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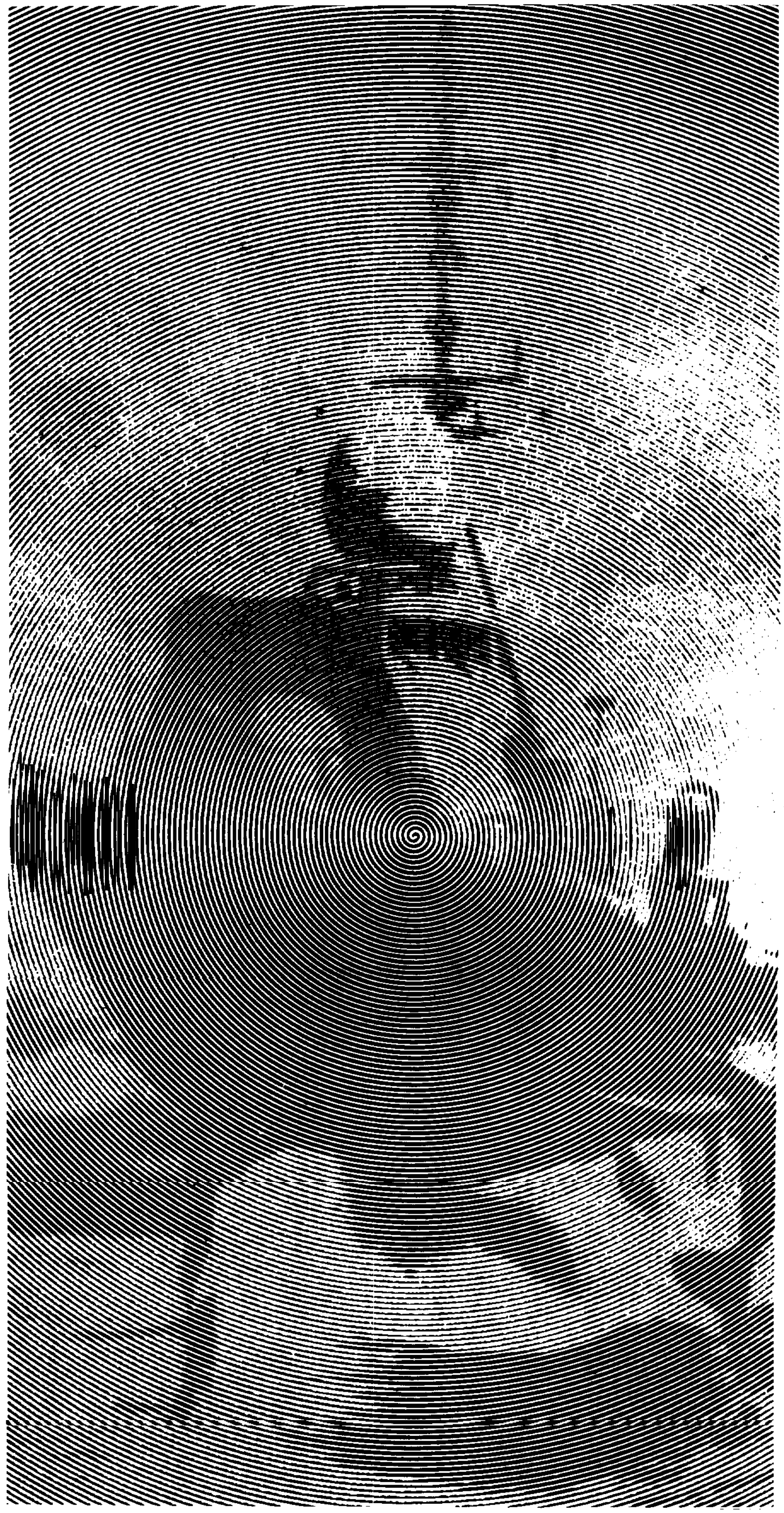

ADVANCED NAVAL VEHICLES CONCEPTS EVALUATION [ANVCE] PROJECT

SUMMARY

VOLUME I

CLASSIFIED BY CHIEF OF NAVAL OPERATIONS(OP-96)

REVIEW ON 31 DECEMBER 1999

[redacted]

UNCLASSIFIED

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ANVCE

MISSION ANALYSIS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This volume presents the results of the military mission analysis of the ANVCE Project. The report first reviews the generic concepts developed in Volume 2, the Technical Evaluation. The projected threat is then examined to determine what platform performance characteristics are significant in amntering this threat. The significant characteristics are then discussed and comparisons among the concepts are made. This volume also summarizes the extensive analysis of the utility of speed at sea which was sponsored by the Project and the results of the ANVCE was game activity.

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More than 200 separate studies, tests, and experiments were conducted by the ANVCE Project to identify concepts that met these broad criteria. This volume is a brief summary of project results as they are presented in

- Volume 2 - Technical Evaluation,
- Volume 3 - Cost Analysis, and
- Volume 4 - Mission Analysis.

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DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, D.C. 20350

IN REPLY REFER TO
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MAR 17 1980

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To: Distribution List

Subj: Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project Report; Letter of Promulgation

Ref: (a) CNO ltr Ser 96/C194136 of 7 Jan 1980

Encl: (1) ANVCE, Volume 1, (Summary)
(2) ANVCE, Volume 4, (Mission Analysis)

1. The Director, Defense Research and Engineering (DDR&E) directed that the Navy undertake the Advanced Naval Vehicle Concept Evaluation project to develop the information needed for a balanced advanced naval vehicle research and development program for the 1980-2000 time period. The project involved research, engineering design and experiment as well as analytic studies to determine which of the nine generic classes of advanced vehicles have the greatest potential for application to naval missions. The R&D efforts included technology assessments and the development of vehicle point designs. The analyses evaluated mission requirements, vehicle effectiveness and costing.

2. Enclosure (1) summarizes the background, technical approach, significant products, findings and recommendations of the ANVCE Project. Enclosure (2) describes the methodology used in the mission analyses and presents the findings of these analyses. Enclosures (1) and (2) are forwarded to complete the distribution of the final report of the ANVCE Project. Volumes 2 and 3 of the report were promulgated earlier by reference (a).

3. The ANVCE Project evaluated six advanced "surface vehicle" concepts (SWATH, planing craft, hydrofoil, surface effect ship, air cushion vehicle, wing-in-ground-effect (WIG)) and three advanced air vehicle concepts (air buoyant, sea loiter a/c and air Loiter a/c). The Project compared the surface vehicle concepts in three classes; 1000 ton, 3000 ton and 25,000 ton (aircraft carrier) and evaluated the three air concepts separately. The analysis assumed common weapons/sensor suites for the members of each surface class and each air concept. Volume 4 reports the evaluation of each member of each class (concept) against the NISC "Circa 2000" threat projection. This analysis identifies the potential counters by which each vehicle meets the threat. The logic diagrams of this

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volume point out the vehicle attributes which are valuable in countering specific threat characteristics.

4. The threat-oriented mission analyses points out that the most significant vehicle characteristics are those which enhance the performance of weapons and sensors, improve the survivability of the platform or provide a reserve payload capacity. Vehicle characteristics which enhance weapons and sensor performance include speed, ride quality, maneuverability and the ability to launch and recover aircraft.

5. The ANVCE Project makes the following recommendations:

a. Development effort for Air Cushion Vehicles should emphasize reduction in costs more than improved performance.

b. Operational testing of the PHM should develop operating tactics and include experiments with various foils to seek improved performance.

C. Research on supercritical hull should be pursued for planing craft

d. Analyze the relative cost effectiveness of high and low length-to-beam ratio Surface Effect ships in the 3000 Ton class

e. Pursue design of 1000 to 3000 Ton SWATH for VSTOL operations

f. Continue active research of supercritical wing and composite materials for aircraft

g. Establish a balanced R&D program in materials for Fully Air Buoyant (FAB) vehicles and develop designs for 1 to 3 mil ft^3 FAB

h. Establish continuing R&D program to address rough-water performance of 'WIG

6. Enclosures (1) and (2) are forwarded for information in support of R&3 program planning.

M. S. Holcomb

M. S. HOLCOMB
Vice Admiral, U.S. Navy
Director, Navy Program Planning

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ADVANCED NAVAL VEHICLES
CONCEPTS EVALUATION (ANVCE) PROJECT

Volume 1

SUMMARY

December 1979

Prepared by :

CHIEF OF NAVAL OPERATIONS (OP-96)

Classified by Chief of Naval Operations (OP-96)

Review on 3 1 December 1999

PREFACE

(U) The final report of the Advanced Naval Vehicles; Concepts Evaluation (ANVCE) Project has been published in four primary volumes as follows:

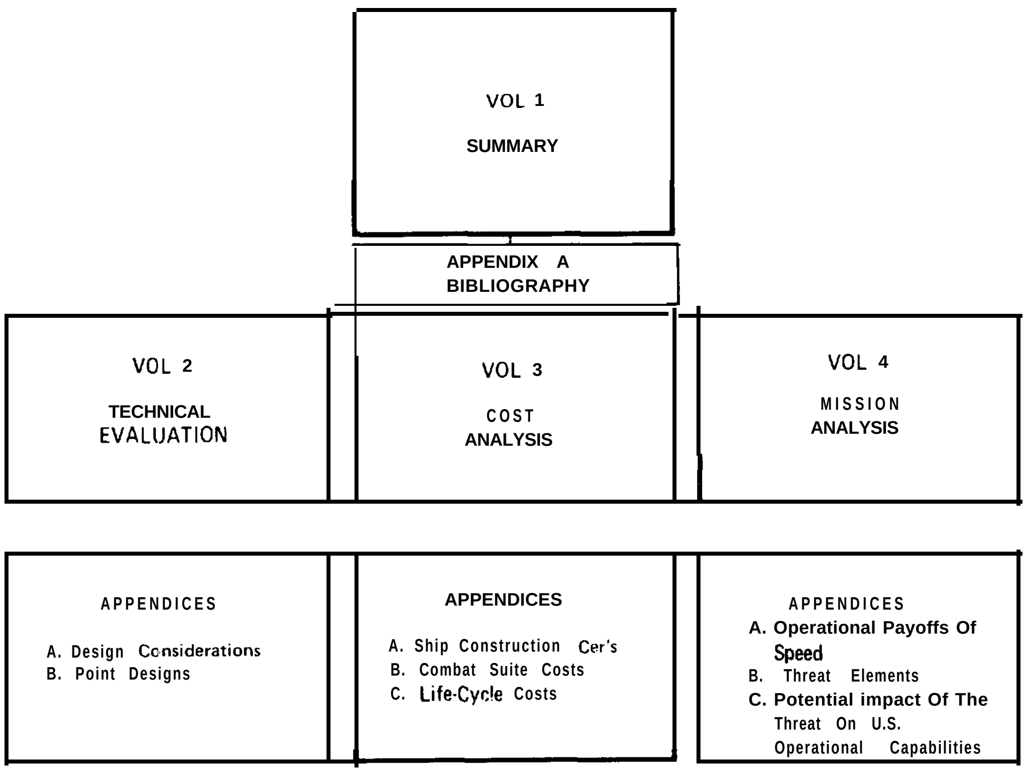
- Volume 1: ***Summary*** -- a summary of the project results, conclusions and recommendations.
- Volume ***2: Technical Evaluation*** -- a description and technical assessment of the feasibility of advanced naval vehicle concepts;
- Volume ***3: Cost Analysis*** -- a detailed treatment of the cost of the ANV point designs; and
- Volume ***4: Mission Analysis*** -- an assessment of future platform performance requirements based on military mission analysis.

Detailed information is presented in appendices to each volume. An illustration of the final documentation for this study is shown in the figure below.

(U) This study is the product of more than 200 separate analyses, tests, and experiments by Navy organizations and contractors too numerous to mention here. Their work is gratefully acknowledged. The ANVCE Project consisted principally of

CAPT Thomas L. Meeks, U.S.N. (OP-96V), Project Officer;
Mr. Peter J. Mantle, Mantle Engineering Company, Technical Director and Deputy Project Manager;
CDR D. Gray, U.S.N. (OP-96V), Project Staff;
Mr. D. Gicking, SAI, Inc., Project Staff; and
CDR C. Graham, U.S.N. (OP-96V), Project Staff.

