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ADVANCED NAVAL VEHICLES CONCEPTS EVALUATION (ANVCE) PROJECT

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TECHNICAL EVALUATION VOLUME 2

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

The objective of this volume is to present the results of the technical evaluation of the feasibility of advanced naval vehicle concepts. To meet this objective, this volume first addresses the scope of the effort, giving the objective, limitations, and assumptions (Chapter I). In Chapter II, the generic concepts and the technical approach are summarized. The evaluation of concepts in Chapters III and IV leads to selection of point designs for surface and air vehicles, respectively, and to specific findings and conclusions about these concepts. After a discussion of the operational performance and usefulness

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characteristics of the advanced vehicles in Chapter V, the conclusions and recommendations of the study are given in Chapter VI. The appendices cover design standards, details of the point designs, and references.

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(2) ANVCE, Volume III, (Cost Analysis)

1. The ANVCE project was directed by DDR&E to develop the information needed for a balanced overall 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 evaluate nine generic classes of advanced vehicles which may have potential application to naval missions. The R&D efforts were mainly technology assessments and point design developments. The analyses involved mission requirements and costing. Enclosures (1) and (2) present the results of the technical evaluation investigation and the cost analysis, respectively. The mission analysis (Volume IV) and the Project Summary (Volume I) which includes the Executive Summary for all four volumes will be promulgated separately.

2. Volume II reports the results of the technical evaluation investigations. These results are the most important products from the ANVCE project. They were derived from 165 separate analyses, surveys, and experiments consuming 70% of the total ANVCE budget. Volume II is not, perforce, a complete compilation of results of this extensive effort, but rather a review of the significant findings and a description of the point designs developed. A complete list of references for Volume II is included. These references will be available to the technical community through the Defense Technical Information Center. Volume II, taken together with its references, is considered a valuable source of heretofore unavailable information. From the nine generic concepts, 23 point designs were developed (13 surface and 10 air). In addition, to provide reference points, four baseline point designs were developed and six existing designs are also presented for comparison.

3. The point designs were developed for use in further mission and cost analyses, but they should be used with the following constraints and limitations in mind:

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a. They are, in fact, point designs, each representing a unique vehicle out of a spectrum of possible configurations. In the future, users may wish to modify the point designs for specific analyses. Some modifications are suggested in Volume II.

b. The vehicles were grouped by size and other principal characteristics and all members of a group are configured with a common weapon and sensor suite. This was done in order to make platform comparisons as independent of payload as possible. One could not expect this approach to lead to the optimum suite of weapons and sensors for each generic concept. Here again, users may wish to vary the payload in specific scenarios in order to highlight the unique features of a given vehicle.

c. The several different advanced vehicle concepts are at different levels of technical maturity. Some exist as fully operational vehicles, some in prototype stages, some in feasibility studies only, and some represent obsolescent technology.

d. Common technology levels were established so that any differences among the concepts would not simply reflect technology level assumptions. Examples are projected material strength in the 1985 timeframe, and projected engine power levels for a given engine in the same timeframe.

4. Volume III is the most comprehensive cost analysis of advanced naval vehicles conducted to date, in that it attempts to estimate the costs of diverse ships and aircraft on a genuinely comparable basis. Taking into account the paucity of historical data and the very broad spectrum of vehicles involved, the cost analysis was well conceived and included as many significant cost elements as possible. Applying techniques and estimating relationships to such a wide variety of vehicles required that they be quite general relationships. Because the cost estimates pertain to future vehicles, the absolute numerical results presented in Volume III should be used with caution, but the relative costs of

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the various vehicles can be used with confidence. Cost estimates of these advanced vehicles are based on the state-of-the-art and design information available in 1978; they should be revised periodically.

5. Enclosures (1) and (2) are forwarded.

mat Holcomb

U.S. NAVY
Vice Admiral, U.S. Navy
Director, Navy Program Planning

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ADVANCED NAVAL VEHICLES
CONCEPTS EVALUATION (ANVCE) PROJECT

Volume 2

TECHNICAL EVALUATION

December 1979

Prepared by:

CHIEF OF NAVAL OPERATIONS (OP-96)

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PREFACE

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

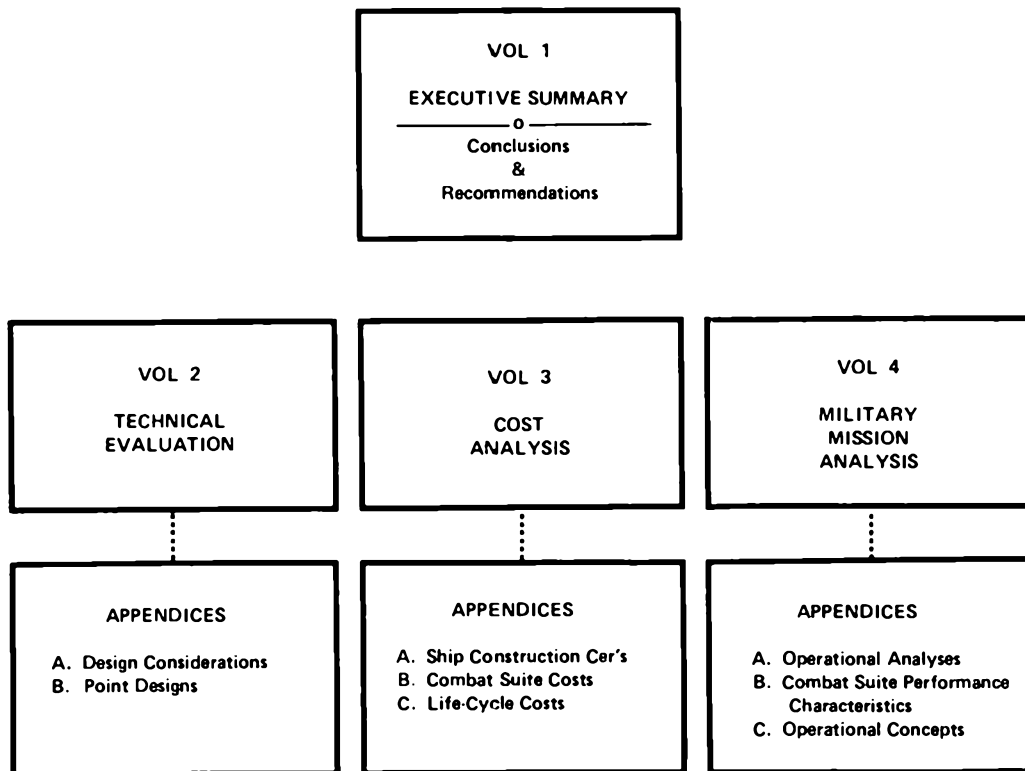
- Volume 1: *Executive Summary* – a summary of the project results, conclusions and recommendations;
- Volume 2: *Technical Evaluation* – a description and technical assessment of the feasibility of advanced naval vehicle concepts;
- Volume 3: *Cost Analysis* – a detailed treatment of the cost of the ANV point designs; and
- Volume 4: *Military 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 specifically. Their work is gratefully acknowledged. The ANVCE Project consisted of

(b) (6) [redacted] U.S.N. (OP-96V), Project Officer;
(b) (6) [redacted] Mantle Engineering Company, Technical Director and
Deputy Project Manager;
(b) (6) [redacted] U.S.N. (OP-96V), Project Staff;
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CHAPTER I INTRODUCTION

1. ANVCE PROJECT

(U) The Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project was undertaken to obtain the information necessary to recommend a balanced overall research and development (R&D) program for naval vehicles in the 1980-2000 time period. Such an R&D program is one in which naval vehicles meet 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 establish concepts that could meet these broad criteria. This volume of the final report uses data from the technical studies to reach conclusions about the technical feasibility of conceptual vehicles (called point designs) and makes recommendations for R&D based on the conclusions. Volumes 3 and 4 address cost and military value, respectively. A summary of the salient findings from all three volumes is presented as Volume 1.

(U) The extensive studies that have supported this technical feasibility effort should be of major interest to the technical community. Reports on many of these studies supply detailed engineering information for specialists. These reports are referred to in this and other volumes as data from them are presented, and the references are again cited at the end of this volume. These and other ANVCE-supported and ANVCE-related documents will be made available from the Defense Technical Information Center. An annotated bibliography of all the documents is presented as an appendix to Volume 1.

2. TECHNICAL FEASIBILITY

(U) The objective of this volume is to present the results of the technical evaluation of the feasibility of advanced naval vehicle concepts. To meet this objective, this volume first addresses the scope of the effort, giving the objective, limitations, and assumptions (Chapter I). In Chapter II, the generic concepts and the technical approach are summarized. The evaluation of concepts in Chapters III and IV leads to selection of point designs for surface and air vehicles, respectively, and to specific findings and conclusions about these concepts. After a discussion of the operational performance and usefulness characteristics of the advanced vehicles in Chapter V, the conclusions and recommendations of the study are given in Chapter VI. The appendices cover design standards, details of the point designs, and references.

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(U) In the technical evaluation presented in this volume, the cost and military value of the point designs have not been addressed except where required to clarify a specific technical issue. Both areas are treated extensively in other volumes.

2.1 Scope

(U) When submarine and aircraft were first used in naval applications earlier in this century, it became necessary to realign the structure of naval missions to make effective use of their unique capabilities. While it is evident that new technology often requires or permits redefinition of missions, the exploitation of new technology sometimes must await the realization of the part it can play in a new or expanded mission. While nothing is currently in view that promises such a radical shift in naval capabilities and missions as that which followed the introduction of aircraft and submarines, new vehicle technology areas must be examined because one area might possibly provide an increase in mission effectiveness or a reduction in cost per unit. In a fiscally constrained environment, the question of whether a particular vehicle concept should be developed for a particular role is one of considerable complexity; it involves a closely tied interaction among platform technology, weapon and sensor technology, cost, and mission needs. The ANVCE Project effort focuses on the development of design and cost information in order to make vehicle comparisons.

(U) In the evaluation, distinctions were made

- between those vehicles that are realistic for the time period considered and those that are not, and
- between those vehicles that are capable of meeting only a narrowly constructed threat and those flexible enough to handle the unexpected threat.

2.2 Limitations

(U) The limitations imposed on the ANVCE Project arose from

- the ANVCE charter or informal guidance associated with the charter,
- the exclusion of hybrid vehicles from consideration, and
- time and funding.

An example of limitations implied within the charter or by the informal guidance associated with the charter is the specific exclusion of submarines from the list of candidate ANV concepts. Another limitation was that the generic air vehicle concepts had to be capable of long endurance in carrying out the maritime patrol aircraft mission, thus excluding advanced, carrier-based, naval aircraft (both follow-on fighter and attack types).

(U) Hybrid vehicles were excluded (except in a restricted sense) since the

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data available on these were neither of sufficient quantity nor consistency for a meaningful evaluation. Although hybrids were specifically excluded, care was taken to interpret the generic concepts in the broadest sense. The ANVCE Project sought to take advantage of the best possible features of each concept rather than to accept as the measure some current vehicle that may not have been representative of the true value of the concept in terms of its ability to meet future needs.

(U) Resource limitations, both time and money, restricted the number of configurations that could be examined, and thus, the selection of concept candidates became a key factor in limiting the scope of the overall evaluation.

2.3 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, called 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. Although it was conceptual rather than analytical in approach, the first phase of Project 2000 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 Report was disseminated to provide a common ground for 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 analysis.

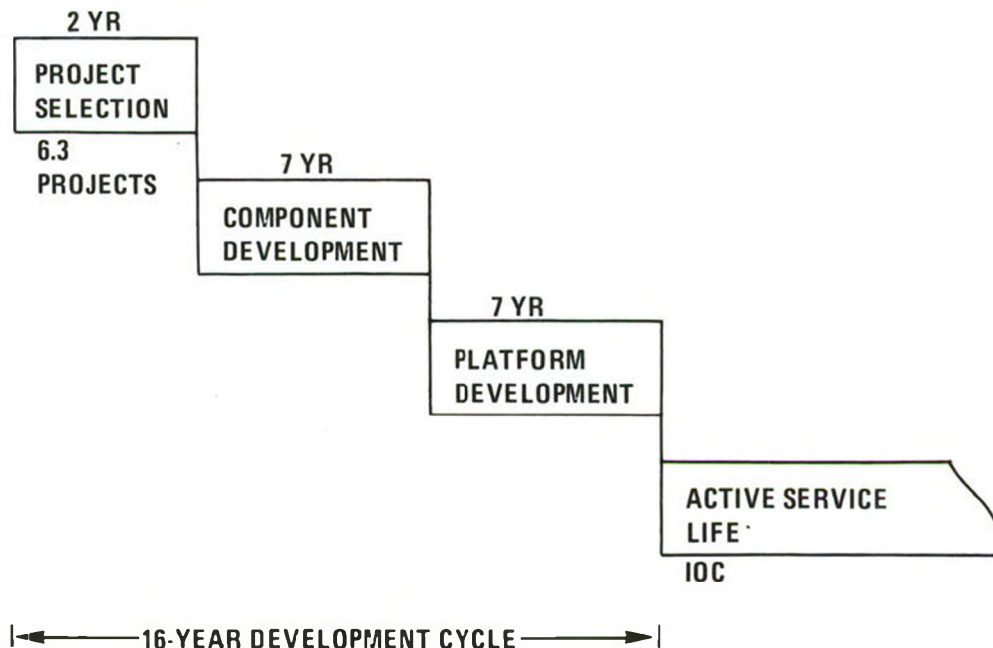
(U) Based on the environment projected by Project 2000, the principal assumptions used in evaluating the ANV concepts are that the

- 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;
- United States will continue to be dependent on overseas resources and markets, leading to an expansion of both commercial maritime activities and naval operations;
- 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;
- Soviet Navy has the capability to employ multiple, coordinated, anti-ship 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.

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In short, the environment envisioned for Project 2000 is much like that of today. What *will change*, however, are the techniques by which the kinds of naval operations are carried out, and those changes which are brought about by changes in the technology and probable threat.

(U) As stated in the objective, the main thrust of the projection is to evaluate those concepts that could lead to operational vehicles by the year 2000. Assuming that the current development cycle for a new platform will continue to be employed, it will take approximately 16 years from start of Category 6.3 (Advanced Development) to initial operational capability (IOC), as illustrated in Figure I-1. Accordingly, for an IOC of 2000, the technology of the platform must be available in about 1984-85. Therefore, a technology "freeze" or base of 1985 was assumed for the technical evaluation.



(U) Figure I-1. DEVELOPMENT CYCLE FOR A NEW PLATFORM

2.4 Approach

(U) The concepts developed in this study (Chapter II) are much broader than examples of such hardware in existence today. Hence, 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 and specific enough to conduct analysis and produce numbers that could be used for military mission analyses.

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(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. The features of the various vehicles are referred to throughout this volume in terms of the uniqueness and advantages of these concepts. 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.
- *R&D Recommendations.* Based on the technical evaluation and the potential application of the concepts to Navy missions, R&D recommendations were made based on the analysis of technical feasibility.

CHAPTER II DEVELOPMENT OF VEHICLE CONCEPTS

1. INTRODUCTION

(U) Nine generic vehicles were selected for evaluation as shown in Figure II-1 in increasing order of their speed capability. These concepts, in alphabetical order, are the

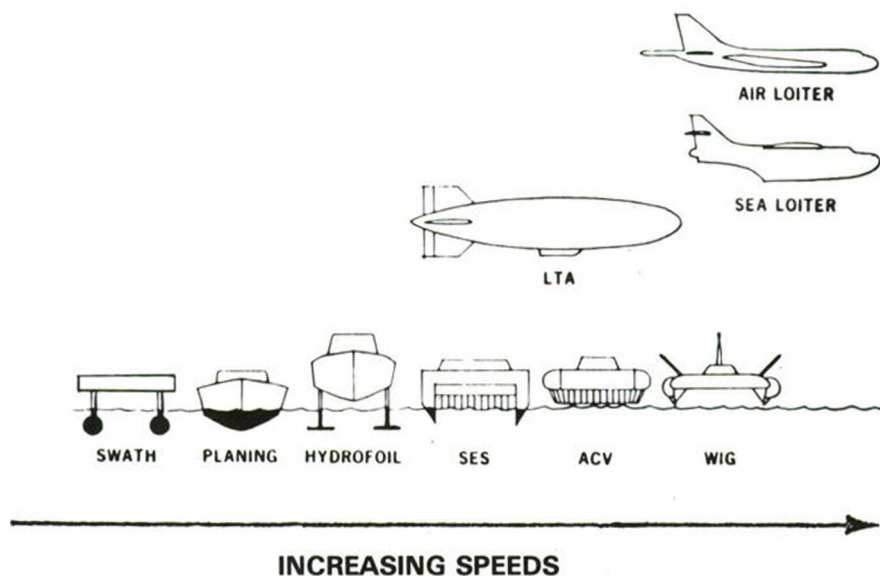
- | | | |
|---------------------|---|--|
| Surface
Vehicles | { | <ul style="list-style-type: none"> • air cushion vehicle (ACV); • hydrofoil; • planing craft; • surface effect ship (SES); • small-waterplane-area, twin-hull (SWATH) ship; |
| Air
Vehicles | { | <ul style="list-style-type: none"> • air loiter aircraft; • lighter-than-air (LTA) vehicle; • sea loiter aircraft; and • wing-in-ground-effect (WIG) vehicle. |

(U) Each of the nine basic generic concepts incorporated some fundamental principle; for example, a craft supported on foils. These concepts were then explored further, to a configurational form that represented different paths of development, which were then further explored through specific designs (Figure II-2). For example, the concept of the hydrofoil can be categorized by subcavitating and supercavitating configurational forms, each requiring quite different R&D and development cycles. By these means, the nine basic generic concepts expanded into 19 configurational forms for study. These configurational forms involved feasibility issues, which led to a set of 23 specific designs (developed to at least the feasibility design level) that resolved feasibility issues and represented points for analysis of the concepts. These designs are referred to as *point designs*.

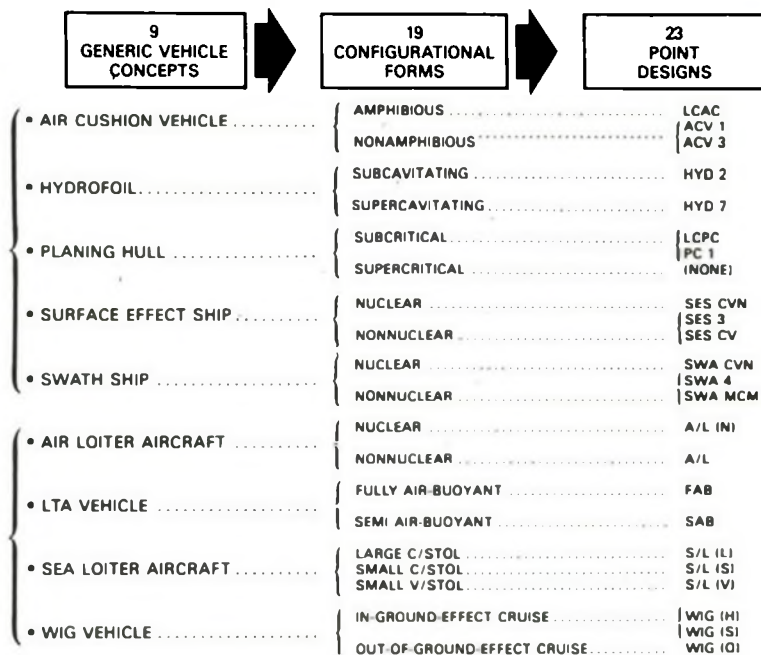
(U) Table II-1 lists these ANVCE Project point designs according to size and mission as they are grouped for the cost (Volume 3) and mission (Volume 4) analyses. (The MONO 3, an advanced-technology monohull point design, and the AVP, an advanced VP aircraft, were used in this evaluation as baseline or reference vehicles and are included in the grouping of point designs shown in Table II-1).

(U) Grouping the generic vehicles concepts into air and surface vehicles is generally clear-cut; however, there are some "transitional" concepts. The WIG is the best example of the latter concept; it can be designed to operate either totally in ground effect or with the capability of occasionally flying out of ground effect. Its technical feasibility and military applicability vary according to the mode selected. Another example of a transitional concept is the long-endurance, sea loiter

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(U) Figure II-1. ADVANCED NAVAL VEHICLE CONCEPTS



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

(U) Table II-1. POINT DESIGN GROUPS

SURFACE VEHICLE GROUPS			AIR VEHICLE GROUPS		SPECIAL-PURPOSE VEHICLES
3000-TONNE CLASS	1000-TONNE CLASS	AIRCRAFT CARRIERS	LARGE, MULTI-MISSION AIRCRAFT	SMALL, ASW AIRCRAFT	
ACV 3 HYD 2 SES 3 SWA 4 MONO 3	ACV 1 HYD 7 PC 1 WIG(S)	SES CV SES CVN SWA CVN	A/L A/L(N) FAB S/L(L) WIG(O)	SAB S/L(S) S/L(V) AVP	SWA MCM WIG(H) LCAC LCPC

aircraft, an extension of the seaplane concept. Because the sea loiter aircraft spends a considerable amount of its operational time on the surface, it has several technical problems in common with the surface vehicles. A less-obvious transitional concept is the LTA vehicle, which, although strictly an air vehicle, could conceivably operate close enough to the surface to tow acoustic sensors. Hence, although the vehicles have been grouped as surface or air vehicles, an effort is made to avoid thinking of them strictly in terms of conventional or historical uses and thereby placing unwarranted restrictions on the concepts.

(U) An additional concept, an advanced-technology monohull, not included in this ANV concept listing is used as a reference point in the evaluation. The concept represents a conventional surface vehicle envisioned for circa 2000 and provides a comparison point for the surface ANVs projected for the same period. To this end, the concept was developed as a point design for use in the various analyses.

2. SELECTED VEHICLE CONCEPTS

2.1 Surface Vehicles

(U) This section briefly introduces, in alphabetical order, each of the generic surface vehicle concepts, presenting the rationale for their selection and the Navy developmental status of the concepts. Surveys of the state of the art of each concept were conducted to determine the features and issues involved. These surveys are referenced.

2.1.1 Air Cushion Vehicle

(U) The ACV's unique capability of being virtually independent of the surface (be it land or water) made it a clear candidate. Moreover, it rides on a cushion of air and thus requires less power for high-speed operation than does a conventional displacement ship. Its characteristic speeds are 40-120 kt. The ACV is generally capable of higher speeds than an SES (an air cushion craft utilizing two sidehulls) of similar size because of the hydrodynamic drag of the sidehulls. However, because of the more-limited propulsion system used on the ACV, it cannot attain the displacement sizes that can be reached by the SES concept.

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(U) The most recent U.S. Navy activity involving the ACV is the amphibious assault landing craft (AALC) program, with two, 155-tonne prototypes currently involved in early trials. Figure II-3 shows the JEFF (B) AALC underway in the Gulf of Mexico near the Navy's test facility at Panama City, Florida.

(U) A complete ACV worldwide state-of-the-art survey through 1976 was made by the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) and is cited in Reference 1.



Figure II-3. JEFF (B) AALC

2.1.2 Hydrofoil

(U) About 2000 hydrofoils are in operation throughout the world, mostly in commercial use and centered in Europe and the USSR. The vast majority of these craft employ surface-piercing foil configurations, and virtually all (surface-piercing and fully submerged foils) operate at subcavitating speeds (up to 50 kt). The hydrofoil offers high speeds in rough seas with excellent maneuverability. Characteristic speeds for both surface-piercing and fully submerged foil systems are 35-50 kt for subcavitating hydrofoils and 50-80 kt for supercavitating hydrofoils. The hydrofoil can operate either as a hullborne craft (as a conventional ship) or a foilborne craft to obtain speed. These characteristics provide a flexibility of operation that offers military potential that is worth exploring. The wide and successful use of surface-piercing hydrofoils in Europe and the cost of these craft compared with that of the craft with fully submerged foils currently used by the U.S. Navy was sufficient to justify an evaluation of this competitive concept.

(U) The most recent U.S. Navy activity involving the hydrofoil is the guided-missile-equipped, patrol hydrofoil (PHM), which is subcavitating and has fully submerged foils (Figure II-4). This craft is in production in limited quantity at this time.

(U) The state of the art of hydrofoils with fully submerged foils was surveyed by DTNSRDC and is reported in Reference 2. To broaden the data base and to take advantage of available foreign technology, a summary of the state of the art of surface-piercing hydrofoils was also undertaken with Supramar AG in Switzerland; this summary is provided in Reference 3.



(U) Figure II-4. PHM UNDER TRIAL

2.1.3 Planing Craft

(U) The planing craft, with its conventional deep-V hull form, is a well-known and widely used concept. Characteristic speeds for planing craft are 40-50 kt. Although usually thought of as a small craft that is confined to littoral waters and that has reached an advanced stage of development with little room for advancement in performance, its high-speed capability and very low cost prompted its consideration for evaluation, provided a technical advancement could be found.

(U) The most recent U.S. Navy experience with the planing craft is the prototype of the coastal patrol interdiction craft (CPIC), shown in Figure II-5.

(U) To explore the possibility of new developments in planing hull technology, a state-of-the-art survey was conducted by DTNSRDC and is presented in Reference 4.

2.1.4 Surface Effect Ship

(U) The SES, which utilizes a cushion of air to provide the support (lift) for the ship, requires less power than a conventional displacement hull for high-speed

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(U) Figure II-5. CPIC UNDERWAY

operation. The SES is a subdivision of the broader classification of air cushion craft. Specifically, if the air cushion craft utilizes two sidehulls housing the propulsion and stability mechanisms, it is referred to as an SES. Characteristic speeds for the SES are 40-100 kt. While not capable of as high a speed as the ACV, it does offer a significant high-speed capability. With increased displacement, the catamaran-like sidehulls of the SES are particularly adaptable to various water propulsion schemes, which are not as limited as air-propulsion schemes (used on some ACVs). Thus, the SES concept offers a high-speed capability of a larger ship.

(U) U.S. Navy efforts in the development of surface ANVs have focused primarily on the SES concept. The most recent U.S. naval activity with the SES involves the SES 100(A) and SES 100(B) test craft (Figure II-6), which are representative of the very-high-speed (80-100 kt), low-L/B (length-to-beam ratio), SES technology, and the manned model, XR 5 (Figure II-7), which is representative of the high-speed (50-60 kt), high-L/B technology.

(U) The state of the art in the development of the SES by the U.S. Navy through 1976 was surveyed by the Naval Sea Systems Command (NAVSEA) and is reported in Reference 5. Again, to take advantage of available foreign technology and to assess the value of lower-speed, lower-cost versions of the SES, technical summaries of a sidehull SES developed by Great Britain were also prepared (References 6, 7, and 8).

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(U) Figure II-6. SES 100(A) AND SES 100(B) UNDER TEST



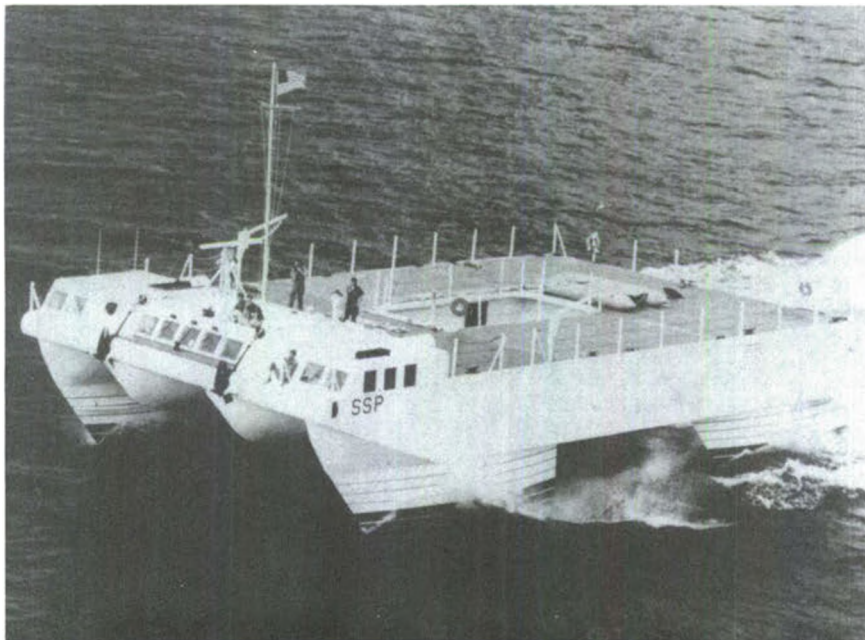
(U) Figure II-7. MANNED MODEL XR-5 UNDER TEST

2.1.5 SWATH Ship

(U) The SWATH concept is an improvement over the conventional catamaran in that the buoyancy hulls are submerged (away from the disturbed sea surface) and small-waterplane-area struts are used for minimum resistance as they lift the main body of the ship above the waves. This particular concept provides a steady platform, with large deck area and internal volume. Since this craft is a variant of the displacement hull, it is most efficient at displacement hull speeds (25-35 kt); because of its steadiness feature, it can maintain these speeds even in high sea states. Because these particular features suggest improved air-capable ship platforms, the SWATH concept was examined by the ANVCE Project.

(U) The most recent U.S. Navy experience with the SWATH ship is the work boat/test craft KAIMALINO, shown in Figure II-8.

(U) A state-of-the-art survey of ship technology applicable to the SWATH concept was made by DTNSRDC and is presented in Reference 9.



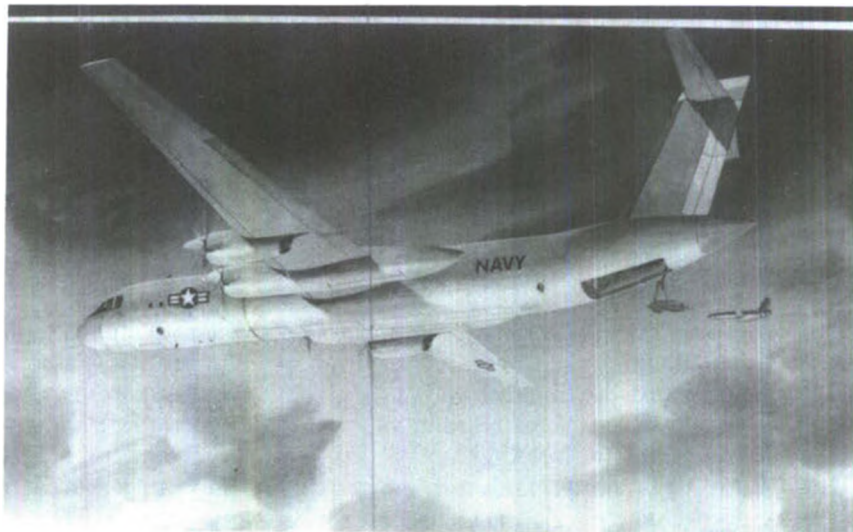
(U) Figure II-8. SWATH SHIP KAIMALINO

2.2 Air Vehicle Concepts

(U) This section briefly introduces, in alphabetical order, each of the generic air vehicle concepts and presents the rationale for its selection and Navy development of the concept to date. State-of-the-art surveys conducted are referenced.

2.2.1 Air Loiter Aircraft

(U) The air loiter concept has been included not because it embodies new principles of aerodynamics but because it can extend current capabilities. Land-based, fixed-wing, maritime patrol (VP) aircraft are currently limited to about 4-6 hr of airborne loiter at a 1500-nmi radius from base. Because of this limited capability, VP aircraft are not useful in escort missions or in conflict situations in which forward bases might be less secure. Accordingly, the ANVCE Project explored possible applications of advanced materials and improvements in the overall efficiency of propulsion systems that could increase the airborne loiter time to at least a day, or perhaps 15 or more days. No current U.S. Navy aircraft has such a capability; however, an artist's rendition of the concept based on the parametric and point design analyses conducted is shown in Figure II-9.



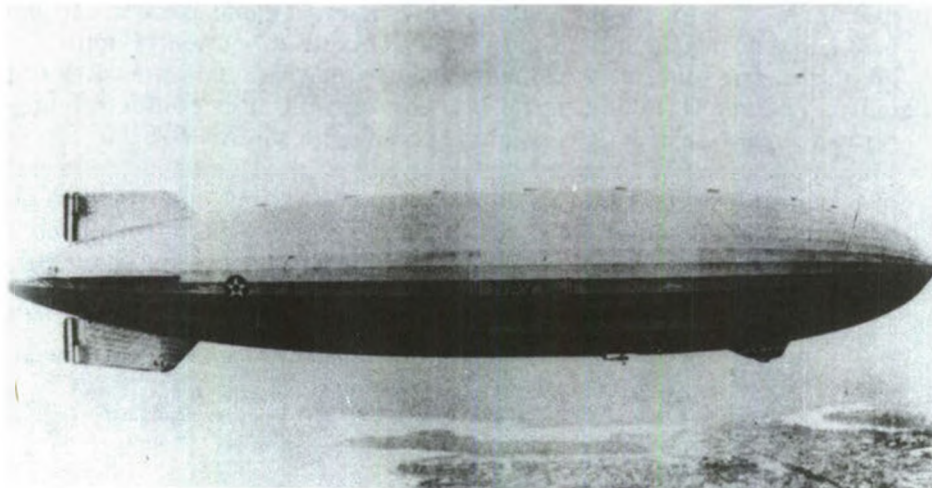
(U) Figure II-9. AIR LOITER AIRCRAFT CONCEPT

(U) A comprehensive, state-of-the-art survey of technologies applicable to such an aircraft was conducted by the Naval Air Development Center (NADC) (Reference 10). This survey covers both conventionally fueled aircraft, including those using fuels such as liquid hydrogen, and nuclear-powered aircraft.

2.2.2 LTA Vehicle

(U) An airship can provide great airborne endurance without significant payload sacrifice. In addition, it can, while airborne, deploy submerged, tethered sensors in sea states in which a surface vehicle would have to decrease its speed appreciably. The airship is not a new concept; airships were utilized by the U.S. Navy

prior to 1962, when they were phased out for technical and nontechnical reasons. To indicate the capabilities of the airship and how it was used in the U.S. Navy, Figure II-10 shows the airship AKRON operating as an aircraft carrier with a small fighter aircraft (F-9C) in launch position.



(U) Figure II-10. U.S. NAVY AIRSHIP AKRON WITH ITS AIRCRAFT

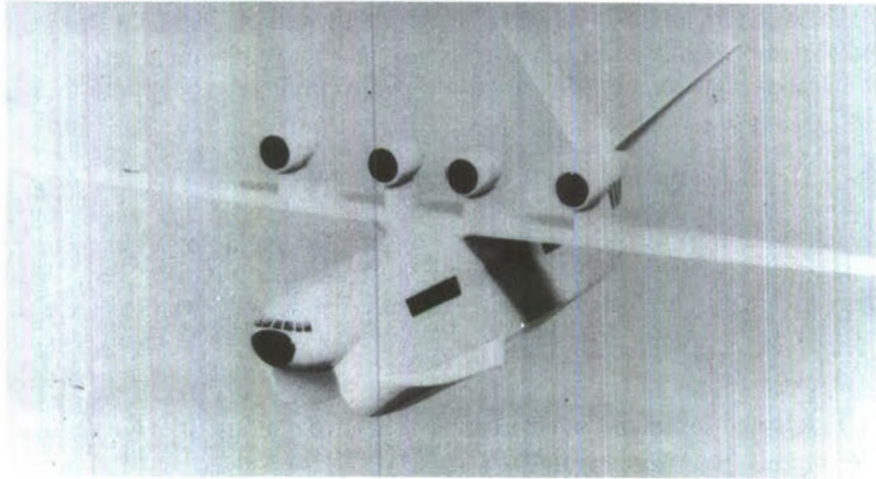
(U) During the airship era, little was known of the aerodynamic and structural theories upon which they were based. Thus, many of the problems associated with the airship, such as lack of control and cumbersome ground handling, could probably be attributed to the lack of good aerodynamic design rather than to the basic LTA concept. Accordingly, a detailed state-of-the-art survey encompassing both the concept of a fully buoyant (classical) airship and the advantages of aerodynamic shaping in semibuoyant airships was made by NADC (Reference 11).

2.2.3 Sea Loiter Aircraft

(U) In a similar vein, the sea loiter aircraft extends the concept of the seaplane (phased out by the U.S. Navy in 1968). The sea loiter aircraft considered by the ANVCE Project is capable of loitering for extended periods of time, sitting on the surface of the sea. In this manner, it differs from the traditional seaplane, which is capable of taking off and landing in a rough sea but is not capable of sitting on such a sea for any significant length of time. The ANVCE Project explored various techniques that could provide the seaplane with a sea loiter capability, making it a more flexible aircraft from a mission viewpoint. To produce a vehicle that could sit on the sea in rough weather without debilitating effects on the crew and equipment and still be satisfactory aerodynamically during flight requires advances in hydrodynamic hull design and the integration of improved lifting mechanisms. The product has different configurations depending on whether the aircraft is small or large.

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(U) Since there is no seaplane in the active fleet of the U.S. Navy, a model of one of the large sea loiter concept designs, employing a catamaran hull, is shown in Figure II-11.



(U) Figure II-11. CATAMARAN, SEA LOITER AIRCRAFT MODEL

(U) A brief summary of the technical state of the art was prepared by DT-NSRDC as part of the ANVCE Project and is provided in Reference 12. The concepts studied included hull shaping as well as various forms of powered lift, such as circulation-controlled, stopped-rotor wings and the more conventional, deflected jet configurations. A significant amount of technical expertise was known to be available in British seaplane work of about 1950, and accordingly, an additional detailed technical summary (Reference 13) was also prepared and used as part of the data base used to explore the concept.

