	9	3 10	1.0 3.0	20.0
STAR III 2000' Scripps	10	3 6	1.0 4.0	24.0
SARS 2000'	6+	2 6	1.0 3.0	20.0

Source: Edward H. Shenton, "Where Have All the Submersibles Gone?" <u>Oceans</u>, November-December 1970, p. 48-49; U.S. Coast Guard Final Technical Report on Rescue of Distressed Submersibles, p. 2-2.

The similarity of these submersibles is readily apparent with the exception of the significantly lower weight of the SARS. Its lower weight may be due in part to the use of the lightweight plexiglass dome forward to enhance the visibility of the operator when working in restricted situations. However, in order to incorporate certain features desirable on a rescue submersible, the lower weight will have to be sacrificed to some extent. Although the helicopter can carry 16 tons, it would reduce significantly the range of this delivery system unless air refueled frequently. In spite of this tradeoff, it would be impractical to exceed nine tons, i.e. a 250 mile unrefueled range. (See Appendix I)

SARS Design Criterion

There are a number of desirable features that would increase a SARS efficiency.

Descent. Because of limited time it would be advantageous if the SARS could power down to the search depth rather than flooding its tanks causing negative buoyancy which would cause it to sink to the bottom. An acceptable design rate of descent would be in the area of 100 feet per minute, a not unrealistic figure. Recently the Pisces recovered a 2,000 pound torpedo from a depth of 1,000 feet in 28 minutes.[1]

Endurance. It is unrealistic to believe that the SARS will descend to the bottom, locate the DISUB immediately, attach a lift line and surface. In view of past experiences with the Alvin and the Deep Quest, this would be the exception rather than the rule. When the Aluminaut tried to place the special toggle bar in the open hatch of the Alvin, the dive had to be aborted on the first try after 12 hours. After modifying the toggle bar ashore, the second dive lasted 18 hours before the ~~Alvin~~ Aluminaut successfully inserted the bar into the hatch.[2] This same job could have been performed in seconds on the surface. In order to allow enough time for the SARS to locate the DISUB and be able to hook on without having to surface to change batteries, the endurance should be as long as practical, limited only by crew fatigue and battery weight limitations. This latter problem may be overcome by the use of fuel cells. A major advantage of fuel cells over conventional lead-acid and even the higher performance silver-zinc battery is the greater level of energy produced per pound of the power system weight achievable by fuel cells.[3] The design criteria should call for an endurance of at least 10 hours in order to provide enough flexibility to handle the worst situation. If standard lifting lugs and training drills were required, the hookup time would be reduced.

Speed. In order to cover the maximum amount of area in the shortest amount of time, a high search speed is essential. Speed will be limited by the capability of the sonar installed, and by a variety of vehicle characteristics such as drag, propulsion efficiency, minimum controllable speed, and available energy. The following problem demonstrates that the time to search a 10 square mile area at a search speed of two knots is 20 hours. The solution to this problem is a higher search speed with a commensurate improvement in the resolution of the sonar presentation at the higher speed.

$$S = \frac{A}{nvt}$$

S- track spacing = .25 mile
A- search area = 10 square miles
n- number of search units = 1
v- search speed = 2 kts
t- time to cover the area

solving for t $$t = \frac{A}{nvs} \qquad \frac{10}{(1)\quad(2)\quad(.25)} = 20 \text{ hrs.}$$

Navigation. In order to adhere to the tracks of the search plan, a navigator must keep an accurate running plot of the geographic position relative to the datum point. Course and speed over the ground will have to be determined and compensated for due to underwater currents. The position relative to datum can be obtained by a "bearings only" solution using signals being transmitted by a pinger implanted at datum by the SARS at commencement of the search pattern. However, there will be a need to know the geographic position within feet. This will require either standard navigation procedures, doppler navigation, satelite, loran C, bathymetric or some mix of the above systems through the use of a navigation computer. Because of the sophistication of this package, the cost and weight will be critical. However, in a dedicated SARS, accurate navigation should be considered absolutely essential to fulfill its mission.

Visibility. The pilot of a rescue submersible must have better visibility than the pilot of a research submersible, because of the proximity of the SARS to the DISUB and the dangers that caused the distress in the first place.

With the use of more and more glass for submersibles, the pilot's conning sphere should be fabricated entirely out of a transparent substance. This will allow for 360 degree viewing as well as above and below. The necessity for working so close to the DISUB and the entrapment source will call for precise maneuvering, especially if there are any strong currents in the vicinity which may ~~necessitate~~ require the SARS to hold on to the DISUB with one manipulator arm while trying to free it with the other. Adequate lighting will have to be incorporated. Low light television should be used for long range viewing and final approach.

Manipulator Arms. The SARS should be equipped with the strongest and most maneuverable arms that technology can provide. To maintain position alongside the DISUB the arms should be designed so that they will be capable of holding the SARS alongside under the worst current conditions that can be expected at any depth below 100 feet. It would also be desirable if the manipulator arms could actually be utilized to exert enough force on the DISUB to cause it to roll or twist so that it might overcome the bottom breakout force or other restraining influence that would preclude the need for an external lift. In addition, the manipulator arms should be so designed that maximum freedom of movement is enjoyed. The maneuverability of these arms would, in connection with standard lifting lugs, overcome the problems of hooking onto the DISUB when it is lying in a precarious position or when the working area is confined due to topography. The possibility of using four arms should be investigated. This would allow two arms to hold on with and two to work with.

Helicopter Design Criterion

The other primary piece of equipment is the Sikorsky CH-53E, or comparable helicopter. It is perhaps the most important part of the proposed system as it is the one piece of equipment that will make the entire submersible-helicopter concept feasible. Unlike the SARS, it can be purchased off the shelf without any significant modifications for approximately 2.5 million dollars.[4] Inasmuch as this helicopter will be an integral part of the overall air mission of the Coast Guard, and can be considered as the "follow-on" to the present HH-3F helicopter, it is not a special piece of equipment solely for the use of the underwater SAR program. Therefore, because it could be expected that the Coast Guard would acquire this helicopter regardless of the need for a SARS delivery system, the cost of these helicopters cannot be attributed solely to the underwater SAR program. Although the Flying Crane (CH-54) can lift more weight, it is not compatible with the overall search and rescue mission of the Coast Guard air arm, and was not considered by the writer to be cost effective in view of the overall capabilities of the CH-53E.

The CH-53E SEAKNIGHT helicopter furnishes all the capability that is needed to deliver the SARS to a precise point in the ocean, and to salvage the DISUB if necessary.

Speed. The speed of the helicopter will be a function of payload and drag. How will the SARS slung beneath the helicopter affect true air speed? We may assume that the SARS will be carried externally, will be stabilized fore and aft and will have the equivalent of 20 feet squared of drag. Appendix II of level flight performance or True Air Speed versus Gross Weight illustrates that with a gross weight of 64,800 pounds (a SARS weight of 15,000 pounds) at take-off, the helicopter could make 150 knots. As fuel was consumed, the helicopter could increase speed to 165 knots, or an average outbound speed of 157 knots for a 300 mile radius.

Payload vs. Range. It is assumed that the SARS will weigh approximately 15,000 pounds. Referring to Appendix I, it can be determined that a non-refueled range of 300 miles could be achieved based on the weight of the SARS. However, this is purely academic inasmuch as the CH-53E can be air refueled from a fixed wing C-130. Slight modifications to the existing Coast Guard C-130's would be necessary in order to air refuel, but this is well within the capabilities of the planes and the pilots. If the weight of the SARS increases to the nine or 10 ton level, the radius would be reduced to the 250 mile, and 200 mile radius respectively. Simply stated, the heavier the SARS the earlier the helicopter would have to refuel. However, as the refueling would take place while flying the same course and at the same speed, little if any time would be lost by the need to refuel. The helicopter would be capable of refueling with or without the SARS slung beneath, which in reality gives the helicopter practically unlimited range.[5] The only limiting factor would be extremely poor flying conditions that would preclude hooking onto the fueling hose.