(U) The final report was produced under the direction of CAPT John S. Daly, USN, Project Officer, assisted by Peter C. Georgallis, Robert A. McCaffery, and Joan E. Rentner of RAMCOR, Inc.



(U) FINAL ANVCE DOCUMENTATION

EXECUTIVE SUMMARY

INTRODUCTION

(U) The Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project was undertaken in response to guidance received from the Director of Defense Research and Engineering (DDR&E) during the Fiscal Year I. 976 budget cycle. The project, begun in July 1975, was to obtain the necessary information to recommend a balanced overall research and development (R&D) program for naval vehicles for the 1980-2000 time period. All advanced air and surface vehicles (except submarines and carrier-based aircraft) that met the criteria of being technically feasible., affordable, and of military value were to be evaluated.

(U) The organization of the Project and the ensuing report was based on these three criteria. The report consists of:

Volume 1: Summary
Volume 2: Technical Evaluation
Volume 3: Cost Analysis
Volume 4: Mission Analysis

While each volume, and the analyses presented in it, is to some degree dependent on the other volumes, each can also stand alone. For example, while the cost results presented in Volume 3 are based on the point designs developed in Volume 2, the cost estimating relationships developed in Volume 3 are not dependent on the point designs. Therefore, to a large degree, Volumes 2, 3, and 4 evaluate vehicle concepts, not merely the identified point designs.

TECHNICAL EVALUATION

(U) The results of the technical evaluation were derived from 16.5 separate analyses, surveys, and experiments consuming 70 percent of the total ANVCE Project budget. Nine generic concepts were explored in depth and, from them, 23 point designs were developed. The generic concepts addressed were:

Surface

- Air cushion vehicle (ACV);
- Hydrofoil;
- Planing craft;
- Surface effect ship (SES);
- Small-waterplane-area, twin hull (SWATH) ship;

Air

- Air loiter aircraft;
- Lighter-than-air (LTA) vehicle;
- Sea loiter aircraft; and
- Wing-in-ground (WIG) effect vehicle.

(U) Volume 2 presents a state-of-the-art review of each generic concept as well as the results of those ANVCE-sponsored studies and experiments that were performed to advance the state of the art. The 23 point designs are described in detail, and four baseline designs are also described for comparison purposes. The technical evaluation led to specific R&D recommendations for each of the generic concepts in addition to recommendations on general performance research in

- seakeeping,
- marine propulsion,
- structural design,
- hull and foil design,
- skirts and seals development,
- lift system,
- lightweight structures, and
- efficiency.

COST ANALYSIS

(U) Volume 3 presents the results of a comprehensive cost analysis that estimates the costs of diverse ships and aircraft in a comparable manner. The cost estimating relationships (CERs) developed are general in order to apply to a wide spectrum of possible concepts. For surface vehicles, CERs were developed for predicting costs by the nine Ships Work Breakdown Structure (SWBS) groups of basic construction. These CERs cover the lead ship and follow-ship construction costs. For the air vehicle, several different CERs were used to estimate airframe, power-plant, and flight avionics costs. CERs were also developed to estimate the total cost to develop, procure, and operate each of the point design vehicles over a 1 S-year period.

(U) The results in Volume 3 follow from the direct application of the CERs to the point designs developed in Volume 2. For each point design, the following cost estimates are presented:

- ***Platform costs*** (for surface platforms: lead-ship and follow-ship: for air platforms: first production unit and second production unit);
- ***Vehicle costs*** (platform costs plus combat suite costs); and
- ***Life-cycle costs*** (for buys of 3, 25, and 100 vehicles).

MISSION ANALYSIS

(U) Volume 4 presents the results of the mission analysis. The search for a method to adequately quantify the military value of advanced naval vehicles (ANVs) took many paths during the course of the project.

(U) It was evident that the platform characterisitic most easily quantified was speed, which varied widely among the point designs. Considerable work was done within ANVCE on the utility of speed and the results are presented in Volume 4. This emphasis on speed, however, did not seem adequate to describe military value even though it could be quantified. Each advanced vehicle was ascribed a common combat suite, and that philosophy led to the search for other ***platform*** characteristics that would distinguish the concepts. A method was developed to discover which platform characteristics were of importance in determining the offensive and defensive capabilities of a platform when opposing the projected threat.

(U) The development of this latter methodology, which is based on the Naval Intelligence Support Center (NISC) CIRCA 2000 threat projection, is the main thrust of Volume 4. The methodology permits identification of each U.S. naval operational capability that could result if the threat develops as projected. Potential counters to the threat in terms of tactics and weapons and sensors are derived by analysis, and advanced naval vehicle performance attributes that support these counters are identified. The analysis is presented in charts that portray the traceable logic between each threat issue and vehicles attributes.

(U) As a result of the threat-oriented mission analysis, weapons and sensors play the dominant role and the significant platform characteristics turn out to be those that enhance the ANV payload capacity, those that complement the performance of weapons and sensors, and those that add to its ability to remain operational. Thus, the characteristics of importance relate to payload (reserve payload capacity and empty weight fraction), combat suite enhancement (stability, ride quality, aircraft handling suitability), and survivability (speed in high seas, reduced signatures, and vulnerability to damage).

RECOMMENDATIONS

- (U) Common cost reporting schemes should be integrated into U.S. Navy construction contracts to record actual costs in each functional area (weight groups, designs, services).

- (U) Further investigation into the costs of LTA vehicles should be preceded by the development of a data base on engineering cost estimates for today's labor rates, labor productivity, and material costs.

- (U) Payload growth potential should be carefully considered in the design of advanced naval vehicles.

- (U) Although the ANVCE Project did considerable innovative work in the study of ride quality with regard to human adaptabilities, research should be undertaken to expand on this effort in order to understand and improve the ANV's ability to handle and operate aircraft.

- (U) A complete review of survivability of all advanced vehicles, especially with regard to damage vulnerability is recommended. More analysis is needed to better determine the vulnerability of ANVs, and more research is needed to develop hardening techniques and reduction in detectable signatures.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

Chapter I
BACKGROUND

(U) The Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project was undertaken to develop the information necessary to recommend a balanced overall research and development (R&D) program for naval vehicles for the 1980-2000 time period. Such an R&D program should lead to the development of naval vehicles that satisfy three broad criteria. They must

- be technically feasible,
- have military value, and
- be affordable.

More than 200 separate studies, tests, and experiments were conducted by the ANVCE Project to identify concepts that meet these broad criteria. This volume is a brief summary of project results as they are presented in

- Volume 2 - Technical Evaluation,
- Volume 3 - Cost Analysis, and
- Volume 4 - Mission Analysis.

1. GUIDANCE

1.1 Formal

(U) The requirement to conduct an evaluation of advanced naval vehicles (ANVs) originated from budget guidance given to the Navy by the Director of Defense Research and Engineering (DDR&E) in February 1975 for the Surface Effect Ship (SES) program. While the main thrust of the guidance was concerned with a major reorientation of the FY-76 SES program, the DDR&E went further: "Conduct R&D and studies necessary to evaluate the technical and military potential and costs of other ANV concepts which offer possible alternatives to the SES." The SES Program Element guidance expanded on the DDR&E memorandum and added, "Where insufficient information exists for evaluation, analysis and testing of models on small-scale prototypes will be performed as necessary to provide it." The evaluation was to include long-range aircraft, with airborne and/or seaborne loiter capability, wing-in-ground (WIG) effect aircraft, airships, high length-to-beam (L/B) ratio SES and low L/B SES, hydrofoils, and small-waterplane-area, twin-hull (SWATH) ships.

1.2 Informal

(U) The formal budget guidance was followed by a much more detailed and comprehensive memorandum from the Navy vehicle staff specialist on the DDR&E staff that was very instrumental in setting the tone and structure for the ANVCE Project. This memorandum established some of the basic features of the ANVCE Project, such as

- the triad of technical feasibility, military value, and costs;
- development of point designs for each concept;
- substantial experimental work to provide basic data that were not available at the time;
- recognition of the importance of the platform/combat suite interdependence; and
- parametric costs.

This guidance presaged a long and difficult but necessary evaluation.

2. OPNAV PROJECT ESTABLISHMENT

(U) Under the direction of the Chief of Naval Operations CNO Executive Board (CEB), a formal project office was established, staffed, and funded to undertake the evaluation of advanced naval vehicles.

2.1 Project Directive

(U) The project directive was signed in July 1975 setting forth the objective and scope of the tasks to be performed.

2.1. I Objective

(U) The objective of the ANVCE Project, as stated in the project directive was:

> "*Objective.* The objective of the Advanced Naval Vehicles Concepts Evaluation is to examine the technology now being developed for carrying naval weapons systems and its applicability to military missions. The study will evaluate each potential advanced naval vehicle in the light of technological feasibility, affordability, and applicability to an existing or projected naval mission. The evaluation will include

examination of all potential naval vehicles using advanced technology, as well as the related areas of technology which may impact on advanced naval vehicles. It is to consider, but not be restricted to:

(1) long-range, long air or sea loiter aircraft,

(2) wing-in-ground effect aircraft,

(3) lighter-than-air vehicles,

(4) surface effect ships,

(5) hydrofoil ships, and

(6) small water area ships.

Critical examination of the technical literature, conduct of point design and model tests where necessary to fill gaps in the engineering data, examination of potential weapon system employment and interface problems, estimates of development and production costs and the impact of each vehicle examined on present or potential Navy mission areas are the principal tasks to be undertaken."

2.1.2 Scope of Evaluation

(U) As can be seen from the above guidance and the stated objective, the scope of the project could be almost limitless within the bounds of naval warfare. Only submarines and carrier-based aircraft were not included. The project was not limited to a review of vehicle technology but was urged "to fill gaps in the engineering data," "to develop point designs and design parameter trade-offs," and "to assess technical risks." In the costing area, it was not only to obtain estimates of development and production costs but also to develop "a set of consistent cost estimating relationships and the methodology for the subsequent cost analysis." In the mission analysis, the evaluation was limited to all potential missions in the time frame of 1980-2000. Some bounds had to be put on the scope of the project. The specific limitations imposed are identified in Chapter II of this volume and discussed in each of the other volumes, but the basic limitation of the evaluation was the number of point designs that could be developed within the time and funding constraints of the project. In all, 23 point designs were developed from the nine generic concepts considered in addition to four baseline designs. The nine generic concepts considered by the ANVCE Project were

- air cushion vehicle (ACV),
- air loiter aircraft,
- hydrofoil,

- lighter-than-air (LTA) vehicle,
- planing craft,
- sea loiter (S/L) aircraft,
- small-waterplane-area, twin-hull (SWATH) ship,
- surface effect ship (SES),
- wing-in-ground (WIG) effect vehicle.