2.2.4 WIG Vehicle

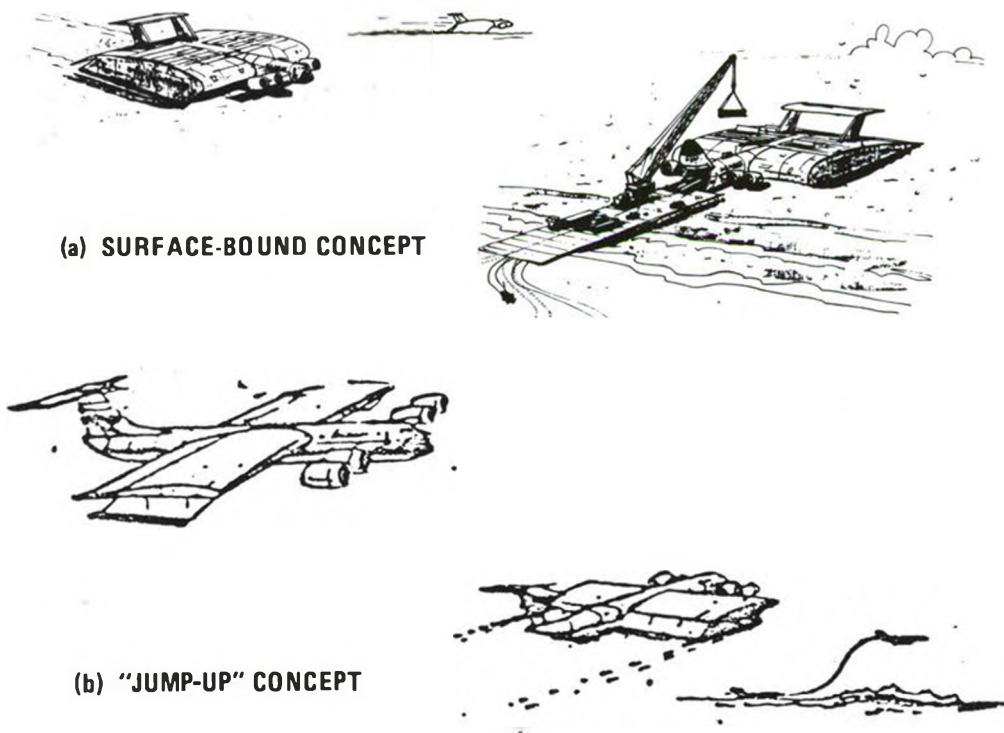
(U) International efforts in WIG technology, which began in the 1920s, have been considerable. The WIG concept is primarily of interest because of the favorable effect on aerodynamic efficiency; however, there is a possibility that very-low-altitude operation might fit in well with certain ASW sensors. Since an aircraft intended to operate in ground effect over the open ocean must necessarily be designed to take occasional wave impacts, it seems likely that any such aircraft would be made into an open-ocean aircraft. On closer examination, however, it becomes clear that there are distinct regimes in which the various concepts are dominant as well as those in which they overlap with other concepts. If the WIG vehicle is to remain in ground effect throughout its entire mission, trade-offs must be made between the aeronautical and hydronautical disciplines to create a configuration that meets that need. If the WIG vehicle is required to spend small portions of its missions "popping up" into the air to fly out of ground effect, the aerodynamic considerations begin to exert greater influence and a more airplane-like

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configuration is likely to evolve. If the mission requires longer periods of time on station, the WIG concept configuration becomes almost indistinguishable from the sea loiter concept and the WIG feature essentially becomes a takeoff and landing aid. If the complete mission were carried out at altitude, the air loiter concept would be used instead of the WIG concept. In studying the WIG concept, technical analyses, model experiments, and design studies were employed to explore these possibilities.

(U) The fact that the USSR is investigating the use of a WIG concept employing a power augmentation feature to boost the low-speed lift mode has strongly influenced the current U.S. Navy thinking on this technology. Since there are no hardware programs in the U.S. Navy to illustrate the WIG concept, Figure II-12 provides an artist's rendition of (a) a surface-bound WIG vehicle (one always in ground effect) and (b) a WIG vehicle capable of occasionally flying out of ground effect.

(U) A brief summary of the current state of the art of WIG technology was prepared as part of the ANVCE Project and is given in Reference 14.



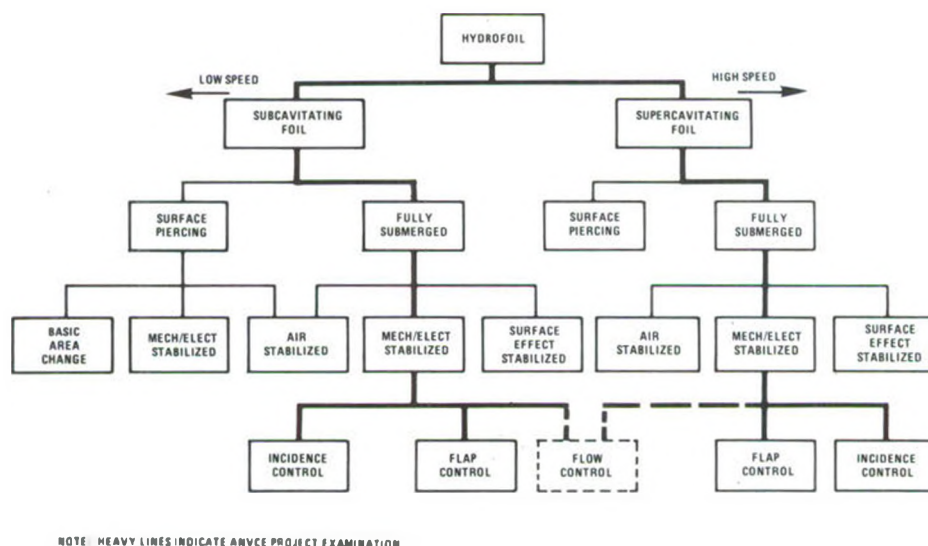
(U) Figure II-12. WIG CONCEPTS

2.3 Technological Exploration of the Concepts

(U) In exploring the nine generic concepts technologically (Section 1), the feasibility of the concepts was tested by developing specific designs representing those concepts. This process involved the development of a concept tree; identification of features and issues; and evaluation through analysis, experiments, and point designs. Based on the findings of this exploration, R&D recommendations were developed. This process is described in the following subsections.

2.3.1 Concept Tree

(U) The conceptual exploration, using the concept tree for the hydrofoil as an example, is shown in Figure II-13. The configurational form has two main branches, the subcavitating and supercavitating foil systems. Further subdivisions relate to whether the basic foil system is surface piercing or fully submerged, which further evolve into the basic forms of stabilization and control. Progressing down through the limbs of the tree, the concept nature gradually shifts into more hardware-like, specific design differences.



(U) Figure II-13. CONCEPT TREE (HYDROFOIL)

(U) The bold lines in the concept tree indicate the focus of the major analysis, experiment, and point design activity within the ANVCE Project. These bold lines do not necessarily indicate the preferred or recommended path of development for the concept; they merely represent a consensus of where the most likely return was expected within the resource limits of the project. Thus, they represent the path followed during the investigation of the concept and its technical issues, not knowl-

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edge gained from those analyses. The recommended paths, based on the technical analyses, experiments, and point design investigations, are presented in Chapter VI of this volume and in Volume 1, which considers the technical recommendations in relation to the cost analysis and military mission analysis recommendations.

2.3.2 Features and Issues

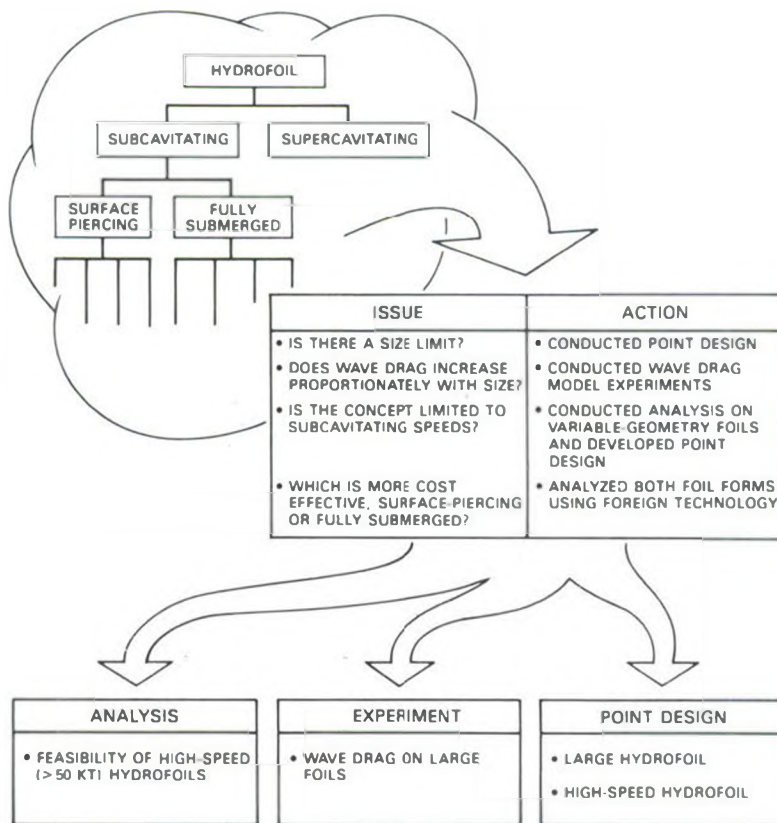
(U) A feature of interest to the ANVCE Project is a technical or operational characteristic of a concept that makes that concept worthy of merit as a military vehicle. The features of an ANV concept make it an improvement over the current mode of operation in fulfilling a mission. Such improvement must either enable the vehicle to perform current tasks better or provide a new capability by which to better meet the threat. While it is difficult to place specific bounds on the degree of improvement that must be represented by the ANV, it must be more than marginal (otherwise the cost of developing the vehicle will negate any advantage it offers).

(U) An issue involves an associated risk in pursuing the concept into further development, be it at the Category 6.1 (Research), 6.2 (Exploratory Development), or 6.3 (Advanced Development) stage. Table II-2 defines the types and levels of risk that could be encountered in resolving a given issue. Generally, an issue involves a moderate or high risk; a low risk usually is not sufficient to have any affect on the development of the concept.

(U) Table II-2. POSSIBLE TECHNICAL RISKS

TYPE OF RISK	LEVEL OF RISK		
	LOW	MODERATE	HIGH
ADMINISTRATIVE	PROGRAM IS REQUIRED; ACTIVITY IS ONGOING.	REQUIRED ACTIVITY IS MODERATE IN COST AND NONCONTROVERSIAL	REQUIRED ACTIVITY HAS MODERATE-TO-HIGH COST AND IS POTENTIALLY CONTROVERSIAL
DESIGN	SIMILAR TO PAST DESIGNS; CRITICAL PARAMETERS CAN BE ESTIMATED WITH CONFIDENCE; MANY DESIGN OPTIONS AVAILABLE	MODERATE EXTENSION FROM PAST DESIGNS AND THE ESTIMATED RANGE OF CRITICAL PARAMETERS IS ACCEPTABLE TO VEHICLE DESIGN; LIMITED NUMBER OF DESIGN OPTIONS AVAILABLE	SIGNIFICANT EXTENSION FROM PAST DESIGNS; ESTIMATED RANGE OF CRITICAL PARAMETERS CAUSES SIGNIFICANT CONCERN IN THE FINAL VEHICLE DESIGN; ONLY ONE OR TWO DESIGN OPTIONS AVAILABLE
DEVELOPMENT	MINIMAL STATE-OF-THE-ART EXTENSION; SEVERAL FEASIBLE APPROACHES DEFINED; R&D UNDERWAY AND SUCCESSFULLY MEETING CRITICAL MILESTONES	MODERATE-TO-SIGNIFICANT EXTENSION; FEASIBLE APPROACHES DEFINED BUT CURRENT R&D NOT SPECIFICALLY ORIENTED TOWARD THE REQUIRED TECHNOLOGY DEVELOPMENTS NECESSARY FOR THE VEHICLE DESIGN	SIGNIFICANT DEVELOPMENT REQUIRED TO EXTEND THE STATE-OF-THE-ART; FEASIBLE APPROACHES HAVE BEEN DEFINED BUT LACK SUPPORTING EXPERIMENTAL EVIDENCE THAT THE APPROACH WILL BE SUCCESSFUL

(U) With these general guidelines, it is possible to identify the technical risks involved in resolving an issue and to pursue those deemed to be worth the risk. Figure II-14 illustrates the general approach, again using the hydrofoil as an example. It shows the progression from the concept tree (concept, configuration, etc.), through the raising of specific issues involved in expanding some aspect of the concept or extending the state of the art of the concept, to resolving those issues whenever possible through analysis, experiment, the development of a point design to ascertain feasibility, or some combination of these methods. As shown in the figure, the issue of how large a hydrofoil can be and still be technically feasible was answered through two activities: an experiment on large foils to resolve hydrodynamic issues related to drag and a point design to resolve issues of subsystem integration. The issue regarding the feasibility of high-speed (supercavitating) hydrofoils was resolved through analysis of existing experimental data on supercavitating foils and development of a point design of a high-speed hydrofoil. The wide disparity between the cost of the European, surface-piercing hydrofoils and the U.S. hydrofoils using fully submerged foils prompted an analysis of the cost trade-offs in the various options for the hydrofoil concept.



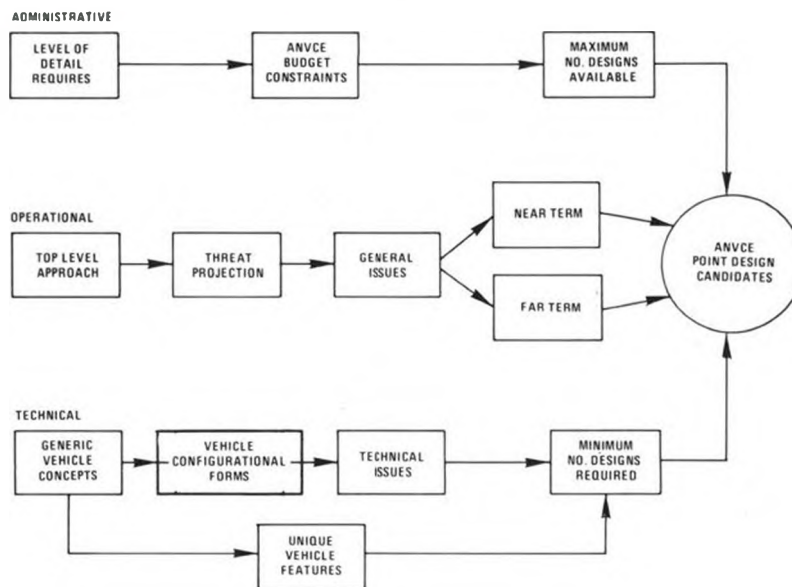
(U) Figure II-14. ANVCE PROJECT TECHNICAL APPROACH

2.3.3 Analyses, Experiments, and Point designs

(U) The military effectiveness of a vehicle is affected by, but not identical with, its performance. For the most part, the military effectiveness of an ANV is a result of the interaction between platform performance per se and the performance of the installed combat suite (sensors and weapons systems). In general, for each vehicle type there will be a broad range of platform configurations and combat suites, each having its own technical feasibility and cost. Since vehicle costs for any particular class of vehicle configuration are most strongly affected by such factors as empty weight, installed power, and overall structural loading and density, the relationships between these factors and the vehicle (platform) characteristics had to be explored.

(U) For such evaluations, the ANVCE Project used a set of scaling laws and parametric relationships and point designs with well-validated performance figures. Except in simple cases, there is usually no way to obtain well-validated performance figures without data from tests of actual vehicles or at a lesser level of confidence, scale models. The point designs provide essential qualitative data on matters such as sensor and weapon interfaces with the platform and indicate gaps in the basic performance data. Moreover, the process of design is often essential in determining the impact of technology on performance.

(U) The point designs were produced through the interaction of administrative, operational, and technical influence, as illustrated in Figure II-15. The administrative influence was in terms of time and budget constraints; it was impossible to study all possible combinations of configurations and technical performance options. The operational influence was in the form of considerations demanded by the impacts of the given functions, threat, and scenarios. The technical influence was embodied in the technical issues involved and the need to explore the gaps in the data on the technological state of the art.



(U) Figure II-15. POINT DESIGN SELECTION LOGIC

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(U) Because the point designs were used to explore the gaps in the data on the technological state of the art as well as to provide reference points in the analytical investigations, the preparation of the specific point designs was a major part of the technical evaluation process. The approach followed in preparing both the surface and air vehicle designs is best described as a feasibility design. The development of the point designs, and the appropriate level of detail, is outlined in Table II-3.

(U) Table II-3. POINT DESIGN DEVELOPMENT

OBJECTIVE	PRODUCTS	PROCESS
DEFINE SERIES OF FEASIBLE SHIPS (AND ASSOCIATED COSTS) THAT MEETS OR APPROACHES PERFORMANCE REQUIREMENTS ACHIEVE BALANCE BETWEEN OPERATIONAL REQUIREMENTS AND PRODUCTION COSTS IDENTIFY MAJOR TECHNICAL RISKS	CONCEPT SELECTION CLASS E OR F COST ESTIMATE (DEPENDING ON RELIABILITY OF COSTS) DEFINITION OF PAYLOAD 1-DIGIT LEVEL WEIGHTS GENERAL ARRANGEMENT DRAWINGS CREW COMPLEMENT MAKEUP TYPE OF MACHINERY SPEED POWER GENERAL SHIP GEOMETRY	SMALL GROUP (3-4 PEOPLE) 5% ACCURACY ON WEIGHTS SYNTHESIS COST PROGRAM PERFORMANCE IN TERMS OF SPEED, ENDURANCE, PAYLOAD, SPECIAL FEATURES RELATIVE ACCURACY VS. "ABSOLUTES" STRESSED BASIC DESIGN METHODOLOGY DEVELOPED PRIOR TO FEASIBILITY STUDY

(U) Using the selection logic shown in Figure II-15, point designs were developed by the ANVCE Project; these designs as well as the baseline and existing designs that were used as references are listed in Table II-4. The majority of the vehicles listed are ANVCE Project point designs. Baseline designs are those taken from other programs but expressed in ANVCE format (a standardization process discussed subsequently in this section). The point designs are presented in Chapters III and IV; to the extent that they are available, details on the designs are given in Appendix B.

(U) An important consideration in the development and subsequent evaluation of the point designs was that consistent design standards be employed in their development. When comparing one point design with another, it is extremely important that they have the same combat suite so that any differences in effectiveness are a result of the *platform concept*, not a design difference such as combat suites.

(U) 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
 - weight groups

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- common levels of technology for
 - engine performance
 - propulsor characteristics
 - materials characteristics
- common criteria for
 - weight margins
 - performance margins
 - hump thrust
 - fuel reserves and range
 - ride quality
 - vehicle system design
 - habitability standards
 - survivability and vulnerability requirements.

(U) Table II-4. POINT DESIGNS

VEHICLE	DEFINITION	ANVCE PROJ- ECT DESIGN	BASELINE DESIGN	EXISTING DESIGN
ACV 1	NOMINAL 1000-TONNE ACV	X		
ACV 3	NOMINAL 3000-TONNE ACV	X		
A/L	AIR LOITER AIRCRAFT	X		
A/L(IN)	NUCLEAR-POWERED, AIR LOITER AIRCRAFT	X		
AVP	ADVANCED PATROL AIRCRAFT		X	
CPIC	COASTAL PATROL INTERDICTION CRAFT			X
CXX	LONG-RANGE CARGO AIRCRAFT (USAF)		X	
FAB	FULLY AIR-BUOYANT LTA VEHICLE	X		
FFG 7	USS PERRY-CLASS, GUIDED-MISSILE FRIGATE			X
HYD 7	NOMINAL, 700-TONNE, HIGH-SPEED HYDROFOIL	X		
HYD 2	NOMINAL, 2000-TONNE HYDROFOIL	X		
HOC	HYDROFOIL, OCEAN COMBATANT			X
LCAC	LANDING CRAFT, AIR CUSHION VEHICLE	X		
LCPC	LANDING CRAFT, PLANING CRAFT	X		
LSES	LARGE SES			X
MONO 3	NOMINAL, 3000-TONNE, ADVANCED-TECHNOLOGY MONOHULL		X	
PC 1	NOMINAL, 1000-TONNE PLANING CRAFT	X		
PHM	GUIDED-MISSILE, PATROL HYDROFOIL			X
SAB	SEMI-AIR-BUOYANT LTA VEHICLE	X		
SES 3	NOMINAL, 3000-TONNE SES	X		
SES CV	SES CARRIER	X		
SES CVN	NUCLEAR-POWERED SES CARRIER	X		
S/L(L)	LARGE, SEA LOITER AIRCRAFT	X		
S/L(S)	SMALL, SEA LOITER AIRCRAFT	X		
S/L(V)	SHIP-BASED, V/STOL, SEA LOITER AIRCRAFT	X		
SWA 4	NOMINAL, 4000-TONNE SWATH FRIGATE	X		
SWA MCM	MINE-COUNTERMEASURES SWATH SHIP	X		
SWA CVN	NUCLEAR-POWERED, SWATH CARRIER	X		
VSS	V/STOL, SUPPORT SHIP		X	
WIG(H)	HARD-END-PLATE WIG VEHICLE	X		
WIG(O)	OUT-OF-GROUND-EFFECT, WIG VEHICLE	X		
WIG(S)	SOFT-END-PLATE, WIG VEHICLE	X		
ZPG	PATROL, LTA VEHICLE			X

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Considerable effort was expended early in the project to ensure that such standards were prepared (Appendix A) and issued before starting to develop the point designs. This proved to be a major effort because of the differences in standards among the U.S. Navy Laboratories and between the Navy and industry. Different standards also existed within the technical communities developing air and surface vehicles and between the two communities. For example, the ship community has no counterpart to the air technical community's "standard atmosphere." Hence, care had to be taken in comparing the performance characteristics of craft designed to different standards. Displacement ships are typically designed to a "standard" day temperature of 80°F, while the current U.S. Navy ACV program is using a 100°F day in its design effort. Since most high-performance craft are powered by gas turbines, which typically have 20 percent less power on a 100°F day than on a 50°F day, the impact of such varying standards can be important.

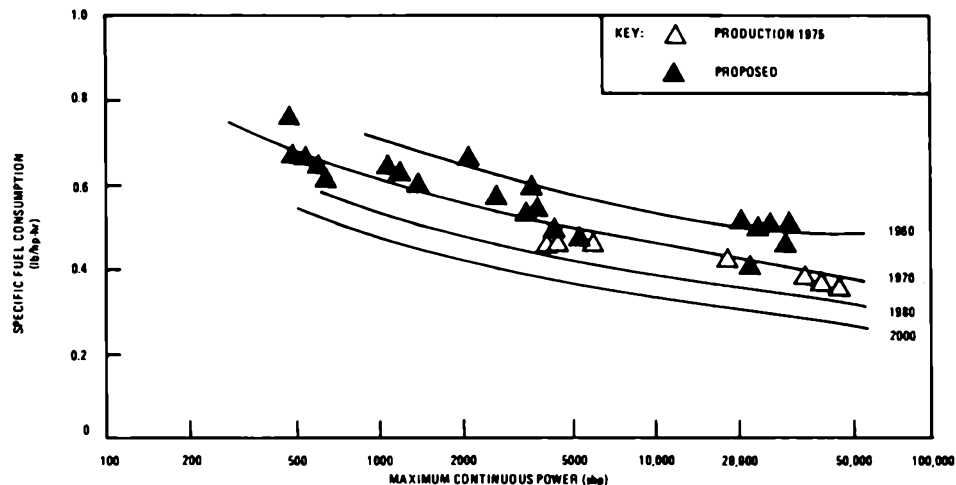
(U) Two other examples illustrate the impact of using different criteria when comparing vehicle performance and capabilities. The first example pertains to descriptions of the sea. Several "standards" exist in the various technical communities to describe the sea surface in terms of wave height, wind speed, encounter frequency, wave length, celerity, and other pertinent characteristics. Table II-5 gives one set, based on the Hydrographic Office description. A wide band of wave heights is grouped under a given sea state, with obvious ramifications on the performance of high-speed vehicles designed to operate in rough seas. In the interest of evaluating concepts operating under similar conditions, those wave heights compatible with the Pierson-Moskowitz spectrum description (shown in boxes in Table II-5), which is the spectrum used in most of the U.S. Navy towing tanks, were specified by the ANVCE Project for use in the evaluation. The associated wind speeds, also shown in Table II-5 are different from the Hydrographic Office values. Wind speed can have an appreciable effect on airborne vehicles that operate close to the waves, such as ACV, SES, and WIG vehicles.

(U) Table II-5. SEA-STATE DEFINITION

SEA STATE	SIGNIFICANT WAVE HEIGHT (M)	WIND SPEED AT 30-FT ELEVATION (KT)
1	0.10 - 0.30	5 - 8.5
2	0.30 - 0.90	8.5 - 14
3	0.90 - 1.40*	10 14 - 16
4	1.40 - 2.10	16 - 19
5	2.10 - 3.05 - 3.96	19 - 25 26
6	3.96 - 4.57 - 7.00	25 - 31 38

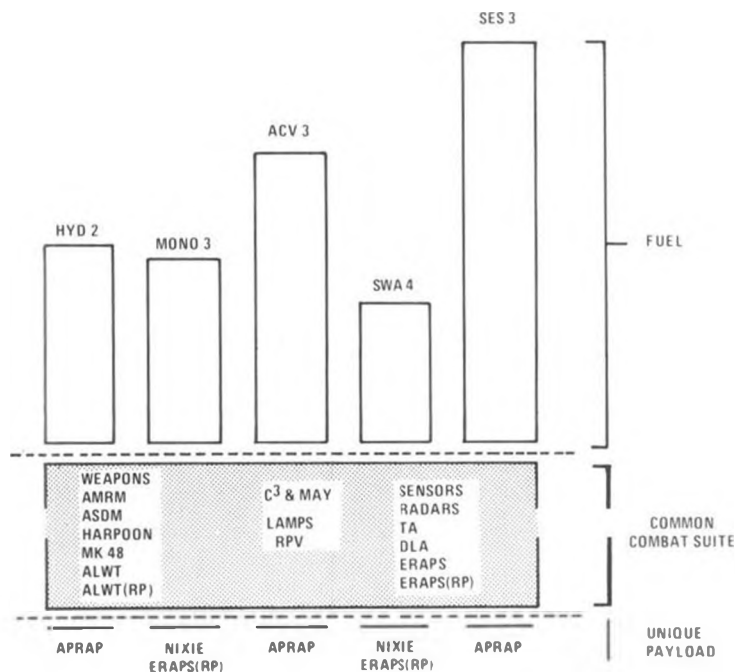
*PIERSON-MOSKOWITZ SPECTRUM DESCRIPTION IN BOXES.
SOURCE: HYDROGRAPHIC OFFICE.

(U) The second example relates to standardization of engine performance and its projection into 1985-95. The range capability of a vehicle is directly related to the specific fuel consumption of the engine(s). As technological improvements are anticipated by the engine manufacturers, the performance quoted will also change significantly. To even out the differences in range characteristics between one vehicle concept and another, the projections of engine performance had to be standardized. Figure II-16 is one such standardized set of data, compiled for marine, gas-turbine fuel consumption. This set of data curves represents the expected technology level for engine performance as a function of continuous power rating for 1960 through 2000.



(U) Figure II-16. STANDARDIZED, MARINE, GAS-TURBINE FUEL CONSUMPTION

(U) The consistency standards (Appendix A) and common combat suites (Appendix A) were not stressed in the near-term vehicles used for comparison since most of them were designed prior to the start of the ANVCE Project (with the exception of the amphibious group). The emphasis in the ANVCE Project has been placed on the far-term vehicles, which were designed using consistent standards, mission objectives, and combat suites. Slight variations have been allowed in the combat suites if the variation is 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, has been placed on the high-speed vehicles but omitted on the slower-speed vehicles. (Details on the common combat suites are given in Appendix A.) Figure II-17 illustrates the philosophy of a common combat suite for a common mission or operation using the air-capable, surface combatant group as an example. The shaded region shows the combat suite [weapons; sensors; command, control, and communications (C³) system; navigation system; and secondary vehicles] common to all the point designs within the group. Below the shaded area are those items of the combat suite that are unique to each platform. The columns above the shaded area show the relative differences in fuel levels required by each vehicle concept to accomplish its objectives within the mission. The amount of fuel needed depends on the consumption and the length of time the vehicle must stay out without refueling; the amount carried affects its weight and cost. Hence, there are many factors involved in each of the point designs. However, while the values are quite



(U) Figure II-17. COMMON COMBAT SUITE PHILOSOPHY

different for each design, they have essentially the same weapon and sensor capabilities. Thus, they can be evaluated for *platform* differences.

(U) Detailed summaries of the point design particulars and general performance characteristics are provided in Appendix B. These summaries represent descriptions of the point designs after corrections, refinements, and adjustments have been made to the original point designs submitted for evaluation. These descriptions reflect (a) corrections to ensure consistency across the point design groups and (b) refinements on the concept in view of analytical findings. (The normalizing standards are described in detail in Appendix A.) Despite these efforts, complete data on all vehicle characteristics over the full performance range could not always be obtained.

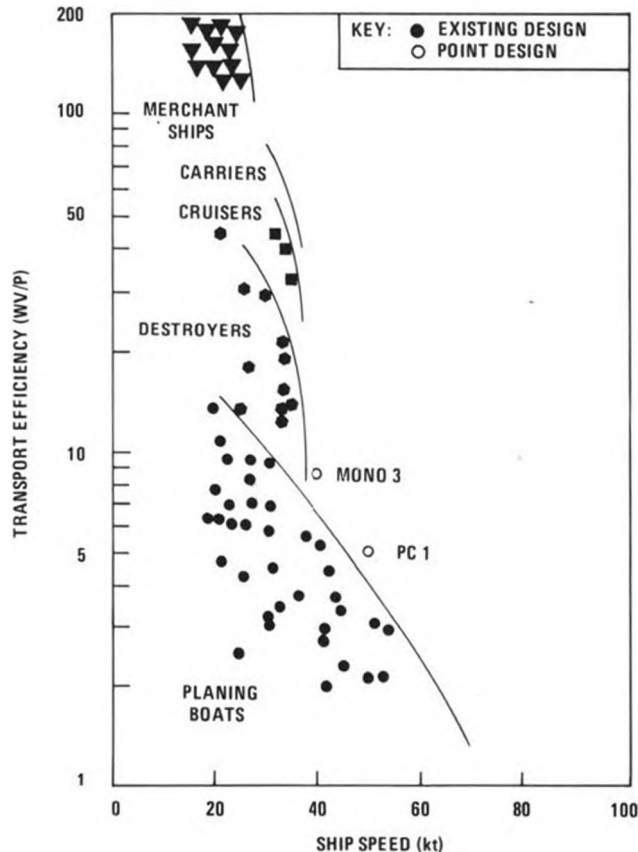
2.3.4 R&D Recommendations

(U) The point designs were used both for technical feasibility studies and assessments. The approach to the technical assessment consisted of comparing the various vehicle parameters with the state of the art of similar or related vehicles and assessing whether any departure from the state of the art can be attributed to an expected technological improvement or to a particular vehicle characteristic.

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(U) While the assessment is frequently made on the actual data taken from the point designs, wherever possible the data are examined in nondimensional form on parametric plots to assess the general characteristics of the concept as distinct from the idiosyncracies of a particular design. For example, Figure II-18 shows the current (1978) state of the art in powering displacement and planing craft in terms of transport efficiency. Transport efficiency is a measure of the "work done" by the vehicle and is computed as the displacement (mass) (W) multiplied by the speed (V) and divided by the total power (P) required to achieve that speed.

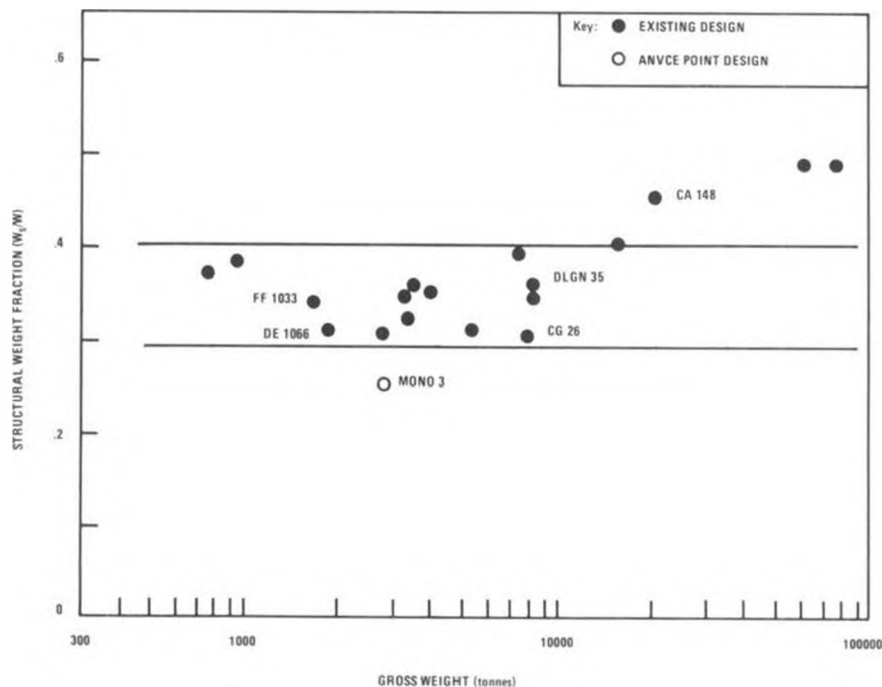
(U) Superimposed on the state-of-the-art plot in Figure II-18 are two of the point designs, the advanced-technology monohull (MONO 3) and the conventional, hard-chine, planing hull (PC 1). The plot suggests that very little extension in hull form efficiency was integrated into the monohull design and that the higher speed was accomplished through increased power. The speed of the planing craft was also increased through an increase in power; efficiency was increased through the benefits of size.



(U) Figure II-18. TRANSPORT EFFICIENCIES OF DISPLACEMENT AND PLANING SHIPS

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(U) A second example is shown in Figure II-19. There the structural weight fraction of the advanced-technology monohull (MONO 3) is compared with that of existing ships. The use of an aluminum hull structure on the MONO 3 has contributed to the low structural weight fraction shown; however, the hull is being subjected to much higher loads because the speed (40 kt) is greater than that of current ships. While by no means complete, these plots illustrate the general approach taken in (a) assessing the technical characteristics of each point design and the concept in general and (b) identifying the technical risks. Such an identification forms the basis for developing the R&D recommendations presented in Chapter VI.



(U) Figure II-19. MONOHULL STRUCTURAL WEIGHT

CHAPTER III SURFACE VEHICLE CONCEPTS EVALUATION

(U) In this chapter, the surface ANVs (ACV, hydrofoil, planing craft, SES, and SWATH ship) introduced in Chapter II are described; in addition, a description of the advanced-technology monohull, used for comparison, is also presented. Each surface vehicle concept is presented through a concept tree, a discussion of the features and issues involved, an examination of those issues, and the results of the investigations. The examination of the particular issues involved in each concept took the form of analyses, experimentation, point design development, or a combination thereof. Since all of the forms of each concept could not be evaluated in terms of their potential for military application, forms that could not be examined within this study but that seem to offer potential are recommended for further investigation.

(U) As discussed in Chapter II, the common combat suites of the surface vehicles contain such secondary vehicles as helicopters and remotely piloted vehicles (RPVs). The aircraft carried as part of the combat suite on surface vehicles differ from the aircraft carried by aircraft carriers in quantity, type, and size (Appendices A and B).

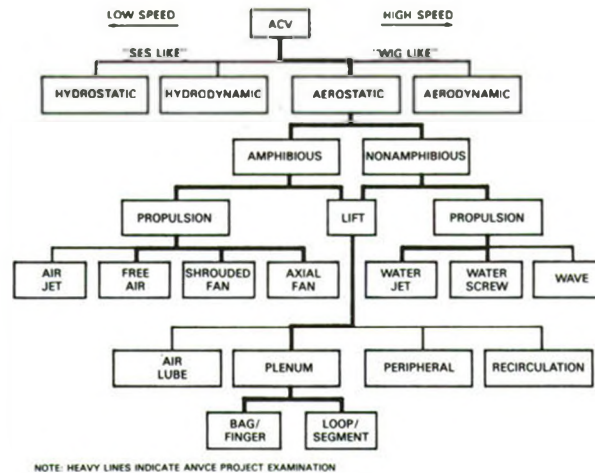
(U) Some subject matters are best described collectively across concepts. Specific detailed comparative analyses were conducted among concepts. These comparisons are presented in Chapter V.