<u>Lift</u>. In order to by-pass the surface support completely, the helicopter must be capable of lifting with its winch as much as it can carry. At the present time the CH-53E can lift 16 tons and is equipped with an 18 ton cargo hook. However, the radius with a 16 ton load slung beneath is practically zero. Nevertheless, it could still

lift a 12.5 ton sub and transport it a distance of 100 miles without having to refuel.[6] This helicopter has the dual capability of being able to fly or winch the helicopter off the bottom, as the winch is capable of handling 16 tons as well.[7]

A comparison of the helicopter delivery method versus a ship delivery method appears below, based on a scenario off Block Island. In order to arrive at a comparison, the most favorable conditions were assumed for the ship delivery. The ship delivery system involves only a very few C-130 air transportable SARS on both coasts. These would be located at Elizabeth City, North Carolina, and San Francisco, California, where the Coast Guard C-130 aircraft are located. With the helicopter system, the submersibles would be based at strategically located Coast Guard Air Stations along the coasts of the United States. See Appendix IV.

Scenario. At 1330 on Sunday, 25 April 1975, the First Coast Guard District Rescue Coordination Center was notified by a member of the Rhode Island Explorer's Club of an underwater distress. A leased submersible, the PLAYTHING III, with two people on board failed to surface from a scheduled two hour dive. The submersible had been diving 23 miles S.E. of Block Island in position L 40 - 53°N, and Long 71 13°W. The PLAYTHING III had been diving to investigate a

World War II German submarine in 174 feet of water. The Coast Guard Underwater Search and Rescue Manual listed emergency life support endurance for the PLAYTHING III as having an 8 hour maximum capability. Therefore, unless the life support system could be extended, all life support would be used up by 1900 that night.

1. The Coast Guard has alerted Elizabeth City Air Station and the Cutter Vigorous out of New London, Conn. to commence immediately the ship delivery underwater SAR plan. In the meantime, Commander Eastern Area has assumed SAR Coordinator for the mission.

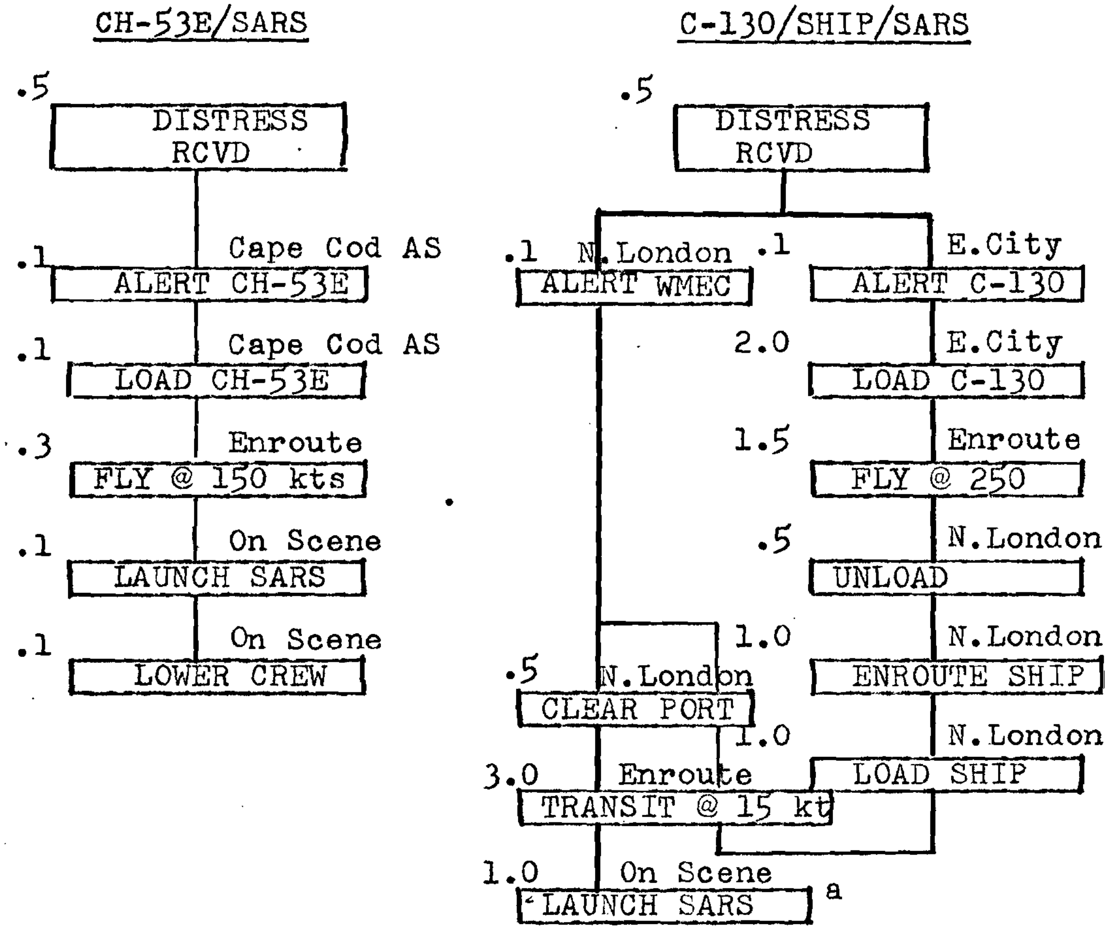
2. The Coast Guard has alerted the Air Station at Otis AFB, Falmouth, Mass. to transport the SARS to the scene. Further instructions are to be delivered enroute via radio. First District is the SAR coordinator in the intra-district operation.

Through simple mathematics (See Figure I) it can be deduced that the ship will not put the SARS in the water until 0030 in the following morning, some five and a half hours after life support would have ceased. In the case of the helicopter, the SARS would be in the water by 1445 that afternoon, exactly 45 minutes after being notified by the District Rescue Coordination Center.

The helicopter concept is far superior to the air transportable-ship delivery concept now in vogue. Not only is it superior, it is the only system at the present time that is capable of success.

FIGURE 1

MISSION ANALYSIS



Total time = 1.2 hrs.

Total time = 11.2 hrs.

---

[a] Cannot launch in seastate 3 or higher

Helicopter/SARS Location

The SARS would be located at present Coast Guard Air Stations along the coast. Utilizing the 300 mile radius and the fixed location of existing air stations, a minimum of nine SARS and their associated helicopters could provide adequate coverage for the continental shelf area of the United States, including the state of Hawaii. (See Appendix IV)

TABLE II

LOCATION OF COAST GUARD AIR STATIONS

East Coast	Gulf Coast	West Coast	Hawaii	Alaska
Cape Cod AS, Falmouth, Mass.	Mobile AS, Alabama	Astoria AS, Oregon	Barber's Point AS	Kodiak AS
Elizabeth City AS, North Carolina		San Francisco AS, California		
Opa Locka AS, Florida		Los Angeles AS, California		

Source: U.S. Coast Guard, Standard Distribution List (Wash., 1970), p. 5.

A minimum of two helicopters will be at each air station and there will be a back-up SARS located at both Elizabeth City, N.C., and San Francisco, California. Two SARS at these locations would not only permit an operational spare, but would also allow for coverage of a multi-unit case in any one of the coastal regions during the same time frame.