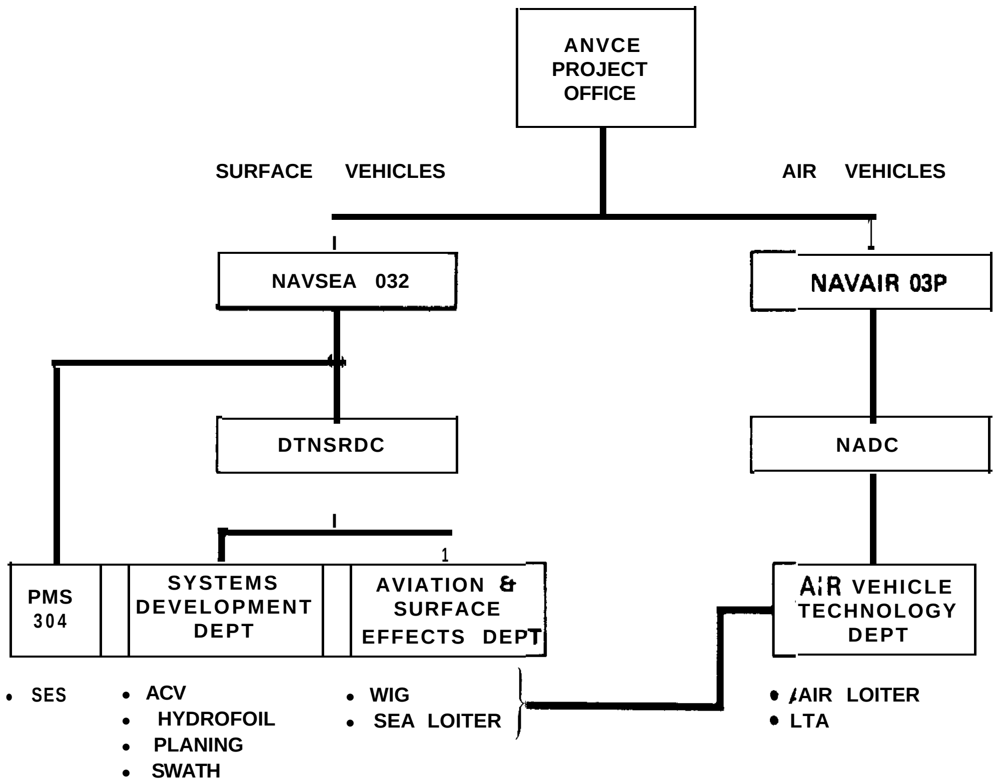
2.2 Project Organization

(U) While established as an OPNAV Project, it is evident from the extent of the evaluation to be performed, that the Project was dependent on the support of the Navy laboratories, Naval Material Command Project Officers, contracting agencies, and industry. Figure I-l shows the general layout of the project organization in terms of the point design development. Figure I-2 indicates the extent of the total project support.

2.3 Technical Review Panel

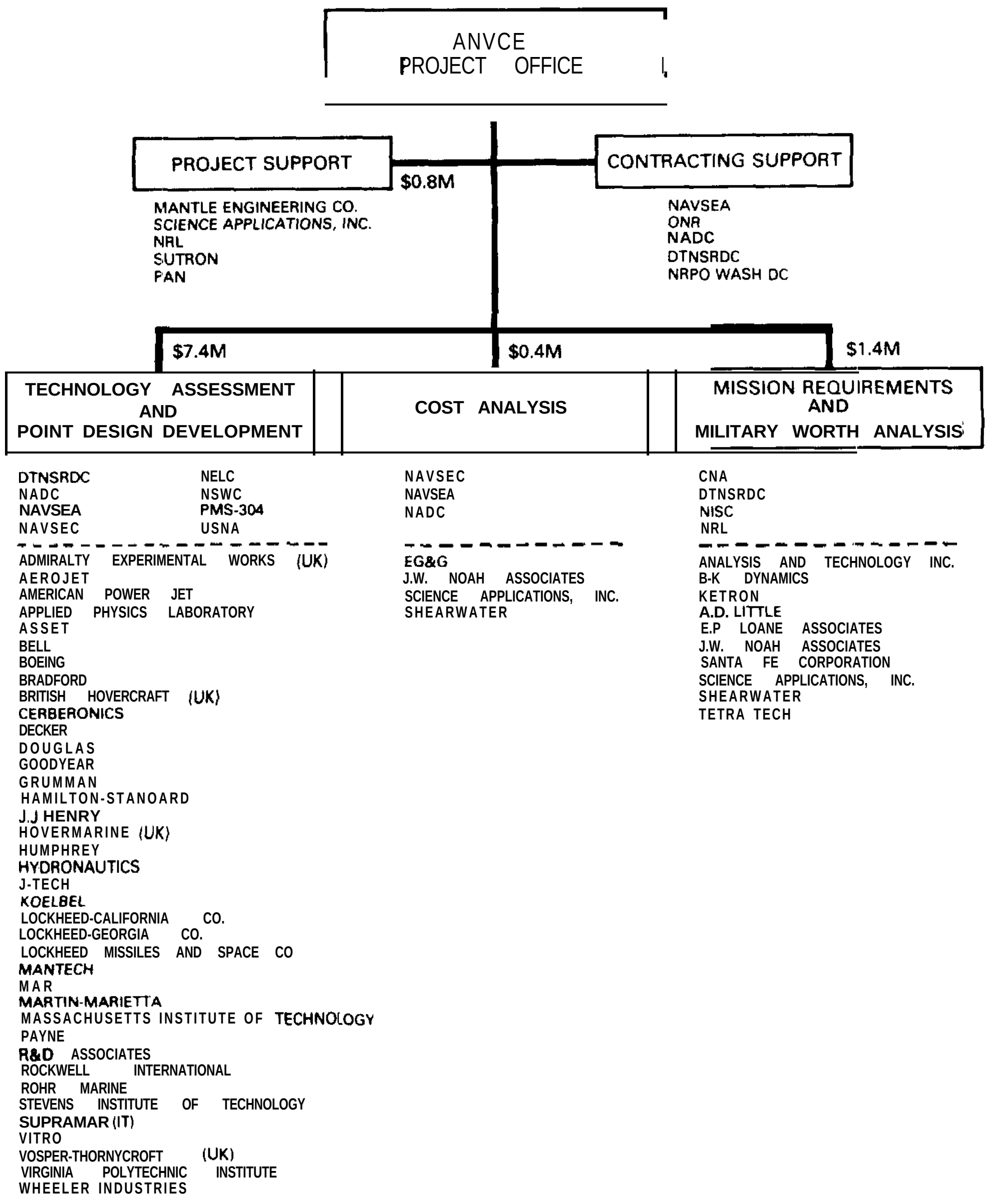
(U) In order to ensure the quality of the evaluation, a panel of independent experts from industry, academia, and government was established to provide- technical review and to monitor progress. The Technical Review Panel (TRP) was chartered to provide a timely technical review and evaluation of the working papers and reports generated by the ANVCE Project Office. The TRP reported directly to OP-96 and provided background briefings to the CNO Advisory Committee. The members of the TRP were:

NAME	ORGANIZATION	SPECIALITY
Dr. Alan Berman	NRL	Chairman
Mr. Al Eaton	APL/JHU	Combat Systems
Dr. James Kramer	NASA	Aerodynamics
Dr. Ray Hettche	NRL	Materials
Dr. Harley Jordan	OP-96D	Parametric Cost Analysis
Dr. Philip Mandel	MIT	Marine Engineering
Mr. Alex Tachmindji	MITRE Corp.	Marine Engineering
Mr. John Underwood	CNA	Operations Research



(U) Figure I- 1. ANVCE PROJECT ORGANIZATION

ANVCE PARTICIPANTS



(U) Figure I-2. ANVCE PROJECT SUPPORT

Chapter II
TECHNICAL APPROACH

(U) The basic ANVCE technical approach involved the exploration of the nine generic concepts and the identification of technical limits as specific issues requiring further investigation. Each issue was then addressed by a separate study, experiment, or a point design. From the nine generic concepts, 23 point designs were developed for advanced vehicles and four baseline point designs were developed for comparison. All ANVCE point designs were based on a set of common standards, technology levels, and combat suites. The point designs then became input data to the cost and mission analyses.

1. PRINCIPAL ASSUMPTIONS

(U) In 1974 the Chief of Naval Operations (CNO) directed that a study be undertaken to determine those trends most likely to affect the shape of the U.S. Navy through the year 2000. Periodic studies of this broad scope and extended range are required because of the long procurement lead times and service lives of naval platforms. This study, referred to as Project 2000. was intended to offer planners at all levels a comprehensive, long-range environment in which to consider Navy missions, available and anticipated technological opportunities, and the projected military threat. Conceptual rather than analytical in approach, the first phase of Project 2000 nonetheless provided an internally consistent view of the political, economic, and strategic world environment through the turn of the century and of a fleet considered appropriate to that environment. While not promulgated by the CNO as a definitive Navy position, the Project 2000 study was disseminated to provide a common ground in discussing and analyzing a wide variety of ideas and proposals,. In that spirit, the ANVCE Project used the Project 2000 assumptions and findings as a basis for its analysis.

(C) Based on the environment projected by Project 2000, the principal assumptions used in evaluating the ANV concepts are that

- the functions performed by the U.S. Navy in 2000 will be the same as those performed today-sea control (including sea denial) and projection of power;
- the United States will continue to be dependent on overseas resources and markets, leading to an expansion of both commercial maritime activities and naval operations;

- the size and capability of the Soviet Navy will continue to pose the primary threat to U.S. naval forces and that threat will continue to increase;

- the Soviet Navy has the capability of employing multiple, coordinated, antiship warfare techniques involving surface, subsurface, and airborne delivery platforms; and

- future naval vehicles must be capable of handling the diverse threat, and to make sure that they will have the necessary flexibility to meet future requirements over a long service life, they **must** be capable of performing multiple missions.

In short, the environment envisioned for circa 2000 is much like that of today. What may change, however, are the techniques by which naval operations are carried out, brought about by changes in technology affecting our forces and the probable threat.

1.1 Technical Evaluation

(U) Two additional major assumptions were made in regard to the technical evaluation. First, it was assumed that current development cycles for a new platform will continue to be approximately 16 years from start of Category 6.3 (Advanced Development) to initial operational capability (IOC), as illustrated in Figure II-l. Accordingly, for an IOC on or before the year 2000, the technology of the platform must be available by about 1984-85. Therefore, a technology "freeze" or base of 1985 was assumed for the technical evaluation.

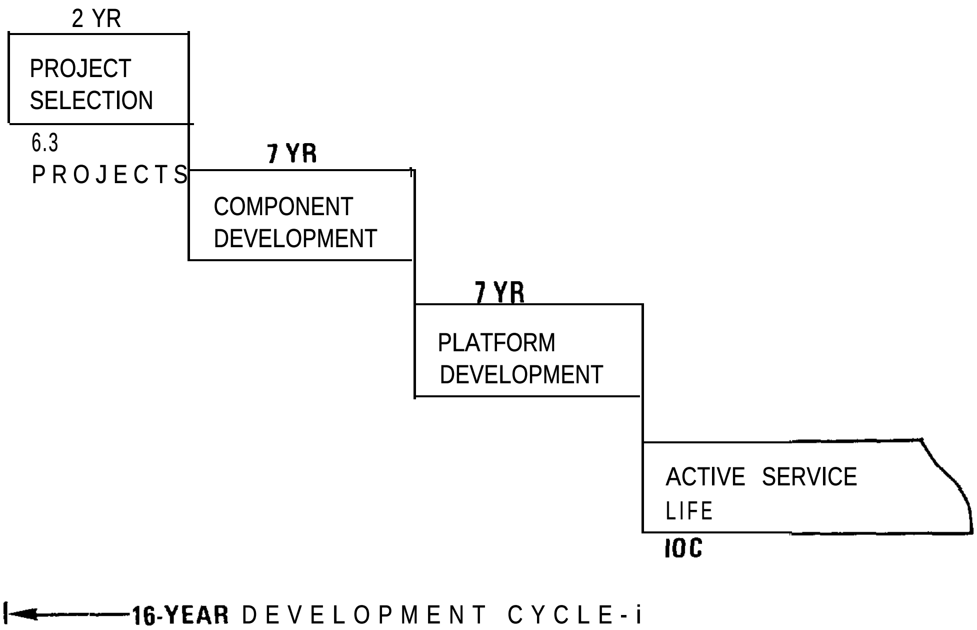
(U) Second, given that the Navy of the future will require multi-mission vehicles, the point designs were developed and evaluated within that context. This assumption precluded the optimization of one vehicle for a single, specific mission for which it might be particularly well suited and in which the uniqueness of the vehicle could be fully exploited.

1.2 Cost Analysis

(U) The overall ground rules and key assumptions used in the cost analysis are as follows:

- All costs are expressed in FY-77 dollars unless otherwise stated, and FY-77 dollars are discounted at 10 percent. The use of constant dollars was agreed upon early in the ANVCE study.

- A 15-year operating period is assumed for all vehicles. Vehicles with service lives greater than that are credited with their residual value at the end of 15 years.



(U) Figure II-l. DEVELOPMENT CYCLE FOR A NEW PLATFORM

- No surface vehicles are purchased solely for R&D purposes. The cost of conducting the required R&D is estimated; however, the cost of the platform used in the research, development, test, and evaluation (RDT&E) is charged against investment costs.