1. AIR CUSHION VEHICLE

1.1 Concept Tree

(U) Figure III-1 shows the concept tree for the ACV. As shown, the ACV can be either amphibious or nonamphibious, depending on the propulsion scheme and can take several configurational forms. In general, the ACV is technically thought of as an aerostatic vehicle because at cruise speeds a significant amount of its lift is generated by the static air pressure in the cushion beneath the craft and only a small amount of dynamic lift is generated by the upper surface. Accordingly, the upper surfaces can be designed to meet functional needs (e.g., space for helicopter hangars, etc.) rather than to maintain the aerodynamic contouring needed to generate lift and minimize drag. A speed range of 40-120 kt, depending on size, propulsion (air or water), and mission, has been used as representative of this concept. Although speeds of more than 150 kt are possible, at such speeds the ACV becomes more of a WIG vehicle and is no longer representative of the ACV concept. The bold lines in Figure III-1 show the particular configurations pursued, in varying amounts of detail, within the ANVCE Project evaluation.

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(U) Figure III-1. ACV CONCEPT TREE

1.2 Features and Issues

(U) Based on the technical approach methodology described in Chapter II, Table III-1 presents the particular features and issues of the ACV concept. The paths taken in resolving the issues and the findings and conclusions of those efforts are discussed in the following subsections. The point designs are considered separately from the analyses and experiments simply for ease of reference.

1.3 Analyses and Experiments

(U) For the ACV, analyses were conducted on water and air propulsion, lift system losses, ride control, and motions. Tests were performed on a towing tank model to gain knowledge of rough water resistance. Finally, the feasibility of producing skirts for large ACVs (1000-3000 tonnes displacement) was analyzed.

1.3.1 Air and Water Propulsion Analyses

(U) An analysis of the most-promising air-propulsor configurations for ACVs was performed (Reference 15); the results are given in Figure III-2. This analysis encompassed ACVs with gross weights between 100 and 5000 tonnes and cruise speeds between 65 and 200 kt. The analysis considered free-air propellers; shrouded-air propellers; and high-density, axial-fan propulsors (Q-fans). The general regions of applicability are shown in the figure. For example, free-air propellers were found to be a feasible proposition for all speeds of interest and for ship displacements up to about 2000 tonnes. Shrouded-air propellers were found to increase the displacement up to about 5000 tonnes if the speeds were kept below 90-100 kt. The Q-fans were

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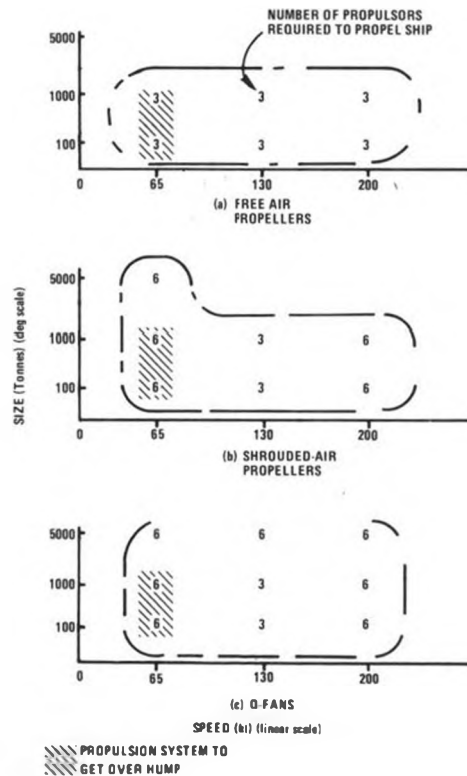
(U) Table III-1. ACV EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
TRULY AMPHIBIOUS	IS THE AMPHIBIOUS FEATURE LIMITED TO SMALL SIZE ACV (LESS THAN 500 TONNES)?	CONDUCTED A PROPULSION SYSTEM ANALYSIS EXAMINING BOTH WATER AND AIR PROPULSION SCHEMES	RESOLUTION OF ISSUE DEPENDS ON SPEED AS WELL AS SIZE; PRACTICAL AIR-PROPELLED (AND AMPHIBIOUS) ACVs WERE FOUND UP TO 4000 TONNES AND GREATER THAN 100 KT. FOR ABOUT 3000 TONNES AND 60-80 KT IT IS BETTER TO BE WATER-PROPELLED (AND NONAMPHIBIOUS)
RIDE QUALITY BETTER THAN CONVENTIONAL HULL FOR GIVEN SPEED AND DISPLACEMENT	CAN RIDE CONTROL BE IMPROVED WHEN OPERATING AT HIGH SPEEDS (50-80 KT) IN HIGH SEAS?	PROBLEM IS THE SAME AS FOR SES AND THE ANALYSIS AND MODEL TESTS CONDUCTED FOR SES ARE THE SAME AS FOR ACV-TUS NO SPECIFIC ACTION TAKEN FOR ACV	RIDE CONTROL IS DEFINITELY NEEDED FOR ANY ACV (OR SES) REQUIRED TO OPERATE FOR LONG PERIODS (AT LEAST 4 HR) AT HIGH SPEEDS IN ROUGH SEAS
BECOMES PROGRESSIVELY MORE EFFICIENT THAN SES AS SPEED INCREASES	—	DEVELOPED POINT DESIGN OF 3000-TONNE-CLASS ACV	CONFIRMS POSTULATED FEATURE
HIGHLY MANEUVERABLE, CAN TURN ON AXIS AT LOW SPEED	CAN MANEUVERABILITY AT HIGH SPEED BE IMPROVED?	TOOK NO PARTICULAR ACTION EXCEPT TO NOTE MANEUVERABILITY OF THE 200, 1000, AND 2000-TONNE-CLASS DESIGNS	PROBLEM IS ALMOST SELF-CORRECTING; HIGH MANEUVERABILITY IS A GOOD FEATURE IN SMALL (200-TONNE) ACV. AS SIZE INCREASES, UNCONTROLLABLE DESIGN WOULD BE A PROBLEM. THE CRAFT BECOMES NONAMPHIBIOUS (SEE ABOVE) AND WATER SCREWS IMPROVE MANEUVER
NOTHING IN WATER ENHANCES INVULNERABILITY TO DAMAGE	DOES STATE OF THE ART OF SKIRT FABRICATION PLACE LIMITS ON ACV SIZE?	STUDIED LARGE SKIRT FABRICATION	FEATURE STANDS UNLESS FABRIC MANUFACTURERS' LOOMS CHANGE AND MARKET IS SUFFICIENTLY HIGH (NOT LIKELY), THERE ARE PRACTICAL PROBLEMS IN MANUFACTURING SKIRTS FOR ACV ABOUT 3000 TONNES AND THIS NEEDS TO BE EXAMINED FURTHER.

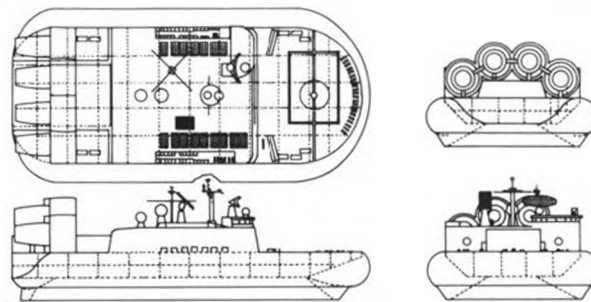
applicable up to 5000 tonnes, the limit of the study, at all speeds (65-200 kt). In some cases, the size of the propulsion system was dictated by the maximum speed condition; in other cases, the requirement to generate sufficient thrust to get over the hump dictated propulsion system size.

(U) To further pursue the feasibility of air propulsion on a large ACV, the results of these analyses were used in a feasibility design concept of a 3000-tonne ACV. The design, by Bell Aerospace Textron (Reference 16), is shown in Figure III-3. Four Q-fans with diameters of 25 ft were used. The principal characteristics of this air-propelled ACV are given in Table III-2. A detailed description of the performance characteristics of this design is provided in Reference 16. Because the forward-located, helicopter landing pad could cause some problems in helicopter deck-handling in rough seas, several alternative configurations were explored. Two of the preferred alternatives are shown in Figure III-4.

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(U) Figure III-2. AIR PROPULSION SIZING FOR ACV



(U) Figure III-3. AIR-PROPELLED, 3000-TONNE ACV

(U) These feasibility studies were sufficient to indicate that there are engineering solutions to the problem of designing of 3000-tonne-class ACV that incorporates both air propulsion and helicopters on the deck.

(U) The use of water propulsion in roughly the same-sized class of ACV was also explored to determine the relative merits of air and water propulsion and, further, to compare a water-propelled ACV with an SES of approximately the same displacement. An analysis of the feasibility of the use of waterborne propulsion for large ACVs is presented in Reference 17. This analysis explored a size range of 1000-3000 tonnes displacement and a speed range of 60-80 kt. Performance and the

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(U) Table III-2. PRINCIPAL CHARACTERISTICS OF AIR-PROPELLED, 3000-TONNE ACV

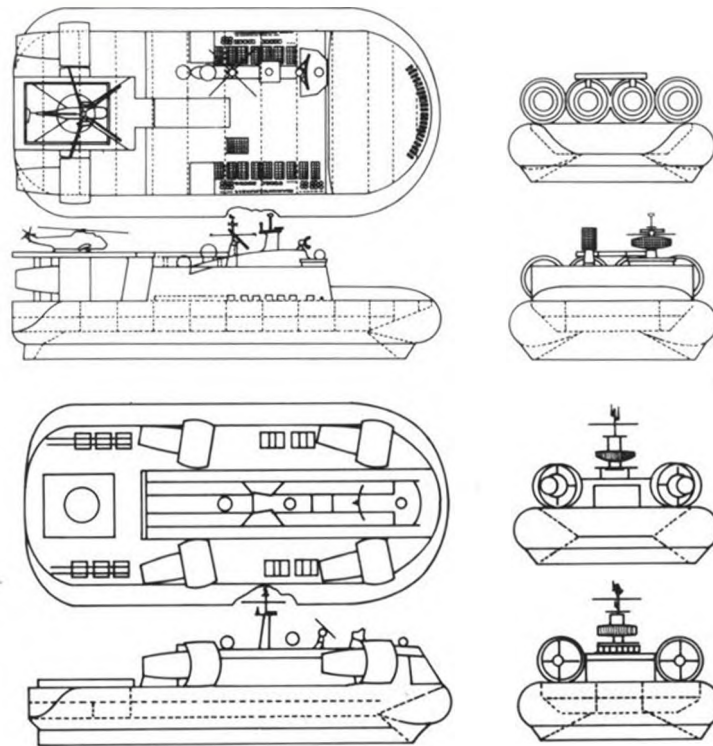
DIMENSIONS:	
LENGTH (OVERALL)	277 FT
BEAM (OVERALL)	
ON CUSHION	136 FT
HARD STRUCTURE	106 FT
CUSHION DEPTH	18 FT
CUSHION BEAM	106 FT
CUSHION AREA	25,122 FT ²
L/B	2.24
CUSHION PRESSURE	263 LB/FT ²
POWER PLANTS:	
PROPULSION ENGINES	FOUR, 50,000-HP MCP MARINE GAS TURBINES
PROPULSORS	FOUR, 25 FT DIAMETER PROP FANS
LIFT ENGINES	TWO, 40,000-HP MCP MARINE GAS TURBINES
LIFT FANS	EIGHT, VARIABLE GEOMETRY DOUBLE ENTRY CENTRIFUGAL
SYSTEMS: ALL OTHER SHIP SYSTEMS INCLUDING THE COMBAT SYSTEM ARE THE SAME AS FOR THE WATER-PROPELLED 3,000 TONNE ACV	
CREW AND COMPLEMENT:	
	16 OFFICERS/11 CPOs/113 EM
WEIGHTS:	
FULL LOAD WEIGHT (DISPLACEMENT)	3,000 TONNE
EMPTY WEIGHT	1,865.1 TONNE
FUEL (LIFT, PROPULSION, AUXILIARY)	
HELICOPTER ¹	1,134.9 TONNE
OTHER LOAD	188.1 TONNE
MOBILITY PERFORMANCE SUMMARY:	
MAXIMUM SPEED (CALM WATER, MCP)	110.1 KT (203.9 KM/HR)
MAXIMUM SPEED (1.4 M SIGNIFICANT WAVE HEIGHT, MCP)	90.0 KT (166.7 KM/HR)
MAXIMUM SPEED (4.57 M SIGNIFICANT WAVE HEIGHT, MCP)	28.1 KT
HUMP MARGIN (1.0 M SIGNIFICANT WAVES, MIP)	29%
AVERAGE BEST RANGE SPEED (CALM WATER) ¹	94.8 KT
AVERAGE BEST RANGE SPEED (AT 1.4 M SIGNIFICANT WAVE HEIGHT) ¹	87.3 KT
TIME TO ACCELERATE TO V _{MAX} (NOMINAL LIFT FLOW, CALM WATER, REVERSE THRUST AT MIP)	302 SEC
TIME TO DECELERATE FROM V _{MAX} (NOMINAL LIFT FLOW, CALM WATER, REVERSE THRUST AT MIP)	85.5 SEC
STOPPING DISTANCE FROM V _{MAX} (NOMINAL LIFT FLOW, CALM WATER, REVERSE THRUST AT MIP)	7,330 FT (2,334 M)
RANGE (CALM WATER)	2,693 NMI
RANGE (1.4 M SIGNIFICANT WAVES)	2,184 NMI
ENDURANCE (CALM WATER)	28.4 HR
ENDURANCE (1.0 M SIGNIFICANT WAVES)	25.0 HR
* FOUR, 50,000-HP PROPULSION TURBINES, FULL LOAD DISPLACEMENT, 80°F, HEAD SEAS.	
** AVERAGE OVER ENTIRE MISSION, CRUISE SPEED AT INITIAL WEIGHT UP TO MAXIMUM SPEED.	

feasibility of transmission and propeller installations were also analyzed. While some installations are preferred over others in a detailed comparison, no major difficulties are foreseen with any of the concepts.

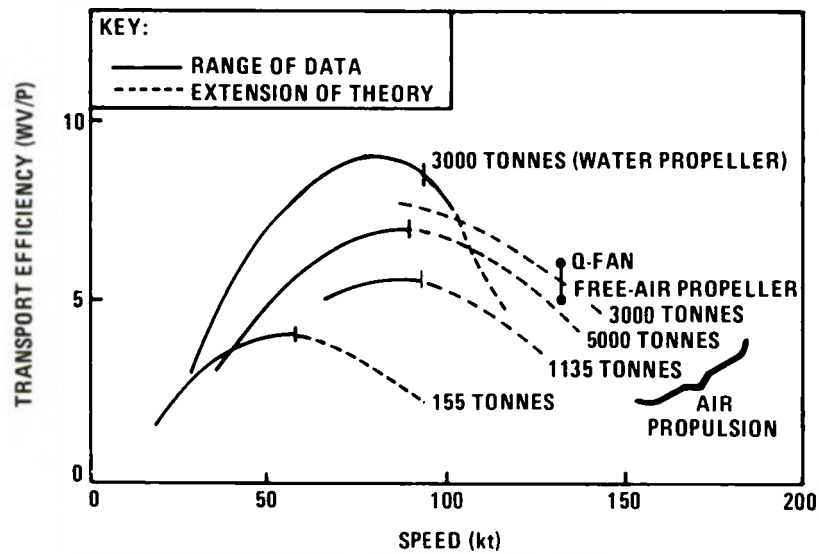
(U) The results of the analyses of water- and air-propelled ACV can be summarized by comparing the speed regions in which they are most efficient. Figure III-5 shows the results from these analyses for a size range of 155 tonnes to 5000 tonnes.

(U) The shape of the transport efficiency vs. speed curves is generally the same for all sizes; however, using the 3000-tonne-class ACV as an illustration, the water-propelled ACV, which reaches its maximum efficiency at about 80 kt, is more efficient (i.e., consumes less total power) than the air-propelled ACV of the same class at speeds up to about 100-110 kt. At higher speeds, the hydrodynamic resistance and the decreasing efficiency of the ACV's water propulsion system begin to degrade performance, and the air-propelled ACV becomes the more-efficient version within the same class. These analyses helped determine issues needed to be resolved through the ACV point designs.

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(U) Figure III-4. TWO GENERAL ARRANGEMENTS FOR AIR-PROPELLED 3000-TONNE ACV (AFT-LOCATED HELICOPTER PAD)



(U) Figure III-5. AIR- AND WATER-PROPELLED ACV REGIMES

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1.3.2 ACV Drag and Motions in Rough Seas

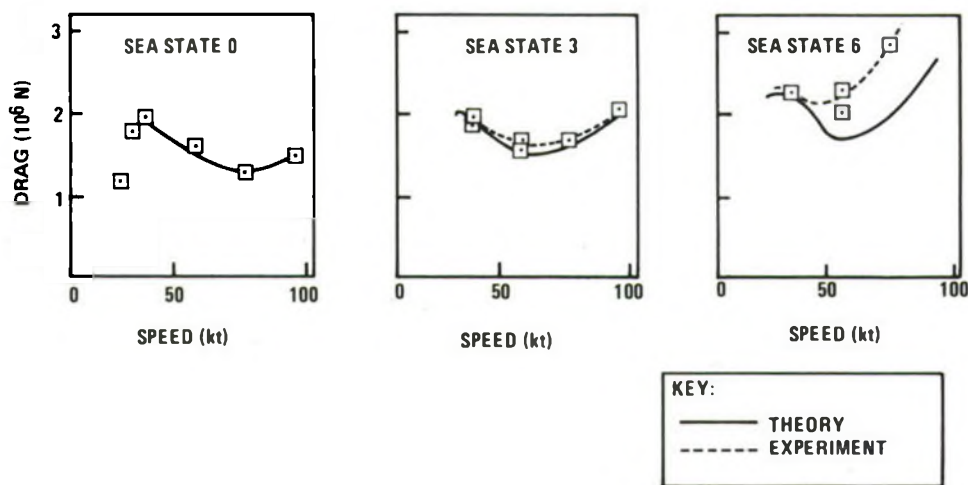
(U) The performance of an ACV in rough seas cannot as yet be predicted with confidence; many of the predictive techniques require adjustments based on model-test data. The drag and motions are also strongly determined by skirt configurations and the pressure in the air cushion needed for the craft to "plane" through the waves. Most of the full-scale, operational ACVs to date have used relatively low cushion pressure and had skirt geometries patterned after the British hovercraft designs. The U.S. Navy has concentrated on more compact vehicles, which require higher cushion pressures (and densities), and on the development of oceangoing craft to meet the functional needs of the U.S. Navy.

(U) Accordingly, the drag and motions of highly loaded, 300-tonne craft having longer (deeper) skirts by which to traverse high waves were studied. For comparison, the concept of a longer skirt was also applied to an ACV with a displacement of 3000 tonnes. The analyses and model tests conducted led to a better understanding of the motions problem. However, the ability to predict the drag characteristics of this type of skirt configuration in very rough seas remains a problem. The detailed data of the model tests are given in Reference 18. Figure III-6 shows the deep-skirt model tested. This model used the pericell type of skirt system that is currently on the JEFF(A) AALC. The model drag data from these tests, scaled to a 3000-tonne-class ACV, is shown in Figure III-7. In comparison with the available theories, Figure III-7 shows good agreement for calm-water and sea-state-3 data, but the agreement becomes poor at sea state 6. This change is caused by several factors. The very high cushion densities coupled with the relatively stiff



(U) Figure III-6. DEEP-SKIRT ACV MODEL UNDER TEST

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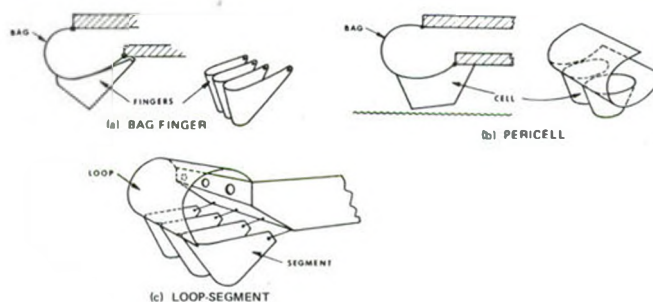
(U) Figure III-7. DEEP-SKIRT ACV DRAG AS A FUNCTION OF SPEED FOR THREE SEA STATES

configuration of the pericell could be causing a scooping action in high waves. Also, while the deeper skirts would be more flexible and therefore forgiving in a seaway, again the actual distortion of the skirt could contribute to a scooping action. Finally, difficulties in modeling the air flow rate may also contribute to a large change in drag.

(U) As might be expected, this type of deep-skirt configuration produces a significantly lower pitch response but experiences about the same heave response.

1.3.3 Alternative Skirt Systems

(U) Basically, three types of skirt configurations are used for ACVs. These configurations, shown in Figure III-8, are the bag-finger, used on the British Hovercraft Corporation (BHC) series of craft; the pericell, used on the JEFF(A) AALC;

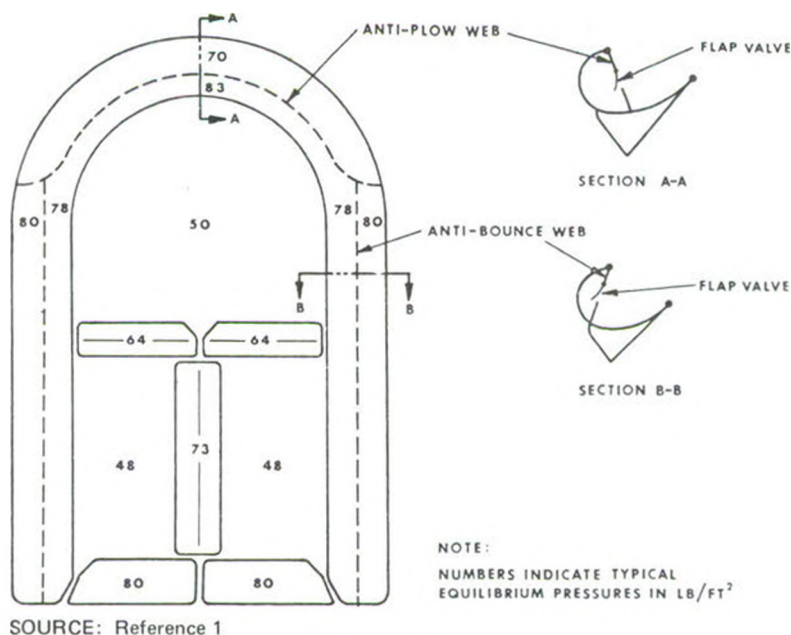


(U) Figure III-8. ACV SKIRT CONFIGURATIONS

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and the loop-segment, used on the Vosper-Thornycroft VT.2. The bag-finger concept involves compartmentation of the bags to provide stability. Figure III-9 shows this configuration for the BHC SR.N4 ACV.

(U) Each of the three systems involves different considerations of performance, producibility, and life-cycle cost. Since the largest ACV built to date is about 300 tonnes displacement, the question of the producibility of skirts for a large ACV prompted an evaluation by the three companies most concerned with their use (Aerojet, Bell, and Vosper-Thornycroft). Their findings are given in References 19, 20, and 21, respectively. Reference 22 is a DTNSRDC summary of the main conclusions on their technical feasibility, producibility, and life-cycle costs.



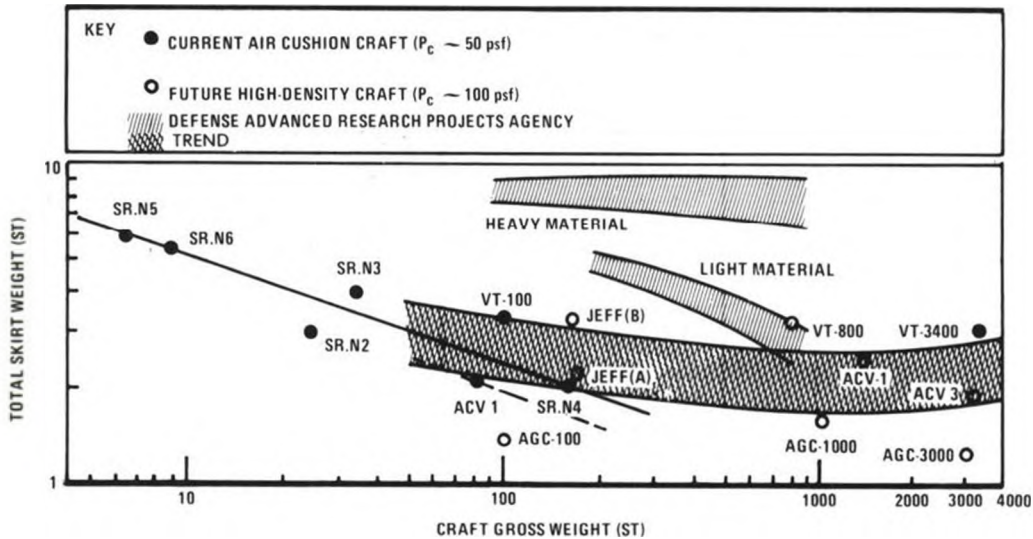
(U) Figure III-9. COMPARTMENTATION ON BAG-FINGER SKIRTS

(U) While there might be some question on details of technical design, these companies generally conclude that only moderate development is required to increase the size of any of the skirt systems by 1990. Strong, durable materials will also have to be developed before the vehicles are economical and well-suited for open-ocean operations. The weights of the skirt systems vary widely, from about 1.5 to 3.5 percent of the ship displacement, depending on both technical differences and designers' optimism (Figure III-10). The life of the skirts (particularly at the lower edge, in contact with the water) is improving as R&D in materials continues. At the present time, a finger life of 450 hr is easily achievable over some operating profiles at speeds of 5-80 kt. A finger life of about 2000 hr might be a realistic projection for the year 2000. Some current data on finger life are shown in Figure III-11.

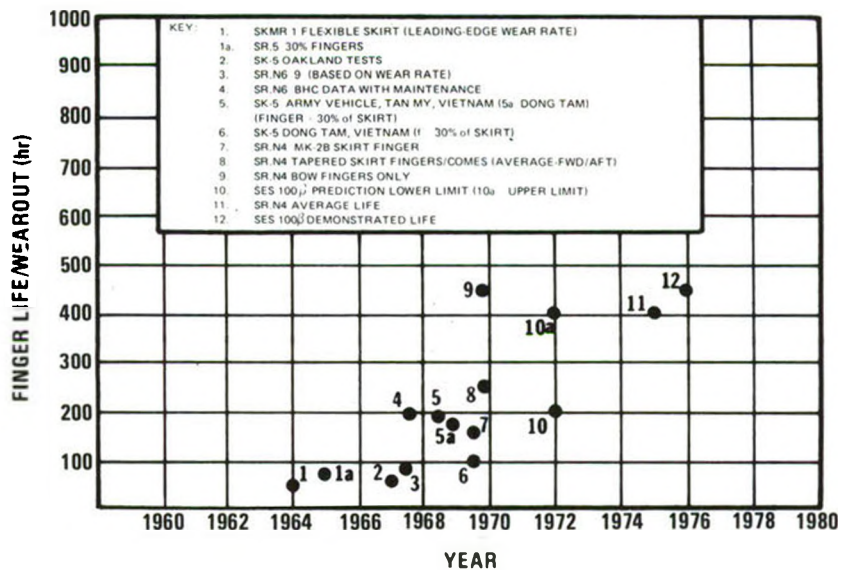
(U) Because of these projected wear rates, the cost of the skirts and their replacement is a source of conjecture; however, costs of between \$600 and \$1100 per operating hour are estimated for replacement and maintenance. Thus, life-cycle

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costs and availability are problems in such large craft. These problems are discussed further in Volume 3, the cost analysis.



(U) Figure III-10. ACV SKIRT SYSTEM WEIGHTS



(U) Figure III-11. ACV (AND SES) SKIRT FINGER LIFE

1.4 Point Designs

(U) To resolve the feasibility issues involved in the concept and to provide quantitative vehicle information for the mission and cost analyses, several point designs were prepared. These point designs are as follows:

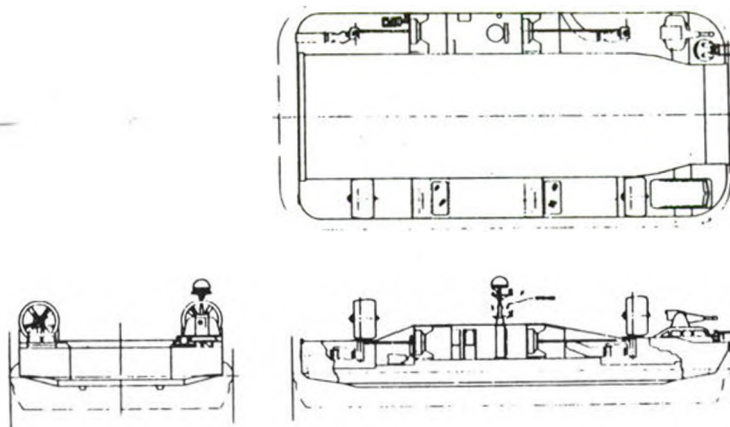
- Amphibious Assault Landing Craft (near term)
 LCAC-A, 155 tonnes displacement
 LCAC-B, 145 tonnes displacement
- Nonair-capable ACV (far term)
 ACV 1, 1264 tonnes displacement
- Air-capable ACV (far term)
 ACV 3, 3000 tonnes displacement

(U) The characteristics of the LCAC-A are described in detail in Reference 23; those of the ACV 1, in Reference 24; and those of the LCAC-B and ACV 3, in Reference 25. As the various point designs were evaluated, it became necessary to make *reiterative* design changes. The results of these changes together with a summary of the final point designs as they were used in the mission and cost analyses are given in Appendix B. For completeness, each of these point designs will be shown here together with a commentary on their features.

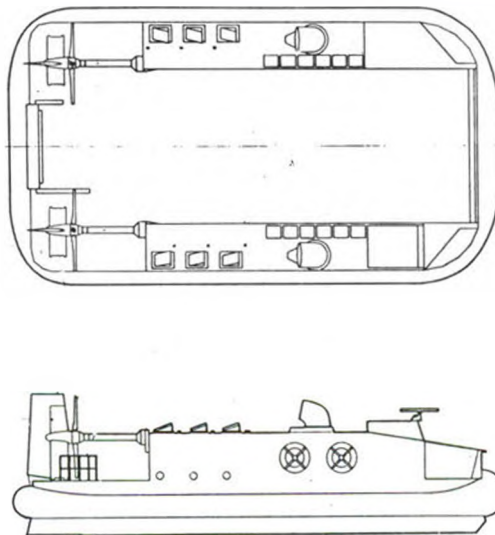
1.4.1 Amphibious Assault Landing Craft

(U) The LCAC-A, which is based on the current JEFF(A) AALC, is shown in Figure III-12. The LCAC-A is essentially the current JEFF(A) craft except that it has been designed to the consistent set of ANVCE design standards, given in Appendix A. Figure III-13 shows the corresponding version based on the current JEFF(B) AALC, the LCAC-B. The leading particulars of these craft are given in Table III-3; detailed information is provided in Appendix B and References 23, 24, and 25. While other versions using different combinations of engines and propulsors were studied and included in the point design references, the values shown in Table III-3 are representative of the point designs studied. These designs are considered to be well within the state of the art and the concepts are competitive with planing craft for the amphibious mission.

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(U) Figure III-12. LCAC-A GENERAL ARRANGEMENT



(U) Figure III-13. LCAC-B GENERAL ARRANGEMENT

(U) Table III-3. LCAC LEADING PARTICULARS

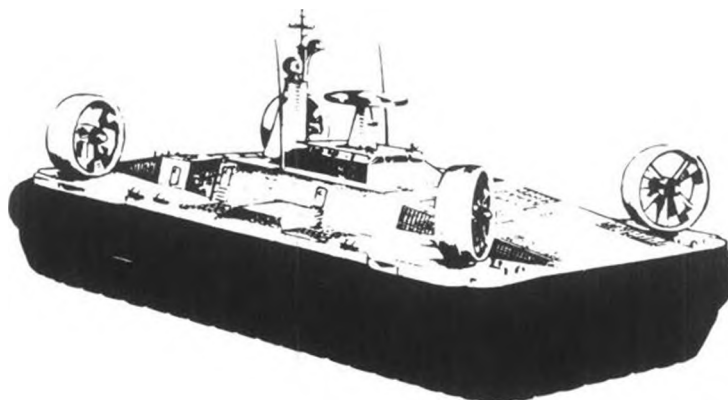
CHARACTERISTICS	LCAC-A	LCAC-B
GROSS WEIGHT (TONNES)	156	145
PAYLOAD (TONNES)	62	55
RANGE AT 57 KT (NMI)	297	200
MAXIMUM SPEED IN SEA STATE 2 (KT)	57	54
SKIRT SYSTEM	PERICELL	BAG-FINGER

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(U) Each of the LCAC candidate designs is capable of carrying one main battle tank. While not studied in the ANVCE Project, it is possible that by stretching the craft, they would be capable of carrying two main battle tanks and still fit within the well deck of a landing ship, dock (LSD). The craft could be stretched with the existing power plants and provide a more equal comparison with the planing craft point design, which carries two main battle tanks. The gross weight of the stretched LCAC would be approximately 230 tonnes.

1.4.2 Nonair-capable ACV

(U) The next major extension of the state of the art in terms of vehicle size is the ACV 1, shown in perspective view in Figure III-14. This 1264-tonne vehicle is capable of open-ocean activity and can be thought of as a larger member of the JEFF(A) class in that it utilizes similar lift systems and propulsion schemes, albeit of much larger scale. The general arrangement for this point design is shown in Figure III-15. The detailed particulars of this point design are given in Appendix B; the leading particulars are given in Table III-4.



(U) Figure III-14. PERSPECTIVE VIEW OF ACV 1

(U) The ACV 1 is a nonair-capable design with a combat suite that is common to the nonair-capable, surface combatant group. This group (Table I-4) is comprised of the ACV 1, the HYD 7, the PC 1, and the WIG(S). The ACV 1, is designed for a 15-day mission and is an ASW and antisurface-ship warfare (ASUW) craft with a point-defense antiair warfare (AAW) capability, as are the other point designs in the group.

III-14
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(U) Table III-4. ACV 1 LEADING PARTICULARS

GROSS WEIGHT (TONNES)	1,264
PAYLOAD (TONNES)	129
RANGE AT 88 KT IN SEA STATE 3 (NMI)	1,070
MAXIMUM SPEED IN SEA STATE 3 (KT)	93
SKIRT SYSTEM	PERICELL TYPE

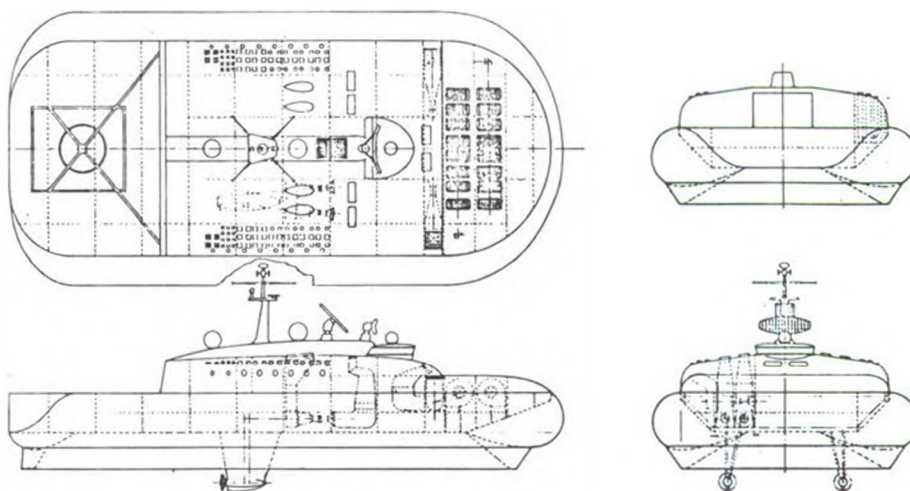
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(U) It was found upon evaluation of the design that some undue optimization appeared in the predicted technical characteristics in scaling from today's craft, and the adjustments to the design have been incorporated in the summary description given in Table III-4 and Appendix B. Over and above these adjustments, two main risk areas appear associated with an ACV of this size. The first is the use of an unproven pericell skirt system. Although based on the French "jupe" system in use on many French ACVs and employed on the JEFF(A) currently undergoing test, this pericell skirt is an unproven design. This factor coupled with the increased size and speed (1264 tonnes displacement and 93 kt) compared to today's capability (155 tonnes and 50 kt) places this design concept in the medium-risk category.

(U) While the development of high-speed, high-power (approximately 40,000-50,000 shp) engines, transmissions, and propulsors is a problem common to all high-speed surface vehicles, the principal risk with the ACV-1 is the development of a transmission. The 40,000 to 5000 shp is to be transmitted through a right-angle gearbox. Because of the allowable stress limits in gear materials, at least two or more meshes would be necessary to transmit such power through a right-angle gearbox to the propulsors and the lift fans, which would require larger gear-cutting machinery than available today.

1.4.3 Air-capable ACV

(U) The largest ACV studied to the point design stage is the 3000-tonne-class ACV. Figure III-16 shows a general arrangement of the ACV 3. This craft is the result of an examination of the various propulsion schemes for larger oceangoing ACVs and a feasibility study of the configuration based on the projected state of the art in 1995. The air-propelled versions of such craft were discussed in connection with the analysis of air and water propulsion systems in Section 1.3.1.