CHAPTER IV

SEARCH AND LOCATION

Discussion

The major problem confronting the search planner for underwater searches as compared to most surface searches is time. In practically every underwater situation, time is critical, and will determine some of the search parameters such as coverage factor. Although most of the research submersibles have up to 48 hours of life support, the smaller recreation submersibles will have no more than eight hours. (See Appendix III on Submersible Characteristics) Because the distress will occur after some portion of the life support has been used up, coupled with the fact that the object of the search cannot be located from a fast moving search vehicle, the need for an almost instantaneous response and ideally, instantaneous location is created in order for the rescue to take place. As in other areas, legislation can go a long way in simplifying the search and location problem. There are two types of searches envisioned; cooperative and non-cooperative.[1]

Cooperative Search. A cooperative submersible would be equipped with some type of locator aid. This could be in the form of an emergency pinger, or the keying of the underwater telephone located on all of the research submersibles used with support ships. A preferred device would be a buoyant homing transmitter.

Transmitter Buoy. The Navy currently utilizes such a device. The transmitting buoy is three inches in diameter, 39 inches long, and weighs less than seven pounds when prepared for launching. It has an antenna which is folded down along the side when the buoy is inserted in the signal flare ejector. The transmitter has a half-watt of power output capable of producing readable signals to the radio horizon for surface craft and about half the radio horizon for aircraft. A water activated battery is the power source. The transmission for the military version of the buoy is "SOS SUB SUNK SOS". . . .[2] The buoy described is applicable to the prototype for a similar civilian device. Rapid increases in electronics technology make it realistic to believe that the range and the transmission endurance will both be increased while the size is decreased. The absence of support vehicles for recreation subs makes it imperative that these devices be made part of the mandatory safety equipment to be carried by all submersibles. A further requirement should be to have the transmitter buoy on a long enough tether to reach the surface, and thus aid in the location of the DISUB. In this case, the SARS would simply follow the tether to the DISUB.

The probability of the transmitter malfunctioning could be decreased by the additional requirement for periodic testing.

Emergency Pinger. In addition to the tethered transmitter buoy, the submersible should be equipped with an externally mounted emergency pinger which would serve two very useful purposes. It would alert other submersibles in the area that there was a submersible distress and would provide a homing signal utilizing a directional listening hydrophone for the rescue submersible to descend and locate. It is possible that as submersible density increases, another submersible, upon hearing the signal, could arrive on the scene and possibly provide some token service. This is not highly probable due to the lack of manipulator arms and other rescue or salvage equipment. However, the rescue submersible could surface and transmit a distress signal to the Coast Guard or relay through another surface unit if necessary.

It is not the intention of safety regulations to burden the submersible with a mass of electronics equipment or to price it out of the market, but under the circumstances, this required equipment of relatively little volume and weight, provides by far the best system for conducting a successful search and rescue mission. Economically speaking, it would be cheaper to subsidize the expense of this equipment than to expend human or material resources on hours or even days of searches that would oftentimes prove fruitless.

Non-Cooperative Search. The lack of the last known position or homing information presents a much more difficult case for the search planners. Such a situation can exist when the locator aids do not function properly, or when the buoyed transmitter has broken its tether and has drifted some distance from datum during the interval of the delay for the search vehicle to arrive on scene. Upon arrival the determination is made concerning the classification of the search effort, i.e. cooperative or non-cooperative. In this regard the Coast Guard will have to develop drift tables for the transmitter buoy just as they have for wind driven small boats. This will permit the SARS to commence the search at the most probable position (MPP) of the DISUB by projecting back to where the buoy should have been upon surfacing.

The search submersible in this situation will arrive on the scene and will immediately commence its descent using a spiraling pattern to determine if the search is to be a cooperative-homing or non-cooperative search. In the latter search mode, the SARS will energize its scanning sonar and will commence the active search at a depth that will allow the optimum use of the installed sonar capabilities. The SARS will begin its selected search pattern based on known or estimated factors such as the beam of the DISUB, reliability of MPP and any water conditions that might affect the range of the search sonar.

Elements of Search Planning. A discussion of the factors used to construct the search pattern will provide a better understanding of the tradeoffs involved. Experience has shown that the factors affecting detection capability can be reduced to four interrelated mathematically expressed terms which can simplify employment of search units:

1. Probability of Detection (P)
2. Sweep Width (W)
3. Track Spacing (S)
4. Coverage Factor (C)[3]

Probability of Detection. A definite, instantaneous probability exists for each scan made by the search unit's detection equipment. The probability pattern develops as the search unit moves along its intended track with successive scans.

Sweep Width. This mathematically expressed measure of detection capability arbitrarily reduces the maximum detection range. It is based on the probability that the number of scattered targets which may be detected outside these limits will be equal to the probability that an equal number will be missed inside these limits. Sweep width tables for the underwater sonar search must include factors such as thermoclines, sound channels, search depth and the topography of the ocean floor. In an electronic search it is quite possible to have sweep with equal track spacing.

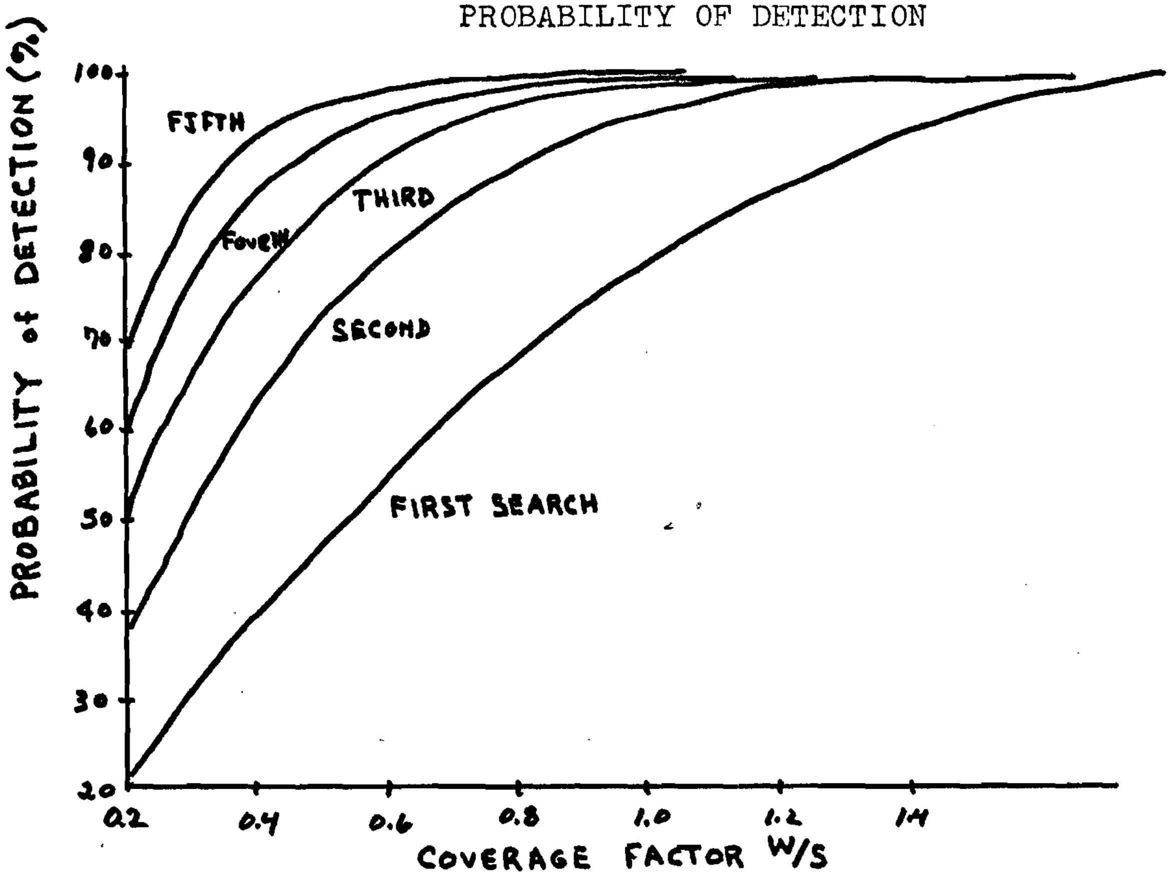
Track Spacing. The track spacing is the distance between adjacent search tracks. It is obvious that decreasing track spacing will increase the probability of detection. There is, however, a limit to which track spacing can be reduced due to accuracy of navigation equipment. A CTFM (Continuous Transmission Frequency Modulated) scanning sonar of the type that Lockheed has suggested for Coast Guard use would have a maximum range of 1,500 yards and a proven 500 yard detection range for a 0 db target.[4] It is apparent therefore, that the track spacing will fall between these two limits depending on the size of the DISUB, time, and probability of detection.