- One air vehicle is purchased out of the R&D (appropriation; any other vehicles required for RDT&E are assumed to become operational at some later time and are charged against investment costs.

- For the investment phase of all surface platforms, an identical learning rate of 97 percent was used; for all air platforms the learning rate was 80 percent. These learning rates represent cumulative average learning.

- Associated systems costs are charged against any surface vehicle that requires at-sea refueling. These costs are estimated by determining the fraction of an underway replenishment (UNREP) unit required to provide at-sea refueling. The UNREP unit consists of one AOR-7. Both investment and operations and support (O&S) costs of the fractional UNREP unit are considered.

- ANVCE cost estimates include outfit and postdelivery costs that are not usually included in Navy acquisition cost displays.

1.3 Mission Analysis

(U) No additional assumptions were required for the mission analysis.

2. APPROACH

2.1 Technical Evaluation

(U) The concepts developed in this project are generalizations of the examples of such hardware in existence today. In order to avoid discarding an entire concept because of some limitation seen in an existing vehicle, it was imperative that the approach to the technical evaluation be both general enough to recognize the capabilities of the concept yet specific enough to describe a point design that would be useful for cost and mission analyses.

(U) The general technical approach used is as follows:

- ***Concept-Tree Development.*** A concept tree was prepared for each concept in order to determine all the likely technical avenues that could be explored for that particular concept. This procedure served to bound the problem and maintain a concept-oriented evaluation as opposed to one oriented toward a specific vehicle. The concepts were developed concurrently with preparation of state-of-the-art summaries and provided a check-and-balance mechanism for the overall technical effort.

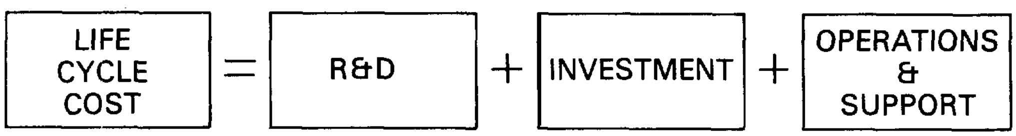
- ***Features and Issues Development.*** After a preliminary bounding of the problem through the use of the concept tree, attention was given to identifying as explicitly as possible the features of' the concept that would indicate merit as a naval platform. In addition to the features, the technical issues of each concept were identified. Some issues were explored through technical analyses, model experiments, feasibility designs, or a combination of all three; others were beyond the scope of this project and could not be explored but were considered in terms of technical recommendations.

- ***Analyses, Experiments, and Point Designs.*** If it appeared that an issue could be resolved or partially resolved within the scope and resources of the ANVCE Project, an analysis, an experiment, a feasibility design, or a combination of these procedures was used to resolve it. Such information might fill in a gap in data on the concept or determine the feasibility of a technical design, a given size, etc. Such efforts were primarily designed to create a more uniform data base for use in the evaluation. but often served to advance the state of the art.

2.2 Cost Analysis

(U) The four principal factors that contribute to the life cycle costs (LCCs) of a vehicle are shown schematically in Figure 11-2. Each of these major cost elements (and subelements) is defined and discussed in detail in Volume 3. For each of these cost elements, emphasis was placed on achieving consistency in the cost estimates across all the vehicles being considered. This consistency was achieved by (a) applying the same basic LCC structure to all the vehicles and (b) formulating the cost estimating relationships (CERs) such that cost differences between vehicles would be due solely to differences in the platform's characteristics.

(U) The estimated costs were computed from CERs derived from historical data and modified where necessary to reflect technological differences. The CERs were adjusted to reflect differences between ANVCE point designs and the CER data base. In the case of surface vehicles, Naval Sea Systems Command (NAVSEA) planning factors were used to reflect costs to the Navy above the actual basic construction costs as reflected by the contracting shipyard. In the case of air vehicles, the cost to the Government is included in the data base development.



(U) Figure II-2. COST METHODOLOGY

2.3 Mission Analysis

(U) The methodology selected to determine ANV performance characteristics that are important to future threat issues involved four steps. These steps were necessary to present the direct and indirect relationships between platform performance characteristics and future threat elements. The methods employed in each step of the analysis are primarily qualitative and should not be considered as an attempt to include all aspects of an engagement between an ANV and a threat platform.

(U) The first step of the analysis was the identification of critical threat issues based on CIRCA 2000 estimates for each of three areas: the submarine threat, the threat posed by land-based aircraft, and the threat presented by surface platforms including sea-based aircraft. The major criteria used in selecting the threat issues for analysis were those of significant performance advances and increases in force levels as they applied to either the threat platforms lhemselves or to their weapons and sensor suites.

(U) The second step of the analysis involved the identification of potential operational deficiencies that could result if threat projections became a reality and current U.S. capabilities were not upgraded.

(U) In the third step, new or improved U.S. naval systems that could minimize or remove these operational deficiencies were identified.

(U) The final step was to determine which platform performance characteristics were affected by each countermeasure approach. The characteristics of interest could have a direct bearing on operations (speed, maneuverability, etc.) or could indirectly support the operation of aircraft, weapons and sensors (payload capacity, ride quality, etc).

(U) The steps described above are depicted graphically in Volume 4 of this report. The antisubmarine warfare (ASW), antiair warfare (AAW), and antisurface ship warfare (ASUW) threats were treated separately to determine which surface platform characteristics are sensitive in a direct confrontation with each enemy weapons system. The ANV platform characteristics that are significant in opposing the projected total threat can then be deduced. These attributes would be desirable for a multimission vehicle.

3. LIMITATKONS

(U) In establishing the ANVCE Project, several kinds of limitations were imposed. First, there were those implied within the charter or the informal guidance associated with the charter. For example, submarines were specifically excluded from the list of candidate advanced vehicle concepts. Moreover, a common thread among the generic air vehicle concepts to be considered was the requirement for long endurance to carry out the maritime patrol aircraft missions. Therefore, advanced, carrier-based, naval aircraft were excluded.

(U) The second type of limitation evolved from the guidance of the Director, Defense Research and Engineering that the Navy was to evaluate "other advanced naval vehicle concepts which offer possible alternatives to the SES (surface effect ship)". This guidance forced the evaluation of the other generic concepts in the multimission context in order to be comparable to the multimission capability of the SES.

(U) The third limitation was one of resources, both time and funds.

3.1 Technical Evaluation

(U) The time and money limitations were felt most directly in the technical evaluation. These resources restricted the number of configurations that could be examined, and then, the selection of concept candidates became a major factor in limiting the scope of the overall evaluation.

(U) A limiting factor that the ANVCE Project imposed on itself was the exclusion of hybrid vehicles. It was felt that the data available on these vehicles were neither of sufficient quantity nor consistency for a meaningful evaluation. Despite this limitation, care was taken to interpret the generic concepts in the broadest sense.

3.2 Cost Analysis

(U) There were no specific preset limitations on the cost analysis. It was known at the outset, however, that much of the cost data base is considered proprietary. This limited the ability to explore the trade between labor and material costs in examining vehicle differences.

3.3 Mission Analysis

(U) Time and resources also were a limiting factor in the mission analysis. The guidance described in Chapter I placed virtually no limits on the missions to be performed by the ANVs. The original intent of the evaluation was to examine each vehicle performance in the operations projected for the Navy by Project 2000. This involved 12 major operations and numerous tactical scenarios. It soon became evident that designing a navy for specific scenarios that might occur in the next 20 years is very risky because of the confidence level of such long-range projections. The cost-effectiveness analysis based on these scenarios did not prove useful, as explained in Volume 4, and a new, qualitative threat-oriented methodology was developed late in the project; as a result, the extent of analysis in Volume 4 was limited by time constraints.

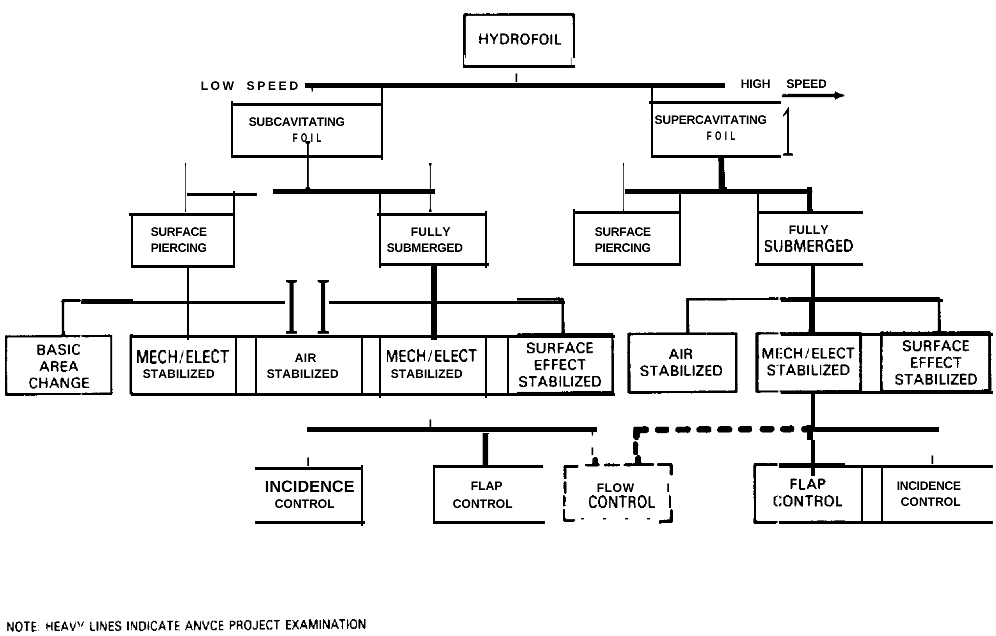
Chapter III
ANVCE PRODUCTS

1. TECHNICAL EVALUATION

(U) Appendix A of this volume contains a list of the documents and reports generated by the ANVCE Project. The majority of these reports are concerned with the technical evaluation of all advanced concepts. This chapter is a brief summary of some of the more interesting and useful products of this endeavor. Volume 2 presents a complete review of the technical evaluation.

1.1 State-of-the-Art Assessments

(U) In each of the generic concepts investigated, an. exhaustive review was made of the state of the art. The primary approach to this process was the concept tree by which all configurations of the concept could be identified. Those configurations that offered the most likely return on the research investment were chosen to be developed into point designs. Even though all possible configurations were not developed into point designs, the technical assessments indicate the possible alternative vehicles that should be explored further. The concept tree for the hydrofoil is shown in Figure 111-l as an example.



(U) Figure III- 1. CONCEPT TREE (HYDROFOIL)

1.2 Analyses and Experiments

(U) Where gaps in the technology were found, analytic investigations, as well as physical experiments, were initiated to obtain the data needed to produce a useful point design. In this way, the ANVCE technical evaluation not only provided a review of the state of the art but also advanced it.

1.3 Point Designs

(U) A major part of the technical evaluation was the preparation of the point designs. The generation of these designs is depicted in Figure III-2. As can be seen from the figure, during the course of the technical evaluation the nine generic concepts were expanded into 19 configurational forms. Each configurational form represented a different path of development so that all features of interest could be evaluated. Twenty-three specific point designs were finally developed to resolve feasibility issues and provide representative points for further analysis. Each point design represents a unique vehicle out of a spectrum of possible configurations.