(U) Figure III-16. ACV 3 GENERAL ARRANGEMENT

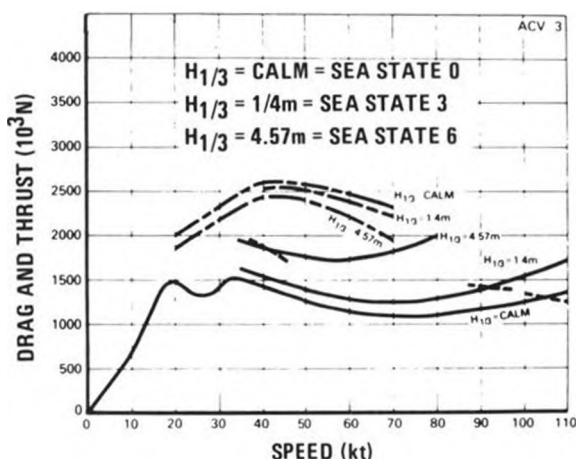
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(U) The leading particulars of the ACV 3 are given in Table III-5. The ACV 3 is air-capable and has a combat suite that is common with the far-term, air-capable, surface combatant group. This group is comprised of the ACV 3, the SES 3, the SWA 4, the HYD 2, and the MONO 3 (Table I-4). The vehicles in this group are designed for either a 15- or 30-day mission and have a multimission combat suite for AAW, ASW, and ASUW. The combat suite includes two LAMPS (light, airborne, multipurpose system) Mk-XX helicopters. As discussed previously, the concept of using water propulsion (jet or screw) is an attractive one if a very large ACV (SES)

GROSS WEIGHT (TONNES)	3,000
PAYLOAD (TONNES)	350
RANGE AT 93 KT IN SEA STATE 3 (NMI)	2,600
MAXIMUM SPEED IN SEA STATE 3 (KT)	93
SKIRT SYSTEM	BAG-FINGER

(U) Table III-5. ACV 3 LEADING PARTICULARS

is postulated. One problem that must be solved for all water-propelled ACVs (or SESs), however, is the ability to transit the hump between subcavitation and supercavitation. Figure III-17 illustrates this problem; the thrust and drag curves for the ACV 3 show a drop in thrust at speeds below 40 kt because ventilation (or cavitation) of the propeller coupled with the existence of the primary and secondary wave



(U) Figure III-17. ACV 3 THRUST AND DRAG

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resistance humps in the drag curve diminish the available accelerating force for "getting over hump." This particular problem is relatively easy to solve for an SES through use of such flow control devices as the transom sidehull ramp, as developed on the SES 100B. However, for an ACV using strut-mounted propellers (Figure III-16), controlling flow through the propeller becomes difficult (although not impossible), and further development will be required. Several schemes can be visualized but model tests will be needed to ascertain their potential.

(U) The risk associated with the water-propulsion (screw-propeller) version of this concept is a medium one. No hydrodynamic problem is foreseen in enlarging the scale since as an ACV it constitutes a moderate scale increase of 2:1 over the largest (air-propelled) ACV today, the SR.N4; about 2.7:1 over the largest high-cushion-density craft to date, JEFF; and about 3:1 over the largest water-propelled ACV, the VT.1. The problem lies in the scaling of the subsystem elements. For example, experience with the subcavitating performance of a small propeller is of little value in moving to a large-scale supercavitating propeller, which increases the risk involved in predicting both the propeller performance and the structured integrity of the blades. However, development of high-power transmissions and large skirts can reduce the risk in these areas.

(U) While the water-propelled, 3000-tonne-class ACV is feasible, the parametric study (Figure III-5) indicates that the improvement in performance over the air-propelled version is slight. A detailed analysis is required to determine the relative vulnerabilities and differences in the development efforts of such variants.

1.5 Findings and Conclusions

(U) The state of the art is best represented in the British craft, which has a displacement of 300 tonnes and a speed of 70-80 kt. ACV development efforts by both the Free World and the Communist Bloc have been extensive. ACVs are in regular, commercial use in Europe, and the USSR is currently producing "several" military amphibious assault landing craft of about 200 tonnes displacement. With planned development, ACVs of up to 3000-5000 tonnes displacement and speeds of 90-100 kt are feasible. Based on the experience gained from the British craft and the JEFF prototypes, the U.S. Navy could develop an ACV at reasonable cost.

(U) Specifically, the findings and conclusions regarding the ACV are as follows:

- The ACV concept can feasibly provide very high speeds (40-120 kt) in displacement sizes up to 5000 tonnes. Although larger sizes were not examined by the ANVCE Project, there appears to be no fundamental size limit beyond this size (sizes up to 10,000 tonnes or more have been examined in previous studies).
- The ACV concept could be well utilized as a small craft (less than 40 tonnes) in inshore warfare. An amphibious capability plus an exceptionally quiet air-propulsion system (cushion or fan) make the ACV ideally suited for such missions. ACVs with displacements of 10 tonnes are operational in the British Army. The expansion of such craft to larger sizes is feasible through engineering development.

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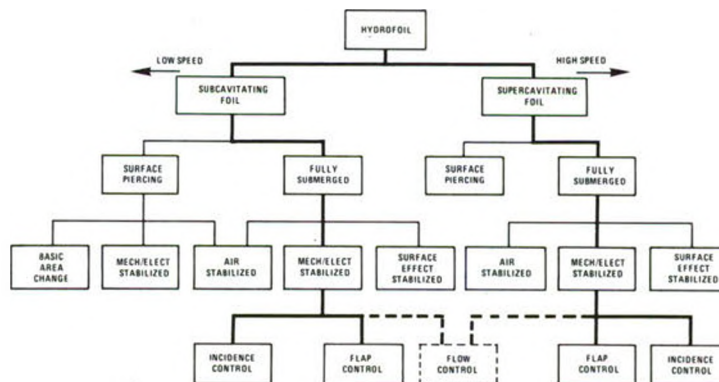
- Current technological efforts by the U.S. Navy in SES development are directly applicable and transferable to ACV development. Such technologies include lift fan and ride control systems and propulsion systems and structural design related to skirt development. In fact, much of the SES development has been based upon ACV experience.

(U) An assessment of selected technical capabilities of competitive concepts is presented in Chapter V. This comparison includes the ACV and SES and their respective capabilities.

2. HYDROFOIL

2.1 Concept Tree

(U) The concept tree for the hydrofoil is shown in Figure III-18. The hydrofoil can be either subcavitating or supercavitating depending upon the speed of the given hydrofoil. Subcavitating foils resemble subsonic airfoil sections and must operate at speeds below the cavitation point, which in normal seawater is about 50 kt. Supercavitating foils resemble supersonic airfoil sections and are shaped to move the cavitating region downstream of the foil trailing edge. Such foil sections can be applied equally well to surface-piercing and fully submerged foils, as shown in Figure III-18.



(U) Figure III-18. HYDROFOIL CONCEPT TREE

(U) The hydrofoil concept, as applied in operational vehicles, is usually designed to be efficient at speeds of 35-40 kt for surface-piercing, subcavitating hydrofoils. In supercavitating foil forms, the foil geometries must permit sustained operation above 50 kt. Supercavitation or superventilating foil sections have only been used on a few hydrofoils: the surface-piercing DENISON [of the Maritime Administration (MARAD)] at 61 kt, the Bras D'Or (of Canada) at 61 kt, and the U.S. Navy hydrofoil with fully submerged foils at 80 kt. These test craft have clearly demonstrated the feasibility of using a supercavitating foil system. Although surface-

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piercing hydrofoils were not analyzed in detail (bold lines in Figure III-18 indicate ANVCE Project examination), a state-of-the-art performance and cost summary was prepared (Reference 3).

2.2 Features and Issues

(U) Based on the technical approach methodology described in Chapter II, Table III-6 presents the particular features and issues of the hydrofoil concept. The paths taken in resolving the issues and the findings and conclusions of those efforts

(U) Table III-6. HYDROFOIL EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
● MAINTAIN A HIGH SPEED (50 KT) IN VERY ROUGH SEAS WITHOUT MAJOR SPEED LOSS ● QUICK RESPONSE TIME IN THAT SHIP CAN RAPIDLY TRANSITION FROM HULLBORNE TO FOILBORNE ● CONTINUOUS SPEED SPECTRUM; CONTINUOUS DRAG CURVE THROUGHOUT SPEED WITHOUT HAVING TO ACCELERATE TO A STABLE SPEED ● IN THE PARTICULAR CASE OF THE VARIABLE-GEOMETRY FOIL HAS A HIGH-SPEED DASH CAPABILITY ● STEADY PLATFORM AT SPEED AND IN ROUGH SEAS	● AS SIZE OF HYDROFOIL INCREASES, DOES THE HIGHER WAVE DRAG INCUR MORE THAN PROPORTIONATELY HIGHER THRUST REQUIREMENTS? ● IS THE HYDROFOIL LIMITED TO SUBCAVITATING SPEEDS (50 KT)? ● IS THERE A SIZE LIMIT TO HYDROFOILS? ● WHICH IS THE MORE COST/EFFECTIVE HYDROFOIL, SURFACE PIERCING OR FULLY SUBMERGED?	● CONDUCTED MODEL EXPERIMENTS ON WAVE DRAG AT LOW FROUDE NUMBERS COMPATIBLE WITH LARGE (2,000- TO 3,000 TONNE) HYDROFOIL ● CONDUCTED ANALYSIS ON VARIABLE-GEOMETRY SUBCAVITATING/SUPERCAVITATION FOILS AND DEVELOPED POINT DESIGN (HYD 7) ● CONDUCTED A POINT DESIGN OF A LARGE HYDROFOIL (2,400 TONNES) ● CONDUCTED AN ANALYSIS USING FOREIGN TECHNOLOGY ON BOTH FOIL FORMS	● ALLOWS SMALLER HYDROFOIL SHIPS TO ACT AS ESCORT TO LARGE CONVENTIONAL SHIPS TRAVELING IN ROUGH SEAS ● IMPROVES ASW SEARCH AND ATTACK ● ALLOWS HYDROFOILS TO PERFORM WIDE VARIETY OF ROLES FROM ESCORTING REPLACEMENT SHIPS TO HIGH-SPEED ATTACK ● PROVIDES EFFICIENT OPERATION OVER WIDE SPEED RANGE (5-75 KT) WITHOUT SACRIFICING FUEL ECONOMY TO ACHIEVE SPEED ● IMPROVES HANDLING OF AIRCRAFT AND EFFICIENCY OF CREWS ● RESULTS SHOW NO PROBLEM, AND CONFIDENCE LEVEL IMPROVED SIGNIFICANTLY ON ABILITY TO PREDICT DRAG, THRUST REQUIREMENTS ARE NOT LIMITING SIZE OF HYDROFOILS ● DESIGN WORK SHOWED THAT A HYDROFOIL WITH AN EFFICIENT CRUISE (AT 50 KT) AND A DASH CAPABILITY TO 70 KT IS A PRACTICAL PROPOSITION AND PROVIDES A LOGICAL SOLUTION TO THE NEED FOR HIGH SPEED ● GENERALLY DETERMINED THAT LARGELY BECAUSE OF STRUT AND FOIL PROBLEMS, THE HYDROFOIL IN ITS PRESENT FORM IS LIMITED TO ABOUT 2,000 TONNES. R&D INTO NEW FORMS MAY WELL RAISE THIS LIMIT ● THE SURFACE-PIERCING HYDROFOIL APPEARS TO BE A VERY PRACTICAL AND LOW-COST SHIP THAT IS DEFINITELY WORTH PURSUING, ESPECIALLY IF THE NEED FOR HIGH SPEED IS NOT PARAMOUNT SPEED RANGE (5-75 KT)

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are discussed in the following subsections. The point designs follow the analysis discussion for ease of reference.

2.3 Analyses and Experiments

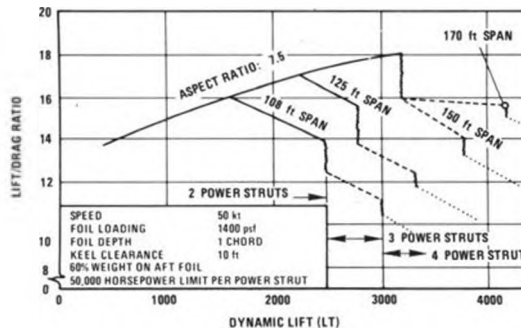
(U) In subcavitating hydrofoils, the larger the subcavitating foil, the greater the wave drag (indicated by a low Froude number). Because in such a hydrodynamic situation the foil wave drag constitutes a larger part of the total drag for the ship, a better prediction capability than the present ± 20 percent is required in order to learn more about this phenomenon and gage it more accurately. Accordingly, in investigating the issue of size, the ANVCE Project conducted model experiments of large, subcavitating foil sections that had low Froude numbers in testing.

(U) To investigate the possibilities of extending the speed capability of hydrofoils beyond 50 kt while retaining their continuous (and efficient) speed spectrum, hydrofoils capable of operating in both the subcavitating and the supercavitating modes were analyzed; models of them were tested; and point designs were developed.

(U) The results of the ANVCE Project investigations into these issues are presented in the following two subsections.

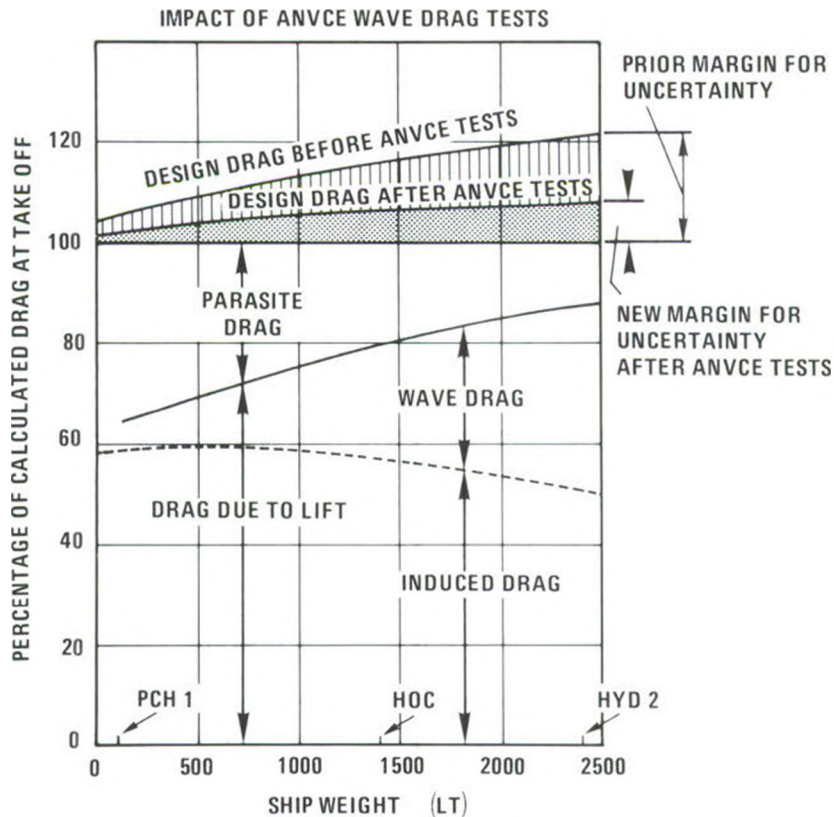
2.3.1 Wave Drag of Large Hydrofoils

(U) As shown in Figure III-19, the foil characteristics of a large craft depend on the number of foils and struts, span limitations, and amount of power capable of being transmitted (through the struts). Previous design studies (prior to the ANVCE Project) indicate that such designs are feasible up to at least 4000 tonnes displacement provided the configuration is modified to meet changes in structural requirements (Figure III-19), instead of simply scaling by Froude numbers.



(U) Figure III-19. EFFECT OF SIZE ON HYDROFOIL PERFORMANCE

(U) The preliminary size study indicated that a hydrofoil of 2000-3000 tonnes displacement could be used as an open-ocean, air-capable, surface combatant in naval operations and would provide the Navy with better information on wave drag measurements. The wave drag tests conducted by the ANVCE Project (Reference 26) resulted in an improved prediction capability. The error of uncertainty in predicting the drag was reduced from ± 20 percent to ± 7 percent (Figure III-20).

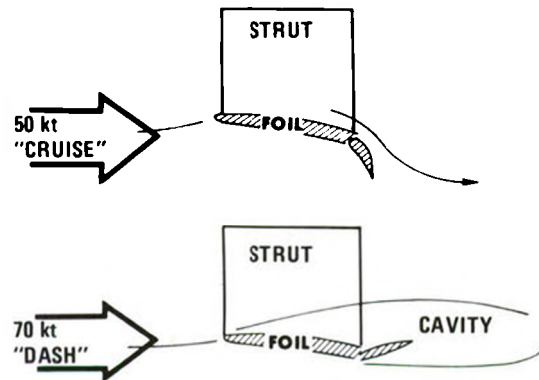


(U) Figure III-20. WAVE DRAG TEST RESULTS FOR LARGE HYDROFOIL

2.3.2 Subcavitation/Supercavitation Capability

(U) Research into foil sections capable of operating efficiently in both the subcavitating and supercavitating flow regimes is being conducted by the U.S. Navy and the National Aeronautics and Space Administration (NASA). One version of such a geometry is shown in Figure III-21. The figure shows the essential elements of the foil. The foil section resembles a conventional foil in that the upper surface is shaped to give the desired pressure (and lift) characteristics in the subcavitating mode. The shape of the underside is designed to maximize supercavitating flow. The

foil is subcavitating up to approximately 50 kt; at that point the trailing edge is raised, making the foil supercavitating. Thus, the flow separates and a cavity is formed over the upper surface; the lift is now on the positive-pressure underside of the foil. While the geometric form may differ, the essential elements remain the same.



(U) Figure III-21. VARIABLE-GEOMETRY FOIL FEATURES

(U) The ANVCE Project conducted several analyses to investigate this issue. A study was conducted into the possibility of applying this feature with a high-speed dash capability (70 kt) to the PHM (patrol hydrofoil, missile) and is reported in Reference 26. While some design changes would be required, the PHM was found to be technically suitable for this feature.

(U) A similar study of a larger hydrofoil (1350 tonnes displacement) with the variable-geometry foil was also undertaken (Reference 27), and the design was found to be feasible for this size of hydrofoil as well.

(U) While it was anticipated that the variable-geometry feature would result in a power savings, the transition from subcavitating to supercavitating flow requires power and affects any savings. However, no additional power is needed, and R&D efforts might lead to the elimination of the transition power requirement.

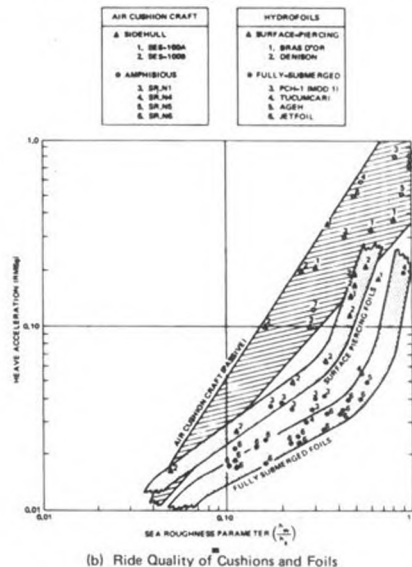
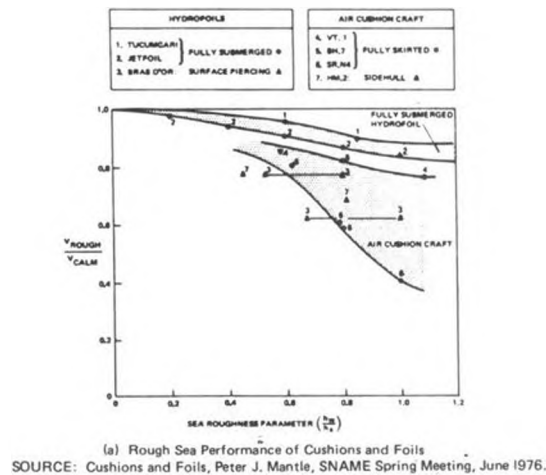
(U) The results of the model experiments on the foil and the two, high-speed application studies were such that a point design of a hydrofoil of about 980 tonnes displacement, the HYD 7, was included in the ANV concept evaluation.

2.3.3 Comparison of Hydrofoil Types

(U) As noted previously, most of the world's hydrofoils are surface-piercing, subcavitating ones, capable of a maximum speed of 35-40 kt. The performance of such a hydrofoil is half way between that of a displacement hull (at the low end of the scale) and that of a hydrofoil with fully submerged foils (at the high end of the scale). However, a surface-piercing, subcavitating hydrofoil has a significant cost advantage over the hydrofoils with fully submerged foils in commercial and military service today.

(U) In terms of speed capability in waves, the surface-piercing hydrofoil encounters a higher degree of degradation in rough seas than does the hydrofoil with fully submerged foils but no more than the air cushion craft (ACV and SES). Again, while the ride quality of the surface-piercing hydrofoil is not as good as that of a hydrofoil with fully submerged foils, it is smoother than that of air cushion craft that do not have ride control systems and about the same as that of those that do (ACV and SES). This comparison is shown in Figure III-22. A comparison of selected features of these craft is presented in Chapter V.

(U) Based on the analysis and review of the technological state of the art in surface-piercing hydrofoils (Reference 3) and their costs (Volume 3), these craft were felt to be warranted for consideration in the evaluation of ANV concepts.



(U) Figure III-22. COMPARISON OF HYDROFOILS AND AIR CUSHION CRAFT PERFORMANCE

2.4 Point Designs

(U) To resolve the feasibility issues involved in the concept and to provide quantitative vehicle information for the cost and mission analyses, several point designs and baseline reference designs were prepared:

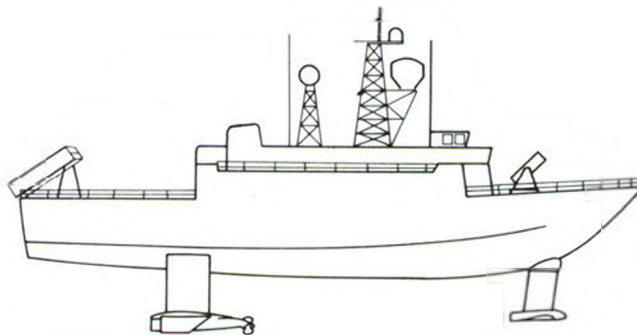
- PHM (near term)
235 tonnes displacement
- Ocean Combatant Hydrofoil (HOC) (near term)
1400 tonnes displacement
- Nonair-capable Hydrofoil (HYD-7) (far term)
980 tonnes displacement
- Air-capable Hydrofoil (HYD-2) (far term)
2400 tonnes displacement.

Detailed descriptions of the characteristics of those designs are given in References 28 (PHM), 29 (HOC), 30 (HYD 7), and 31 (HYD 2). As the various designs were evaluated, it became necessary to make reiterative design changes. The final, modified characteristics are given in Appendix B.

(U) To concentrate attention on the point designs, which were designed to a set of consistent standards, rather than on the baseline references, only the leading particulars and characteristics of the two ANVCE point designs (HYD 7 and HYD 2) will be summarized here.

2.4.1 Nonair-capable Hydrofoil

(U) The nonair-capable hydrofoil point design (HYD 7), shown in Figure III-23, included the variable-geometry foil feature, which provides it with a dash capability. The leading particulars for the HYD 7 are given in Table III-7. Detailed information is contained in Appendix B and Reference 29. The basic performance characteristics pertaining to this multimode-operation craft are shown in Figure III-24. The three modes of operation for the HYD 7 are (a) hullborne, up to 25 kt; (b) foilborne (subcavitating), up to 60 kt; and (c) foilborne (supercavitating), up to



(U) Figure III-23. HYD 7 DESIGN

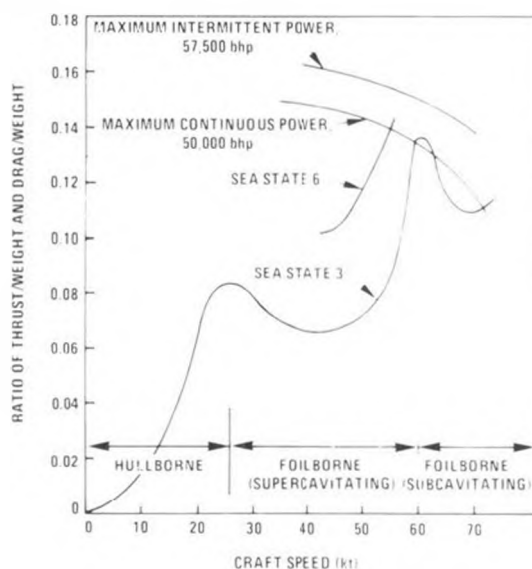
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its maximum speed, 71 kt in sea state 3. Using the available model test data, which were not optimized data with regard to minimizing transition power, a high drag rise occurs around 60 kt. With proper selection of foil characteristics, however, this speed could probably be traversed using the maximum continuous power rating.

(U) This particular variable-geometry feature enables a hydrofoil that normally operates at low speed (with conventional displacement ships) to also be capable of high-speed (50 kt) and dash-speed (71 kt) operations. Moreover, these speeds can be attained while retaining good fuel economy.

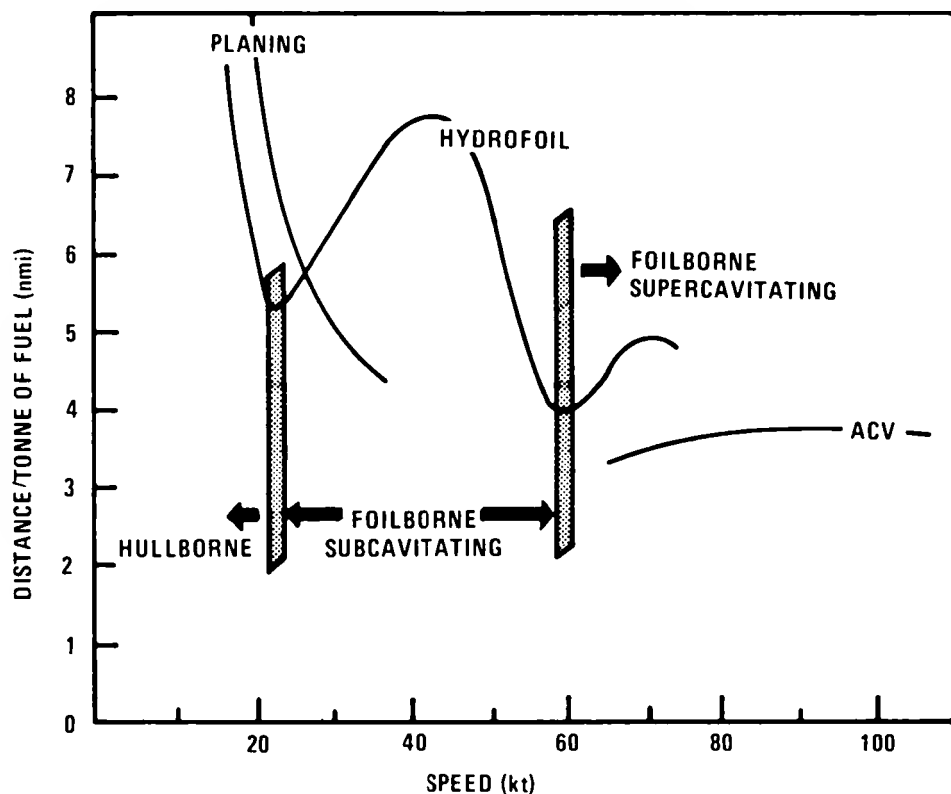
(U) Table III-7. HYD 7 LEADING PARTICULARS

GROSS WEIGHT (TONNES)	986
PAYLOAD (TONNES)	113
RANGE AT 16 KT (NMI)	2,000
HULLBORNE AT 25 KT	953
FOILBORNE (SEA STATE 3) AT 71 KT	851
MAXIMUM SPEED IN SEA STATE 3 (KT)	
SUBCAVITATING	55
SUPERCAVITATING	71



(U) Figure III-24. HYD 7 THRUST AND DRAG AS A FUNCTION OF SPEED FOR TWO SEA STATES

(U) Figure III-25 shows the specific range capability, expressed in nautical miles traveled per tonne of fuel, of the HYD 7 compared with those of the 1000-tonne-class planing craft (PC 1) and air cushion vehicle (ACV 1). At displacement ship speeds, when sitting on its hull, the HYD 7 has performance and range capability similar to that of a conventional planing hull. In a subcavitating foilborne mode, it gains considerably in range capability, falling off only as it approaches the transition region (approximately 60 kt). However, even at the transition, the range capability of the HYD 7 is still greater than that of other concepts. As the HYD 7, with its variable-geometry feature, moves into its supercavitating mode, its range capability increases and it is more efficient than the ACV at its design speed. In this particular point design, the HYD 7, a power limitation is reached at 71 kt; however, hydrodynamically a speed of at least 80 kt is possible.



(U) Figure III-25. RANGE CAPABILITIES OF HYD 7, PC 1, AND ACV 1 (1000-TONNE CLASS)

(U) The risk associated with this concept is primarily related to the problem of developing a variable-geometry foil that is consistent with the designed performance level. In examining this problem, various solutions were explored.

(U) For consistency, thrust margins of 25 percent over drag values were established for each of the concepts that involved transiting a hump speed. The HYD 7 meets this thrust margin at the 25-kt hump but not at the 60-kt hump. Why this

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condition is not met in the higher speed ranges is not understood. Perhaps it should not be expected to meet this thrust margin.

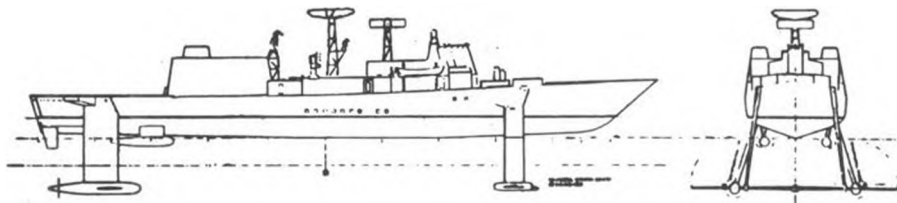
(U) Given the uncertainty in the model drag data, other solutions to this issue were sought. The solution tried in the point design was to use a transcavitating tractor propeller to gain propulsive efficiency. To save weight to allow for the high propulsive power, retractable struts were not used. This design decision led to the use of short struts to minimize the draft. However, short struts limit the hydrofoil's capability in high sea states, which is a main feature of the concept.

(U) Hence, further design efforts are needed to find a solution to this transition problem between the subcavitating and supercavitating modes.

(U) Another issue to be solved is one common to all high-speed surface vehicles, i.e., the development of high-speed, high-power (approximately 50,000-hp) transmission systems, engines, and propulsors.

2.4.2 Air-capable Hydrofoil

(U) As part of the technical evaluation of the feasibility of developing large hydrofoils, a point design for a hydrofoil of 2400 tonnes displacement (the HYD 2) was developed. This design is shown in Figure III-26. Details on the HYD 2 characteristics are provided in Reference 31, and the modified characteristics used in the ANVCE analyses are presented in Appendix B. The leading particulars are given in Table III-8.



(U) Figure III-26. HYD 2 DESIGN

(U) Table III-8. HYD 2 LEADING PARTICULARS

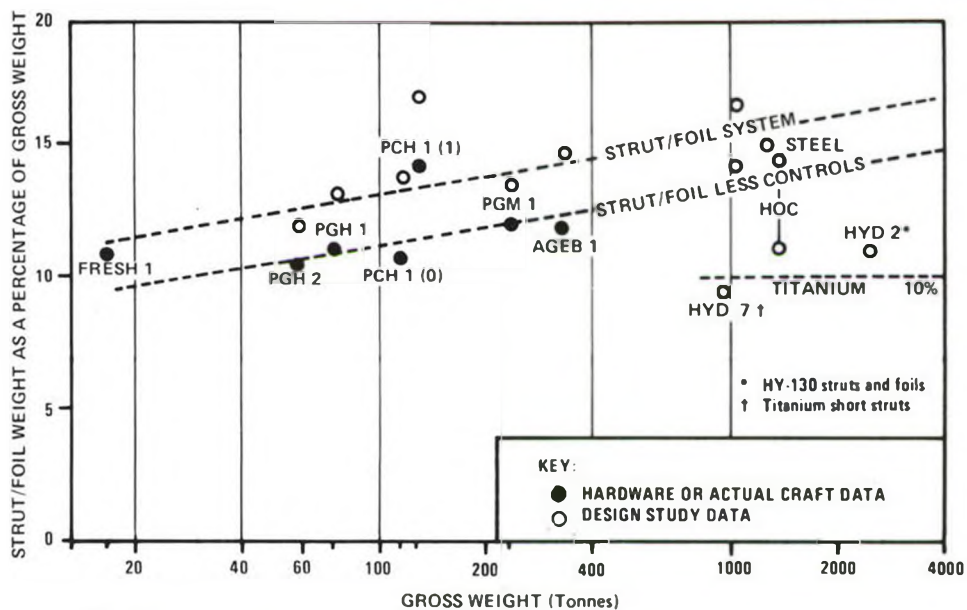
GROSS WEIGHT (TONNES)	2,400
PAYLOAD (TONNES)	335
RANGE (NMI)	
HULLBORNE AT 14 KT	5,900
FOILBORNE AT 45 KT (SEA STATE 3)	2,600
MAXIMUM SPEED IN SEA STATE 3 (KT)	53

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(U) The HYD 2 is an air-capable hydrofoil with a combat suite that is common to the air-capable, surface combatant group. This group includes the ACV 3, SES 3, SWA 4, HYD 2, and MONO 3. Like the other designs in the group, the HYD 2 is designed for a 15-day mission and has a multimission (AAW, ASW and ASUW) combat suite. The combat suite includes two LAMPS Mk-XX helicopters.

(U) While the concept of a large hydrofoil using subcavitating foil sections is technically feasible, the gross displacement given for this point design is probably low, even allowing for improvements in technology for 1995. While the other point designs within the group vary in displacement from 3000 to 3600 tonnes for approximately the same payload, a displacement of 2400 tonnes for the hydrofoil appears to be less than that expected on the basis of the differences among the concepts.

(U) This optimism can be illustrated through an examination of the design features. Figure III-27 shows the weights of the lift system or strut and foil system for other hydrofoils with fully submerged foils, both actual craft and projected designs. The upper line in Figure III-27 shows the trend for the total lift systems [Group 567 in the U.S. Navy Ships Work Breakdown Structure (SWBS)]. The lower line is the trend for the struts, pods, and foils—the lift system minus the electronics, hydraulics, and other ancillary equipment. The data shown are mainly for steel strut and foil systems. The HOC designs shown illustrate the expected improvements if the struts and foils are made out of titanium instead of steel. The HYD 7 has short struts and also uses titanium as the building material for them, while the HYD 2 has struts of “normal” length for its size and uses HY-130. Furthermore, on the HYD 2, a pi-foil geometry is used for both stern and bow foils, and all foils retract. Each of these features tends to increase weight, and values of 13-15 percent may be more representative than the 10 percent (including the standardized weight margin) shown. In considering these features, the weight given could be off by more than 100 tonnes.



(U) Figure III-27. WEIGHT COMPARISON OF HYDROFOIL STRUT/FOIL SYSTEMS

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(U) Such indications that the design weight given is optimistic will be considered again in the cost analysis (Volume 3) since subsystem weights have an impact on basic platform costs.

2.5 Findings and Conclusions

(U) Most of the operational experience that has been gained in surface ANVs has been in hydrofoils. More than 2000 hydrofoils and hydrofoil variants are operational in the world today. The state of the art is represented by operational surface-piercing hydrofoils of up to 340 tonnes displacement and speeds of 34-40 kt; operational hydrofoils with fully submerged foils that have displacements of up to 240 tonnes and speeds of up to 40-50 kt; and experimental hydrofoils with speeds up to 80 kt.

(U) The ANVCE Project studies have indicated that with planned development, subcavitating hydrofoils of up to 2500-3000 tonnes displacement with speeds up to 50-60 kt are feasible. Moreover, it has been found that hydrofoils with very high speeds (in excess of 70 kt) but lesser displacement (on the order of 1000 tonnes) are also technically feasible.

(U) However, the fact that such sizes and speeds are technically feasible is not sufficient justification for proceeding toward development. Such development would depend on cost and military usefulness. However, since hydrofoils do have a seakeeping ability equal to that of much larger displacement ships plus a definite speed advantage, they should be superior to monohull displacement ships on a cost/benefit basis.

(U) The findings and conclusions of the technical analysis of hydrofoils are as follows:

- The hydrofoil concept currently operational is of the subcavitating foil design with speeds of about 50-55 kt depending on the sea conditions. The use of newly developed, variable-geometry foils will allow operation at supercavitating speeds of 70-80 kt.
- Because of its multimode capability, a single hydrofoil is capable (when hullborne) of operating efficiently at a maximum speed of about 25 kt; when foilborne and subcavitating, it can operate at a maximum speed of about 50-60 kt; and when foilborne and making use of the variable-geometry foil to become supercavitating, it can operate at a maximum speed of about 70-80 kt. Thus, the hydrofoil has the unique capability of operating efficiently and compatibly with the conventional fleet or operating as a high-speed craft capable of meeting other military needs. This multimode capability applies equally well to hydrofoils with fully submerged and surface-piercing foils.
- Using current configurations of strut and foil arrangements, hydrofoils with fully submerged foils are probably limited to about 3000-4000 tonnes displacement. It is not known whether surface-piercing hydrofoils can attain similar sizes and still be efficient. Since this issue was not

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studied by the ANVCE Project and since no other studies have provided satisfactory quantification, it should be further analyzed.