Coverage Factor. The coverage for any sweep depends upon the relation between the sweep width and the track spacing. Entering a probability of detection graph similar to Figure 1 with coverage factor and the search number, the probability of detection can be determined.

Probability may be raised or lowered depending on the fixity of other search parameters. For example, if P is too high and the entire search area will not be covered in the time remaining, then S should be increased a commensurate amount. Under normal conditions a 75 per cent probability of detection is selected for the first search but this may be higher depending on the situation.

FIGURE 2

PROBABILITY OF DETECTION



Source: U.S. Coast Guard National Search and Rescue Manual, p. 7-9.

Search Area. The search area is derived in such a way that it normally forms a circle centered on the MPP or datum. The radius of this circle is a function of the DISUB's navigational error, the delivery vehicle's navigational error and the drift of the DISUB due to currents during the elapsed time. By using an extended search radius (See Table III) a safety margin is added on to each search to reduce the chance of missing the search object on the edge of the search area.

TABLE III

SEARCH RADIUS SAFETY FACTOR

SEARCH	SEARCH RADIUS
1	1.1R
2	1.6R
3	2.0R
4	2.3R
5	2.5R

Source: U.S. Coast Guard National Search and Rescue Manual, p. 6-12.

Delimiting the Search Area. Possible solutions for attempting to provide a better datum or MPP would be the establishment of certain underwater recreation zones or the submission of voluntary voyage plans similar to an aircraft flight plan. The first case would be highly unpopular with the boating public, but it would give the Coast Guard a head start in delimiting the area of distress if a submersible failed to surface on schedule. Due to its unpopularity, it is doubtful that this would be an acceptable solution. However, the Coast Guard should educate the submersible operators that they stand a better chance of rescue by remaining in prescribed areas. The second plan allows for flexibility of travel, but only before the voyage plan is submitted. If the area of operations were changed after the voyage plan had been filed, it would probably prove fatal because the rescuers would initiate the search in the wrong area. When the rescuers do not know the position of the DISUB, then the task becomes almost impossible. Any successful effort will be very lucky as well as quite costly. Because of the slow speed of the search submersible, a large area search would not be feasible unless an inordinate number of search submersibles were employed throughout the estimated area. For a hundred square mile search area with five hours of life support remaining, it would take 13 search submersibles using a 1,000 yard track spacing to cover the area.

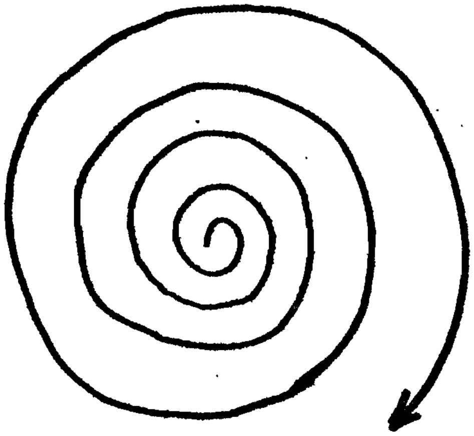
Active Search Patterns. There are three search patterns that are employed when the most probable position of the distress can be fixed fairly accurately. All three types would have to be "terrain" modified. That is, the bottom contour would have to be considered in carrying out the search pattern. Heretofore these searches have been utilized on one plane only. Thus the SARS would be the first vehicle to undertake a three dimensional search, going into canyons, around outcroppings, over or around guyots and seamounts, etc.

The three search patterns best suited for this situation are the expanding spiral, expanding square and the sector search.

Expanding Spiral. Although the expanding spiral is theoretically the best search, there is at present no navigation equipment for following such a path. This equipment could be developed in the near future. The advantage of this plan is that the sweep width to track spacing ratio is varied as the search vehicle travels away from datum. This allows a higher ratio near datum where the probability density function is the highest and a lower ratio near the periphery of the search area where the probability density function is the lowest.[5] If this were not true it would be justifiable to start the search at the outside limit of the area and search inward.

FIGURE 3

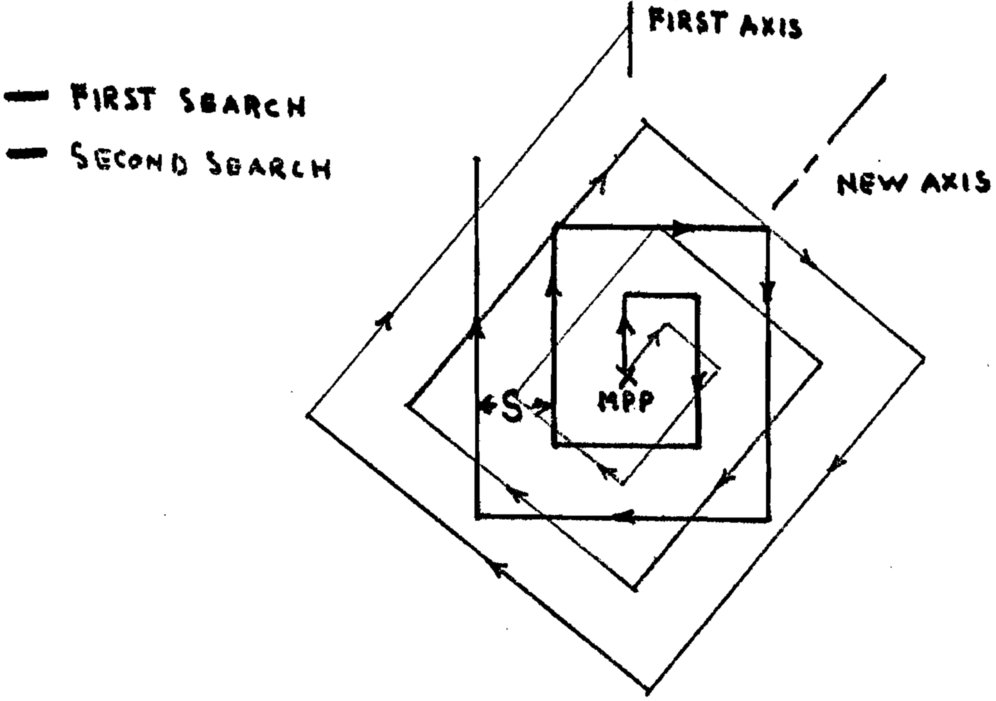
EXPANDING SPIRAL SEARCH



Expanding Square. The expanding square search (Figure 4) is started at the MPP or datum point and expanded outward. It is a relatively easy search to conduct. Normally the pattern is oriented on an axis running due North magnetic, and for subsequent searches the pattern is rotated 45 degrees in a clockwise direction with the area expanded as shown in Figure 4. The disadvantage of this system is the constant track spacing everywhere throughout the search.