9 GENERIC VEHICLE CONCEPTS	19 CONFIGURATIONAL FORMS	23 POINT DESIGNS
AIR CUSHION VEHICLE	AMPHIBIOUS	LCAC
	NONAMPHIBIOUS	ACV 1, ACV 3
HYDROFOIL	SUBCAVITATING	HYD 2
	SUPERCAVITATING	HYD 7
PLANING HULL	SUBCRITICAL	LCPC, PC 1
	SUPERCRITICAL	(NONE)
SURFACE EFFECT SHIP	NUCLEAR	SES CVN
	NONNUCLEAR	SES 3, SES CV
SWATH SHIP	NUCLEAR	SWA CVN
	NONNUCLEAR	SWA 4, SWA MCM
AIR LOITER AIRCRAFT	NUCLEAR	A/L (N)
	NONNUCLEAR	A/L
LTA VEHICLE	FULLY AIR-BUOYANT	FAB
	SEMI AIR-BUOYANT	SAB
SEA LOITER AIRCRAFT	LARGE C/STOL	S/L (L)
	SMALL C/STOL	S/L (S)
	SMALL V/STOL	S/L (V)
WIG VEHICLE	IN-GROUND-EFFECT CRUISE	WIG (H), WIG (S)
	OUT-OF-GROUND-EFFECT CRUISE	WIG (O)

(U) Figure III-2. EXPLORATION OF CONCEPTS AND VEHICLES UNDER EVALUATION

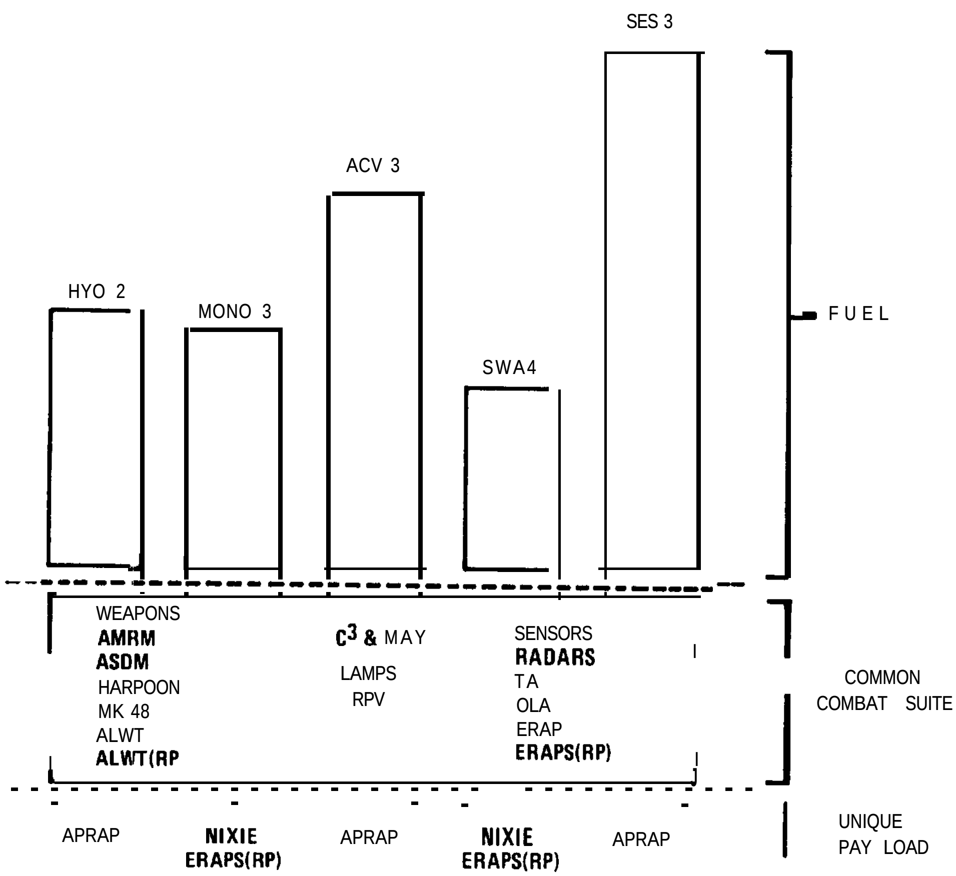
1.3.1 Consistent Design Standards

(U) The ANVCE Project could find no set of standard definitions or common design standards within the advanced vehicle technical community. This made performance and cost comparisons most difficult. When comparing one point design with another, it was extremely important that the designs be developed using a standard set of design standards. Considerable effort was expended early in the project to ensure that such standards were prepared and issued prior to developing the point designs (Appendix A of Volume 2). This set of standards should be useful :in further analyses of advanced vehicles. The common design standards specifically involved include

- common definitions of
  - standard day conditions,
  - sea-state characteristics,
  - winds aloft,
  - speed and power,
  - lift/drag ratio,
  - transport efficiency,
  - range, and
  - weight groups;
- common levels of technology for
  - engine performance,
  - propulsor characteristics,
  - materials characteristics, and
  - range; and
- common criteria for
  - weight margins and
  - performance margins, including
    - hump thrust,
    - fuel reserves and range,
    - ride quality,
    - vehicle system design,
    - habitability standards, and
    - survivability and vulnerability requirements.

1.3.2 Common Combat Suites

(U) In addition to the consistency standards in design, the ANVCE Project adopted a philosophy of common combat suites for 'vehicles of approximately the same size. In this way, the point designs of similar size could be evaluated in such a way that any differences would, for the most part, be platform differences. The common suites included weapons; sensors; command, control, and communication (C^3) systems; navigation systems; and secondary vehicles. Slight variations were allowed in the combat suites if the variation was directly attributable to a platform concept characteristic, e.g., the active/passive. reliable acoustic path (APRAP) sensor, which requires a platform with a high-speed capability to offset the "dead-in-the-water" listening time, was placed on the high-speed vehicles but not on the slower-speed vehicles. The common combat suite philosophy is illustrated in Figure III-3 for the 3000-tonne group. The amount of fuel used varied with the mission and could not be arbitrarily set. The comparisons in Figure III-3 indicate the relative efficiencies. The common combat suites are described in Appendix A of Volume 2 a:nd offer a "shopping list" for future point design development. The MONO 3 is a baseline point design.



(U) Figure 111-3. COMMON COMBAT SUITE PHILOSOPHY

1.3.3 Ride Quality Criteria

(U) One of the most interesting collateral issues to arise during the ANVCE effort was that of ride quality not only of advanced concepts but also of conventional displacement ships. It was discovered that the issue was treated differently by each advocate and there was no coordinated research program on the subject. The ANVCE Project expended a considerable effort on this problem and developed ride-quality criteria based on crew acceptability. Much more research, however, is needed in this area, not only in the field of human tolerance but also on aircraft operation and handling.

2. COST ANALYSIS

(U) The ANVCE cost is the most comprehensive such an analysis of ANVs conducted to date, in that it attempts to estimate the costs of diverse ships and aircraft on a generally comparable basis. The results follow directly from the technical approach described in Chapter II.

2.1 Cost Estimating Relationships

2.1. I Platform Costs

(U) For surface vehicles, CERs were developed for predicting the costs by the following nine SWBS groups of basic construction:

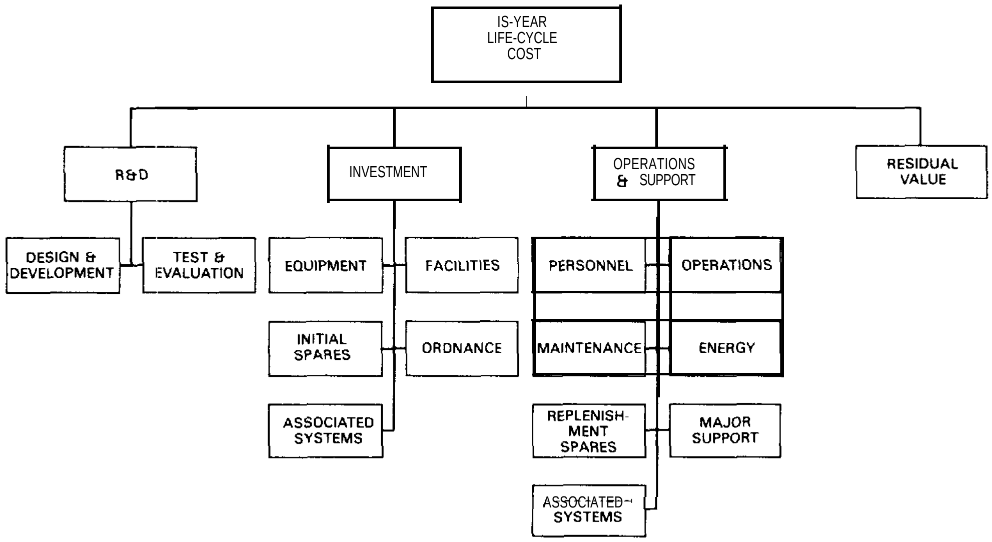
GROUP	DESCRIPTION
	Hull structure
2	Propulsion
3	Electric plant
4	Communication and control
5	Auxiliary systems
6	Outfit and furnishings
7	Armament
8	Design and engineering services
9	Construction services

The CERs cover the lead-ship and follow-ship construction costs

(U) For the air vehicles, several different CERs were used to estimate airframe, power plant, and flight avionics costs. For airframes, different CERs were used for heavier-than-air (HTA) and lighter-than-air (LTA) estimates because of the very different manufacturing methods and methodologies involved. Three CERs were used for the power-plant estimates: one for turbo-jet/fan engines, one for turboshaft engines, and one for turboprop engines.

2.1.2 Life-Cycle Costs

(U) CERs were developed to estimate the total cost to develop, pro cure, and operate each of the point design vehicles over a 15-year period. The cost elements included are shown in Figure III-4 as appropriate for surface and air vehicles.



(U) Figure 1114. MAJOR LIFE-CYCLE COST ELEMENTS

2.2 Results

2.2.1 Platform Costs

(U) The terminology and methodology for estimating platform costs were different for surface and air platforms. For surface platforms, the significant terms are lead-ship platform cost and follow-ship platform cost. The lead-ship platform cost includes the detailed design cost, the construction cost attributed to each SWBS group, government-furnished equipment (GFE) costs, and appropriate NAVSEA planning factors to account for such items as profit, change orders, government laboratory support, and outfitting and furnishing.

(U) For air platforms the significant term is the first-unit production cost, which includes the cost of the airframe, engines, and avionics but does not include the combat suite items or detailed design costs.

(U) The estimated costs of the first and second platform con [redacted] are summarized in Table III-l. Second-platform costs (first follow-ship platform cost for surface vehicles; second-production-unit cost for air vehicles) are included in the table since this is the first stage at which detailed design costs are not included in either the surface or air vehicle cost estimates.

(U) Volume 3 presents the results of platform cost analyses by SWBS group and by the size of the buy for surface vehicles and by major cost group and size of buy for air vehicles.

2.2.2 Vehicle Costs

(U) Vehicle costs consists of platform costs plus combat suite costs, including the costs of the basic equipment, related expendables (e.g., ordnance), and subvehicles. Thus, the results discussed include (a) the average cost of the individual vehicles as a function of the size of the buy, which reflects the impact of the learning rate, and (b) the breakdown of average costs by platform costs and combat suite costs (including ordinance and subvehicles).

(U) The estimated costs of the first and second vehicles (surface and air) constructed are summarized in Table 111-2. The difference between the costs of the first and second vehicles primarily results from the change in platform costs. For surface vehicles, the cost of the combat suite for the follow vehicle is generally 10 percent lower than that for the lead vehicle. After the first follow vehicle, no further learning-rate reductions occur. For air vehicles, the cost of the combat suite is the same for the second vehicle (and all other vehicles) as that for the first vehicle, i.e., no learning was assumed for the air combat suite.

(U) The principal findings regarding the vehicle costs for the surface and air vehicles are as follows:

- Combat suite costs are proportionately greater for surface vehicles than air vehicles equipped for similar missions.
- The costs for small buys of all multimission, air combatants except the fully air buoyant (FAB) vehicle, are in the same range as those for multimission, surface combatants; however, because of the high learning rate associated with the air platforms, cost decreases quite rapidly with number procured.
- The larger the vehicle, the larger the combat suite cost portion of the total cost, the tendency being to add additional combat suite capability to the additional platform capability but at a greater rate.