- With fully submerged foils, the hydrofoil is extremely maneuverable and capable of maintaining both high speed and excellent seakeeping (steady deck characteristics) in high sea states.
- The characteristics of the surface-piercing hydrofoil are similar to those of the fully submerged foil hydrofoil but not to the same degree. Improvements developed in Europe for passive ride-control systems on surface-piercing hydrofoils are minimizing the difference in the seakeeping characteristics between the two types of hydrofoils.
- The U.S. Navy has developed a hydrofoil with fully submerged foils that has superior performance; however, a significant cost difference exists between such hydrofoils and the surface-piercing hydrofoils developed in Europe and the Soviet Union. Specific cost information is provided in Volume 3. Since both hydrofoil forms are technically feasible, the possible application of the surface-piercing hydrofoil to U.S. Navy missions should be analyzed further.

(U) Comparisons of specific features of hydrofoils with other ANV concepts are made in Chapter V.

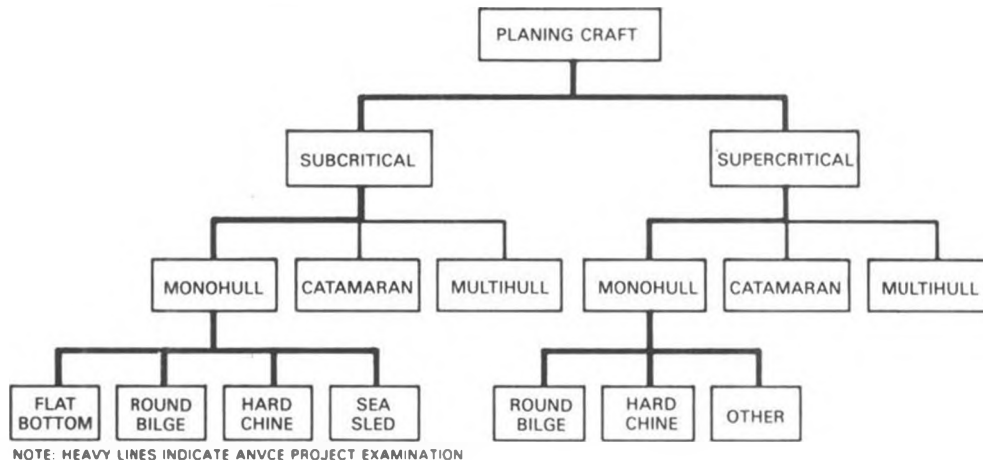
3. PLANING CRAFT

3.1 Concept Tree

(U) The principal feature of the planing hull is its ability to operate at high speed in relatively calm water. Planing occurs when hydrodynamic forces dominate rather than hydrostatic or buoyancy forces, as in the case of displacement hulls. Displacement hull form configuration and speed progress from the basic displacement hull (series 60), through high-speed displacement hulls with round bilges, to high-speed planing hulls with hard chines. The speed at which planing occurs is strongly dependent on the size of the ship. A small craft can be planing at 20-30 kt, whereas a 3000-tonne ship will probably not be able to plane at 40 kt, e.g., the advanced monohull (MONO 3), discussed in Section 6, is still a displacement hull at 40 kt.

(U) Thus, the categorization of a planing hull is strongly influenced by considerations of performance and sea state. The pounding of planing hulls at high speed in rough water is a well-known characteristic, and extensive research has been conducted toward developing new hull forms with better seakeeping characteristics than the planing craft while retaining its high-speed characteristics (i.e., 40-50 kt for craft of 200-1000 tonnes). These hull forms encompass monohull as well as planing catamaran and other multihull configurations.

(U) From a technical viewpoint, the key element in evaluating a planing hull is to recognize the ramifications of combining high speed and rough-sea operation in one hull form. The concept tree, shown in Figure III-28, has two main branches,



(U) Figure III-28. PLANING CRAFT CONCEPT TREE

“subcritical” hull forms and “supercritical” hull forms. This categorization applies to displacement hulls as well as planing hull forms and expresses the ship response characteristics operating at speed in rough water. Specifically, a parameter may be defined as

$$\Omega = \frac{\text{Wave Encounter Frequency}}{\text{Ship Natural Frequency}}$$

For $\Omega < 1$, the hull forms are subcritical, which covers by far the bulk of planing craft developed to date. For such craft, ship response and hull pounding increase as the ship increases speed in rougher seas. Conversely, for $\Omega > 1$, supercritical hull forms are used. In such craft ship response and hull pounding decrease as the ship speed is increased in rougher seas. No hull can be designed to maintain subcritical or supercritical operation throughout its operational profile. The terms are used here as categories of design, particularly design point, for the hull. The objective of any R&D program for such planing hulls would be to devise hull forms with as wide an operating region as possible in order to maximize its flexibility as a military vehicle.

3.2 Features and Issues

(U) Table III-9 presents the particular features and issues of the planing craft concept. The paths taken in resolving the issues and the findings and conclusions of those efforts are discussed in the following subsections. The point designs developed are discussed separately from the analytical issues.

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(U) Table III-9. PLANING CRAFT EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
● REASONABLE COST FOR HIGH-SPEED PLATFORM	● CAN THE STRUCTURAL POINING BE RELIEVED ON PLANING BOATS? ● HOW LARGE CAN A PLANING CRAFT GET? ● CAN ITS RIDE QUALITY IN ROUGH SEAS BE IMPROVED?	● CONDUCTED ANALYSIS OF STRUCTURAL LOADS ON PLANING SHIPS ● DEVELOPED POINT DESIGN OF A LARGE (1,000-TONNE) PLANING CRAFT ● CONDUCTED MODEL TESTS ON IMPROVED HULL FORM THAT IMPROVES RIDE AS SEAS GET ROUGHER (SUPER-CRITICAL HULL FORM)	● SEE FOLLOWING COMMENT ON SIZE ● IN CONVENTIONAL, HARD-CHINA PLANING, RELIEF IS UNLIKELY ● FOR HYDRODYNAMIC AND POWERING REASONS IT APPEARS THAT 1,000 TONNES REPRESENTS A PRACTICAL LIMIT TO PLANING CRAFT, BUT AT THIS SIZE IT IS STILL A REASONABLY PRICED HIGH-SPEED PLATFORM ● SUFFICIENT MODEL TESTS AND PRE-ANVCE, MAN-CARRYING TEST BOAT DEMONSTRATION SHOW DEFINITE PROMISE FOR THIS HULL FORM AND MORE R&D SHOULD BE PURSUED TO EXPLORE ITS APPLICATION IN DESIGN; MAY ALSO ALLOW LARGER-SIZED PLANING SHIPS ● USEFUL IN LITTORAL WATERS ● FLEXIBILITY IN OPERATION THROUGH LOW-SPEED ENDURANCE AND HIGH-SPEED DASH
● SHALLOW DRAFT ● CONTINUOUS SPEED SPECTRUM			

3.3 Analyses and Experiments

(U) Analyses were conducted to (a) parametrically determine the weights, volumes, and stability of monohull planing hulls and (b) determine the loads and response characteristics of the well-known, subcritical planing hulls operating in rough seas.

(U) Experiments were conducted on planing hulls using semisubmerged propellers to reduce drag and power requirements. Also, experiments were conducted on a particular hull form designed to operate in the supercritical region to determine the feasibility of providing planing hulls with a rough-water capability. A brief summary of these analyses and experiments and their findings are presented in the following subsections.

3.3.1 Parameteric Analysis

(U) An analytical model, based on subcritical planing hull data, was developed to determine the basic sizing of planing hulls (Reference 32). Concentration was

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given to describing the structural features since the craft are designed to operate in rough water. The three main findings are:

- Up to displacements of about 1100-1400 tonnes, structural weight fractions decrease as displacement increases.
- The use of higher-yield-strength aluminum instead of current materials for craft of about 1100-1400 tonnes displacement will not improve the structural weight fraction significantly.
- Reduction of acceleration loads has little effect on the structural weight of planing hulls of about 1100-1400 tonnes displacement.

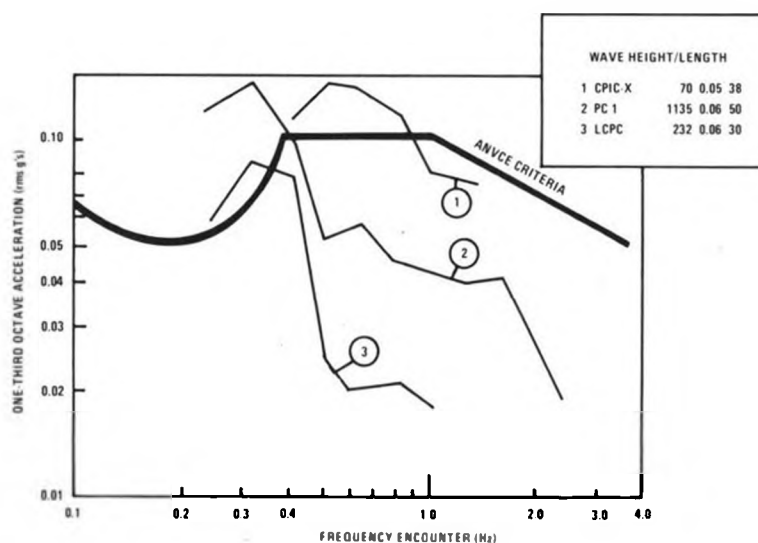
Two principal conclusions can be drawn from these findings: (a) the current conventional hull form for planing craft has already reached an advanced stage of development and no significant improvement in structural design is envisioned, and (b) for planing craft of about 1100-1400 tonnes the structural design is governed more by basic sizes and overall bending movements than by speed and acceleration effects. Since the application of this feasibility model to other less-conventional planing hull forms is questionable, the conclusions reached should not be extended to include other hull shapes.

3.3.2 Structural Load Prediction

(U) In comparison with the other ANV concepts examined, the planing craft requires more power to operate at high speeds. To briefly explore the possibility of reducing the power requirements of the planing hull, the ANVCE Project furthered the investigations into the use of partially submerged propellers. DT-NSRDC test results (Reference 33) showed that under certain conditions of propeller operation, a small power savings (about 10 percent) could be achieved; however, the large lifting force under the stern caused control problems. Based on this testing, the use of partially submerged propellers does not offer significant power savings.

3.3.3 Supercritical Hull Testing

(U) Considerable effort was expended within the ANVCE Project to learn more about the ride quality in ships. There is no universally accepted standard, and the ride quality attributed to any particular vehicle or concept is frequently subjective and difficult to quantify. Details on the ANVCE design standards are given in Appendix A. Accepting for the moment that the "average acceleration" levels are indicative of the relative motions of the various vehicles, then the comparison of the vehicles using root mean square (rms) provides a qualified but measurable comparison. The planing hull in its conventional, subcritical hull form configuration is known to have a "pounding" action at high speeds in high sea states, which translates into high peaks of acceleration for short periods of time. The rms of such acceleration levels is considerably less, however. Figure III-29 shows results of some planing craft.

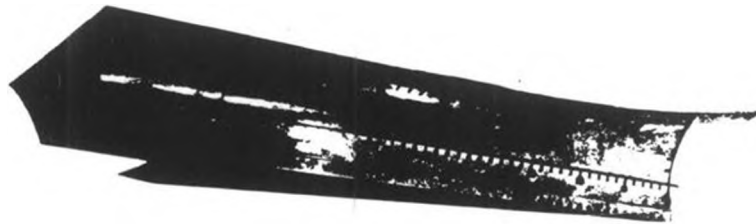


(U) Figure III-29. RIDE QUALITY OF THE CONVENTIONAL PLANING HULL FORM

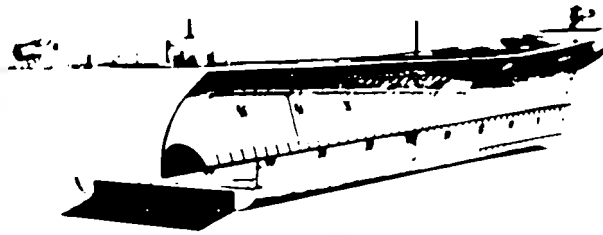
(U) Based on a consensus of available seakeeping criteria, the ANVCE Project developed ride-quality criteria that set motion limits acceptable to crew members on a 4-hr watch. These criteria are shown in Figure III-29. For a high encounter frequency, above 0.5-0.6 Hz, the criteria pertain to a fatigue limit. For low-frequency vibrations, below the 0.5- to 0.6-Hz encounter frequency, the criteria generally pertain to a motion-sickness limit.

(U) In terms of these criteria, the Coastal Patrol Interdiction Craft (CPIC) traveling at 38 kt into 2 1/2 ft waves [wave height (h_w)/length (L) = 0.05] would generate a motion that is marginally acceptable. Using these data and scaling to a 1135-tonne-displacement planing hull (Section 3.4) operating at 50 kt into 2 1/2 ft waves (h_w/L = 0.06) the fatigue limit does not appear to be a problem; the large size tends to push the craft motion into lower encounter frequencies, which cause motion sickness problems. A smaller design (Section 3.4) operating at a lower speed (30 kt) into the same size waves has much better seakeeping. These ships and their seakeeping can also be compared to the PHM, a hydrofoil with fully submerged foils, operating at more than 40 kt in similar seas. Such acceleration levels can also be compared to those of the ACV, hydrofoil, and SES.

(U) An effort was made to find a planing hull form that would eliminate or reduce this problem of ride quality. According to the state-of-the-art report on planing craft (Reference 4), the acceleration levels could be reduced if (a) the deadrise were increased, (b) the trim angle were reduced, (c) the beam were reduced, or (d) any combination of these features were used. Many of these features are embodied in the Payne, super-critical hull form, the SEA KNIFE. Two principal configurations of this hull form (the hard chine and the rounded bilge configurations) were tested both in the United States (at the U.S. Naval Academy) and in Great Britain (at the Admiralty Experimental Works). These models are shown in Figure III-30.



(a) HARD CHINE



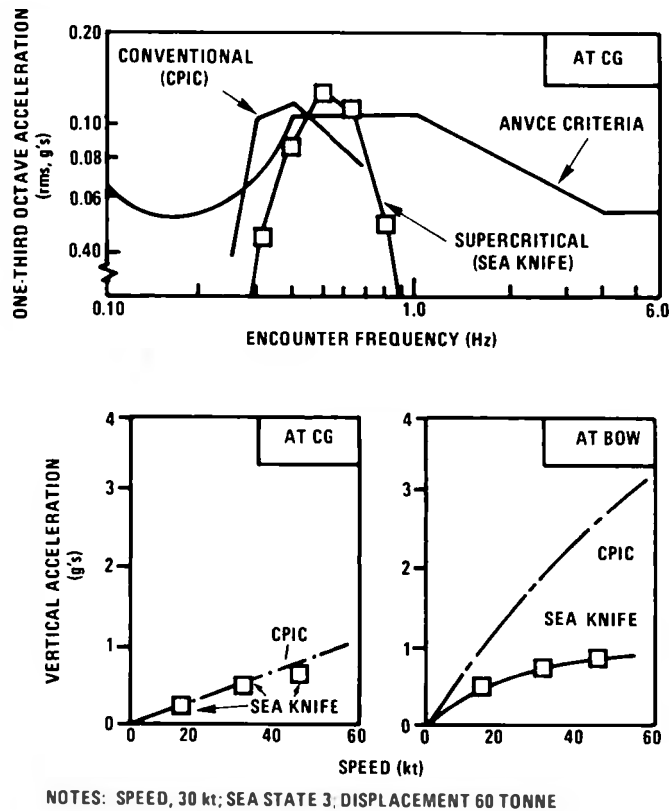
(b) ROUND BILGE

(U) Figure III-30. SEA KNIFE SUPERCritical HULL FORM MODELS TESTED

(U) Tests were conducted on these hull forms in both calm and rough water, exercising various geometric variations such as trim tabs and spray reversers. Although a complete series of tests was not performed and testing difficulties precluded proper reduction of the data, the following insights were gained:

- For the blunt transom configuration tested, the calm-water drag of a supercritical hull with a displacement of 60 tonnes is higher than an equivalent, conventional hard-chine planing hull (scale based on the CPIC) by approximately 32 percent at a design speed of 40 kt. Model tests on a boat-tailed transom, which would significantly reduce this difference, were not conducted. Further research in this area is needed.
- The difference in drag between a supercritical hull and a conventional, subcritical hull in rough water could not be determined because of facility test reduction difficulties. The difference is thought to be much less and, based on move records, may be less than a conventional planing hull.
- The acceleration levels for the supercritical hull are significantly less than those for the conventional, subcritical hull.

(U) As shown in Figure III-31, using a supercritical hull form increases the ride quality by a factor of 3:1 over that of the best-designed, subcritical hull form. The supercritical hull rides almost free of pitching, while the subcritical hull shows the characteristic pitching (high acceleration at the bow).



(U) Figure III-31. SUBCRITICAL AND SUPERCRITICAL MODEL ACCELERATION RESULTS

(U) In addition to these exploratory model tests, some basic layouts of ship designs were made. These layouts highlight the need to develop a method by which to regain the volume in the supercritical hull form that was lost because of the high deadrise. Several methods seem possible; however, none of them was explored in any detail by the ANVCE Project.

3.4 Point Designs

(U) To resolve the feasibility issues involved in the concept and to provide quantitative vehicle information for the cost and mission analyses, several point designs were prepared. These point designs are

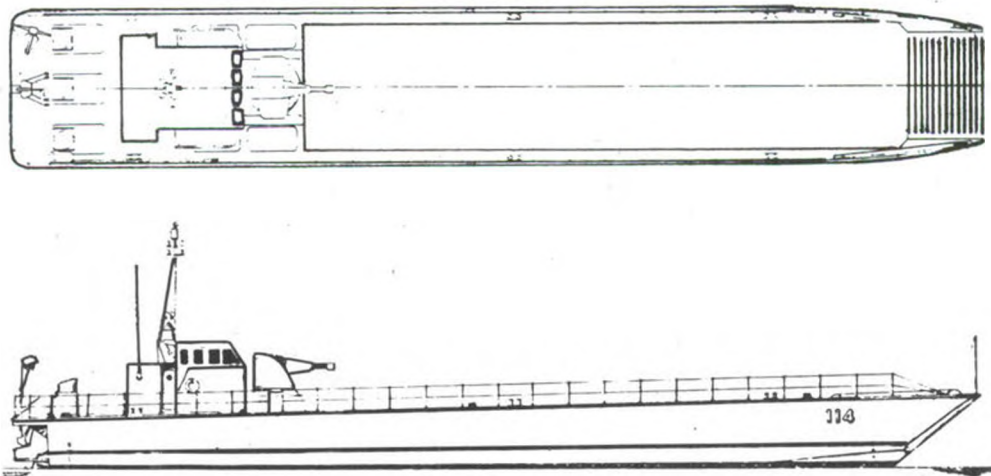
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- Amphibious Landing Craft (near term)
LCPC, 237 tonnes displacement
- Coastal Patrol Craft (near term)
CPIC, 72 tonnes displacement
- Nonair-capable, Planing Craft (far term)
PC 1, 1127 tonnes displacement

A detailed description of the characteristics of the LCPC is given in Reference 34; the CPIC (in ANVCE format), in Reference 35; and the PC 1, in Reference 36. Details of these designs as used by the ANVCE Project are given in Appendix B. The CPIC, an existing design, was used as a reference point. The two point designs reflecting consistent technology criteria and design standards are the LCPC (near term) and PC 1 (far term).

3.4.1 Amphibious Landing Craft

(U) The LCPC is a design that utilizes today's technology in planing hulls modified to accommodate two tanks, which must be transported to the beachhead. An inboard profile and plan view of the LCPC are shown in Figure III-32. Details of the LCPC and its performance are given in Appendix B and Reference 34. The landing particulars for the LCPC are given in Table III-10. Although, the LCPC and LCAC have been grouped as competitive concepts for the amphibious assault mission, any comparisons of the concept should take into consideration that the LCPC was designed to carry two main battle tanks, whereas the LCAC was designed to carry only one.



(U) Figure III-32. LCPC GENERAL ARRANGEMENT

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(U) Table III-10. LCPC LEADING PARTICULARS

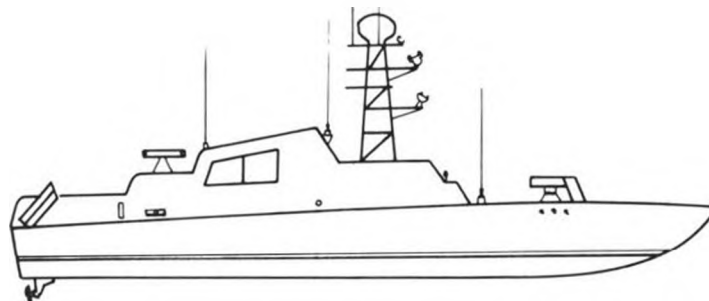
GROSS WEIGHT (TONNES)	237
PAYLOAD WITH 2 TANKS (TONNES)	116
RANGE AT 30 KT (SEA STATE 3) (NMI)	305
MAXIMUM SPEED IN SEA STATE 3 (KT)	30

(U) Since the LCPC does not involve technology beyond 1980 improvements in unique performance and waterjet pump performance, the risk associated with this design is minimal.

3.4.2 Nonair-capable, Planing Craft

(U) As part of the investigation into feasible sizes for planing craft, a point design was developed of a large planing craft, the PC 1 (Figure III-33). The details of this point design are given in Appendix B, and the leading particulars are given in Table III-11.

(U) The PC 1, a nonair-capable design, has a combat suite that is common to nonair-capable, surface combatant group (far term). This group comprises the ACV 1, the HYD 7, the WIG(S), and the PC 1. The PC 1, like other designs in this group, is designed for ASW, AAW, and ASUW missions of 15 days' duration. A description of the common combat suite is given in Appendix A.



(U) Figure III-33. PC 1 POINT DESIGN

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(U) Table III-11. PC 1 LEADING PARTICULARS

GROSS WEIGHT (TONNES)	1,127
PAYLOAD (TONNES)	151
RANGE (NMI)	
AT 10 KT	14,800
AT 53 KT	1,500
MAXIMUM SUSTAINED SPEED IN SEA STATE 3 (KT)	53

(U) Based on an evaluation of the point design, a planing craft of about 1100 tonnes displacement with a maximum speed of more than 50 kt is technically feasible. However, a question still remains as to whether the ride quality would be acceptable or whether the structural integrity of the hull would be adequate for continual operation at very high speeds. The problems and risks are greatly reduced if the speed capability is reduced to 40-45 kt, which is a significant improvement over equivalent displacement ships. The feasibility of using the supercritical hull form to increase the size of the planing craft was not analyzed.

3.5 Findings and Conclusions

(U) The planing craft has many advantages. It represents the least departure from current naval ship forms and thus involves the least cost in R&D, hardware, and probably operation. It offers speed capability of 50-55 kt, which is more than sufficient for most naval missions.

(U) Two limitations of the planing craft concept are size and seakeeping. Even exploiting the latest technology, planing craft larger than about 1000 tonnes displacement are only marginally feasible. Moreover, conventional planing hull technology is a limiting factor in terms of the seakeeping capability of the planing craft at high speed. The analysis and model testing performed within the ANVCE Project indicate a considerable degree of merit in developing the supercritical hull form, which shows significant improvements in ride quality and seakeeping over conventional planing hull forms. Since the supercritical hull becomes more efficient when highly loaded (more so than conventional planing hulls), it is possible that the displacement could be increased to more than 1000 tonnes. However, the ANVCE Project did not conduct an analysis on the supercritical hull form.

(U) Based on these findings, it was concluded that:

- The planing craft using conventional hull forms is a technically feasible concept up to a size of about 1000 tonnes displacement and a maximum speed of 50-55 kt. Its seakeeping capability is limited to about a sea state 3 in the acceptable range.

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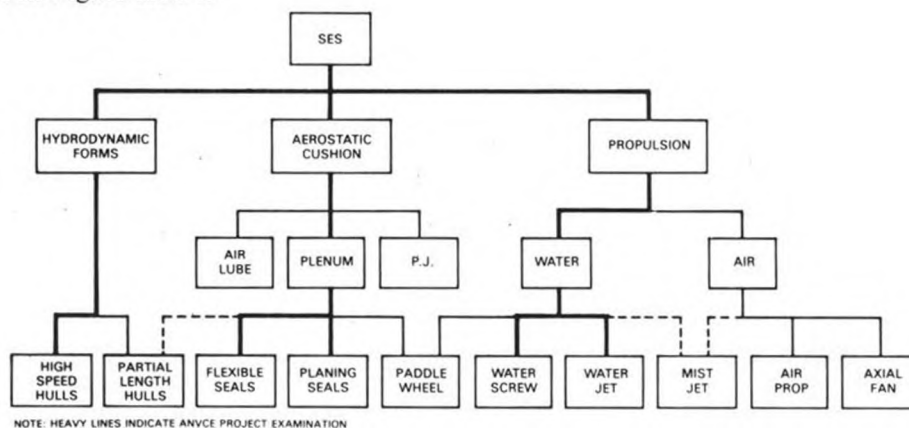
- Opportunities exist to develop a planing hull form that provides a significantly improved seakeeping capability for 1000-tonne, 50- to 55-kt craft. The supercritical hull form, which has been tested in model scale and actual size, should be analyzed for its feasibility as a naval ship larger than 1000 tonnes.

4. SURFACE EFFECT SHIP

4.1 Concept Tree

(U) The SES is a subdivision of the more general classification of air cushion craft. Specifically, if the air cushion craft utilizes two sidehulls housing the propulsion and stability mechanisms, it has become common to refer to it as an SES instead of an ACV. If the water propulsion system is housed in a central hull or on pods, the craft is classified as a nonamphibious ACV (Section 1.4 of this chapter).

(U) Such variations within the concept and between it and the ACV require a different illustrative technique that can show the SES variations that can be developed. The concept tree (Figure III-34) shows three main branches. The branches represent the main distinguishing features: the form of the sidehulls, the air cushion, and the propulsion scheme. Most of the configurational forms possible for the SES have been studied previously, although in varying degrees of detail. These studies have considered such aspects as "partial-length sidehulls," to reduce hydrodynamic drag and improve directional stability; different seals such as the "bag-and-finger" seals developed for the British ACV and the "planing seals" under development for the U.S. Navy 3KSES prototype; and various propulsion schemes, including waterjet and waterscrew, air, and "mist-jet" (air and water combination). Integrating seals and propulsion through "paddle-wheel" propulsion has also been proposed in some British designs. While each of these schemes has merit and deserves further study, the forms examined by the ANVCE Project were those it felt had the greatest potential. The paths of the ANVCE Project investigations are indicated by the bold lines in Figure III-34.



(U) Figure III-34. SES CONCEPT TREE

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4.2 Features and Issues

(U) Table III-12 presents the particular features and issues of the SES concept. The paths taken in resolving the issues and the findings and conclusions of those efforts are discussed in the following subsections. The point design developed are discussed separately from the analytical issues.

(U) Table III-12. SES EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
● SHALLOW DRAFT WHEN ON CUSHION LESSENS VULNERABILITY TO TORPEDOES	● IS THE SIZE OF SES LIMITED BY ITS CAPABILITY TO OPERATE SUFFICIENT CUSHION PRESSURES? ● IS THERE A SOLUTION TO REDUCING THE HIGH POWER REQUIREMENTS OF SES?	● CONDUCTED DESIGN OF LARGE SES (10,000 TONNES) AND ANALYZED LIFT SYSTEM ● CONDUCTED HIGH-L/B MODEL TESTS TOWARD LOWERING THE DRAG OF SES ● CONDUCTED MODEL TESTS OF MULTIPROPELLER INSTALLATIONS	● FEATURE NOT AS GOOD AS ON ACV AND ACTUALLY HAS MORE DRAFT THAN CONVENTIONAL SHIP WHEN OFF-CUSHION. THUS, A QUALIFIED FEATURE ● THE PRACTICAL LIMIT USING CONVENTIONAL SINGLE STAGE LIFT-FAN SYSTEMS SEEMS TO BE 8,000 TONNES. ABOVE THIS SIZE MULTISTAGING OF FANS WILL BE REQUIRED. R&D NEEDS TO BE PURSUED FOR MARINE APPLICATION OF MULTISTAGE FAN ● THIS SOLUTION IS A VERY ATTRACTIVE ONE IN REDUCING POWER REQUIREMENTS AND IS ESPECIALLY ATTRACTIVE IF NEED FOR SPEED CAN BE REDUCED AND 50 KT IS ACCEPTABLE SPEED ● FLEXIBILITY OF USING (HIGHER-EFFICIENCY) WATER PROPELLERS DETERMINED WITH ATTRACTIVE RESULTS; MORE MODEL TESTS AND DESIGN WORK NEED TO BE FOLLOWED TO CONFIRM THE POWER SAVINGS INDICATED IN THESE TESTS
● RIDE QUALITY BETTER THAN CONVENTIONAL HULL FOR GIVEN SPEED AND DISPLACEMENT	● CAN RIDE CONTROL BE IMPROVED WHEN OPERATING AT HIGH SPEEDS (50-80 KTS) IN HIGH SEAS?	● CONDUCTED ANALYSIS OF RIDE QUALITY OF SES (AND OTHER PLATFORMS) TO DETERMINE LIMITS AND CAPABILITIES OF LATEST RIDE CONTROL SYSTEMS (DISCUSSED UNDER ACV EXAMINATION)	● DISTINCT IMPROVEMENTS IN RIDE QUALITY ARE PROBABLE USING LATEST VERSIONS OF ACTIVE RIDE CONTROL SYSTEMS MOST LIKELY TO HAVE LIMITATIONS IN THE HIGHEST WAVE COMBINATION CORNER OF THE OPERATING ENVELOPE. R&D AND TEST OPERATION OF PROTOTYPES CAN SHED MORE LIGHT ON THIS
● CATAMARAN HULL CONFIGURATION PROVIDES FLEXIBILITY OR PROPULSION SYSTEM AND REDUCES SEAL PROBLEM	● IS THERE A LIMIT ON SEAL SIZE?	● ANALYZED NEW SEAL DESIGNS BEING PROPOSED FOR SES USE (DISCUSSED UNDER ACV EXAMINATION)	● TRUE ● NEW SEAL DESIGNS WILL BE REQUIRED FOR LARGE SES AND R&D IS PROCEEDING TO GAIN SMALL-SCALE (MAN CARRYING TEST CRAFT UP TO 100 TONNES) EXPERIENCE ON MUCH SEALS. R&D WILL BE REQUIRED TO GAIN CONFIDENCE ON THE NEW LARGE SEALS

4.3 Analyses and Experiments

(U) Hydrodynamically, the SES, like many other vehicles, becomes relatively more efficient as size (displacement) increases. However, although the SES becomes relatively more efficient in absolute terms, the power requirements increase, which strains the state of the art in developing lift fan, skirt, propulsion, and transmission systems to meet those requirements. In addition, the SES becomes more efficient at a speed of 80-100 kt, which not only results in high power requirements but also introduces phenomena associated with the hydrodynamics of sidehulls and air cushions at very high speeds. Accordingly, most of the analyses and experiments associated with the SES concept were directed toward exploring methods by which the power requirements could be reduced and the speed maintained.

(U) Larger sizes of lift-fan systems, more-slender (high-L/B) configurations, and various propeller systems that could improve SES propulsive efficiencies were explored as means by which propulsion power requirements could be reduced.

4.3.1 Lift-Fan Systems

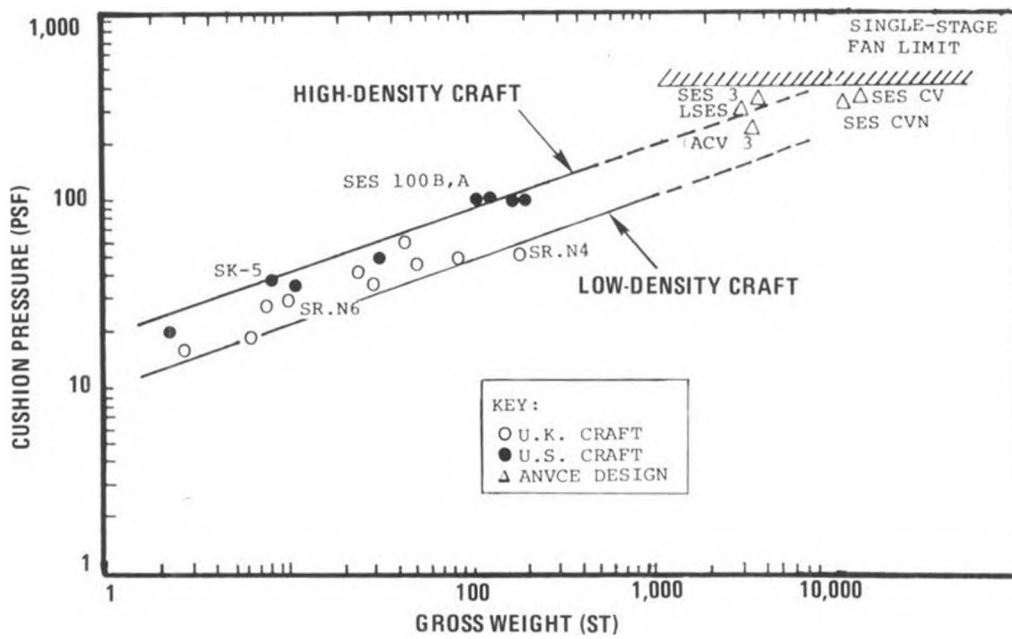
(U) As the size of the SES increases, the cushion pressure to support the craft also increases. Cushion pressures for existing craft typically vary between 50 and 100 psf depending on the size and design features. However, depending on the particular design, the lift fan(s) must generate a static pressure about 20-40 percent higher than the cushion pressure values to compensate for duct and other system losses.

(U) To date, all ACV and SES (up to about 300 tonnes displacement) designs have used either centrifugal, mixed-flow or axial-flow, single-stage fan(s) to provide these pressures. However, these single-stage fans will not be able to generate sufficient pressure for a larger SES; some form of staging will be required. At this point, fan technology becomes more sophisticated, reaching the degree of complexity associated with compressor technology.

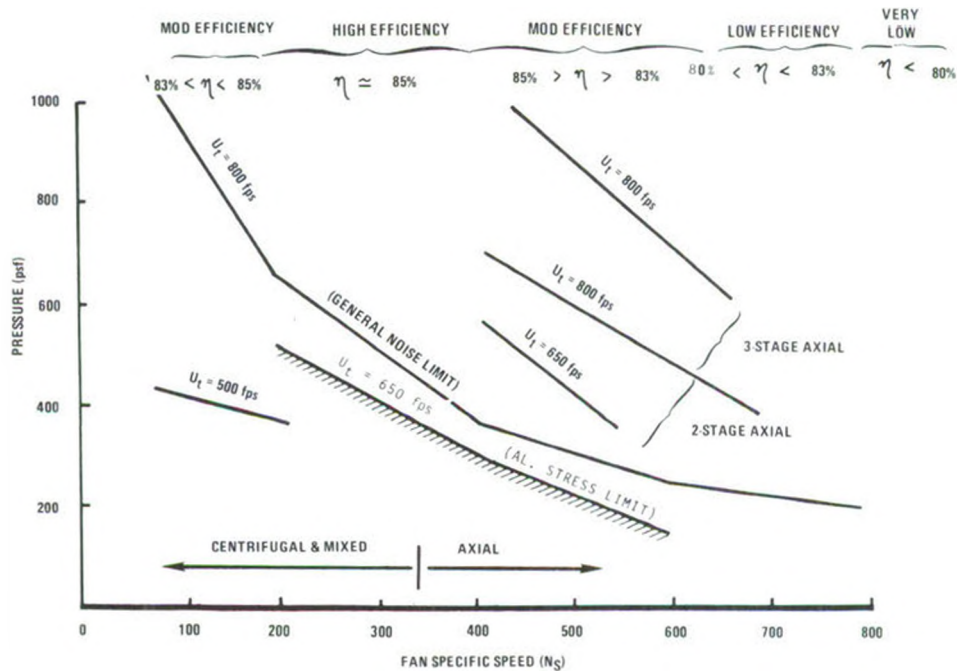
(U) Figure III-35 illustrates the problems associated with the increased cushion pressure required by larger ACV and SES. For an SES of approximately 10,000 tonnes displacement, a cushion pressure of between 350 and 400 psf plus pressure loss factor is required, placing the pressure ratio beyond the practical capability of single-stage fans. This limit in single-stage fans and current fan technology is shown in Figure III-36.

(U) While improved specific fans may be designed, it is generally agreed that the main parameters are those shown in Figure III-36. The saw-toothed line indicates the best pressure (static) versus speed and efficiency for current, single-stage fans. Any further increase in pressure, regardless of whether a centrifugal, mixed-flow or axial-flow, single-stage fan is used, results in problems of noise or materials stress limits. Therefore, multistage fans must be developed before the size of the SES can be increased.