FIGURE 4

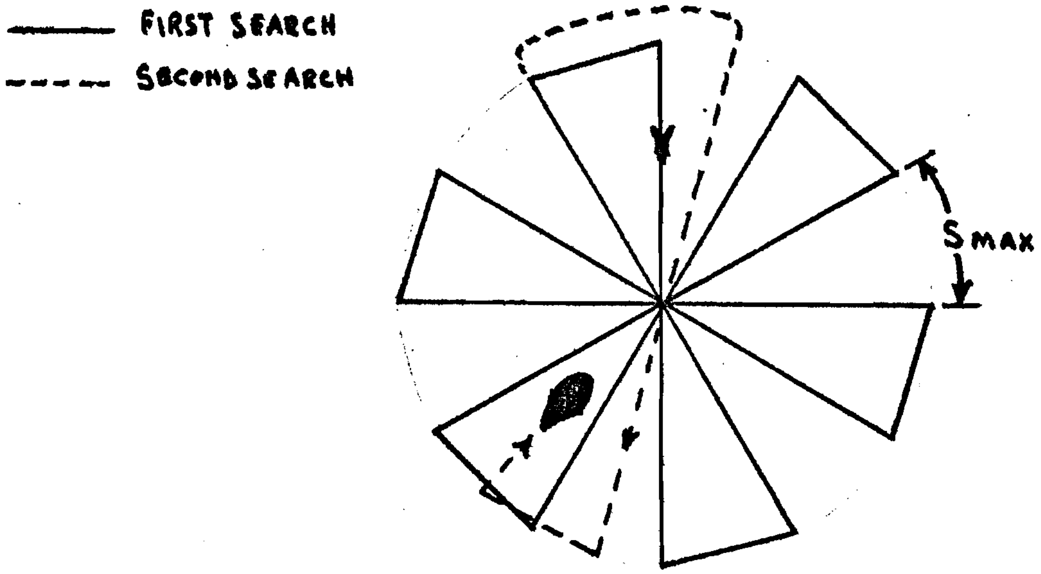
EXPANDING SQUARE



Sector Search. The sector search is perhaps the best practical pattern. (Figure 5) While easy to conduct, it allows the track spacing near the MPP to be small, while gradually expanding it as the search vehicle proceeds towards the periphery of the area. For a search of this type, the axis would be North magnetic. On subsequent searches the axis should be rotated so that the legs on the second coverage are midway between the ones flown on the first coverage.[6]

FIGURE 5

SECTOR SEARCH



<u>Contour Search</u>. The contour search may also be employed when the position of the DISUB is known but the position lies on the slope of the continental shelf or on the side of the seamount. (Figure 6) In the case of the slope, it would take the form of a parallel sweep search down the face of the slope. (Figure 7) On the side of a seamount or guyot, the search would normally be of the parallel sweep if a large area had to be covered or a contour pattern around the protrusion if it was a small diameter ridge.

FIGURE 6

CONTOUR SEARCH

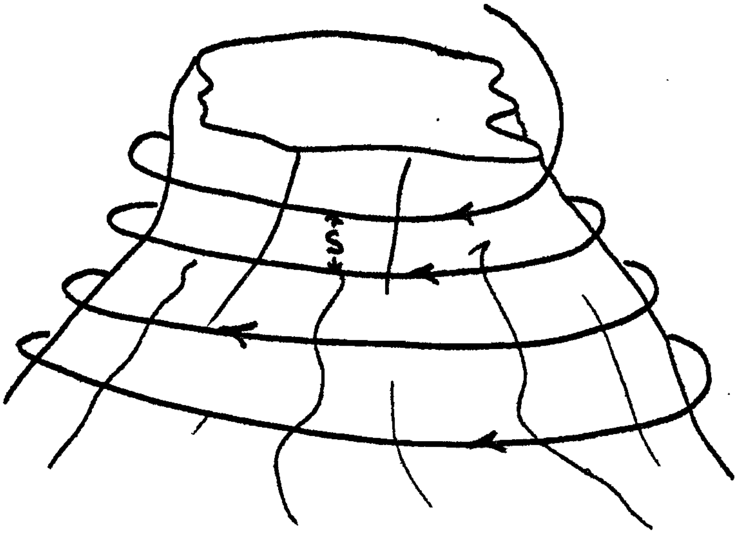
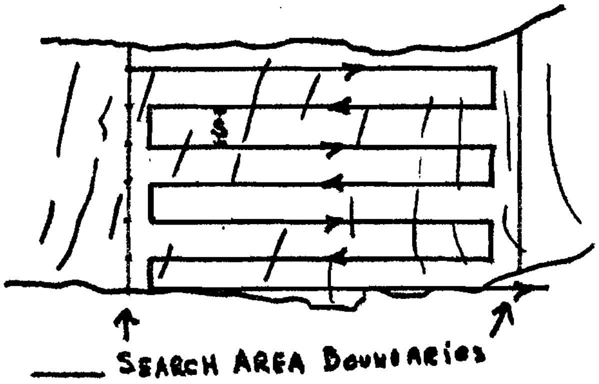


FIGURE 7

PARALLEL SWEEP



Search Requirements. The Coast Guard must develop an entirely new search planning system. Although a great deal of the material is already contained in the present search and rescue manual, a need exists for proven underwater search and rescue methods to be incorporated as soon as possible. Until these search plans are carried out underwater, their effectiveness in that environment will remain a matter of conjecture. The immediate area of concentration should be legislation requiring tethered buoy transmitters and emergency pingers. The development of these locator aids should be coincidental with procedures for non-cooperative search plans. The sector search best meets the needs for relatively flat terrain while the more rugged terrain will have to be searched using a pattern modified for a contour as well.

CHAPTER V

RESCUE OF PERSONNEL

Discussion

The number of options open to the Coast Guard for the recovery of personnel is indeed limited. No two submersibles are configured exactly alike which removes the standardization luxury that the Navy enjoys during their rescue phase. There are two practical methods that can be considered; mating to the DISUB and rescue by salvage. The type of salvage employed will be dependent on the type of distress situation involved. The salvage phase could range from a simple maneuver lasting a few minutes, to a more sophisticated evolution lasting several hours or even days.

Mating. Utilizing this method, it would be necessary for a rescue submersible to position itself over a universal escape hatch located on a DISUB in such a way as to allow the survivors to enter the survivor sphere of the SARS through a pressurized bell or skirt fitted flush with the hull of the DISUB. Because the Navy has a standardized escape hatch, the Navy can mate to the DISUB to rescue submersibles. However, there are several other features that are necessary.

Universal Escape Hatch. In order to marry-up to non-military submersibles, a universal escape hatch would be required on every submersible in order that the skirt of the SARS would fit snugly to the hull around the hatch. Not only would this require legislation, it would also require substantial cost to the builder as it affects the overall design of the hull shape.

Flat Surface. In order to position the SARS on top of the DISUB and maintain that position while the survivors boarded the SARS, a flat, smooth resting place or "bearing surface" would have to be part of the hull surface. This surface would have to be relatively flat. However, as the diameter of the largest research submersible is only 17 feet today, the smaller recreation submersibles will have a significantly smaller diameter, probably in the order of six to 10 feet. Therefore, the small diameter of the recreation submersibles precludes the use of the mating system for the rescue of personnel due to the curvature of the hull.

Thrusters. A mating system requires the rescue submersible to maintain a steady position over the escape hatch of the DISUB. This means the rescue submersible must be able to offset any lateral movement due to undersea currents. The Navy's DSVR has incorporated a series of

RV

thrusters around the rim of the bottom hatch in order to offset these external forces, allowing the rescue submersible to maintain its position over the escape hatch during the period of time necessary to effect the rescue of survivors. This system incorporated in the SARS increases the cost substantially.