[redacted]able III-1. SUMMARY OF SURFACE AND AIR PLATFORM COSTS (U)

VEHICLE	SURFACE PLATFORM ($ MILLION)		AIR PLATFORM ($ MILLION)	
	LEAD-SHIP	FOLLOW-SHIP	FIRST PRODUCTION UNIT	SECOND PRODUCTION UNIT
ACV 3	468	214		
HYD 2	490	223		
SES 3	529	241		
SWA4	366	170		
MONO 3	386	178		
ACV 1	339	158		
HYD 7	311	145		
PC 1	212	101		
WIG(S)	266	125		
SES CV	1,241	539		
SES CVN	1,295	638		
SWA CVN	1,130	550		
LCAC	35	24		
LCPC	14	9		
SWA MCM	175	114		
WIG(H)			462	277
A/L			318	191
A/L(N)			882	529
FAB			63	38
S/L(L)			606	364
WIG(O)			685	411
SAB			44	26
S/L(S)			162	97
S/L(V)			86	52
AVP			186	112

2.2. *3 Life-Cycle Costs*

(U) Life-cycle costs, based on an operating period of 15 years, were computed for each of the point designs considered in the ANVCE Project. Computations for "buys" of 3, 25, and 100 vehicles are given in Appendix C of Volume 3. Table III-3 summarizes the estimated LCC for a buy of 25 vehicles according to the four major LCC categories – R&D, investment, O&S, and residual value.

(U) The most immediate observation is that the LCC results correlate almost directly with the platform and vehicle cost results presented above. That is, there were no cases in which the higher vehicle costs were offset by reduced R&D or O&S costs. This correlation partially results from the fact that three of the O&S CERs (operations, maintenance, and major support) use the vehicle weight and costs as inputs and the principal R&D CER uses platform and combat: suite costs as inputs.

[redacted]

[redacted] Table III-2. COSTS OF FIRST AND SECOND VEHICLES (U)

VEHICLE	FIRST - VEHICLE COST (FY-77 $ MILLIONS)			SECOND - VEHWCLE COST (FY-77 $ MILLIONS)		
	PLATFORM	COMBAT SUITE	VEHICLE	PLATFORM	COMBAT SUITE	VEHICLE
ACV 3	468	183	651	214	162	376
HYD 2	490	183	673	223	162	365
SES 3	529	183	712	241	162	403
SWA 4	366	180	546	170	159	329
MONO 3	386	180	566	178	159	337
ACV 1	339	68	407	158	58	216
HYD 7	311	74	385	145	63	208
PC 1	212	74	286	201	63	164
WIG(S)	266	68	334	125	58	183
SES CV	1.241	867	2,108	539	807	1,346
SES CVN	1,295	867	2.162	638	807	1.445
SWA CVN	1.130	1,096	2,226	550	1,036	1.586
A/L	318	25	343	191	25	216
A/L(N)	682	36	918	529	36	565
FAB	63	37	100	38	37	75
S/L(L)	606	24	630	364	24	388
WIG(O)	685	26	711	411	26	437
SAB	44	9	53	26	9	35
S/L(S)	162	5	167	97	5	102
S/L(V)	86	3	89	52	3	55
AVP	186	6	192	112	6	118
LCAC	35	6	41	24	5	29
LCPC	14	7	21	9	5	14
SWA MCM	175	90	265	114	81	195
WIG(H)	462	0	462	277	0	277

(C) Table III-3. SUMMARY OF LCC's FOR A BUY OF 25 VEHICLES (U)

VEHICLE	COST (FY-77 $ BILLIONS)									
	UNDISCOUNTED					DISCOUNTED AT 10 PERCENT				
	R&D	INV	O&S	RESIDUAL VALUE	15-YEAR LCC	R&D	INV	O&S	RESIDUAL VALUE	15-YEAR LCC
ACV 3	1.0	10.6	7.8	1.0	18.4	0.4	2.1	0.6	b	3.0
HYD 2	1.0	10.7	6.0	1.1	16.6	0.3	2.2	0.4	b	2.9
SES3	1.2	11.3	7.9	1.1	19.2	0.5	2.3	0.6	b	3.3
SWA 4	0.9	9.3	5.2	0.8	14.5	0.3	1.9	0.4	b	2.5
MONO 3	1.3	9.5	5.2	0.8	15.1	0.5	1.9	0.4	b	2.7
AC" 1	0.7	5.9	5.1	0.7	10.9	0.2	1.2	0.4	b	1.7
HYD 7	0.8	5.6	3.6	0.7	9.3	0.3	1.1	0.3	b	1.7
PC 1	0.5	4.5	3.2	0.5	7.8	0.2	0.9	0.2	b	1.3
WIG(S)	0.6	5.1	6.0	0.3	11.4	0.3	1.0	0.5	b	1.7
A/L	2.0	3.6	1.5	0.3	6.8	0.8	0.6	0.5	b	1.5
A/L(N)	7.7	8.8	2.4	0.8	18.0	3.9	1.6	0.2	b	5.6
FAB	0.4	1.7	1.2	0.1	3.2	0.1	0.3	0.1	b	0.5
S/L(L)	4.4	6.0	1.8	0.6	11.7	1.7	1.1	0.1	b	2.9
WIG(O)	4.0	6.8	2.4	0.6	12.5	1.7	1.2	0.2	b	3.1
SAB	0.3	0.7	0.7	**	1.7	0.1	0.1	0.1	b	0.3
S/L(S)	1.9	1.6	0.6	0.2	3.9	0.5	0.3	**	b	0.9
S,L(V)	2.1	0.9	0.4	0.1	3.3	0.9	0.2	**	b	1.1
AVP	1.3	1.8	0.8	0.2	3.8	0.4	0.3	0.1	b	0.8
SES CV	3.2	39.7	20.5	2.6	60.8	1.4	8.0	1.5	0.1	10.8
SES CVN	5.3	42.0	20.6	3.0	64.9	2.7	8.5	1.6	0.1	12.6
SWA CVN	3.3	47.3	26.4	4.5	72.5	1.1	9.5	2.0 t	0.1	125
LCAC	0.1	0.8	0.5	0.1	1.2	b	0.4	0.1	b	0.5
LCPC	b	0.4	0.3	b	0.7	b	0.2	0.1	b	0.3
S'NA MCM	0.4	5.5	5.0	0.9	10.0	0.3	2.9	1.0	0.1	4.1
WIG(H)	4.0	4.1	2.1	0.4	9.7	1.7	0.7	0.2	b	2.6

b . Less than $0.05 million

[redacted]

3. MISSION ANALYSIS

(U) Early attempts to evaluate each group of point designs on a head-to-head, cost-effectiveness basis had to be abandoned when it became apparent that these results could bring about more confusion than enlightement. The ANVCE Project was well aware throughout the effort that the quantification of military value would be difficult for such a wide spectrum of concepts. The two main reasons for the difficulty with cost-effectiveness analysis in the ANVCE were: (a) the variations in performance among the concepts are either so large that the concepts should not be compared in the same missions or (b) the vehicles (as projected) were so similar that the differences in performance cannot be estimated. For example, although there are many differences between the advanced ACV and the advanced SES, it is difficult to model these conceptual vehicles and obtain quantified differences in effectiveness. Thus, the least expensive of two will always appear the most "cost-effective", which may not be the case. On the other hand, dissimilar concepts such as the 30-kt SWATH ship and the 200-kt WIG vehicle will most likely be employed differently, and no single measure of effectiveness (MOE) is satisfactory.

(U) It became evident that, in most representative scenarios, the platform attribute most easily modeled and most easily distinguishable among the concepts was speed. This led to considerable analysis of the utility of speed in surface vessels, and the results of this analysis are a valuable by-product of the ANVCE military mission analysis. This emphasis on speed, however, did not seem adequate to describe military value even though it could be quantified. Each advanced vehicle was ascribed a common combat suite and that philosophy led to the search for other *platform* characteristics that would distinguish the concepts. A method was developed to discover which vehicle characteristics were of interest in determining the value of a platform. This method, although qualitative, is based on the needs of advanced platforms in confrontation with the expected threat.

3.1 Threat Assessment Methodology

(U) In an effort to sort out the platform characteristics that should receive the most attention when considering future combat vehicles it was decided that all aspects of the projected threat must be examined and all potential deficiencies identified. Platform characteristics that contribute to the removal of potential deficiencies would then be considered to have the most military value. This methodology is described in Volume 4. It is flexible, traceable and dynamic, and it appears that it could also be the basis for a thorough analysis of the military value of weapons and sensors.

3.2 Significant Platform Characteristics

(U) The outcome of the threat assessment provided better insight into the significance of certain platform characteristics in a conflict environment. Two required characteristics are carrying capacity and survivability. Even with the common combat suite philosophy of the ANVCE Project this fact cannot be overlooked in the search for platform characteristics of importance. This points to the importance of such platform attributes as reserve payload capacity, empty weight fractions, ride quality, stability, etc. In other words, a most important characteristic of an advanced vehicle is the ability to carry and operate weapons and sensors. A second most important characteristic of any vehicle is its ability to survive and defeat the projected threat. This capability translates into another related group of characteristics; reduced vulnerability, reduced signatures (acoustics, infrared, visual, and radar), speed (especially in a high sea state), and maneuverability.

3.3 Utility of Speed

(U) Since one distinguishing feature of advanced vehicles is speed, extensive review of the utility of speed was undertaken. The results of this work are presented in Appendix A of Volume 4 and are considered a valuable contribution to the understanding of advanced vehicles. In addition to the quantifiable advantage of high speed and retained speed in a high sea state, as discussed in Volume 4, there are intangible advantages to be considered such as increased tactical options.

Chapter IV
FINDINGS AND RECOMMENDATIONS

1. GENERAL

1.1 Platform/Combat Suite Interface

(U) The ANVCE Project found significant uncertainty and misinformation about helicopter deck-handling limits, remotely piloted vehicles (RPV) launch and recovery requirements, towed-array reeling requirements, etc., within the design communities. These differences led to very different conclusions as to the acceptability of a particular platform design concept. Moreover, while a displacement-hull ship, because of its buoyant nature, can be enlarged to accommodate a weapons system that may not have been developed for the platform; it is possible that a dynamic ANV cannot. In developing dynamic ANVs, plal.form and combat suite designers must work very closely together, as is done in the aircraft community.

(U) The combat systems data sheets developed by the ANVCE Project for use by the surface platform community proved useful. Such sheets (expanded in content, given wider distribution, and updated as new combat system information becomes available) could assist in attaining a closer interface between the designers working in the two communities. In addition, seminars held on a regular (annual or semiannual) basis would be useful for exchanging design information on capabilities and limitations of developing systems between the two communities.

1.2 Platform/Cost Interface

(U) The ANVCE Project found that for the platform/cost interface as for the platform/combat suite interface a close working relationship must be established between the cost and design staffs. Too often considerable effort was spent in improving the design and performance of a particular subsystem in a vehicle at a significant cost increase without significantly improving the overall vehicle performance. On the other hand, considerable effort was sometimes spent in reducing the cost of a specific component by as much as a factor of four, only to find that the resultant effect on the cost of the total vehicle was less than the uncertainty in the vehicle cost.

(U) The ANVCE Project sought to develop common cost-estimating relationships which could be used over the wide spectrum of air and surface vehicles. Because of the many areas of advanced technology involved in the various ANVCE concepts, it is natural that widely differing costing methods were developed and used prior to the establishment of this Project and, consequently, cost comparisons were difficult.

1.3 Cost-Effectiveness

(U) The ANVCE cost analysis is a most comprehensive cost analysis of advanced naval vehicles and it attempts to estimate costs of diverse ships and aircraft on a genuinely comparable basis. Applying techniques and estimating relationships to such a wide variety of vehicles required that they be quite general relationships and not equally applicable to each concept.

(U) On the effectiveness side, the difficulty of quantifying equitably the military effectiveness of a wide variety of point designs was recognized early in the project. The technical risks associated with the individual concepts differ markedly and the point designs are extrapolations in various levels of technical maturity. Therefore, the characteristics which are given each point design in Volume 2 are only approximations which may vary as the state of the art varies and any measurements of vehicle effectiveness should take this into account.

(U) Because of these uncertainties in both cost and effectiveness, the considerable amount of cost-effectiveness analysis done by the Project in conjunction with specific tactical scenarios was considered to be incomplete and the results are not incurred in this report.