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(U) Figure III-35. CUSHION PRESSURES REQUIRED BY VARIOUS SIZES OF AIR CUSHION CRAFT

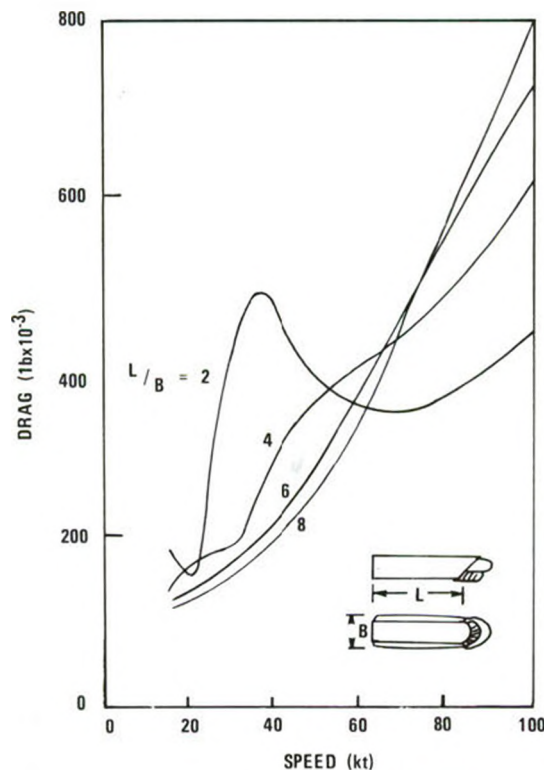


(U) Figure III-36. STATE OF THE ART IN FAN TECHNOLOGY

4.3.2 Experiments with High-L/B Models

(U) There are two major parameters that influence the power requirements of an SES (or ACV): the cushion pressure (P_c), or in its normalized form cushion density ($P_c/S^{1/2}$), and L/B. An increase in cushion density has several ramifications. In addition to high fan-power requirements, it generates a requirement for high propulsion power at low speeds because of the increase in wave drag resulting from the larger cushion. This condition can be greatly improved by increasing the length of the ship such that high wave drag occurs at a speed much faster than the operating speed of the ship.

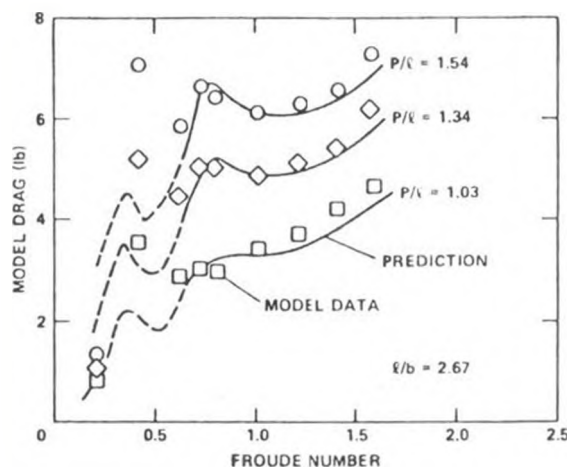
(U) Figure III-37 shows predicted drag curves for a 4000-tonne SES at different slenderness ratios. The curves are typical for various displacements and illustrate the general rule that if the SES is to be designed for very high speeds (about 80-100 kt), then the geometry of the SES should have a "low" L/B ratio (approximately 2). If, on the other hand, mission requirements indicate SES speeds of 50-60 kt, a much higher L/B ratio (about 4-8) is better in terms of power requirements.



(U) Figure III-37. WAVE DRAG FOR DIFFERENT SES SLENDERNESS RATIO

(U) The current SES prototypes (the SES 100A and SES 100B) and the projected 3KSES, which have design speeds of 80-100 kt, are of the low-L/B configuration. Since the DOD guidance directed the Navy to look at the high-L/B SES, the ANVCE Project investigated the technology of SES with L/B ratios of 2-8, shown in Figure III-37. Model experiments were conducted for an L/B range of 3.36 to 6.45 (Reference 37). Encouraging agreement was obtained between the predictions and the model data, as shown in Figure III-38. Figures III-37 and III-38 indicate that considerable power savings are possible (with obvious ramifications in cost) if a design speed of 50-60 kt is employed instead of 80-100 kt and the L/B ratio is about 6 instead of 2.

(U) This effect on ship design is discussed further in Section 4.4, which presents the aircraft carrier point designs. It was envisioned that the SES CV point design would be high-L/B, but design compromises reduced it to 3.5.



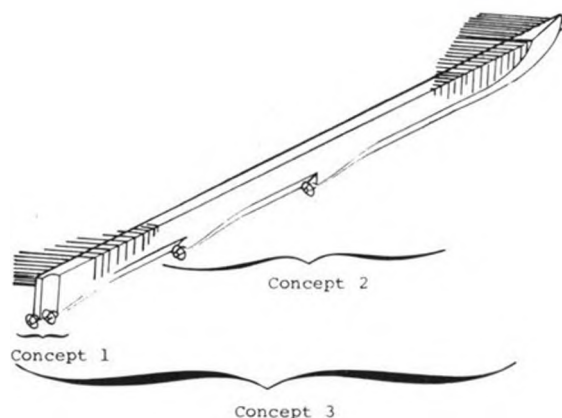
(U) Figure III-38. DRAG EXPERIMENTS ON HIGH-L/B MODELS

4.3.3 Multiple-Propeller Experiments

(U) Water propellers generally have 5-10 percent more efficiency "points" than equivalent water-jet propulsors. Since this difference in efficiency can have a considerable impact in terms of absolute power for a large craft, an analysis and model experiments were conducted to determine whether the use of propellers would reduce the power requirements of a high-speed SES. Although the supercavitating water propellers used on the SES 100B proved highly successful, it was found that scaling such propellers to a large SES strains the limits of current technology on material strengths within small blade sections. Therefore, for the present, scaling is not considered a feasible method of increasing propeller size.

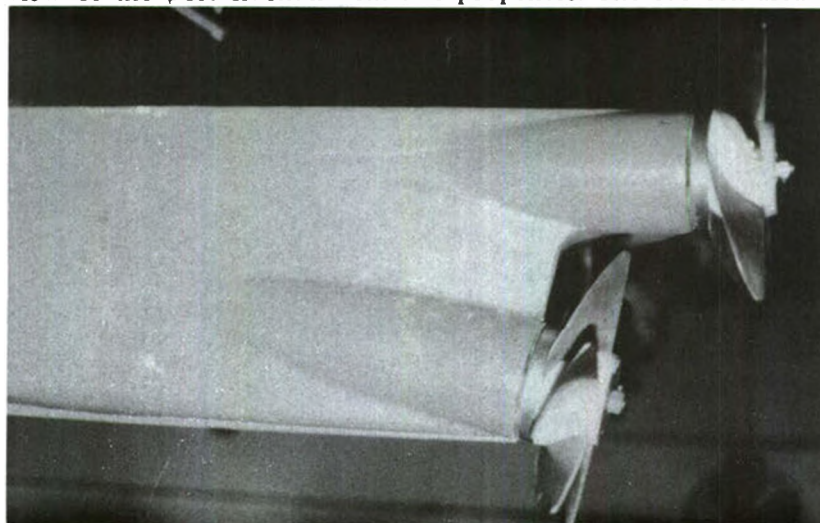
(U) Another analysis was then conducted to determine whether the size could be increased by using two or more propellers (of the same type) per sidehull instead of one. While the analysis indicated that this method had potential as a solution to the problem, it did not resolve the issue of a possible interface effect resulting from two supercavitating, semisubmerged propellers in proximity behind the sidehull transom.

(U) Figure III-39 shows three possible configurations of propeller sidehulls. Concept 1 shows the two-propeller configuration at the transom, Concept 2 illustrates the use of inclined shafts to avoid development of right-angled transmission systems, and Concept 3 uses multiple propellers installed along the sidehull on inclined shafts.



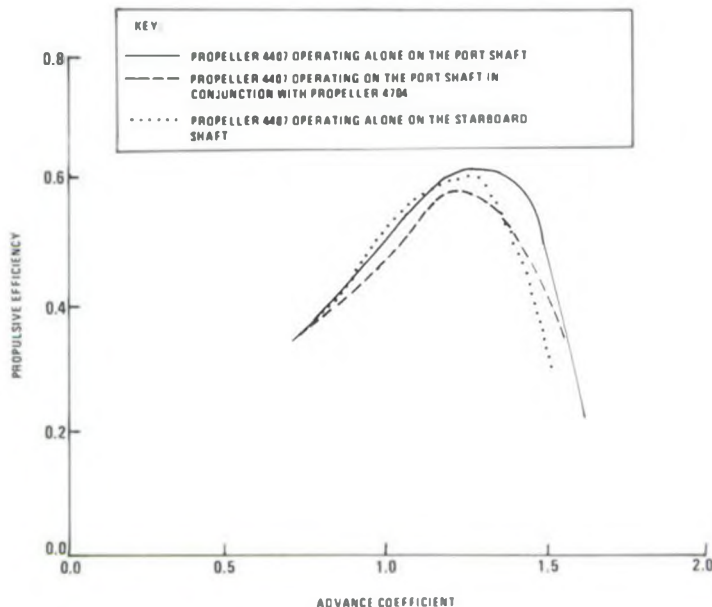
(U) Figure III-39. MULTIPLE-PROPELLER SIDEHULL CONFIGURATIONS

(U) In order to resolve the interface issue, model tests were conducted using the double-propeller transom configuration (Concept 1). Figure III-40 shows a fish-eye view of the port sidehull with two propellers. The cushion area would be



(U) Figure III-40. DOUBLE PROPELLER TRANSOM CONFIGURATION

toward the top of the photograph. The results of the model tests were encouraging (Reference 38). Figure III-41 summarizes the main findings of the model experiments. As shown, propulsive efficiencies of about 60 percent can be achieved and propeller interference does not present a problem.



(U) FIGURE III-41. MODEL TESTS RESULTS: TWO PROPELLERS/SIDEHULL

4.4 Point Designs

(U) To resolve the feasibility issues involved in the concept and to provide quantitative vehicle information for the cost and missions analyses, several point designs were prepared. These point designs are as follows:

- Air-capable, Surface Combatant (near term)
LSES, 3048 tonnes displacement
- Air-capable, Surface Combatant (far term)
SES 3, 3658 tonnes displacement
- Aircraft Carrier (far term)
SES CV, 11,165 tonnes displacement
SES CVN, 9,862 tonnes displacement.

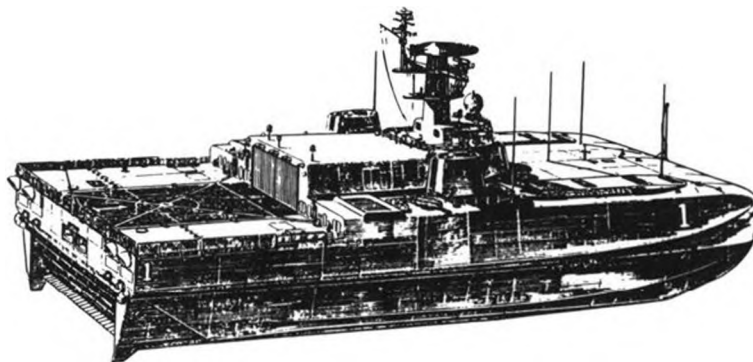
(U) Although two versions of the near-term and far-term, air-capable, surface combatants had been designed and were under development by two independent contractors (Bell and Rohr) as part of the 3000-tonne-class SES (3KSES) competition, only one of the designs was used as the basis for the point design. The descriptions of each of the designs, modified to varying degrees to comply with the standards for the ANVCE Project evaluation, are given in References 39 (Bell LSES),

40 (Rohr LSES), 41 (Bell SES 3), and 42 (Rohr SES 3). The descriptions of the aircraft carrier (conventional and nuclear-powered) point designs developed by the ANVCE Project are given in References 43 (SES CV) and 44 (SES CVN). Moreover, some reiterative design changes were made on the basis of the technical evaluation. The detailed descriptions of these final point designs used in the cost and mission analyses are presented in Appendix B. Summaries of these various designs are presented in this subsection.

4.4.1 Near-Term, Air-Capable, Surface Combatant

(U) Although both the Bell and the Rohr versions of a near-term, large (3000-tonne-class) SES were examined as part of the technical evaluation, the Rohr design was used as the basis for the point design. The two designs represented different technical approaches. The Bell LSES (large SES), for example, used a development of the bag-and-finger seal used on the British ACV and the SES 100B, while the Rohr LSES used a new planing-type seal currently under development for the XR-1D and the modified SES 100A. Other technical differences were noted and considered in the technical evaluation. Since both designs were examined in the technical evaluation, the Bell LSES design is also discussed to some extent to this point design summary.

(U) Figure III-42 shows an isometric view of the near-term, air-capable, surface combatant, the LSES. Since an existing design—the Rohr LSES, which has a scheduled launch date of 1982-83—was used as the point design, only minor modifications were made to standardize the design to the ANVCE Project point design format. For example, the LSES does not have a combat suite in common with any other point design within the ANVCE Project. Therefore, caution should be used in interpreting any results especially in terms of cost and mission usefulness.



(U) Figure III-42. LSES POINT DESIGN

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(U) The leading particulars of both LSES designs (Bell and Rohr) are given in Table III-13. Detailed descriptions of the designs are given in the references cited; the details of the point design used in the cost and mission analyses are given in Appendix B.

(U) Table III-13. LSES LEADING PARTICULARS

CHARACTERISTICS	BELL	ROHR
GROSS WEIGHT (TONNES)	2,896	3,048
PAYLOAD (TONNES)	169	204
RANGE (NMI)	3,018 (AT 81 KT)	3,000 (AT 77 KT)
MAXIMUM SPEED IN SEA STATE 3 (KT)	74	86

4.4.2 Far-Term, Air-Capable, Surface Combatant

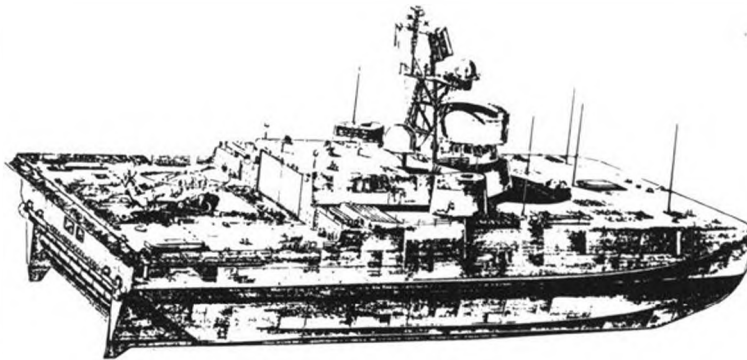
(U) The main thrust of the ANVCE Project has been in the far-term period, 1995-2000. In that period, the point designs are distinct from any current programs and the specific response of those programs. Thus, the point designs could be developed by the ANVCE Project around common mission requirements with a common technical base, in contrast to the partial standardization of the near-term LSES.

(U) The SES 3 point design incorporates far-term technology and a compatible combat suite for the same time frame that is common to other point designs in the class. In addition to the far-term, air-capable, surface combatant, the SES 3, this 3000-tonne class includes the HYD 2, ACV 3, SWA 4, and the baseline displacement ship (MONO 3).

(U) Figure III-43 shows an isometric view of the SES 3. As with the LSES, two designs (Bell and Rohr) were examined in the technical evaluation, but the Rohr design was selected as the basis for the point design used by the ANVCE Project in its cost and mission analyses.

(U) In comparing the SES 3 (Figure III-43) with the LSES (Figure III-42), several differences can be seen in their external configurations. The difference in the combat suite is most clearly visible. The combat suite of the SES 3 has a much greater capability in AAW, ASW, and ASUW. Less-obvious improvements in the SES 3 are the use of higher power engines (LM 5000), better seal systems, more-efficient waterjet propulsion systems, and other subsystem differences.

(U) The leading particulars of both SES 3 designs (Bell and Rohr) are given in Table III-14. Detailed descriptions of the designs are given in the references cited previously and in Appendix B.



(U) Figure III-43. SES 3 POINT DESIGN

(U) Table III-14. SES 3 LEADING PARTICULARS

CHARACTERISTICS	BELL	ROHR
GROSS WEIGHT (TONNES)	3,450	3,658
PAYLOAD (TONNES)	333.02	391
RANGE AT CRUISE SPEED IN SEA STATE 3 (NMI)	3,570 (AT 80 KT)	3,208 (AT 92 KT)
MAXIMUM SPEED IN SEA STATE 3 (KT)	84	97

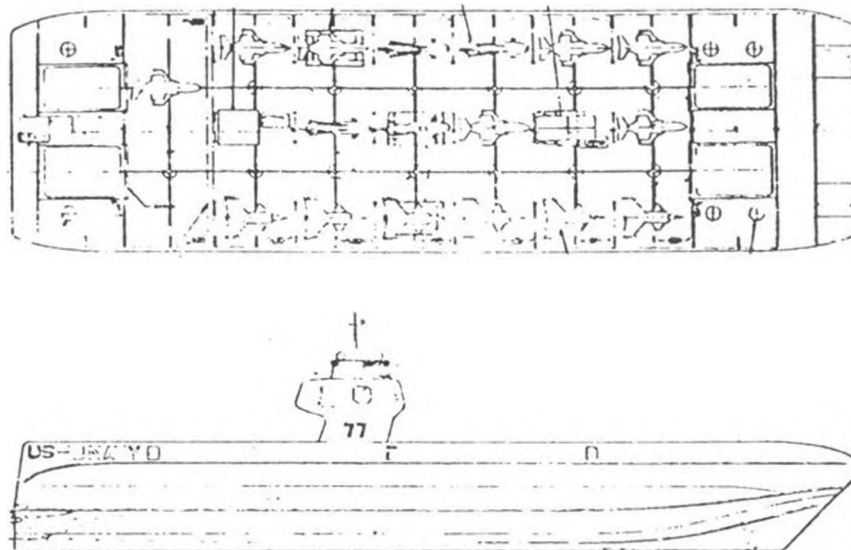
(U) The far-term, 3000-tonne SES (SES 3) represents a significant improvement in capability over the near-term, 3000-tonne SES (LSES). Its combat suite is much more capable, reflecting the more severe threat projected for circa 2000 and also the fact that the near-term ship is a test design with only a modest combat suite. The SES 3 represents a technical challenge. It has 45 percent greater power installed and much higher speeds (106 kt in calm water at full-load displacement) than the LSES (92 kt at half fuel load). Improvements in waterjet efficiencies and seal design are also projected as areas in which the SES 3 will have developed beyond the LSES state of the art.

4.4.3 Aircraft Carrier

(U) As discussed in Section 4.3 of this chapter, experiments on high-L/B models indicate that (a) long, slender ships would be better suited for aircraft runways and deck handling and (b) speeds of 50-60 kt, which are compatible with high-L/B hydrodynamics, are sufficient for aircraft carrier operations. An SES that

combines these capabilities could represent an improvement in the area of aircraft carrier operations. Its high speed would allow shorter runways (possibly a smaller ship) for its V/STOL (vertical/short takeoff and landing) aircraft and the "box-like" structure of an SES together with its relatively low density (compared with conventional displacement hulls) would be suitable for the stowage of aircraft. Accordingly, SES designs that would be applicable for such missions were developed.

(U) Figure III-44 shows the side elevation and aircraft stowage deck for the ANVCE Project point design of a far-term, conventionally powered SES aircraft carrier, the SES CV. This design meets the two basic requirements: (a) high-L/B hydrodynamics to keep power and speed within bounds for an SES of 3000 tonnes displacement and (b) sufficient beams to accommodate two runways, which ensures that at least one runway (and elevators) is available during operational conditions. Because these two requirements are not readily compatible, a compromise geometry was integrated into the design. The SES CV in the 10,000-tonne class represents a significant advance in the state of the art.



(U) Figure III-44. SES CV POINT DESIGN

(U) Previous studies (by PMS 304) have postulated smaller, less-expensive carriers that could provide rapid strike but had limited endurance and limited on-board maintenance capability. In comparison, the SES CV point design developed by the ANVCE Project is a larger carrier (for the same number of aircraft) that provides long endurance and an on-board maintenance capability as well as rapid strike. The 10,000-tonne-class SES CV carries approximately 20 percent of the number of aircraft carried on current displacement-hull carriers of the 90,000-tonne class; this, "numbers difference" has been partially offset by equipping the SES CV itself with a very capable combat suite in addition to its 17 aircraft. Thus, the SES CV represents a potentially significant change in capability that should be studied

in depth to determine the most effective means of utilizing this concept. The AN-VCE Project progressed through several design iterations in developing the SES CV (Reference 43); the design differences are discussed in Chapter V, which presents selected technical assessments and operational considerations.

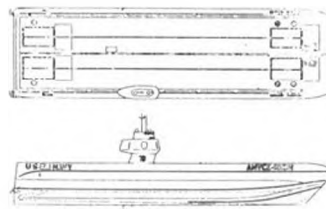
(U) Table III-15 gives the leading particulars of the SES CV point design. A detailed description is presented in Appendix B. The 3.5 L/B ratio of the SES CV is the result of the compromise geometry used in the design.

(U) Table III-15. SES CV LEADING PARTICULARS

GROSS WEIGHT (TONNES)	11,165
PAYLOAD (TONNES)	2,040
RANGE (NMI)	
AT CRUISE SPEED (35 KT) IN SEA STATE 3	7,000
AT MAXIMUM SUSTAINED SPEED (58 KT) IN SEA STATE 3	3,733
MAXIMUM SUSTAINED SPEED IN SEA STATE 3 (KT)	58

(U) Technically, such a large SES presents a challenge in several areas, including the transmission of 360,000 hp to the propulsion and lift systems and the development of multistage fans to accommodate the high cushion pressure (Section 4.3 of this chapter).

(U) A fundamental issue with all high-speed surface concepts is the basic incompatibility of providing both high speed and long endurance in the same ship. As a means of resolving this problem, consideration was given to the use of nuclear power. However, to avoid the weight problem of conventional pressurized-water-reactor (PWR), nuclear power plants, such as those used in today's nuclear-powered, displacement ships, lightweight nuclear propulsion (LWNP) was considered. A point design, the SES CVN, was developed to explore the feasibility of such a concept.* Figure III-45 shows the SES CVN designed; both a side view and main deck view are given.



(U) Figure III-45. SES CVN POINT DESIGN

*The ANVCE Project did not extensively explore the technology of LWNP; the feasibility of LWNP was assumed. The ANVCE Project only investigated the feasibility of utilizing LWNP in an ANV concept.

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(U) For ease of design, the external geometry of the SES CVN (Reference 44) was kept the same as that of the SES CV. The decreased displacement resulted primarily from the use of the nuclear power plant and the change in fuel load. Comments pertaining to the technical development items cited for the SES CV generally apply to the SES CVN except for those pertaining to the multistage fan design. Moreover, the SES CVN carries 17 aircraft. Also, the incorporation of (gas-cooled) LWNP is unique to the SES CVN.

(U) A detailed description of the SES CVN point design, as modified for the evaluation, is presented in Appendix B. Table III-16 gives the leading particulars. It should be noted that since the SES CVN is nuclear-powered, its endurance is limited only by the crew provisions it can carry.

(U) Table III-16. SES CVN LEADING PARTICULARS

GROSS WEIGHT (TONNES)	9,862
PAYLOAD (TONNES)	2,040
RANGE (NMI)	UNLIMITED
MAXIMUM SUSTAINED SPEED IN SEA STATE 3 (KT)	65

(U) Since the ANVCE Project's charter was to evaluate platform concepts and not specific development items such as nuclear power plants, the approach taken was essentially to determine whether (a) LWNP is technically feasible for the SES, and (b) it provides a cost/effectiveness advantage over current vehicles in performing the same mission. Since a large platform is required to carry even the lightest nuclear power plant, the ANVCE Project only considered its application when a concept was limited because of high fuel consumption and could feasibly be designed to carry such a power plant. The SES was an ideal candidate for such an evaluation.

(U) A considerable amount of literature exists as to the technical feasibility of LWNP (both the gas- and metal-cooled versions). Despite these extensive studies by many groups during the past years, some technical issues remain unresolved. However, assuming the feasibility of LWNP, no major technical problem is seen in integrating LWNP into an SES.

4.5 Findings and Conclusions

(U) The SES offers many advantages. To date, it represents the largest expenditure on R/D efforts in new surface platforms in recent years. Accordingly, a significant technology base exists. This base coupled with the significant ACV technology base, in which the SES has its beginnings, represents a confidence level that will be valuable asset in terms of future planning.

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(U) However, the SES is primarily a concept that is designed to operate at very high speeds. Therefore, it generally uses a propulsion system that enables it to operate in the supercavitating flow region, which increases the technical risk involved. Although a technology base exists for SES of 100 tonnes displacement and capable of speeds up to 80-90 kt (specifically the SES 100A and SES 100B test craft and associated smaller test vehicles, models, and analyses of the U.S. Navy), as the displacement of the SES is increased, the technical risk is also increased. These risks can be reduced somewhat by lowering the speed requirements (from the data base of 80-90 kt) as the displacement increases (as was shown through the SES CV and CVN designs). Based on the SES literature and the results of the ANVCE analyses, model experiments, and point designs, the following specific findings and conclusions pertaining to SES are:

- The SES concept has been demonstrated in sizes up to 100 tonnes displacement and to speeds of 80-90 kt in calm water. Based on extensive analysis, model testing, and manned-craft testing by the U.S. Navy (PMS 304), projections extending this capability up to 3000 tonnes displacement have been made. As with the other advanced concepts, the technical risks associated with propelling an SES of this displacement at such a speed are still considered to be high because of the high power levels to be handled by the engines, transmission, and propulsors. Development and hardware test programs on each of these subsystems are included in the U.S. Navy SES program.
- To use the SES concept as an aircraft carrier, a much larger displacement (about 9,000-12,000 tonnes) will be required than that required for other SES uses. To reduce the power requirements and technical risk to reasonable levels, the speed capability must be reduced to about 50-60 kt. Although this speed is much lower than the very high speeds at which an SES usually operates, 50-60 kt is still about two to three times the speed capability of conventional displacement ships.
- As it is presently designed, the SES concept represents a high technology investment. It requires the use of sophisticated structures, high-power propulsion systems, developmental lift-fan systems to provide acceptable seakeeping, and developmental seals to operate reliably in a seaway. All of these factors combine to increase the cost of the SES (both the initial investment and the operating cost). Accordingly, options within the SES concept that can lower those costs must be sought; otherwise, such costs could have an adverse impact on a concept that could be highly effective. Based on the ANVCE Project findings, the development of features that could lower the power requirements, such as more-slender configurations (high L/B); use of propellers; and a reduction in operating speeds are essential elements in producing a cost/effective SES.

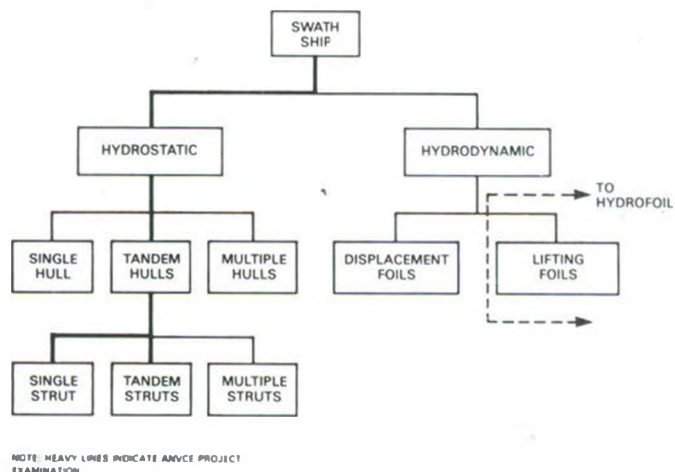
(U) Specific comparisons of technical measures of the SES and other competitive concepts are provided in Chapters V and VI.

5. SWATH SHIP

5.1 Concept Tree

(U) The SWATH (small-waterplane-area, twin-hull) ship is considered a supercritical hull form because its design eliminates the effects of high encounter frequencies in high sea states. The SWATH design utilizes two cylindrical hulls that are submerged at a depth below the surface wave action and small-waterplane-area (both horizontally and vertically) struts supporting the main body above the waves.

(U) Conceptually, the SWATH form, which is between the fully buoyant or hydrostatic displacement hull and the fully dynamic hydrofoil, can follow either the hydrostatic (low-speed) or hydrodynamic (high-speed) path. These paths are shown in the SWATH concept tree (Figure III-46). The SWATH ship normally operates in speed regions associated with displacement hulls (about 25-40 kt depending on the size). As Figure III-46 shows, the low-speed form, in which hydrostatic forces are dominant, can be configured in several ways. At higher speeds, the displacement hulls begin to resemble large pods with stabilizer foils attached, and eventually at high speed (about 40 kt) the pods tend toward hydrodynamic foils, becoming indistinguishable from those of the hydrofoil concept. This is a case in which hybrid forms of the SWATH and hydrofoil concepts could prove useful for specific mission objectives. However, such hybrid concepts were not explored within the ANVCE Project, which followed the path of investigation indicated by the bold lines in the figure.



(U) Figure III-46. SWATH SHIP CONCEPT TREE

(U) While the SWATH concept can have a single hull, two hulls, or even multiple hulls, it most commonly has a type of catamaran configuration with the two hulls submerged. The number of struts needed to support each hull is derived from such considerations as structural integrity, the hydrodynamics associated with the lift and drag of the strut(s) and submerged hull, and motions in beam and following seas. The state of the art is not advanced enough to determine the optimum configuration(s) for a particular operating condition (in terms of speed, displacement, sea state, seakeeping, and maneuvering requirements).

5.2 Features and Issues

(U) Table III-17 presents the particular features and issues of the SWATH concept. The paths taken in resolving the issues and the findings and conclusions of those efforts discussed in the following subsections. The point designs developed follow the discussion of the analyses and experiments.

5.3 Analyses and Experiments

(U) Because the SWATH concept is relatively new, the data base is insufficient and cannot provide the basis for sound decisions regarding design. Several analyses and experiments were undertaken to explore the various issues raised in reviewing the state of the art of the SWATH concept. Those study efforts are discussed in the following subsections.

5.3.1 Maneuverability

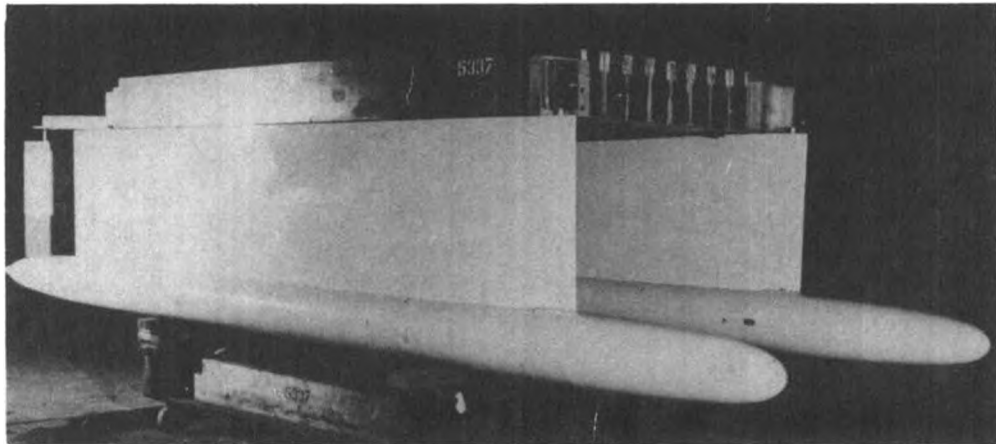
(U) One of the issues was to determine the maneuverability of SWATH ships of various displacements (up to about 20,000-30,000 tonnes) at various speeds (up to 20-30 kt). The ship control requirements could not be delineated until the turning performance and pitch, heave, and roll control of the SWATH concept were determined. One area of concern was whether the side struts would provide such strong directional stability that the state-of-the-art powering systems would be unable to provide the rudder control forces needed for turning. Furthermore, the use of active forward and aft horizontal fins would lead to a need for fixed horizontal stabilizers to control pitch and heave, resulting in increased complexity and cost.

(U) Therefore, the ANVCE Project conducted a study effort to resolve this issue through model tests to define several of the parameters. Figure III-47 shows the plan of the model and its elevation for the maneuverability geometries and location, turning foil, and forward and aft fins. Figure III-48 shows this model (about 3.25 m (10 ft) long) in its spade-rudder configuration. Extensive, rotating-arm experiments were conducted with this model (Reference 45). The basic hydrodynamic data (Reference 45) were integrated into a general maneuvering computer model (Reference 46).

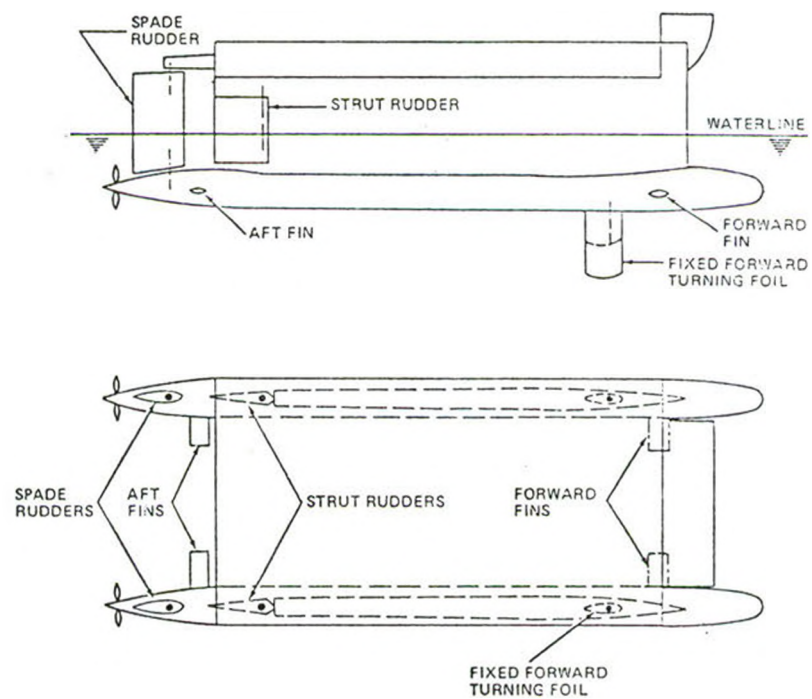
(U) Table III-17. SWATH SHIP EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
● CONVENTIONAL MONO-HULL CALM-WATER SPEEDS MAINTAINED INTO VERY HIGH SEAS ● BOX-LIKE HULL LENDS ITSELF TO IMPROVED UTILIZATION OF AREA AND SPACE FOR PAYLOAD ● STEADY PLATFORM IN HIGH SEA STATES	● ARE RUDDER CONTROL REQUIREMENTS PROHIBITIVE SINCE THE SWATH SHIP IS HIGHLY STABLE DIRECTIONALLY? ● CAN POWERING BE OBTAINED THROUGH BETTER HYDRO DYNAMIC SHAPING? ● CAN THE POOR MOTIONS IN BEAM AND FOLLOWING SEAS BE IMPROVED? ● ARE DRAFT AND BEAM A PROBLEM?	● CONDUCTED MODEL TESTS OF SEVERAL RUDDER CONFIGURATIONS ● CONDUCTED ANALYSIS AND MODEL TESTS ON VARIOUS SHAPES ● CONDUCTED ANALYSIS OF AVAILABLE TEST DATA AND FURTHER MODEL TESTS ON SUCH MOTIONS ● ANALYZED GEOMETRIES OF SWATH SHIPS OF VARIOUS SIZES AND EVALUATED AVAILABLE DOCK FACILITIES	● AGAIN ALLOWS A SMALL SWATH SHIP TO ACT AS ESCORT TO LARGE SHIPS WITHOUT THEIR HAVING TO SLOW DOWN ● ESPECIALLY ADAPTABLE TO AIRCRAFT HANDLING ON SMALL SHIPS AND FOR AIRCRAFT CARRIER CONSIDERATION ● PARTICULARLY TRUE AT LOW SPEEDS AND THUS APPLICABLE TO THOSE MISSIONS REQUIRING SLOW OR STOPPED OPERATION IE G. MINE COUNTERMEASURES ● NO LONGER A CONCERN. RUDDER DESIGNS ARE MORE THAN ADEQUATE ● SIGNIFICANT IMPROVEMENTS IN DRAG AND POWERING REQUIREMENTS CAN BE ATTAINED WITH ONLY MODEST CHANGES IN HULL GEOMETRY ● CONFIGURATIONS ARE AVAILABLE TO ALLEVIATE MANY OF THESE PROBLEMS (BY WING MULTISTRUT, FOR EXAMPLE). R&D SHOULD BE SPECIFICALLY DIRECTED AT THIS ISSUE ● ONLY POSTULATED AT THIS TIME BUT WORTH PURSUING WITH WEAPONS R&D ● BEAM IS LESS THAN MOST SHIPS BEING CONSIDERED. DRAFT IS A PROBLEM AND WILL RESTRICT CLOSE-IN OPERATION

(U) The results of these tests (given in References 45 and 46) were quite encouraging. Based on the tests, the best low-speed maneuvering is attained by using differential thrust on the propellers; with this technique the SWATH ship has a better turning radius at low speed than does a similar displacement monohull. At high speed, the spade rudder was found to be the most effective means of maneuvering.