SARS Configuration. Any system of this type would require a much larger SARS vehicle in order to carry the survivors to the surface. A survivor's "hut" would necessitate an additional pressurized sphere, complicating and enlarging all internal systems, while at the same time adding substantially to the size and weight of the SARS. This would in all probability, preclude the SARS from being helicopter deliverable, thus reducing the effectiveness of the entire system.

Disadvantage of the Escape Hatch. The probability that the submersible may be laying on its side or even upside down at the time of location precludes the use of the universal escape hatch as an effective method of rescue. The cost of installing more than one such hatch is prohibitive.

Emergency Ascent. There are a number of systems utilized for making emergency ascents. This is normally accomplished through a controlled ballast system, using water, lead shot released in desired amounts, ballast bars or a combination of the above. Water ballast is used extensively by the shallower diving subs for descent and ascent. Because returning to the surface is the most important part of the diving operation, submersibles have incorporated redundant or duplicate systems of buoyancy control. In addition, external features mounted on the hull, or even the batteries can be dropped to increase the buoyancy.[1] There are some submersibles that are capable of severing all umbilical services from the rest of the sub, enabling the pressurized sphere to rise to the surface.[2] However, these systems are not an absolute guarantee that the submersible will return to the surface in every emergency situation.

<u>Types of Distress Cases</u>. There are generally four categories of causes that could possibly prevent a submersible from surfacing:

a. Entanglement--cables, nets, wrecks, structures, rocks, outcroppings and sediment

b. Flooding--buoyancy spheres may flood

c. System Failures--life support, electrical trim, or variable buoyancy

d. Fire--personnel pressure hull, control boards

The blowing of ballast tanks at great depths may cause submersibles upon surfacing to broach, roll over, lose the air out of the bottom of the tank, reflood and sink to the bottom.[3] Another rare situation that can cause a submersible to be affected by an external source is the possible collision with a large marine animal or an attack by marine life. The DRV Alvin was recently attacked in 1,800 feet of water by a 200 pound swordfish without any obvious or intentional provocation on the part of the Alvin.[4] Although the swordfish ended up second best in this case, it did manage to wedge its sword in a narrow opening in the hull. A swordfish or similar marine animal could become lodged in such a way as to render the submersible inoperable. The impact alone on a small submersible could knock out a vital system, causing a disaster.

Rescue by Salvage. The simplest cases of rescue would be the clearing of an entanglement by use of manipulator arms. In a recent case, the DRV Deep Quest got a line wrapped in her screw while maneuvering around a sunken plane near San Diego. The DRV Nekton, which happened to be close by at the time, located the Deep Quest and promptly cut the line by using a knife grasped by one of its manipulator arms.[5] Another type of rescue would be imparting the necessary force to free the DISUB from its restraining influence, be it mired in sediment or wedged beneath an overhang. This would normally be handled by either pushing gently with the SARS, towing with a short length of cable or by hauling on it from above. The entrapment of a submersible by sediment and oozes may pose more of a problem than might be expected. The Alvin collided with an underwater bank during a certification dive and several minutes were required to free the vehicle. Another craft, DRV Deepstar, was unable to surface during bottom operations in a different area and was forced to jettison equipment in order to achieve sufficient buoyancy to break free of the bottom. It is apparent from the accounts of grounded vehicles that entrapment of submersibles by bottom suction are not exaggerated.[6] With the advent of underpowered submersibles piloted by amateur operators, the possibility of hitting the bottom or a bank hard enough to become entrapped beyond the buoyant capacity of their ballasting system, seems likely.

Surface Lift. Surface lift is the most difficult type of salvage. There are three types of lift that are currently available, but only surface lift is a tried and proven method. The other two are helicopter or air lift and buoyancy pack lift. Although a surface lift was utilized in the Alvin case, it is a complicated and extremely time consuming undertaking. Because any type of surface lift has to contend with surface motion, it imparts a whole new set of dynamics to the lift cable. Some of these forces such as surge on braided nylon can be reduced by hauling through a center well, but even then these forces are only reduced and are further alleviated by means of a constant tension winch system. With this type of system and because the most turbulent conditions, i.e. heave factors, are experienced in the first 50 feet of depth, lifting of the submersible would have to be terminated below this depth. While suspended underneath the surface vessel the DISUB is transferred to a crane capable of extending well over the side of a barge for the remainder of the trip to the surface. In order to overcome the forces that were reduced through hauling through a center well, the remainder of the lift would have to be made in calm waters. If this situation did not exist at the scene, then towing of the submersible to calmer waters using floats would have to be considered as an alternative to risking submersible loss due to parting of the cable.[7]

Unless ideal sea surface conditions (Sea State 3 or less) prevailed, the rescue of personnel by salvage from the surface with any degree of success, is not feasible. This is assuming, of course, that the surface vessel can get there in time.

Buoyancy Lift. One of the more feasible methods of lift would be some type of rubberized buoyancy pack that could be attached to the DISUB prior to being inflated by a self-contained gas generation device from the SARS. This system obviates the need for surface support and is independent of seastate. The device is well within technological capability, and by providing standardized attachment points, the package could be attached to the DISUB in a minimum amount of time. The Navy is presently working on such a system for deep ocean lift. Lockheed has suggested that a lift capability of 2,000 pounds should be sufficient for most of the smaller submersibles.[8]

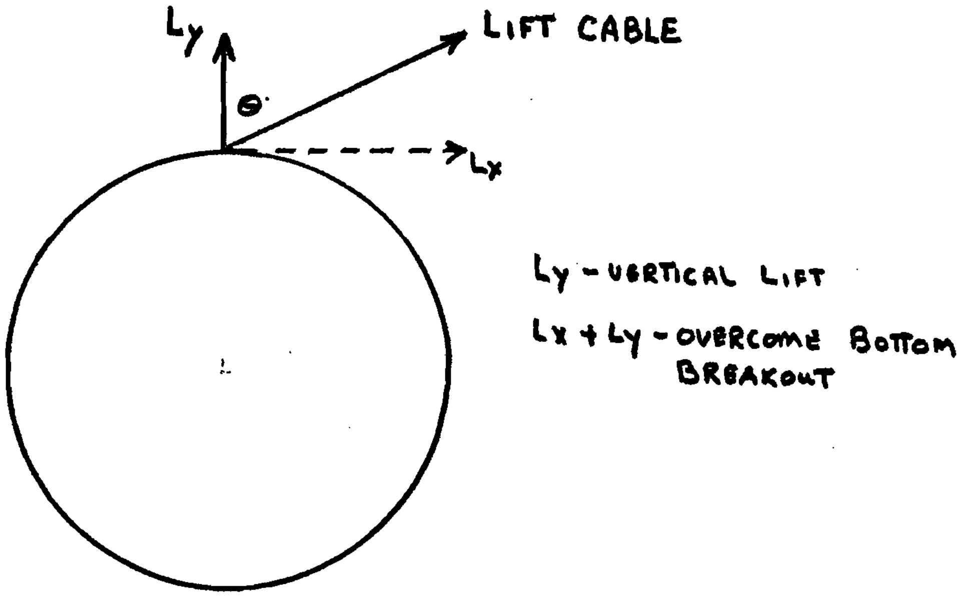
<u>Helicopter Lift</u>. This system would utilize one of two types of helicopters depending on the amount of lift required. If the CH53E was used, the Coast Guard could have a completely integrated system which would be extremely cost effective. The SARS would hook onto the lifting lugs on the submersible and then would reel out the selected type of hauling cable as it surfaced. Upon surfacing the helicopter could hook onto the bitter end of the hauling line and commence lifting either by increasing altitude or by hoisting with its winch. Once the DISUB was at the surface, the personnel could be rescued by the SARS personnel or by personnel lowered by the helicopter. These survivors would then be lifted to the helicopter which, with the DISUB

slung beneath it, would return to the closest base. In the meantime, a second helicopter could pick up the SARS and its crew in a like manner.