2. TECHNICAL EVALUATION

2.1 Concepts

2.1.1 Air Cushion Vehicle

(U) The uniqueness of the ACV lies in the fact that it is independent of the surface, which makes it ideally suited for amphibious operations. Since the state of the art in ACV technology permits craft of up to 300 tonnes with a speed of 70 kt, development of an amphibious craft of 150 tonnes displacement (carrying one main battle tank) with a speed of 50 kt is low risk. Development and subsequent production of these craft should continue but the technical designs should be optimized to significantly reduce the cost rather than to improve performance any further.

(U) The technical risk areas in the development of the ACV are

- skirt sizes for ACVs of more than 3000 tonnes displacement would strain the capability of manufacturing looms; and
- air propulsion, using conventional air propellers (shrouded or unshrouded), becomes impractical for ACVs of more than 4000 tonnes; at this point, water propulsion (screw propeller or waterjet) becomes less of a risk.

Intensive studies should also be made to determine methods to significantly reduce cost in the manufacture of ACV subsystems.

2.1.2 Hydrofoil

(C) The uniqueness of the hydrofoil is that it is a multimode, variable-geometry concept. It can operate alternately as a monohull displacement ship and as a foilborne craft in many different configurational forms. An additional unique capability of the hydrofoil concept has been demonstrated in connection with mine warfare. Demonstrations have shown that two small hydrofoil ships can, by operating close together in tandem formation, generate a pressure field in the water equivalent to that of a much larger displacement ship. Thus, by passing through a mine field, this hydrofoil team can detonate the mines. Because of their speed, such detonations occur behind them and do not inflict damage to the hydrofoil ships.

(U) ***Once a 50-kt PHM class is in operation, its ships should be fitted with variable-geometry foils to give them a dash capability of 70-80 kt.*** The tactical, open-ocean use of such a foil is best explored under actual conditions.

(U) ***The surface-piercing hydrofoil should be evaluated particularly in terms of the PHM hull form.*** The surface-piercing hydrofoil is relatively lower in cost than a hydrofoil with fully submerged foils and also has a self-stabilizing capability.

(U) ***Hydrofoils in the 1000- to 2000-tonne class should be explored first. to avoid the greater technical risk and higher costs which are associated with heavier hydrofoils.***

2.1.3 Planing Craft

(U) The planing craft is a well-founded concept; the U.S. Navy already has small planing craft in its inventory. Very little fundamental research is required to expand the size of the hard-chine hull form. However, the powering requirements of such hull forms preclude practical planing ships much above 800 to 1000 tonnes. The powering and seakeeping limitations of the hard-chine hull forms remain.

(U) The supercritical hull form, which was pursued to a limited degree within the ANVCE Project, has the potential for achieving high speed (approximately 50 kt) in rough seas with good seakeeping (much reduced hull pounding). Its seakeeping advantages were verified by model tests within the ANVCE Project.

(U) ***Further development of the supercritical hull is highly recommended. Research is needed on design parameters for supercritical hulls that will allow sufficient internal volume to meet payload requirements without jeopardizing the hydrodynamic advantages of the hull form. Research should also be conducted toward reducing its relatively high calm-water resistance while still retaining its good rough-sea performance.***

2.1.4 Surface Effect Ship

(U) An extensive R&D program is underway to resolve the various technical issues of the SES. The currently planned 3000-tonne-class SES contains the following development items:

- new form of bow seal.
- new form of waterjet inlet,
- new form of lift fan and ride control, and
- development engines.

(U) These features are integrated into a ship with a speed of more than 80 kt, which will be exploring new performance boundaries. Despite a concerted effort. by diligent engineering communities that are actively engaged in removing the risk from each of these items in an orderly and well-thought-out manner, there is risk involved. Therefore, to reduce the risk, the following recommendations are made for the SES program now underway:

- ***severely restrict the operating envelope to no more than 50 kt in any sea state until all engineering tests in that portion of the planned operating envelope are complete***; and
- ***study a 50-kt SES in the 3000-tonne class for the same missions as the 80-kt SES to determine cost-effectiveness.*** The results of analyses performed by the ANVCE Project indicate that by using high-L/B-ratio platforms, the investment cost of the platform can be cut in half.

2.1.5 SWATH Ship

(U) In its simplest form, the SWATH concept represents only a modest departure from state-of-the-art, displacement ship technology. The application of advanced technology in the form of sophisticated shaping of the demihulls gives measurable improvements in performance; however, the cost could not be measured quantitatively in view of inadequate knowledge and the limited data base. The main features distinguishing the SWATH ship are its rectangular, box-like, main hull (which lends itself readily to aircraft runways and to the housing of maintenance and other areas) and its steady motion characteristics, resulting from the widely spaced demihulls and the small waterplane area of the struts.

(U) 'The steady platform feature of the small SWATH ship provides it with the seakeeping characteristics of a large displacement ship. This capability is similar to that of a hydrofoil; however, because the SWATH ship uses buoyancy forces instead of dynamic lift forces, it can maintain steadiness at very low speeds.

This feature makes the SWATH ship an ideal escort for conventional forces. Its box-like structure enables the SWATH ship to carry helicopters and vertical/short takeoff and landing (V/STOL) aircraft. ***SWATH ship design efforts should be pursued, with concentration focused on the simplicity of design features and small sizes (approximately 1000 to 3000 tonnes) to determine the suitability of the SWATH ship to roles utilizing these features.***

(U) As a form of displacement ship, the SWATH ship has good fuel economy at 15-30 kt. However, since a small size is recommended, it is limited by fuel storage space. Because of its catamaran-like configuration, the SWATH ship is particularly well-suited for towing. ***The feasibility of extending the range capability of the SWATH ship through the use of towed fuel pods should be explored.***

2.1.6 Air Loiter Aircraft

(U) The advantage of the air loiter aircraft is long endurance (days rather than hours). A long-endurance aircraft capable of maintaining about 24 hr on station does not represent a great departure from the state of the art. An aircraft capable of more than 3 days endurance would require the use of lightweight nuclear propulsion (LWNP). Use of LWNP was assumed to be feasible although its technical feasibility was not addressed within the ANVCE Project. LWNP was used in the point design for the nuclear-powered, air loiter aircraft.

(U) Since the air loiter aircraft does not represent a great departure from the state of the art, no major technical risks are seen. ***R&D in the air loiter concept should continue to define specific missions, supercritical wing aerodynamics, and advanced composite structural material use.***

2.1.7 LTA Vehicle

(U) The ANVCE Project explored two main avenues in the LTA concept: the FAB configuration and the SAB (semiair-buoyant) configuration. In order to carry multimission payloads of about 50 tonnes, the FAB vehicle becomes extremely large and therefore impractical in terms of ground handling and storage facility requirements. Even with vectored thrust, the sheer size of the craft induces large, fluctuating forces in gusting wind conditions that do not appear to be sufficiently controllable to permit precision landing.

(U) Despite these problems, the large FAB LTA vehicle, because it is relatively low in cost, has promise in the maritime patrol aircraft role. ***Therefore, R&D is recommended in the use of improved materials and shapes for the FAB concept applied to vehicles of 1 million to 3 million ft^3 of internal volume for use in ASW surveillance missions.***

(U) The technology of aerodynamic lift as applied to LTA vehicles was not sufficiently well developed during the ANVCE Project to generate reliable designs. It was felt that the SAB point design was larger than it needed to be although the SAB LTA vehicle design had a dash speed of 150 kt (as opposed to the 80-kt dash speed of the FAB design). Some quick analyses were done within the ANVCE Project to ascertain the technical feasibility of a smaller SAB LTA vehicle (about 1 million ft^3) with a payload approaching that of the S/L(V). Based on these analyses, the Project recommends that ***investigation of the technical feasibility of a small, ship-supporting SAB LTA should be pursued.***

2.1.8 Sea Loiter Aircraft

(U) The distinguishing characteristic of the sea loiter aircraft is its ability to get to a crisis area at aircraft speeds and then remain at the scene without fuel expenditure.

(U) ***The sea loiter concept does not look sufficiently promising to warrant any special R&D efforts; however, some of the recommendations regarding functional technology areas, such as those related to seakeeping, structural design, and lightweight materials, apply to the sea loiter aircraft.***

2.1.9 WIG Vehicle

(U) The uniqueness of the WIG vehicle is that it borders on becoming a high-speed, surface platform (with reduced drag) in one form, a version of the sea loiter platform in another, and an aircraft (with a WIG-vehicle takeoff and landing aid) in yet another. Since many technical unknowns exist in each of the technical approaches, only one basic, “pure” form was examined in order to bound the problem to best examine the issues. However, differentiation was a constant problem luring the WIG concept investigations because of the relatively limited data base nd the uncertainty as to where the WIG vehicle in its overall concept sense and arious forms would be most effective.

(U) The WIG vehicle operating only in ground effect does not compare favorably with ships and aircraft in the logistics role: ships and aircraft can perform the function better. Similarly, the “out-of-ground-effect” WIG did not fare well compared to an aircraft in the given naval missions. However, applications for the truly unique capability of a WIG vehicle, that of operating (fairly efficiently) in ground effect and being able to “hop up” into the air for a short period of time to perform a task were not fully explored.

(U) The technical examination of the WIG vehicle focused on the design, the power augmented ramjet (PAR)-wing approach, favored by the Navy technical community. The investigation did not solve the design problems. Solutions examined for stability involved the use of water skis, hydrofoils, and similar devices, but all lacked a degree of practicality for operation in rough water. The WIG vehicle in R&D Category 6.2 (Exploratory Development) until the technical issues are resolved.

(U) ***R&D should concentrate on solving the rough-water stability and performance problems. The use of ACV-like skirts should be explored through R&D efforts.***

2.2 General Performance

(U) This section presents those recommendations related to vehicle general performance. They generally apply to more than one concept and are more in the line of basic research than the development of a specific concept or vehicle.

(U) There must be continuing programs of research and technology development in many areas supporting advanced vehicles. These programs should address such important topics as investigation of flow fields around various shapes, development of improved bonding techniques, development of improved mathematical simulations of stress fields in complex structures, etc.

(U) The eight key functional areas justifying R&D programs (listed by priority, with the more-critical areas given first) are:

- seakeeping,
- marine propulsion,
- structural design,
- hull and foil design,
- skirts and seals.
- lift systems,
- lightweight structures, and
- efficiency.

The R&D programs recommended for these eight areas are discussed in the following subsections.

2.2.1 Seakeeping

(U) The recommended R&D activities in seakeeping are to advance the state of the art for ACV, hydrofoil, planing craft, SES, SWATH ship, sea loiter aircraft, and WIG vehicles. The seakeeping problem is twofold:

- The motions of the various concept types are quite often radically different, and no satisfactory means exists for comparing the motions or even analyzing them in any meaningful manner. The current methods essentially revolve around averaging the motions (by some root-mean-square method), thus normalizing out the differences.
- No satisfactory criterion exists on human tolerance levels against which the motion (analyzed as discussed above) can be compared. In addition to an incomplete data base for human tolerance, the data base on equipment (including aircraft and aircraft handling equipment) tolerance to various motions is extremely small.

The impact of these two facets of the seakeeping problem on the design of ships and those aircraft designed to operate from the sea surface is extensive. In the case of ACV and SES, agreement is needed on the ride-quality and seakeeping criteria for such vehicles before the lift and ride-control systems can be optimized.