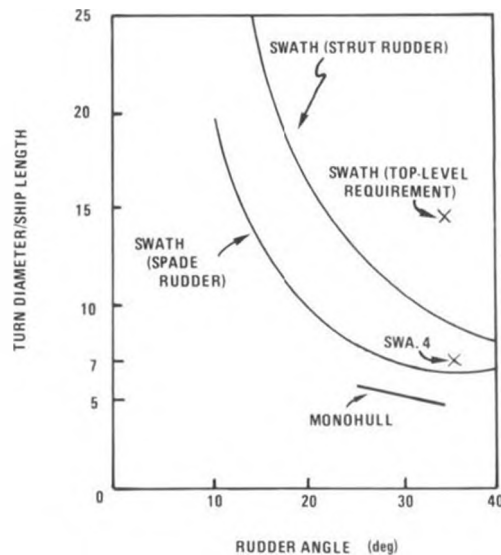


(U) Figure III-47. SWATH MODEL USED FOR MANEUVERABILITY TESTS



(U) Figure III-48. SWATH MODEL

(U) Figure III-49 illustrates a typical set of turning experiment results. As shown, a turning diameter within seven ship lengths without excessive rudder action was reached. While the turning radius of a SWATH ship was found to be better than that of a conventional displacement ship (the monohull) at low speed, the reverse is true at high speed although the turning radius of the SWATH ship is still at acceptable values.



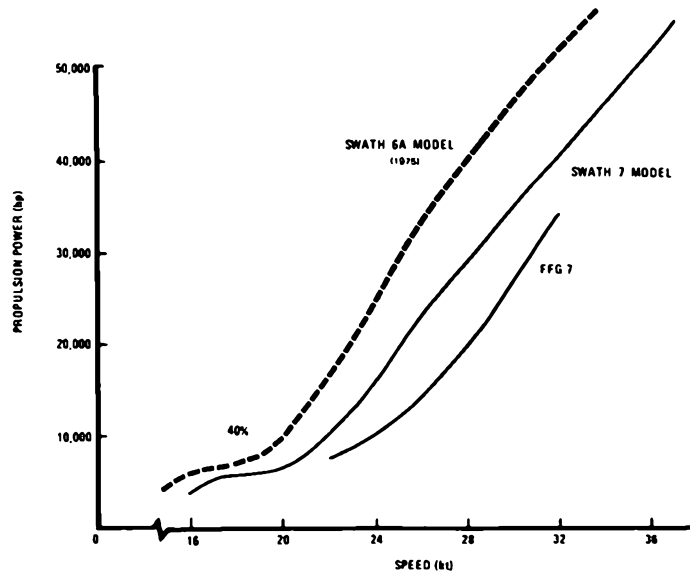
(U) Figure III-49. HIGH-SPEED TURN DATA USING SPADE AND STRUT RUDDER

5.3.2 Powering Requirements

(U) In recognition of the high cost of many of the advanced naval surface vehicles, emphasis was placed on retaining simple shapes for the structure, e.g., the underwater hulls were comprised of cylinders with hemispherical nose caps and conical tail cones. While such simplicity in design reduces manufacturing costs, it also results in shapes that do not have very low resistance.

(U) However, several possibilities are available for improving the hydrodynamic shaping of the struts and the underwater hulls of SWATH ship. Some involve relatively simple shaping and others involve quite complicated variations in cross-section to accommodate the wave drag and skin frictional resistance coefficient idiosyncracies of varying speed capabilities and displacements. Model tests conducted by the ANVCE Project indicate that significant improvements in drag (and powering requirements) can be attained with only modest changes in hull geometry.

(U) Figure III-50 shows the propulsion power requirements of two SWATH configurations and an equivalent monohull, the FFG 7. As shown, a previous SWATH configuration (circa 1975) was much less efficient than an equivalent displacement monohull, while an improved SWATH configuration (SWATH 7) that retains the cylindrical body but has a more hydrodynamically shaped nose comes much closer to the monohull resistance curve (FFG 7). Further refinements are possible and are currently under investigation.



(U) Figure III-50. SWATH SHIP POWERING REQUIREMENTS

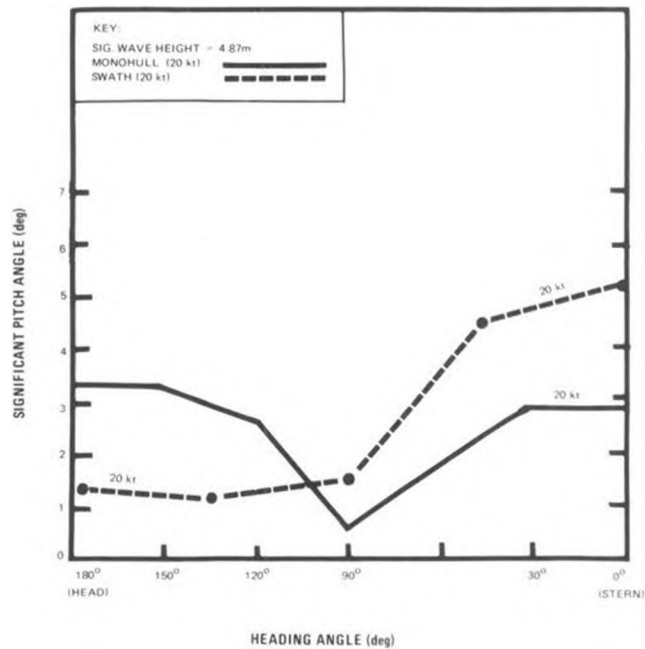
5.3.3 Motions in Beam and Following Seas

(U) The basic SWATH concept provides a significant improvement in seakeeping in head seas over the seakeeping of a conventional displacement hull. In beam seas, however, a large roll motion can be induced when the waves hit the large sideboard of the struts. This motion can be minimized by using two (or more) struts, which is the primary reason that more than one strut is used.

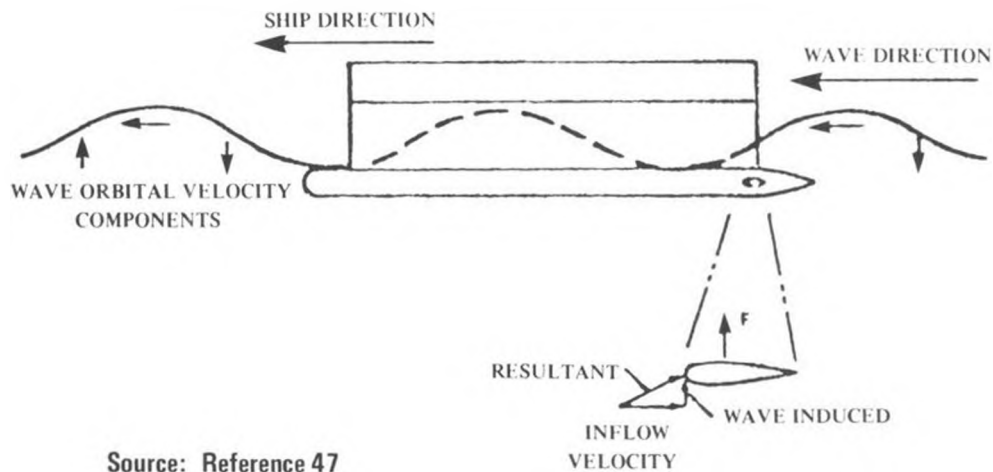
(U) Another issue involving the SWATH ship's seakeeping capability is the motion created in following seas. Figure III-51 shows a comparison of a SWATH ship and a monohull in the same sea conditions and at the same speed. While the SWATH ship has a better seakeeping capability than the monohull in head seas, this situation is reversed in following seas. The reduced seakeeping capability of the SWATH concept in following seas is caused primarily by its fixed stern fins, which

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induce an upward lifting force in such seas. Figure III-52 shows this condition. However, proper design of active fins can minimize or eliminate this particular characteristic.



(U) Figure III-51. EFFECT OF SHIP HEADING ON PITCH MOTIONS

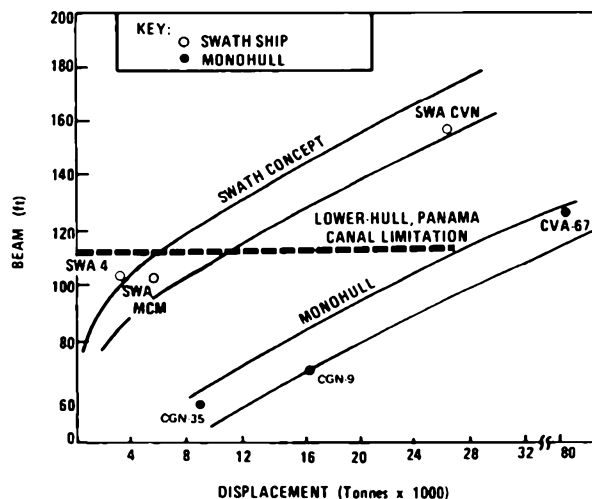


(U) Figure III-52. EFFECT OF FOLLOWING SEAS ON SWATH SHIP

5.3.4 Beam and Draft of SWATH Concept

(U) The SWATH ship usually has a wide beam (compared to a monohull of equivalent displacement) to provide roll stability and to avoid wave effects. The wide beam provides separation between the buoyancy hull, which reduces the wave orbital velocity influence. To avoid wave impact on the main structure, the SWATH ship also has deep draft and a high freeboard. However, while these characteristics provide the required stability and seakeeping, they also create problems of transiting through restricted channels and of handling in dry docks.

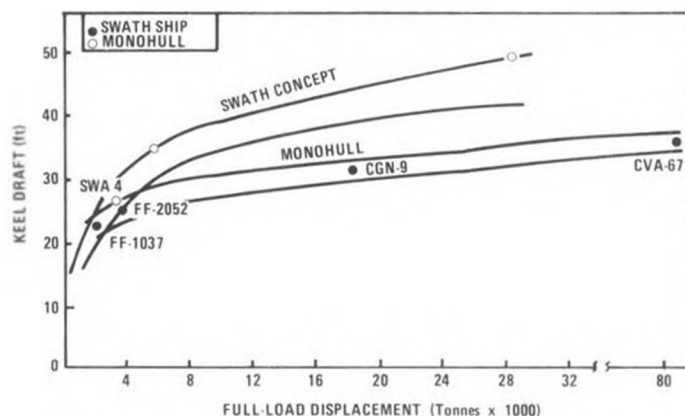
(U) Figure III-53 shows the difference in beam between the SWATH concept (and SES, which has similar dimensional problems) and the monohull (the conventional, displacement ship used by the Navy today). As shown, the SWATH ship has a considerably wider beam than a monohull of the same displacement. The operational problem caused by this difference is seen in the context of the familiar, and important, restriction of the Panama Canal (108 ft). To pass through the present canal, a SWATH ship (or SES) is limited by its beam to about 3500-4000 tonnes, whereas a monohull can be of about 25,000 tonnes.



(U) Figure III-53. SWATH SHIP/MONOHULL BEAM COMPARISON

(U) Figure III-54 shows the difference in draft between the SWATH concept and the monohull. Again, except for very small displacements, the SWATH ship has a much deeper draft than a monohull of the same displacement. In comparison, when off-cushion, an SES has a draft similar to that of a SWATH ship; however, on-cushion, an SES has considerably less draft than even a monohull.

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(U) Figure III-54. COMPARISON OF SWATH SHIP/MONOHULL DRAFTS

(U) The large draft of the SWATH concept, as is its large beam, presents both operational and maintenance problems. For instance, to operate in a shoal area or restricted waterway having a depth of 35 ft, the SWATH ship (and off-cushion SES) would have to be less than 6000-8000 tonnes, whereas a monohull of 80,000 tonnes could operate in such an area.

(U) In investigating the impact of the large beam and draft of the SWATH ship (or SES) on maintenance handling, the anvce Project examined the availability of suitable dry docks. Table III-18 lists the location and number of dry docks available to U.S. SWATH ships of various sizes. As the table indicates, there is a

(U) Table III-18. DRY DOCKS AVAILABLE TO U.S. SWATH SHIPS

LOCATION	NUMBER OF DRY DOCKS/SWATH SHIP SIZE (TONNES)						
	4,000	8,000	12,000	16,000	20,000	24,000	28,000
UNITED STATES							
ATLANTIC COAST	6	5	3	1	1	0	0
GULF COAST	2	2	2	0	0	0	0
PACIFIC COAST	5	3	3	2	1	0	0
FAR EAST	3	2	2	2	2	2	1
EUROPE, ATLANTIC	3	3	1	1	1	1	1
MEDITERRANEAN	2	2	2	2	1	1	0

sufficient number of compatible dry docks available for SWATH ships of 4000-12,000 tonnes displacement at present. Therefore, although maintenance handling presents some problems, it is not a major obstacle.

(U) While the large beam and draft of the SWATH concept are of concern, they are, in general, not significant drawbacks with one exception—the SWATH ship's inability to transit the Panama Canal. Given that the number of U.S. naval ships is declining, the ability to move ships rapidly from one ocean to another is a major operational consideration. Thus, the inability of a large SWATH ship to transit the Panama Canal and the inherent higher cost of such a high-performance craft in comparison with a conventional, displacement ship are disadvantages of this concept.

5.4 Point Designs

(U) To resolve the feasibility issues involved in the concept and to provide quantitative vehicle information for the cost and mission analyses, the following point designs were prepared:

- Mine-Countermeasures (MCM) Ship (near term)
SWA MCM, 5868 tonnes displacement
- Air-capable, SWATH Ship (far term)
SWA 4, 3408 tonnes displacement
- Aircraft Carrier (far term)
SWA CVN, 28,549 tonnes displacement.

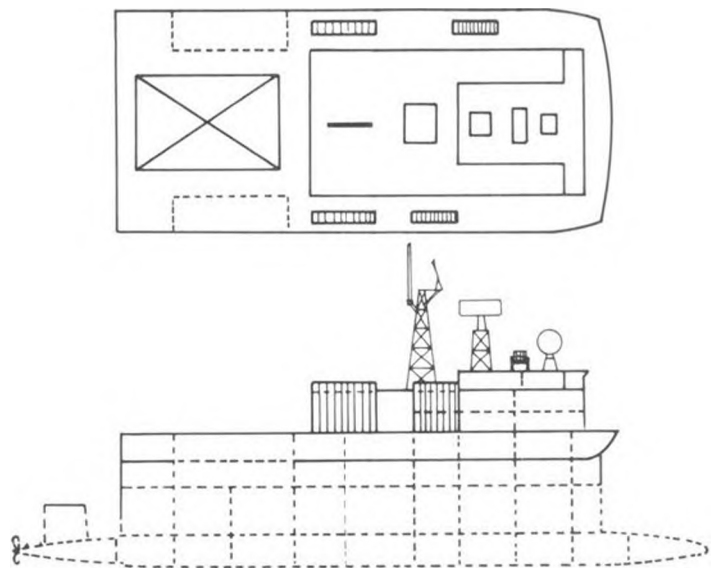
Detailed descriptions of the initial designs are given in References 48 (SWA MCM), 49 (SWA 4), and 50 (SWA CVN). As was the case in the other ANV evaluations, reiterative design changes were made during the technical evaluation of the SWATH concept. A detailed description of each of the final point designs used in the cost and mission analyses is presented in Appendix B.

(U) The two, far-term SWATH concept point designs, the SWA 4 and the SWA CVN, were developed by the ANVCE Project and, therefore, completely meet the standards established for common combat suites, etc. The near-term SWATH concept, the SWA MCM, was adapted for use by the ANVCE Project and is not as consistent in meeting these standards. Only the two far-term point designs developed by the ANVCE Project to determine their feasibility are discussed in the following subsections.

5.4.1 Air-capable, SWATH Ship

(U) The SWA 4 plan and elevation are shown in Figure III-55; the leading

particulars are given in Table III-19. Details of the SWA 4 characteristics are given in Appendix B.



(U) Figure III-55. SWA 4 POINT DESIGN

(U) Table III-19. SWA 4 LEADING PARTICULARS

GROSS WEIGHT (TONNES)	3,408
PAYLOAD (TONNES)	364
RANGE IN SEA STATE 3 (NMI)	
AT MAXIMUM SUSTAINED SPEED (37 KT)	1,330
AT CRUISE SPEED (19 KT)	3,950
MAXIMUM SPEED IN SEA STATE 3 (KT)	37

(U) The SWA 4 is an air-capable design with the combat suite common to the far-term, air-capable, surface combatant group. This group is comprised of the SWA 4, ACV 3, SES 3, and HYD 2. The advanced-technology monohull, MONO 3, is

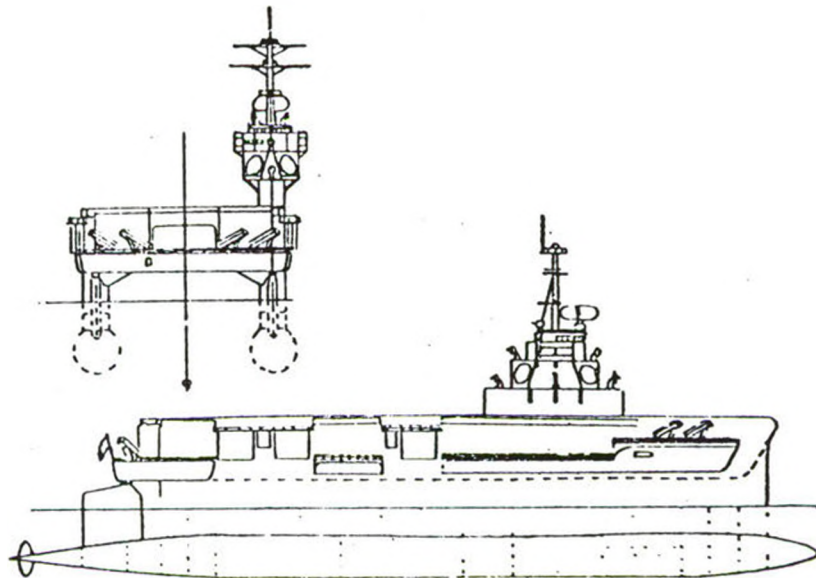
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also included for comparison. As is the HYD 2 and the MONO 3, the SWA 4 is designed for a mission duration of 30 days because of its inherent long-range capability. Its multipurpose combat suite is designed for AAW, ASW, and ASUW and includes two LAMPS Mk-XX helicopters. (Appendix A presents the combat suite details.) Because the box-like hull of the SWA 4 is well-suited to stowage of aircraft and helicopters, an iteration of the combat suite using four helicopters was also studied.

(U) A particular feature of the SWA 4 point design is the use of superconducting electrical propulsion machinery. This machinery was used in the design to explore the feasibility of utilizing such technology in the SWATH concept to avoid the complications of high-powered, right-angled transmission systems.

5.4.2 Aircraft Carrier

(U) The SWATH aircraft carrier design, the SWA CVN, is shown (end and elevation views) in Figure III-56. For the SWATH concept, a PWR, nuclear power plant was used instead of LWNP used for the SES concept. As with the SES CVN, the nuclear power provides this SWATH concept with an endurance limited only by



(U) Figure III-56. SWA CVN POINT DESIGN

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a need for crew provisions. The initial SWA CVN point design is described in Reference 50; a detailed description of the final version is given in Appendix B. The leading particulars are given in Table III-20.

(U) Table III-20. SWA CVN LEADING PARTICULARS

GROSS WEIGHT (TONNES)	28,549
PAYLOAD (TONNES)	5,524
RANGE (NMI)	UNLIMITED
MAXIMUM SUSTAINED SPEED IN SEA STATE 3 (KT)	29

(U) The point designs of the aircraft carrier group are the SES CV, SES CVN, and the SWA CVN. The evaluation of nuclear power to these concepts covered a wide range in weights, from gas-cooled LWNP on the SES to the heavier, PWR nuclear power plant on the SWATH concept. The use of these different plants has resulted in a range of displacements from about 10,000 tonnes to about 29,000 tonnes. The disparity in displacement among the concepts made common payloads (combat suites), including aircraft, inappropriate. Thus, each of the SES carriers has 17 aircraft, the SWA CVN can carry 29 aircraft, and the VSS (taken from other programs and not designed to the common technology and design standards within ANVCE Project) has 26 aircraft. These differences should be taken into account in the evaluations and in the cost and mission analyses.

5.5 Findings and Conclusions

(U) The SWATH concept represents an extension of the well-established catamaran hull form into a form which, because of its SWA feature, has excellent seakeeping characteristics and minimum speed loss in rough seas. Because of its relationship to the conventional monohull and catamaran displacement ships, it has a low technical risk.

(U) Despite the fact that the SWATH concept is not new and is not a large departure from conventional, displacement hull technology, the development efforts for this concept have been limited, leaving several technology and design gaps. These gaps must be filled before a SWATH ship of any oceangoing displacement class can be built.

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(U) Specifically, the findings and conclusions on the SWATH concept are as follows:

- The development of the SWATH concept to date is represented by the 190-tonne-displacement KAIMALINO, which has a maximum speed of about 19 kt. However, a considerable number of model tests and analyses have shown that a SWATH ship of more than 30,000 tonnes displacement with a speed of 30-40 kt is technically feasible.
- The principal advantage of the SWATH concept is its improved seakeeping over that of a small-displacement monohull. However, because the seakeeping and motions of the monohull get better with increased displacement, the advantage of the SWATH concept soon diminishes. Furthermore, to obtain what advantage it does offer, the SWATH concept will require development, which increases its cost slightly over that of a conventional ship. Because of these two facts, to provide a better naval capability the SWATH concept should be of a smaller displacement than a monohull of the same capability for the same mission. The ANVCE Project did not conduct the investigations needed to determine where these size boundaries should be drawn. Indications are that the SWATH concept has a considerable seakeeping advantage in sizes up to about 15,000 tonnes displacement.
- The physical dimensions of the SWATH ship, specifically beam and draft, cause some problems in terms of maintenance handling and operating areas, particularly in passing through the Panama Canal. SWATH ships with displacements of 4000-8000 tonnes or more would be unable to pass through the Panama Canal. This restriction is the greatest drawback to application of the SWATH concept.

6. MONOHULL

(U) The emphasis on the advanced naval surface vehicle concepts has been on the far term (IOC 1995), using projected technologies. These projected technologies include improvements such as materials of higher strength-to-weight ratios, power plants with lower specific weights, gear trains with higher power absorption capabilities, and power plants with lower specific fuel consumption (SFC). The ANVCE charter also implied that when evaluating the cost/effectiveness of such ANVs, the performance is to be compared with that available in conventional ships. Since by 1995 the displacement ship design will also take advantage of many of the technological improvements available to the ACV, hydrofoil, SES, and SWATH ship, comparisons between the advanced-technology monohull (conventional, displacement ship) and the ANVs are needed.

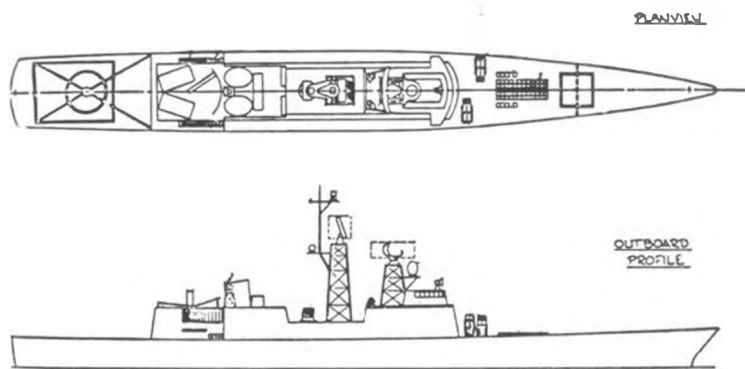
(U) Accordingly, a point design for an advanced-technology monohull, the MONO 3, was developed to be a baseline for the far-term, 3000-tonne surface combatant group. No major effort was expended in documenting the state of the art in

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monohull displacement ships although a risk assessment associated with the application of advanced technology to such ships was included in the work to serve as a data base. This risk assessment and the development of the MONO 3 are described in Reference 51.

6.1 Baseline Point Design

(U) The baseline design selected to represent the displacement hull technology in circa 2000 is the 3000-tonne-class, advanced-technology monohull (MONO 3). Figure III-57 shows its general arrangement. The final MONO 3 point design characteristics are given in Appendix B. The leading particulars are given in Table III-21.



(U) Figure III-57. MONO 3 POINT DESIGN

(U) Table III-21. MONO 3 LEADING PARTICULARS

GROSS WEIGHT (TONNES)	2,934
PAYLOAD (TONNES)	392
RANGE IN SEA STATE 3 (NMI)	
AT CRUISE SPEED (15 KT)	6,641
AT MAXIMUM SUSTAINED SPEED (40 KT)	1,647
MAXIMUM SUSTAINED SPEED AT SEA STATE 3 (KT)	40

(U) The MONO 3 is an air-capable design with the combat suite common to the far-term, air-capable, surface combatant group. This group is comprised of the ACV 3, SES 3, SWA 4, and HYD 2. The MONO 3 serves as a baseline for this group. Because of its long-range capability, the MONO 3, like the HYD 2 and SWA 4, is designed for a 30-day mission duration. Its multipurpose combat suite is equipped for AAW, ASW, and ASUW. This common combat suite includes two LAMPS Mk-XX helicopters (as described in Appendix A).

6.2 Findings and Conclusions

(U) While the concept of an advanced-technology, monohull displacement ship is certainly feasible, the risk associated with such a ship involves the new features integrated into the design and places it in the "high-performance" class of the ANV concepts being evaluated. These features include

- an all high-grade aluminum hull,
- a 40-kt speed capability,
- a superconducting electrical transmission system, and
- a transcavitating propeller with Prairie Masker.

These features involve development risks that vary from medium to high. For the 2934-tonne MONO 3 to have a speed capability of 40 kt, a 50,000-hp electrical motor must be developed. A considerable development effort would have to be expended to achieve this goal by 1995. (The largest motor to date is an experimental, 4000-hp unit developed by Great Britain.)

(U) The performance of such an advanced-technology monohull in relation to the technical assessments of the other concepts is discussed in Chapter V.

CHAPTER IV AIR VEHICLE CONCEPTS EVALUATION

(U) This chapter presents the air ANVs [the air loiter aircraft, lighter-than-air (LTA) vehicle, sea loiter aircraft, and wing-in-ground-effect (WIG) vehicle]. It provides a summary of the program followed in evaluating these concepts in terms of development (concept tree); their features and issues; parametric analyses, experiments, and point designs used by the ANVCE Project to resolve any issues; and the findings and conclusions. Because the concept trees for the air and sea loiter concepts are very simple and direct, that step has been omitted in those examinations. Parametric analyses were conducted on the air vehicle concepts because so much less was known about them than the surface vehicle concepts and a more exploratory approach was needed. Furthermore, not all of the forms of any concept could be examined in the cost and mission analyses (Volumes 3 and 4, respectively). Any such concepts that appear to be worthy of further investigation on the basis of the technical evaluation are so indicated.

(U) Some matters are best described across concepts. Specified detailed comparative analyses between concepts (such as time-on-station and productivity comparisons) were conducted among concepts. These comparisons are presented in Chapter V.

1. AIR LOITER

(U) The air loiter aircraft is not a totally new concept in the sense of many of the other ANVs evaluated; it is more the application of new technology to conventional aircraft. The advanced aspect of this concept is its longer endurance (days rather than hours) and increased payload. These requirements are based on the postulated scenarios and increased, multiple threat presented by Project 2000.

1.1 Features and Issues

(U) Table IV-1 presents the particular features and issues of the air loiter aircraft concept. The paths taken in resolving the issues (parametric analysis and point design development) as well as the findings and conclusions of these efforts are discussed in the following subsections.

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(U) Table IV-1. AIR LOITER AIRCRAFT EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
● MOST LIKE CONVENTIONAL AIRCRAFT AND THUS CLOSE TO THE STATE OF THE ART ● LONG ENDURANCE AT ALTITUDE	● WHAT IS THE BEST CONFIGURATION FOR LONG ENDURANCE? ● CAN LWNP BE APPLIED TO AIRCRAFT WITHOUT THE DESIGNS BECOMING IMPRACTICAL?	● PARAMETRICALLY STUDIED VARIOUS CONFIGURATIONS AND CHOICE OF PROPULSION SYSTEM ● PARAMETRICALLY STUDIED NUCLEAR-POWERED AIRCRAFT AND DEVELOPED POINT DESIGN	● CONVENTIONAL TURBO-PROP AIRCRAFT WITH SUPERCRITICAL WING GEOMETRY APPEARS PRACTICAL AND CAPABLE OF MEETING REQUIREMENT ● IF LWNP TECHNOLOGY IS PROVEN PRACTICAL, THERE APPEARS TO BE NO PROBLEM IN APPLYING IT TO THE AIRPLANE

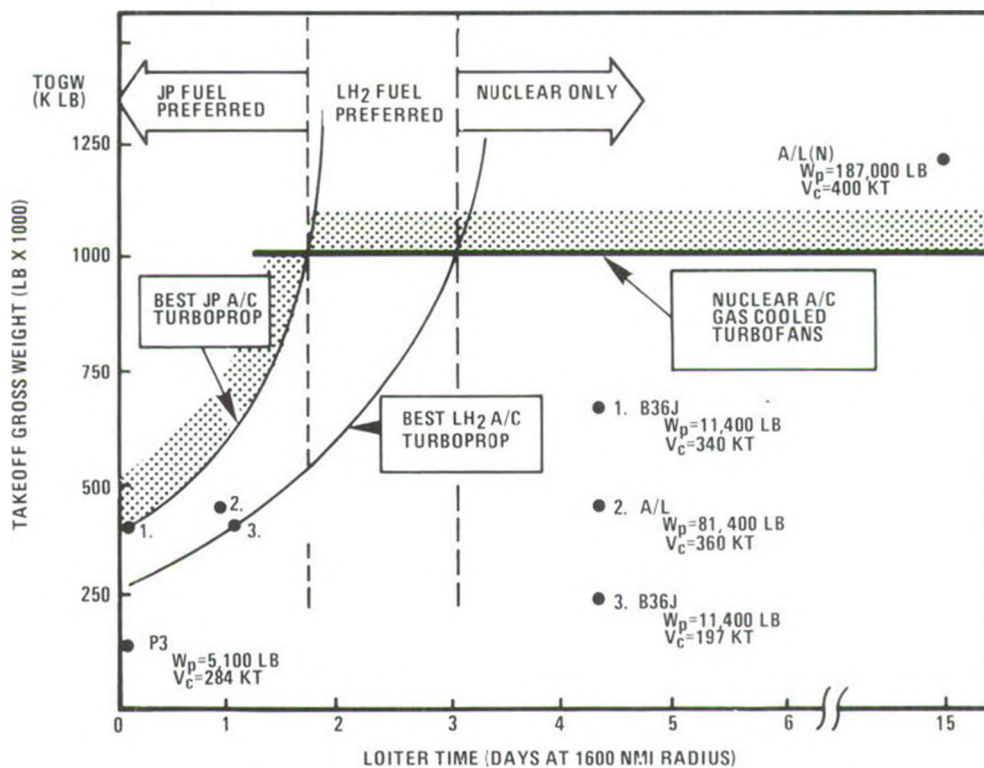
1.2 Parametric Analysis

(U) In determining the characteristics of an air loiter (long-endurance) aircraft, several basic assumptions were made. An IOC date of approximately 1990-95 required a technology freeze date of 1985. Therefore, the following aerodynamic and structural features were considered:

- high-aspect-ratio wing with a supercritical airfoil section for improved cruise and loiter lift-to-drag ratio;
- use of laminar flow control to reduce drag and improve the cruise and loiter lift-to-drag ratio;
- use of advanced composite materials in wing, fuselage, and empennage structure encompassing both primary and secondary structural elements;
- an active flight control system with full-time stability and control augmentation for relaxed static stability and load alleviation;
- use of advanced propulsion systems, both turbofan and turboprop, to provide improvements in specific fuel consumption and thrust-to-weight ratios;
- use of liquid hydrogen fuel with its high heating value to increase range beyond that attainable with conventional hydrocarbon fuel; and
- use of LWNP, providing a practically unlimited endurance capability.

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All of these features and technological advances were included in the parametric analysis in various combinations along with a variety of possible payloads. The payloads examined were based on an analysis of the mission requirements and covered AAW, ASW, and ASUW as well as surveillance. The range of these payloads varied from 20,000 to 100,000 lb for the conventional air loiter and up to 380,000 lb for a nuclear-powered aircraft with a 30-day endurance. The specific details of the many parametric designs and results are given in Reference 52 for the fossil-fueled aircraft and liquid-hydrogen-fueled aircraft and in Reference 53 for the nuclear-powered aircraft. The principal results of the parametric analyses on the air loiter aircraft are summarized in Figure IV-1. The curves shown for the "best" turboprop fueled with JP-5, the "best" turboprop fueled with liquid hydrogen (LH_2), and the nuclear-powered turboprop aircraft are envelopes of the various parametric designs pursued drawn at the lowest weight, i.e., smallest aircraft that could accomplish the stated endurance or loiter time.



(U) Figure IV-1. PARAMETRIC ANALYSIS RESULTS ON
AIR LOITER AIRCRAFT

(U) The size of the conventional, fossil-fueled, turboprop aircraft increases rapidly as its endurance progresses beyond one day. This is the result of the compounding effects of the increased volume needed to carry the fuel, the power required to propel such a large aircraft, and the drag on that craft.

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(U) As might be expected, the use of liquid-hydrogen fuel improves the endurance, but because of the low density of such fuel, fuselages of much larger volumes are required. The resultant increase in drag and power requirements offsets to some extent the advantage gained. In short, an extra day of endurance can be achieved for any given aircraft by using liquid-hydrogen fuel.

(U) Other than crew limits, there is no discernible limit to the endurance of the nuclear-powered aircraft. Its size is determined by the payload to be carried.

(U) Based on these parametric analyses, two point designs were developed: a conventional fossil-fueled (JP-5), air loiter aircraft with a 1-day endurance capability and a nuclear-powered aircraft with a 15-day capability. These designs represented the ends of the spectrum. The liquid-hydrogen-fueled aircraft, while of possible interest, currently does not offer a sufficient improvement over the fossil-fueled aircraft to warrant further investigation.

1.3 Point Designs

(U) To determine the feasibility of various forms of the air loiter concept and to provide quantitative information for the cost and mission analyses, the following far-term point designs were prepared:

- Air Loiter Aircraft (Fossil-Fueled)
A/L, 204 tonnes takeoff gross weight (TOGW)
- Air Loiter Aircraft (Nuclear-Powered)
A/L(N), 560 tonnes TOGW

1.3.1 Air Loiter Aircraft (Fossil-Fueled)

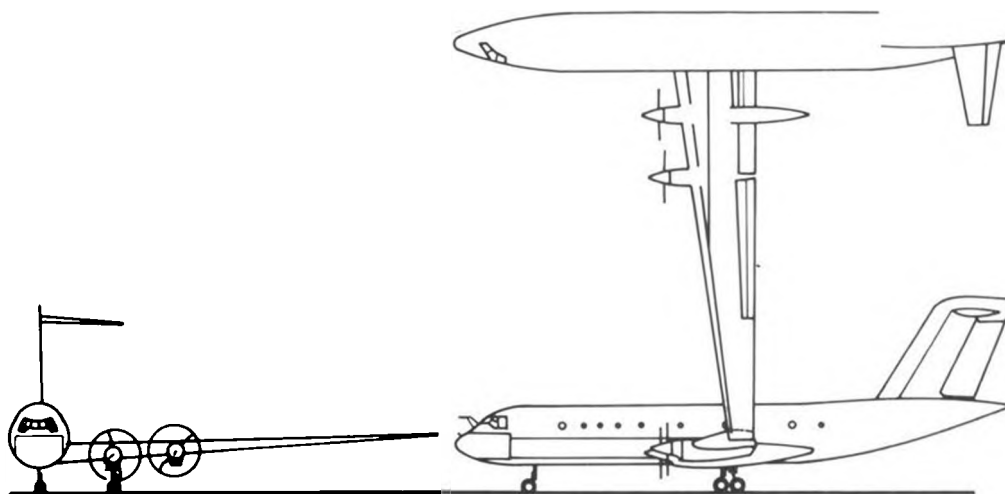
(U) Figures IV-2 (artist's rendering) and IV-3 show the fossil-fueled, air loiter aircraft, the A/L. These figures show its general features. A detailed description of



(U) Figure IV-2. ARTIST'S RENDERING OF A/L

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the A/L is given in Reference 54; however, some modifications (e.g., size of combat suite) were made in the design as a result of the the technical evaluation. A description of the revised, final design is presented in Appendix B. The leading particulars are given in Table IV-2.