Breakout Force. In salvaging a submersible that has bottomed, it will be necessary to determine the amount of bottom breakout force that will have to be overcome. In the case of the Alvin, the nature of the bottom and the position relative to the bottom were known through photographs. Calculations based on the type of sediments and the immersed area were determined to be 25 per cent of the deadweight lift force.[9] As breakout lift force is time dependent, it can be reduced to 10 per cent of the lift force by slow and steady application of the lift. In the case of the Alvin, the lift plan was to gradually increase the strain on the line to 14,000 pounds and hold it at this level until breakout occurred. During lift, the tension remained constant at 9,000 pounds throughout. Previous calculations indicated that the Alvin weighed 8,800 pounds fully flooded.[10] In addition, the force should be exerted at an angle in order to roll the submersible off the bottom rather than trying to pull directly upwards. By pulling at an angle, (Figure 8) the total strain is not imparted to the lift cable instantaneously, rather some component of the total lift force depending on the angle to the vertical.

FIGURE 8

LIFT VECTORS



Time Factor. As in all other phases of this operation, time has been the limiting factor. Because of the extremely short lift support endurance expected to be installed on the recreation submersibles, it is absolutely essential for a SARS to be able to extend externally the DISUB's life support endurance. This external life support package is also technologically feasible and like the lifting lugs and buoyancy pack attachment points, the coupling or hull fitting for the hose would also have to be legislated in a Coast Guard safety package. Because the submersible might be resting in a number of positions when located, it would be necessary to specify that there be a number of fittings available on the hull to preclude being covered up. This system could be lowered by the helicopter so that the additional life support would be independent of the SARS dive endurance. The external life support component is the single most important feature of the underwater rescue phase.

A newer concept in water depths from 600 to 1,000 feet is that of using a lockout type of submersible from which a saturated diver would emerge to perform whatever rescue task were necessary to free the DISUB. At these depths the delay involved in hooking on the lift cable or in working with the relatively slow manipulator arms could be substantially reduced by performing the same task with a diver. There is a limited capability at these depths now but the Coast Guard would be remiss if they failed to incorporate this feature into the proposed SARS. However, if it is found that the extra weight as a result of incorporating the lockout system exceeds what a helicopter could carry, then the idea should be abandoned until such time as the lift capability exceeds the weight of the lockout SARS. It is much more important for the SARS to at least reach the DISUB and extend the life support while awaiting additional surface support, than not to be able to reach the ~~SARS~~ DISUB in time.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

It is obvious that the age of the submersible is in its infancy and that a large number of various types of submersibles will be sailed through U.S. waters above the continental shelf in the near future. The fact that the Mutual Assistance Rescue and Salvage Plan is unable to cope with the small number of submersibles today, coupled with the lack of progress toward implementing a realistic underwater SAR plan, is evidence that we are progressively worsening an already bad situation.

Because the smaller submersibles create a severe problem due to their short life support endurance, the necessity for a fast-response system is readily apparent. This time element may be neutralized by employing a helicopter to deliver the Search and Rescue Submersible (SARS) to the scene of the distress at a speed well in excess of 100 knots. Of course, the arrival of the SARS on scene at the earliest possible moment is only a partial solution. The need to locate the submersible and to rescue the personnel inside the DISUB are the major segments of the total problem.

There will be a need for the Coast Guard to seek legislation to require standardized safety features in order to simplify the location and rescue by salvage problem to a point where it becomes a viable concept of operations. The latter stage may range from a simple maneuver to free an entangled DISUB to a more complex lift to the surface for rescue. Because the great majority of the submersibles probably will be small, the present capability of the helicopter to furnish the necessary lifting force at a relatively rapid rate should be adequate for the immediate future. It is realized that not all situations will be capable of success within the allotted time, thus a means of extending life support to the DISUB while alternate procedures are being carried out must be expected to be an integral part of the rescue system.

Conclusions

1. The helicopter-SARS concept is realistic.

2. Legislation will be required for the below standardization of safety features.

    a. A high and low frequency emergency pinger must be installed on the submersible for homing purposes.

    b. Standardized lifting lugs or padeyes must be brightly and clearly marked for ease in identification.

    c. An approved proturbance or horns that would allow the SARS to hold on to the DISUB when working alongside must be attached to all submersible hulls.

d. Multiple female fittings, where a probe could be inserted in order to extend life support, must be an integral part of submersible hull construction.

e. Standardized attachment points for attachment of the gas generation lift packs must be located on the periphery of the hull.

f. Primary and secondary tethered buoyed transmitters capable of broadcasting a distress on the surface as well as aiding the SARS in locating the DISUB quickly must be carried by all U.S. submersibles.

3. A heavy lift helicopter provides the best mix of speed launch, lift and recovery to cope with the overall problem.

4. The present MARSAP is of little value and is completely incapable of coping with the expected growth of submersibles.

5. The Coast Guard must start the procurement process for a prototype SARS and the commensurate training of Coast Guard personnel to man and support this vehicle.

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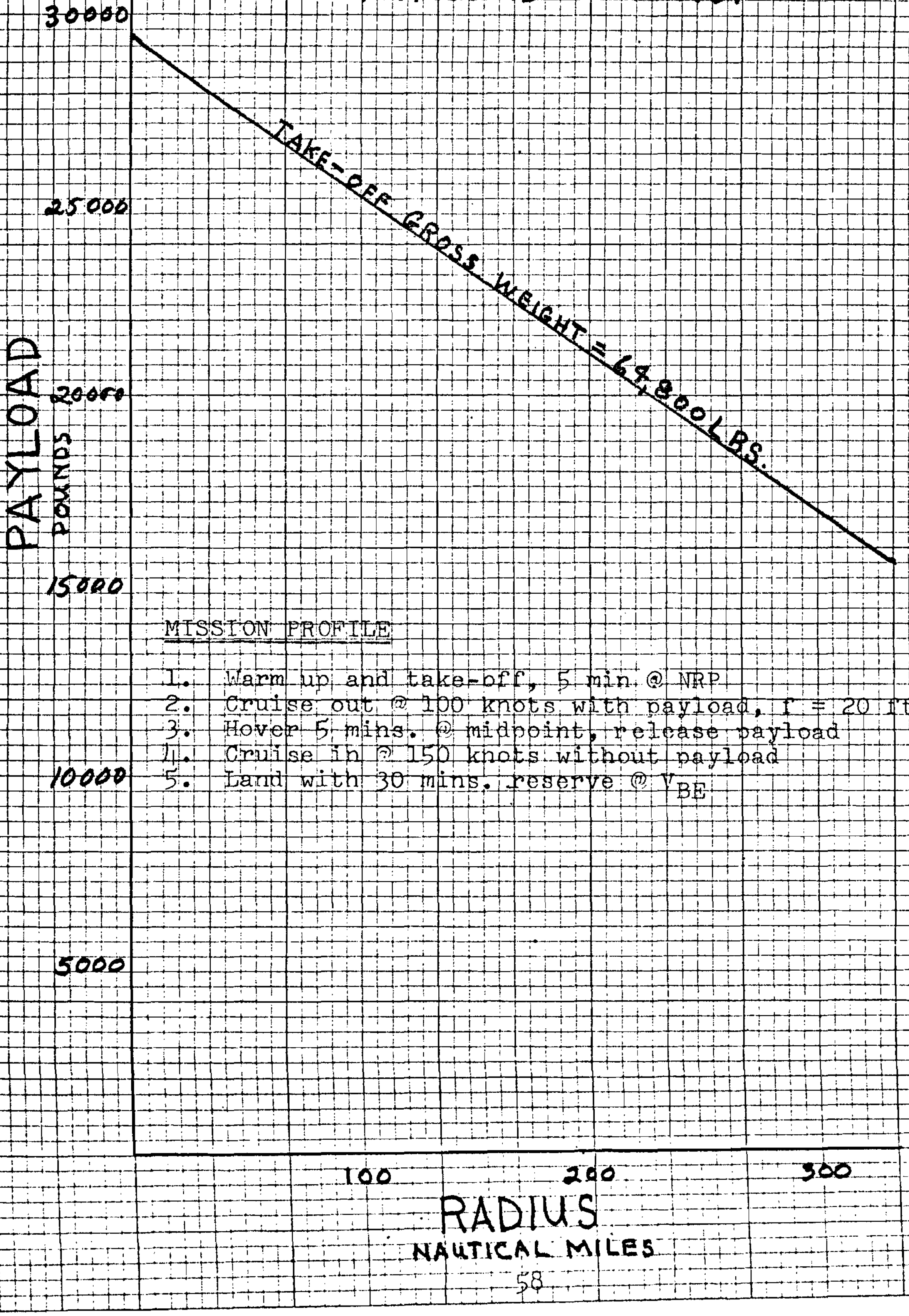
CH 53E
PAYLOAD vs. RADIUS