(U) Specifically, the recommendations for a seakeeping R&D program are: ***first, the nature of the motion of the ACV, hydrofoil, planing craft, SES, SWATH ship, sea loiter aircraft, and WIG vehicle when operating both at rest and in forward motion in a range of sea conditions should be defined in engineering terms. This program should include analysis and model test, but most importantly it should include at-sea data from man-carrying platforms on short- and long-term statistical bases. After that, the human and equipment tolerance levels for the various types of motion incurred by the concepts considered must be defined (again, in quantitative engineering terms).***

2.2.2 Marine Propulsion

(U) The recommended R&D activities in marine propulsion apply to the ACV, SES, planing craft, hydrofoil, high-performance displacement ships, sea loiter aircraft, and WIG vehicles. The R&D recommendations in the area of marine propulsion are:

- ***Develop marine gas-turbine engines at various power levels up to 50,000 hp per engine, with assured long life in a salt-laden atmosphere.***

- ***To protect the marine gas-turbine engines develop improved filtration systems without incurring excessive power losses and large increases in weight and volume. An initial survey needs to be conducted to document the relative performance and lift of gas turbines in Navy use and the weight, volume, and performance of the filtration systems.***

- ***Develop marine propulsors (both water-screw and waterjet) at various power levels up to 50,000 hp per shaft and operating at inflow velocities from 40 to 100 kt. Specific attention should be given to operating in supercavitating flow.***

- ***Develop high-speed (4000-9000 rpm), lightweight, marine, mechanical transmission systems for high-performance surface craft, with particular emphasis on right-angle transmission systems. Power levels from 50,000 hp to 100,000 hp should be developed for transmission systems operating under varying loads and in a marine environment.***

- The use of superconducting machinery did not appear to offer any unique advantage to the displacement ship. ***However, continued research into electrical machinery drive, in general, and superconducting machinery, in particular, should be pursued together with some application studies to determine if future benefits can be determined.***

- ***Develop high-bypass-ratio fan engines of*** 45,000 ***to 95,000 lb of thrust that are capable of operating in a high-salt-spray environment for use on sea loiter and WIG-type vehicles.***

2.2.3 Structural Design

(U) The recommended R&D activities in structural design apply to the ACV, SES, planing craft, hydrofoil, sea loiter aircraft, and WIG vehicles. Each of these vehicles operates at high speed in rough seas. Many of the design criteria used in displacement ship design are based on empirical data with conservative safety factors built in to account for the unknowns. In the case of dynamic vehicles, where the forces involved are a strong function of the forward speed of the vehicle, a more analytical design method is required to allow for the lightest-weight structure commensurate with the operating conditions likely to be encountered.

(U) ***A structural design R&D program should establish the loads that are likely to occur on those vehicles separated from the water by a layer of pressurized air (ACV, SES, and WIG vehicle) to determine the nature of any load alleviation. Particular attention should be paid to operation in random seas of varying headings. R&D efforts should also establish the dynamic loading at SO-250 kt on high-speed hull forms without any air separation (planing craft, sea loiter aircraft, and WIG vehicle).***

2.2.4 Hull and Foil Design

(U) The recommended R&D activities in hull and foil design apply to the hydrofoil, SWATH ship, SES, sea loiter aircraft, and WIG vehicle. The nature of the problem is twofold in that it involves the hydrodynamic design of hull forms at low speeds (Froude numbers of less than 1 .O) and at high speeds (Froude numbers greater than 1 .O and cavitation numbers less than about 0.10). While in many respects the R&D efforts in this area would be similar to those described in the previous R&D recommendations on structural design, the main emphasis here is on the hydrodynamic performance aspects of hull and foil design.

(U) ***R&D efforts should continue toward development of variable-geometry foil designs that will allow efficient operation of hydrofoils at subcavitating speeds (less than 50 kt) and provide a dash capability to supercavitating speeds (50-80 kt). As a corollary to this research, the development of such foil's as control devices on SES hulls should be examined.***

(U) ***A hydrodynamic data bank on long, slender hull forms should be established.*** It should contain data used by all designers concerned with the design of long, slender ships (such as SWATH hulls, SES sidehulls, sea loiter hull forms, and WIG vehicle hard end-plates). The hydrodynamic data include lift, draft, side force, and moment data in both subcavitating and supercavitating flows. The data should be directed to bodies of revolution (e.g., sea loiter hull) acting in symmetrical flow. Data should also be obtained on hulls acting in asymmetrical flow (such as for the SES and WIG vehicle), where the water level on one side of the foil is depressed below the free water level by the presence of the pressurized air cushion.

2.2.5 Skirts and Seals Development

(U) The recommended R&D activities in the development of skirts and seals apply to the ACV, SES, and WIG vehicle concepts. Various skirt and seal forms have been used for the ACV and SES. Only a rudimentary exploration has been made into skirt forms for the WIG vehicle.

(U) ***A skirts and seals R&D program should continue development of skirts and seals for use on high-speed (50-100 kt) ACV and SES, placing particular emphasis on developing materials for long life and low maintenance. Consideration should also be given to developing the production methods needed for skirts and seals for craft sizes in the 200- to lO,OOO-tonne range. In addition, R&D on ACV-like skirts able to survive speeds of up to 250 kt should be initiated.***

2.2.6 ***Lift Systems***

(U) The recommended R&D activities in lift systems apply to the ACV and SES concepts and possibly the WIG vehicle concept. The nature of the problem is twofold, involving (a) the development of lift systems to control the ride quality to acceptable levels and (b) the ability to generate basic lift power for large displacement craft.

(U) ***R&D should be continued toward development of lift-fan systems for application to ACV of 200-4000 tonnes displacement and SES of up to 10,000 tonnes displacement. The lift-fan systems should be capable of generating a pressure increase of from 150 psf to 500 psf and flow rates of up to 10,000 cfs. The systems should be designed to control the ride to within the acceleration levels established within ANVCE Project (Appendix A, Point Design Standards). In addition, development of multistage fans for large-displacement (8000 tonnes or more) ACV and SES capable of operating in a marine environment and generating cushion pressures of greater than 500 psf should be initiated.***

2.2.7 Lightweight Structures

(U) The recommended R&D activities in lightweight structures apply to the ACV, SES, LTA vehicle, sea loiter and air loiter aircraft, and WIG vehicle concepts. The definition of lightweight structures includes improved strength-to-weight ratio metallic (aluminum, titanium, etc.) structures; composite structures; and for the LTA vehicle, fabric structures. The problem of developing materials is threefold. It involves developing materials that can (a) maintain their properties in a marine environment, (b) be used in construction for low cost (limited special tooling), and (c) be easily maintained and repairable "in the fleet".

(U) ***A lightweight structure R&D program should continue toward development of lightweight metallic structures and composite structures applicable to the primary structure of ACV, SES, sea loiter aircraft, and WIG vehicle. Particular attention should be given to performance in terms of marine fabrication and repairability. In addition, development of composite structures in the primary structure of airframe of air loiter aircraft should be continued, with particular emphasis***

on ease of fabrication and low cost. The application of improved elastomer-coated fabrics to LTA vehicles should be explored, with particular emphasis on ease of fabrication and low cost.

2.2.8 Efficiency

(U) The recommended R&D activities in operating efficiency apply to the ACV, SES, and WIG vehicle. These particular surface-bound, dynamic-lift vehicles generally are not very efficient at low speed (about 5-30 kt) and thus do not function well with conventional forces. ***To make these particular craft more versatile and efficient at such speeds, R&D needs to be pursued on the low-speed (5-30 kt) performance of the ACV, SES, and WIG vehicles, with particular emphasis on providing such craft with efficiency of performance (ideally, comparable to displacement ships).*** For example, a solution for an SES might be to operate in a "partial-cushion" mode. Such techniques and others need to be explored to improve the efficiency and fuel consumption of such craft.

3. COST ANALYSIS

3.1 Findings

(U) Confidence in the estimates of platform acquisition and life-cycle O&S costs of ***any*** vehicle is dependent upon the quality of the CERs and whether they appropriately reflect the essential features of the candidate designs. In some areas, a CER could not be developed because of the confusion and misinformation regarding the cost data bases available.

(U) For surface vehicles, the driving parameters in platform acquisition costs are the hull structure cost (Group 1), the propulsion cost (Group 2), and the auxiliary system cost (Group 5). The relative importance (in terms of cost) of each group is a function of the particular concept. For example, for the hydrofoil the Group 5 cost (which includes the lift system) is the dominant cost term, whereas for the advanced technology monohull, the Group 2 cost (propulsion system) is the main cost factor.

(U) One of the collaterial issues inherent in the ANVCE charter is the utility of speed. The feasibility of higher speed and the operational need for higher speed are addressed in Volumes 2 and 4, respectively. While not documented in this report, it was found that within each concept the cost varied approxirnately as the cube of the speed. Thus, to reduce cost as speed is increased from 30 kt to 40 kt or more,it becomes necessary to change the concept from displacement ship to hydrofoil to cushion-supported vehicles. With a cubic equation of this kind, a practical upper bound exists on design speed; above that upper bound, the platform cost increases are sharply disproportionate for a corresponding speed increase. For displacement ships (monohull and SWATH) this upper limit occurs between 30-40 kt. If an operation requires a surface vehicle to have still greater speed, then a change of concept to a dynamic-lift vehicle is required. In the design range from 40 to 70 kt several advanced concepts are available: hydrofoils, ACV, and SES.

(U) From these relationships, the following conclusions relative to the cost of speed can be drawn:

- For speeds to 30 kt, a displacement-type ship offers the lowest cost alternative.

- For higher speeds, dynamic-lift vehicles provide the lower-cost design solution but at a higher cost than for a displacement ship with a speed of O-30 kt.

- Although the absolute platform cost increases with increased design speed, the relative rate of increased cost diminishes with increased speed as the dynamic-lift vehicles are introduced.

- There is a significant cost threshold to overcome when exceeding the 30-kt limit of the displacement ship.

(U) Among the air vehicles, the platform CER for HTA craft was based on a parametric relationship involving AMPR weight, speed, and thrust. While this approach may be valid when applied to configurations similar to those in the cost data base (e.g., AVP), it is certainly questionable to apply the same relationship to radically different configurations such as the WIG(O) and S/L(L). LTA vehicles appear to offer potential for significantly lower cost as maritime patrol options where minimum response time or very high speed is not required. For rigid LTA vehicles, however, the data base is 46 years old.

3.2 Recommendations

(U) The following general recommendations are made regarding future cost analysis efforts:

- ***Common cost reporting schemes should be integrated into U.S. Navy construction contracts to record actual costs in each functional area (weight groups, designs, services).***

- ***Further investigation into the costs of LTA vehicles should be preceded by the development of a data base on engineering cost estimates for today's labor rates, labor productivity, and material costs.***

4. MISSION ANALYSIS

(U) The development of a method to quantify the military value of advanced naval vehicles took a number of paths during the course of the ANVCE Project. Early in the Project, and before any significant analysis could be completed to determine the relative contribution of the ANV performance characteristics, speed was considered one of the most distinguishing features of ANVs. Of all the characteristics, speed had the largest variation among ANVs and received most of the attention. As a result, a significant amount of analytical effort was devoted to the issue of speed, including sprint speed, speed in high sea states, and flexible speed range. As the point designs for the ANVs neared completion, it became evident that there were other performance characteristics of the surface combatants that exhibited important variations between vehicle types.

(U) An analytical technique was developed that allows a qualitative but explicit delineation of the relationships between each of the ANV characteristics and its specific contribution to countering various aspects of the projected enemy threat. During the application of that analytical technique an additional number of important ANV characteristics were identified, particularly payload capacity, payload growth potential, and payload flexibility.

4.1 Findings

- Weapons and sensors are the vital elements of future naval force. Payload growth potential to accommodate adequate weapons/ sensors loads is very important to the military effectiveness of future naval vehicles.

- Aircraft give an added dimension to surface combatants. The ability of each surface platform to handle and operate aircraft was not specifically addressed by the ANVCE Project, but, as with payload, this feature of an ANV was found to be one of the most significant.

- The real cost of an ANV is its replacement cost. The platform's ability to carry weapons and sensors, is important, but it is just as important that the vehicle remain operational in order to bring the combat suite to bear on the enemy. Survivability translates into reduced signatures, less damage vulnerability, and improved speed and maneuverability.

- The prospect of a considerable increase in speed capability in advanced vehicles suggests that new tactical options will become available. This increased capability may be most significant in ASW against the projected improvement in Soviet submarine speed.

4.2 Recommendations

- *Payload growth potential should be carefully considered in the design of advanced naval vehicles.*

- *Although the ANVCE Project did considerable innovative work in the study of ride quality with regard to human adaptabilities, research should be undertaken to expand on this effort in order to understand and improve the ANV's ability to handle and operate aircraft.*

- *A complete review of survivability of all advanced vehicles, especially with regard to damage vulnerability is recommended. More analysis is needed to better determine the vulnerability of ANVs, and more research is needed to develop hardening techniques and reduction in detectable signatures.*

APPENDIX A

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