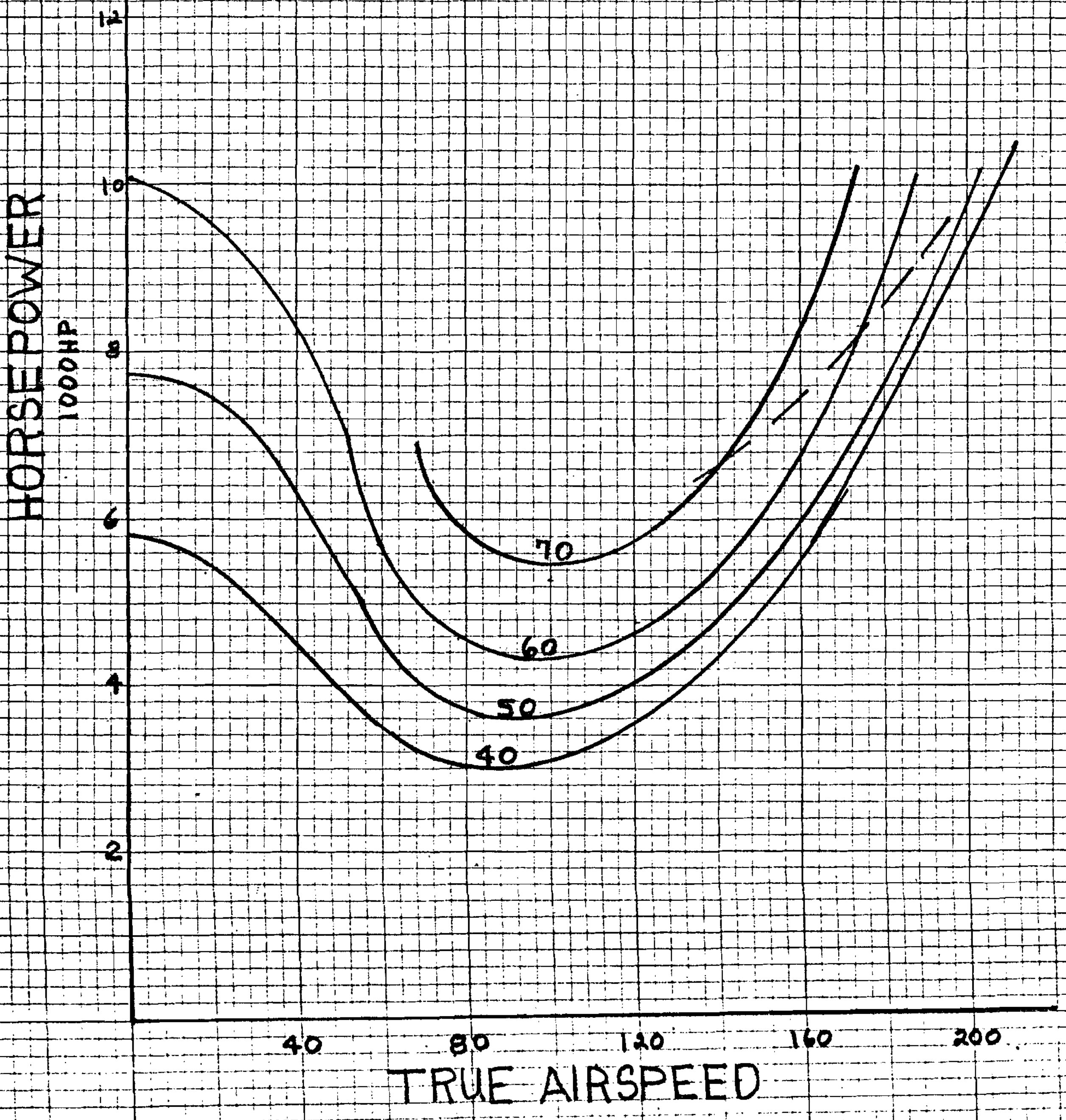


MISSION PROFILE

1. Warm up and take-off, 5 min. @ NRP
2. Cruise out @ 100 knots with payload, f = 20 ft.^{2}
3. Hover 5 mins. @ midpoint, release payload
4. Cruise in @ 150 knots without payload
5. Land with 30 mins. reserve @ V_{BE}

APPENDIX II

LEVEL FLIGHT PERFORMANCE



APPENDIX III

U.S. SUBMERSIBLE SAR CHARACTERISTICS

Name	Depth (ft.)	Wt. (Dry Tons)	Crew	Max Life Support (Hrs.)
ALUMINAUT	6,250	78	4-6	72
ALVIN	6,000	17	3	48 MH[a]
AMERSUB 300	300	11	2	8
AMERSUB 600	600	1.75	2	16
ASHER AH	600	4.2	2	48
AUTEC	6,500	21	3	100 MH
BEAVER IV	2,000	16	3	44
BEN FRANKLIN	2,000	130	6	42 days
BEMTHOS V	600	2	2	16
CUBMARINE 3X	150	2.3	2	20
CUBMARINE 3C	300	2.3	2	20
CUBMARINE 3C	300	2.3	2	20
CUBMARINE 3B	600	2.7	2	10
DEEP DIVER[b]	1,335	3.2	4	18
DEEP JEEP	2,000	4.5	2	48
DEEP QUEST	8,000	52	4	48
DEEPSTAR 2000	2,000	9	3	8
DEEPSTAR 4000	4,000	9	3	48
DEEPSTAR 20,000	20,000	42	3	48
DEEP VIEW	1,500	3.5	2	
DOW B	6,500	9.6	3	40
MORAY	6,000	17	2	24
NAI'A (PC-5)	1,200	5	3	
NEKTOM	1,000	2.2	2	
NEMO	600	1	2	
PAULO I	1,000	2	2	
PERRY PC9	2,000	10.5	3	
SEA CLIFF	6,500	24	3	50
SHELF DIVER	800	8.5	4	48
STAR I	200	1.4	1	18
STAR II	1,200	4.3	2	48
STAR III	2,000	10	3	24
SUBMANAUT[c]	2,000	2	2	
SUBMARAY	375	1.5	2	16
TRIESTE II	20,000	50	3	24
TURTLE	6,500	24	3	50
VAST MK III	250	1.2	1	

[a] MH = Man Hours; New titamium hull will reduce weight and increase depth capability to 15,000 feet.

[b] lock-out, lock-in capability.

[c] maximum depth attained - 200 feet.

APPENDIX IV

United States