(U) Figure IV-3. A/L POINT DESIGN

(U) Table IV-2. A/L LEADING PARTICULARS

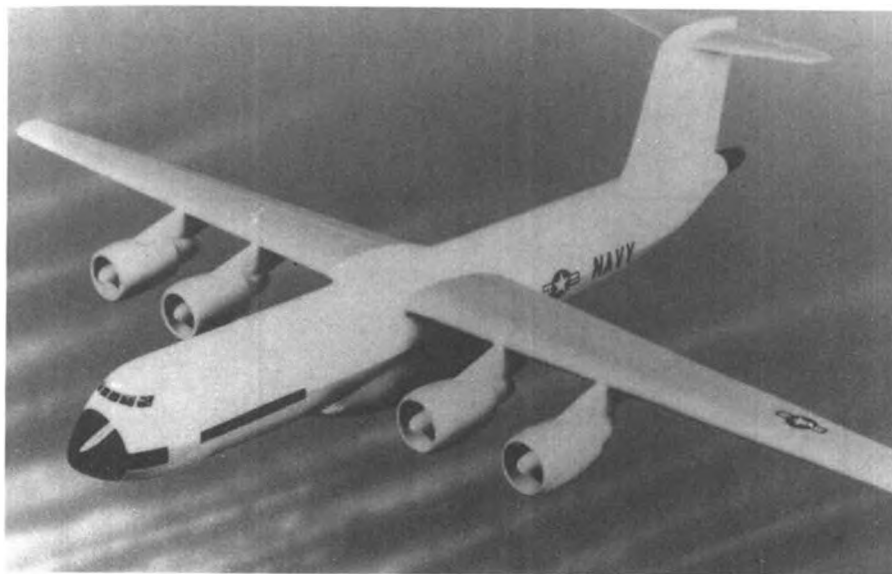
GROSS WEIGHT (TONNES)	204
PAYLOAD (TONNES)	38
CRUISE SPEED (KT)	360
MAXIMUM ALTITUDE (FT)	34,000
TIME ON STATION (DAYS)	1
RADIUS OF ACTION (NMI)	1,600

(U) The combat suite for the A/L includes a remotely piloted vehicle (RPV). This combat suite is common to the multimission air combatant group, which includes the A/L, S/L(L), A/L(N), WIG(O), and FAB. The mission durations of these vehicles vary because of the variations within the concept; the A/L is designed for a mission duration of one day.

(U) The A/L features a high-aspect-ratio (14) wing and a thick (20 percent), supercritical airfoil optimized for loiter operation. The thick wing also provides for reduced weight and increased volume. The use of an advanced turboshaft engine and a high-disc-loading turboprop fan provides for significant cruise and loiter specific fuel consumption (SFC) gains as well as a reduction in propulsion system weight. Advanced, composite materials (principally graphite-epoxy) in a portion of the primary structure (approximately 68 percent in the fuselage and 34 percent in the wing) also provide significant weight reductions.

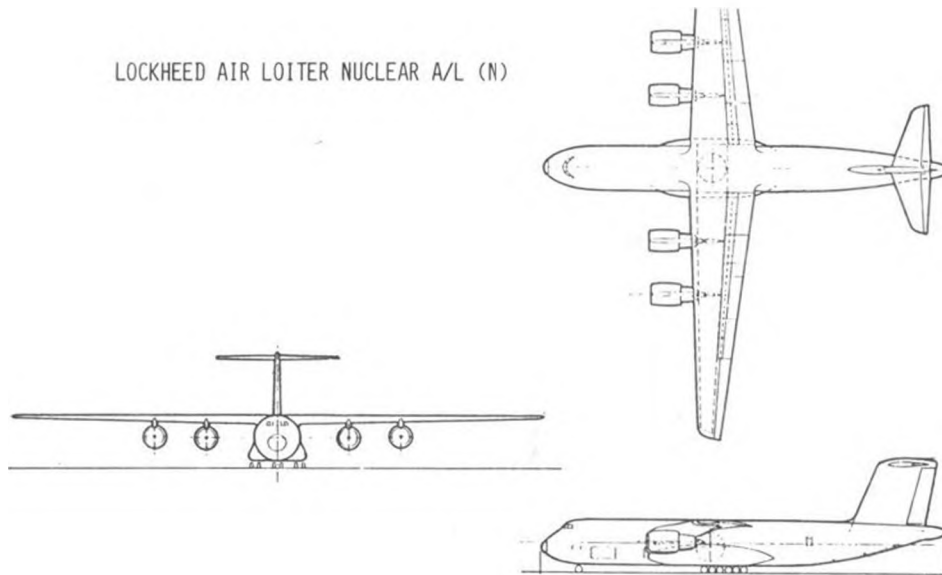
1.3.2 Air Loiter Aircraft (Nuclear-Powered)

(U) Figure IV-4 (artist's rendering) and IV-5 show the nuclear-powered, air loiter concept, the A/L(N), which is more than twice the size of the conventionally powered A/L.



(U) Figure IV-4. ARTIST'S RENDERING OF A/L(N)

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(U) Figure IV-5. A/L(N) POINT DESIGN

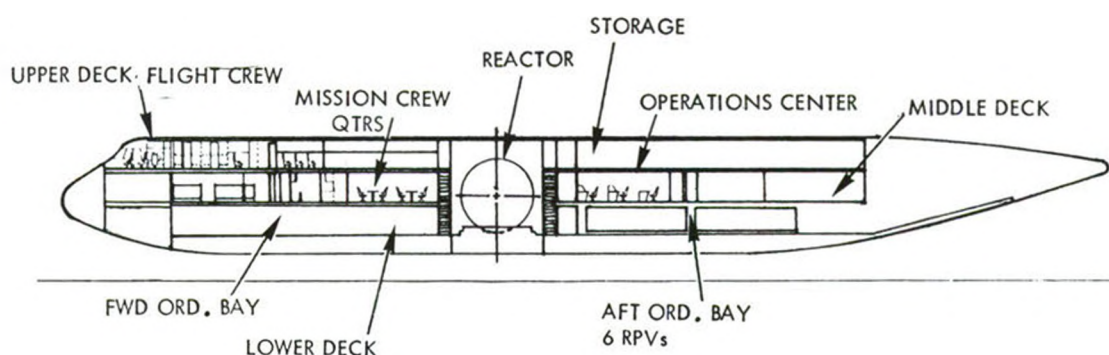
(U) The A/L(N) is a member of the same multimission, air combatant group as the A/L. However, the A/L(N) is designed for a mission duration of 15 days and, therefore, has a combat suite that is more compatible with its longer mission duration. These variations plus a subsequent reiteration to a 4-day version are described in Appendices A (combat suites) and B (point designs). The variations on the original point design given in Reference 55 are important to note when examining the military use of the aircraft. The leading particulars of the A/L(N) are given in Table IV-3.

(U) Table IV-3. A/L(N) LEADING PARTICULARS

GROSS WEIGHT (TONNES)	560
PAYLOAD (TONNES)	88
CRUISE SPEED (KT)	407
MAXIMUM ALTITUDE (FT)	35,000
TIME ON STATION (DAYS)	15
RADIUS OF ACTION (NMI)	1,600

(U) Although the ANVCE Project did not undertake an in-depth analysis of the technical feasibility of LWNP, it did explore the cost and military use of a nuclear-powered, air loiter aircraft on the assumption that lightweight nuclear

propulsion (LWNP) is a technically feasible concept. Many of the advanced-technology features embodied in the A/L are incorporated into the A/L(N); however, because the A/L(N) had no design requirements for fuel economy, the speed could be increased from 360 to 407 kt. This higher speed allowed consideration of turbofan propulsion. The configuration includes a high-wing, T-tail, and a three-deck fuselage arrangement to accommodate the equipment and payload requirements for a long-endurance mission. Figure IV-6 shows the general arrangement of the fuselage. The reactor can be seen in respect to the other systems and decks.



(U) Figure IV-6. GENERAL ARRANGEMENT OF A/L(N) FUSELAGE

(U) Although LWNP was not studied in detail, the analysis went into sufficient detail to ensure that the system was compatible with the nuclear engineering projections for the time period and was based on the technology that has been developing since about 1960. The reactor is a gas (helium)-cooled, graphite-moderated, epithermal type with a liquid-metal (NaK), secondary-loop nuclear power plant sized to provide the thrust required. For safety reasons, JP-5 fuel is used for takeoffs and landings. Four, dual-mode, high (13) BPR (bypass ratio) turbofans are mounted beneath the wings. Much of the element fabrication is based on nuclear-rocket (NERVA) technology.

1.4 Findings and Conclusions

(U) Based on technology projections for each of the subsystems mentioned (supercritical wing aerodynamics, advanced composite material structures, etc.), the "concept" of an air loiter (long-endurance) aircraft is well within the bounds of 1985 technology. The projection of nuclear power plant technology also appears to be well-founded in consideration of current nuclear-power technology.

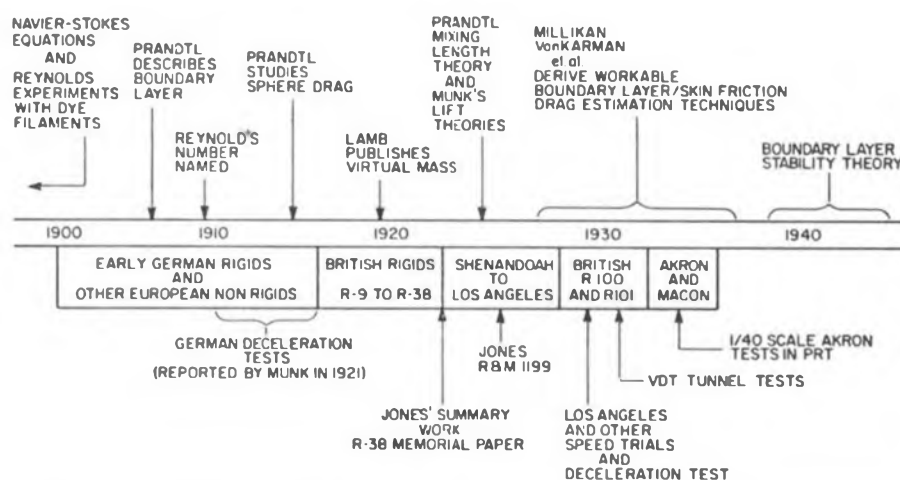
(U) Thus, based on this technical evaluation, no major extensions of the state of the art are involved, and following an ordered engineering development program, a practical air loiter aircraft with a time on station of a day or, if LWNP is used, 4-15 days is feasible.

2. LTA VEHICLE

(U) The LTA vehicle reached operational status in Germany in the 1920s and was part of the U.S. Navy's fleet from 1930 through 1961, when the last airship was decommissioned. Between 1940 and 1960, the LTA vehicle was employed in the U.S. Navy in ASW patrol squadrons of nonrigid "blimps," reaching a peak of about 40 blimps in 1955. Since 1961, only the Goodyear blimps, which are small craft used for advertising and promotional purposes, remain.

(U) The reasons for discontinuing the use of airships by the U.S. Navy are both nontechnical and technical. The nontechnical reasons involve political and emotional issues (e.g., safety and vulnerability). The accident to the German LTA HINDENBURG in 1937 was labeled as "one of the greatest disasters of all times." That label has stuck to the airship to this day despite the fact that the airship had more flying hours between accidents than heavier-than-air craft of the same era. During World War II, the U.S. Navy flew 55,900 operational flights with nonrigid airships for a total of 550,000 flying hours with only one airship lost to enemy action and only one crewman lost. While the HINDENBURG accident is classed as a "disaster" since 35 people lost their lives, almost twice as many people (61) survived. This is a point worth noting in that while a large airship may be more likely to sustain a hit, its buoyant nature and relatively low speed, allow a slow descent, which permits the people aboard to prepare for escape. On the other hand, heavier-than-air craft (even modern jetliners) do not have very high passenger survival rates in such situations.

(U) Similarly, the era of the airship occurred during the very early days of what has become known as classical aerodynamics. All the various basic working tools of pressure distributions, boundary-layer phenomena, aerodynamic loads, etc., that the airplane designer uses to ensure a safe airplane were either unknown or in their formative stages when airships were being designed and built. Figure IV-7 shows the chronological development of these basic aerodynamic tools and the development of various ships.

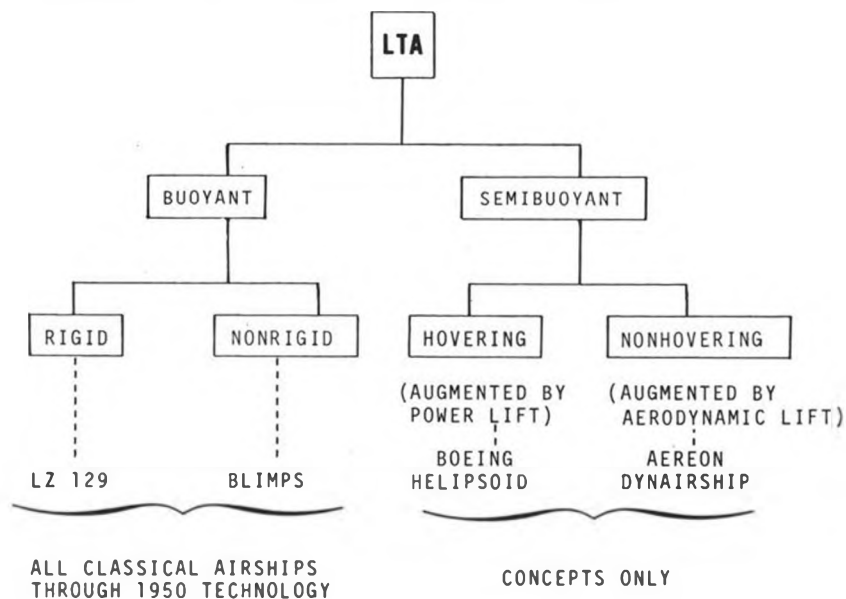


(U) Figure IV-7. TIME LINE FOR DEVELOPMENT OF AIRSHIPS
AND AERODYNAMIC THEORIES

(U) These facts and the employment potential of a low-cost platform with a speed capability of 50-100 kt in military missions prompted the ANVCE Project to consider the possibilities of an advanced airship.

2.1 Concept Tree

(U) The LTA concept can assume different forms, depending on whether it is treated as a fully air-buoyant vehicle (such as the classical airship) or whether it embodies some shaping that takes advantage of aerodynamic lift. Figure IV-8, which shows the concept tree for the LTA vehicle, illustrates these possibilities. Since even a fully air-buoyant (FAB) airship can gain about 15 percent of its lift aerodynamically merely by operating at a small angle of attack to the oncoming airflow, an arbitrary distinction is made that those LTA vehicles that have a ratio of dynamic lift to total lift of less than 15 percent are placed in the FAB category, while those that have a dynamic lift to total lift ratio greater than 15 percent are grouped in the semiair-buoyant (SAB) configuration category.



FORMS FOR ANVCE PROGRAM ON LTA

(U) Figure IV-8. LTA VEHICLE CONCEPT TREE

(U) In the FAB configuration category, the structure can be classed as either rigid (e.g., the HINDENBURG, AKRON, MACON) or nonrigid (e.g., blimps). In the SAB configuration category, the lift can be augmented by power, e.g., the Boeing HELIPSOID and Piasecki's HELISTAT, or by aerodynamic shaping.

2.2 Features and Issues

(U) Based on an assessment of the state of the art of LTA technology (Reference 11), the particular features and issues of the LTA concept are given in Table IV-4. The paths taken in resolving the issues (parametric analysis and point design development) as well as the findings and conclusions of these efforts are discussed in the following subsections.

(U) Table IV-4. LTA VEHICLE EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
• LOW ENERGY CONSUMING VEHICLE FOR GIVEN PAYLOAD AND ENDURANCE • LOW INVESTMENT AND OPERATING CAPABILITY • LONG ENDURANCE CAPABILITY • MORE EFFICIENT IN THE 80 TO 100 KT SPEED RANGE THAN SURFACE VEHICLE AND RIDE NOT DEPENDENT OF SEA STATE	• DOES THE LARGE SIZE IMPOSE GROUND HANDLING AND STORAGE PROBLEMS? • CAN IMPROVEMENTS IN TECHNOLOGY IN AERODYNAMICS AND MATERIALS IMPROVE THE FAB? • CAN THE ADDITION OF AERODYNAMIC LIFT ENHANCE THE LTA CONCEPT?	• PARAMETRICALLY STUDIED POWERED (VECTORED) CONTROL PROP AND DEVELOPED A DESIGN OF LARGE FAB VEHICLE • PARAMETRICALLY STUDIED, APPLYING LATEST TECHNOLOGY, AND DEVELOPED POINT DESIGN • PARAMETRICALLY STUDIED AND DEVELOPED POINT DESIGN OF A SAB LTA VEHICLE	• APPEARS TO BE A VEHICLE OPTION FOR ASW SEARCH AND POSSIBLE PROSECUTION • GENERALLY CONCLUDE THAT PROBLEM STILL EXISTS DESPITE IMPROVED VECTOR CONTROL BUT IT APPEARS THAT FAB DESIGN APPROACH IS GOOD • WHILE SOME IMPROVEMENTS ARE SEEN IN WEIGHT CONTROL, NO OTHER FUNDAMENTAL IMPROVEMENTS ARE FORESEEN • PROVIDED THE VEHICLE DOES NOT BECOME LARGE (GREATER THAN ABOUT 1.2 X 10⁶ CU FT) THERE IS ADVANTAGE IN THAT A LOW COST, MEDIUM SPEED (150 KT) VEHICLE CAN BE USED IN ASW PROSECUTION AND OTHER ROLES

2.3 Parametric Analyses

(U) Parametric analyses were performed for the two basic configurational forms discussed, the FAB and SAB LTA concepts, and contributed to the selection of point designs with specific payloads (combat suites).

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The parametric analyses included effects of payload, maximum speed, endurance, operating altitude, range, and buoyancy ratio. Given an 1995 IOC, the following technological improvements were considered in the parametric analyses:

- knowledge of aerodynamic shaping to give the desired pressure distribution for both FAB and SAB configurations;
- use of improved, lightweight, impenetrable outer skin envelopes to improve lifting capability;
- use of light and more-efficient power plants;
- use of rotatable pylons to improve thrust control and low-speed maneuvering; and
- knowledge of stability and control characteristics of bodies of revolution and aerodynamic fin combinations.

(U) Detailed results of the parametric analyses of the FAB and SAB configurations are given in References 56 and 57, respectively. Summary results from these analyses and commentary are provided here.

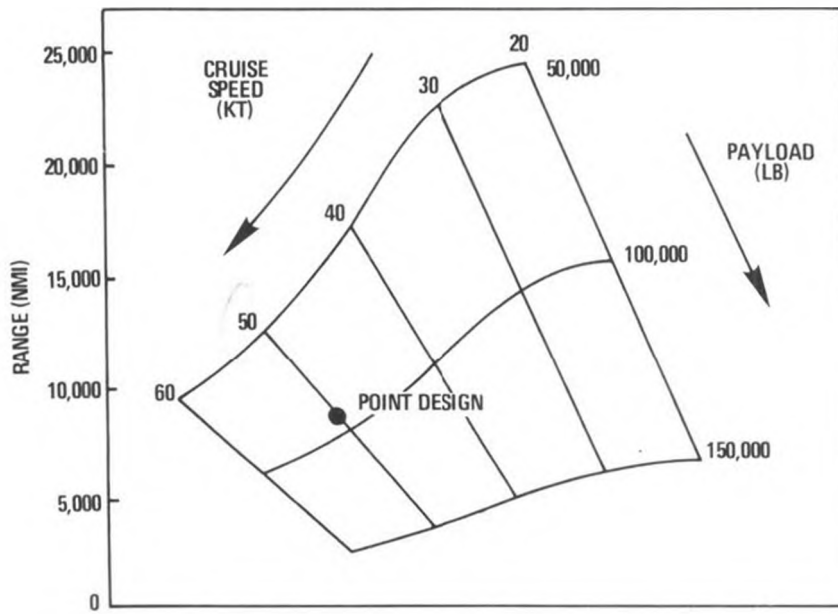
2.3.1 FAB LTA Configuration

(U) Based on the analysis of the mission requirements, the following range of parameters was established as a guide for the parametric analyses:

- Payload: 50,000-150,000 lb,
- Maximum speed: 80-100 kt,
- Endurance: up to 15 days,
- Operating altitudes: 10,000 and 15,000 ft,
- Range: 1,000-10,000 nmi, and
- Buoyancy ratio: 0.85 or more.

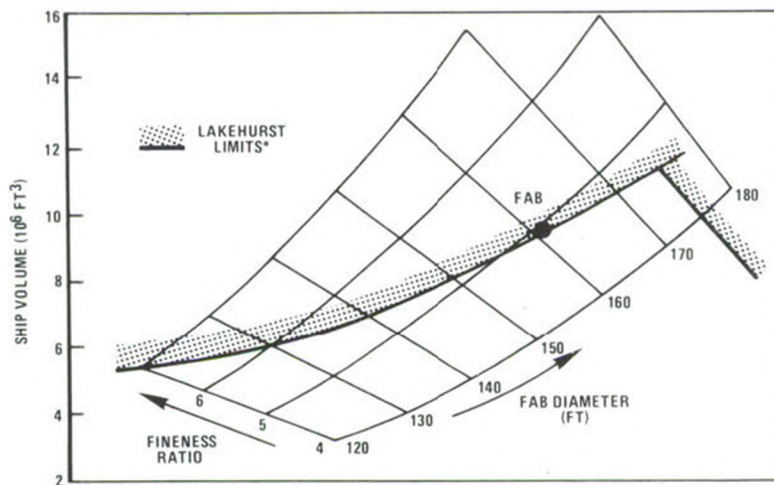
To indicate the type and scope of analysis, Figure IV-9 shows the results of a parametric analysis considering speed, payload, and range. The point design indicated was selected on the basis of this analysis and is discussed in Section 2.4 of this chapter. As the figure shows, if (air) cruise speeds are kept below 40 kt, range is considerably greater than at higher speeds, especially for the smaller payloads. However, because of the need to keep the ground speed high to meet availability and other mission objectives, such low speeds are not attractive. A higher cruise speed also ensures sufficient aerodynamic control, gust alleviation, and improved ride quality. Therefore, a 50-kt air speed cruise point was emphasized.

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(U) Figure IV-9. FAB VEHICLE PAYLOAD-SPEED-RANGE PARAMETRICS

(U) Figure IV-10 shows the parametric analysis of size. Even allowing for improved lift mechanisms and impenetrable skins, a payload of 50,000-150,000 lb was felt to be needed. To carry this payload, the volumetric capacity of the FAB LTA vehicle would have to be about 23 percent larger than the HINDENBURG. However, the length-to-diameter ratio is such that even the larger FAB could use existing terminal facilities.



(U) Figure IV-10. FAB VEHICLE SIZING PARAMETRICS

2.3.2 SAB LTA Configuration

(U) A parametric analysis to explore the characteristics of LTA vehicles that utilize aerodynamic lift was conducted in a manner similar to that for the FAB vehicle.

(U) Since aerodynamically designed vehicles show greater efficiency in smaller sizes than aerostats, a smaller payload than that used for the FAB vehicle was examined for the SAB vehicle. Since the vehicle would be much smaller, it was hoped that a competitive craft could be found that would be in the advanced VP (land-based, fixed-wing, maritime patrol) aircraft class but that would cost considerably less than a heavier-than-air craft used for the same mission. It was also hoped that a SAB vehicle could exhibit the time-on-station capability of the FAB vehicle.

(U) Based on these desired features, the following parameters were established as guidelines for the parametric analysis:

- Payload: comparable to VP aircraft (approximately 29,000 lb),
- Cruise speed: approximately 150 kt (i.e., faster than a high-speed, ANV surface vehicle concept but slower than heavier-than-air craft), and
- Nominal buoyancy ratio: 0.70.

To achieve aerodynamic lift of reasonable proportions, the characteristic (watermelon-like) shape of FAB vehicles must be changed to a more-efficient aerodynamic shape. The aerodynamic lift (and drag) will be related to the wetted area. This condition, known as "volumetric efficiency," is a key parameter in determining the geometry of the SAB LTA vehicle. The wetted area is the determining factor for both the structural weight and the lift and drag of the vehicle. In addition to this geometric relationship, the relative positions of the center of buoyancy (CB) and center of gravity (CG) need to be close during the cruise mode to minimize trim drag; however, in the lightweight condition, a coincident CB and CG is required. All these factors influence the choice of geometry and mass characteristics for a SAB vehicle.

(U) The specific results of the parametric analysis of SAB vehicles are reported in Reference 57. The results are variable since, as in any analysis, the results depend on the inputs. In this particular analysis (Reference 57), the mission requirements were for a shore-based SAB that would have a range of 5000 nmi. These "requirements" led to selection of long-endurance, FAB LTA vehicles although the 100- to 150-kt dash capability allowed some aerodynamic considerations.

(U) However, if the mission requirements had specified a ship-based, short-range SAB vehicle, the parametric analysis would have centered more on smaller, relatively less-expensive LTA vehicles that could be used as consorts, providing synergistic military-effectiveness advantage.

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(U) However, despite these shortcomings, several significant results pertinent to SAB LTA vehicles were obtained. Previous work by the National Aeronautics and Space Administration (NASA) showed that a deltoid shape, i.e., a delta-wing platform with a thick section for buoyancy, was the best configuration, optimizing the LTA features through the aerodynamic and structural properties of the vehicle. An aspect ratio of about 0.60 and a thickness ratio of 0.20 to 0.25 produced the maximum volumetric efficiency. Because of the long-endurance constraint, buoyancy ratios approaching 0.90 seemed to be optimal; however, with a lower range requirement, buoyancy ratios of about 0.60-0.70 appeared to be better for SAB LTA vehicles.

2.4 Point Designs

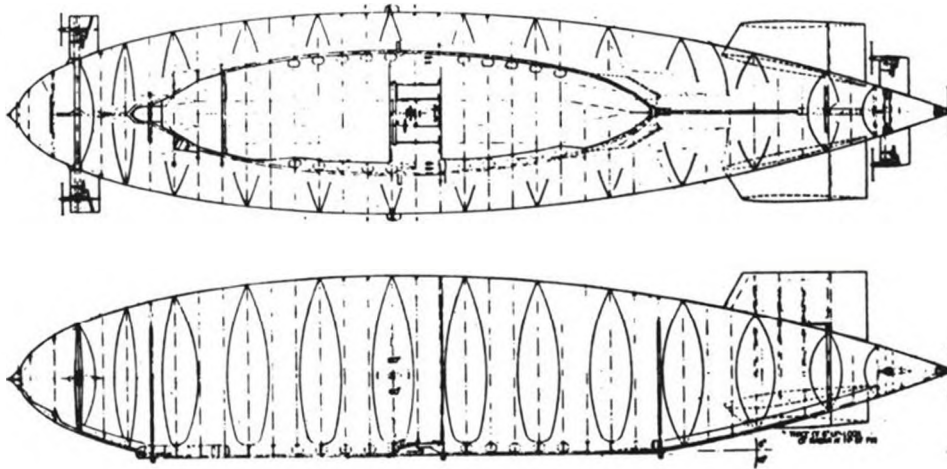
(U) Based on the parametric analyses and related studies of materials and helium-gas availability, two far-term point designs and one, near-term baseline reference were prepared:

- Patrol LTA Vehicle (Near Term)
ZPG X, 44 tonnes displacement
- FAB LTA Vehicle (Far Term)
FAB, 188 tonnes displacement
- SAB LTA Vehicle (Far Term)
SAB, 101 tonnes displacement.

A detailed description of the ZPG X, used as the baseline reference, is given in Reference 58. This design is similar to the 1960-era, U.S. Navy airship ZPG 3W but has been modified to include vertical takeoff and landing (VTOL) and hover capabilities. The design represents a near-term, low-risk version of the 1960 airship that includes current improvements in low-speed flight control. This design is used in Chapter V as a reference or "anchor point" for a comparison of the technical capabilities of other designs.

2.4.1 FAB LTA Vehicle

(U) Side-elevation and underneath views of the FAB LTA vehicle point design, called the FAB, are shown in Figure IV-11. The hull is enclosed by a gas-tight envelope, which is separated into 14 compartments by ballonets. The extreme forward and aft compartments are open to the atmosphere, while the remaining 12 compartments are helium-filled. The FAB also features a propeller 40 ft in diameter that is located at the stern and coupled to two diesel engines, providing a long-endurance cruise capability. The design also has four gas-turbine engines mounted on rotatable pylons at the bow and stern to provide positive control in maneuvering at low speeds. The flat bottom configuration is designed to create a cushioning effect by displacing air laterally near the ground as it descends. This feature is designed to improve the ground-handling problem of classical airships, which involves a combination of airship inertia, fragile understructure, and gusting winds.



(U) Figure IV-11. FAB POINT DESIGN

(U) A detailed description of the FAB is given in Reference 56; the final point design as modified during the technical analysis is described in Appendix B. The leading particulars for the FAB are given in Table IV-5.

(U) Table IV-5. FAB LEADING PARTICULARS

GROSS WEIGHT (TONNES)	188
VOLUME (M ³)	263,900
PAYLOAD (TONNES)	50
SPEED (KT)	
CRUISE	50
MAXIMUM SUSTAINED	80
ALTITUDE (FT)	10,000
TIME ON STATION (DAYS)	4
RADIUS OF ACTION (NMI)	1,200

(U) The FAB point design is a multimission air vehicle with a combat suite that is common to the multipurpose, air combatant group. This group is comprised of the FAB, A/L, A/L(N), S/L(N), and the WIG(O). The length of time each of these vehicles can stay out on a mission differs. The FAB was originally designed (Reference 56) for a mission duration of 8 days; however, during the technical analysis the design was modified to better meet the common design standards of

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the ANVCE Project, reducing the time on station to 5.7 days. Further modification of the combat suite reduced the time on station to 4 days.

(U) In the parametric analysis, solutions were sought to the problems of ground handling and low-speed flight control, and in the FAB point design vectoring thrust control and the flat bottom configuration were used to reduce these problems. However, the design is still affected by certain wind conditions in landing. The analysis (Reference 56) indicated that because of the large weathercock stability of the FAB, landings should not be attempted if wind speeds were at about 40 kt and that landing should be aided by a ground crew unless the wind speed was 25 kt or less. In many respects, the problem is similar to that of attempting to bring a large surface ship into a dock in high winds; some external assistance is required.

(U) Although not pursued during the ANVCE Project point design process, powered descent by means external to the airship may be a good solution to the problem. This idea is illustrated in Figure IV-12. In this artist's conception, the airship maneuvers into a mooring ring on top of a mast. The powered mooring ring holding the airship is then brought down to the ground in a controlled descent. As stated, the analysis and point design examinations of the ANVCE Project indicate that such a scheme is needed in other than slight winds and appears technically feasible; however, no detailed examination of such schemes was undertaken.

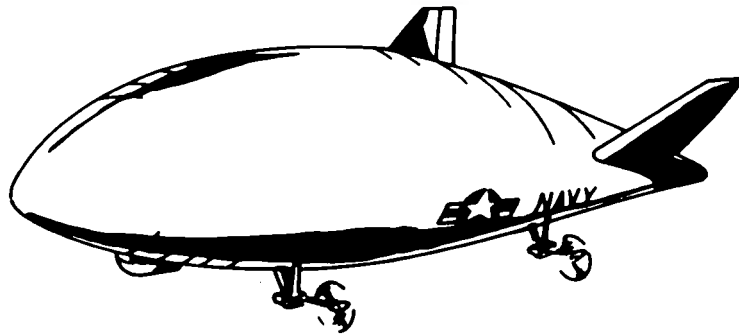


(U) Figure IV-12. GROUND-HANDLING CONCEPT FOR FAB LTA VEHICLE

2.4.2 SAB LTA Vehicle

(U) The SAB is a single-mission, air vehicle grouped in the single-mission, air combatant group, which is comprised of the SAB, S/L(S), S/L(B), and for reference, an advanced VP aircraft (the AVP). Because of the wide range of sizes and types of craft within this group, the combat suites differ considerably among the vehicles. The details of the combat suites are provided in Appendix A.

(U) A sketch of the SAB LTA vehicle point design, the SAB, is given in Figure IV-13. A detailed description of the design is given in Reference 59; the final, revised version used for the cost and mission analyses is presented in detail in Appendix B. Table IV-6 gives the SAB leading particulars.



(U) Figure IV-13. SAB POINT DESIGN

(U) Table IV-6. SAB LEADING PARTICULARS

GROSS WEIGHT (TONNES)	101
VOLUME (M ³)	90,907
PAYLOAD (TONNES)	12
SPEED (KT)	
CRUISE	60
DASH	150
ALTITUDE (FT)	8,000
TIME ON STATION (HR)	53
RADIUS OF ACTION (NMI)	1,600

3,210,335 ft³

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(U) As stated in the discussion of the parametric analysis on the SAB configuration, because of the requirements, the results tended to direct the design effort toward a FAB or large LTA vehicle. Thus, with these constraints the SAB point design with a volume of 90,907 m³ was longer than an FFG 7. A subsequent analysis during the technical evaluation produced another, smaller SAB vehicle, the SAB(S), with the leading particulars given in Table IV-7.

(U) Table IV-7. SAB(S) LEADING PARTICULARS

GROSS WEIGHT (TONNES)	37
PAYLOAD (TONNES)	3.7
SPEED (KT)	
CRUISE	60
DASH	150
ALTITUDE (FT)	8,000
TIME ON STATION (DAYS)	2
RADIUS OF ACTION (NMI)	1,000

(U) Although a larger vehicle than the P-3C, the SAB (S) is competitive with that aircraft in terms of payload (3.5 tonnes) and radius of action. In comparing the speed and loiter time of the P-3C with those of the SAB(S), given in Table IV-7, the P-3C is faster (379 kt) but can only stay on station for 4.6 hr. Other comparisons of some technical aspects and capabilities of these competitive air vehicles are discussed in Chapter V. Cost comparisons are presented in Volume 3.

2.5 Findings and Conclusions

(U) The LTA vehicle concept is attractive because of the inherent simplicity of the design and its relatively low cost (Volume 3). Moreover, in a forced landing, an LTA vehicle can descend at a slower rate and land more softly than a conventional, heavier-than-air craft, making it safer. (Despite fears to the contrary, the LTA vehicles have better safety records than heavier-than-air craft.) Because of the large size of these craft, vital systems and components such as engines, personnel, and combat suites are widely dispersed, which makes it more difficult for an enemy to destroy.

(U) However, because of the handling, maintenance, and storage problems of large LTA vehicles, small LTA vehicles in larger numbers may be more cost/effective than a small number of large, unmanageable LTA vehicles.

(U) In summary, the specific findings and conclusions on LTAs are as follows:

- To carry the necessary multimission payload, the FAB LTA vehicle will always be extremely large. For example, to carry 50 tonnes of payload a FAB will be about three times the size (length) of a heavier-than-air craft. Such large sizes involve handling problems as well as aerodynamic control problems.
- A fundamental problem of the airship is control during low-speed flight in gusting wind. Although many features were integrated by the ANVCE Project into the point design for the FAB LTA vehicle to combat this problem, in ground winds of 25 kt or more some external handling means will be needed. Further research is needed on this problem.
- The advantages of aerodynamic lift, while explored in some depth in the ANVCE Project, were only explored within the given mission constraints. The smaller SAB design, the SAB(S), is more useful than the SAB, which has a volume of 90,907 m³. The smaller size might provide a ship-based LTA vehicle that is easier to handle. Such a vehicle would have characteristics and advantages similar to those of a FAB LTA vehicle (long TOS at low cost) but have the additional advantage of a high-speed dash comparable to that of a helicopter (~ 150 kt).

(U) In summary, while the LTA vehicle concept appears to offer several expected advantages, further analysis, particularly of the SAB(S) concept, is needed. The low cost of the LTA vehicle (Volume 3) demands an in-depth analysis of this concept before its potential can be properly evaluated.

3. SEA LOITER

(U) The sea loiter vehicle is an extension of the seaplane, which was last used by the U.S. Navy in the early 1960s in the form of P-5M patrol seaplanes and P-6M prototypes. The seaplanes of that period were designed to take off and land in rough water but not to loiter or sit on the water for any appreciable period of time during bad weather.

(U) The sea loiter concept is distinct from the traditional seaplane concept in that a sea loiter vehicle is capable of operating as a seaplane and also of sitting on the sea for extended periods of time. Unlike the air loiter concept, which although reasonably efficient still requires large amounts of fuel for its loiter speed of 300-400 kt, a sea loiter aircraft has a considerable TOS capability because it sits on the sea surface and requires less fuel but has the same ROA as the air loiter vehicle. This capability is useful in several military operations.

(U) As stated previously, the sea loiter concept is quite straightforward, and therefore, no concept tree was used in the examination of this aircraft. The other steps were followed and are discussed in the following subsections.

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3.1 Features and Issues

(U) Table IV-8 presents the particular features and issues associated with the sea loiter aircraft. The paths taken in resolving the particular issues (parametric analysis and point design development) as well as the findings and conclusions of those efforts are discussed herein.

(U) Table IV-8. SEA LOITER AIRCRAFT EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
LONG-ENDURANCE AIRCRAFT WITH ABILITY TO SIT ON THE SEA	- WHAT IS THE BEST CONFIGURATION FOR SITTING ON THE SEA? - CAN SEA LOITER TAKE OFF AND LAND IN ROUGH SEAS? - WILL SPRAY INTO ENGINES CAUSE PROBLEMS?	- PARAMETRICALLY STUDIED AND DEVELOPED POINT DESIGNS - ANALYZED MOTIONS AND TAKEOFF AND LANDING MODE - CONDUCTED MODEL TESTS ON POWERED LIFT OVER WATER	- VERY DIFFICULT TO ACHIEVE CONFIGURATION THAT WILL ALLOW SIGNIFICANT IMPROVEMENTS IN RIDE QUALITY WHILE SEA SITTING. BUT CATAMARAN HULL FORM WORTH PURSUING IN THIS REGARD; SMALL SEA LOITER AIRCRAFT SHOWS NO ADVANTAGE; VTOL SEA LOITER AIRCRAFT WITH CIRCULATION-CONTROLLED, STOPPED-ROTOR CONFIGURATION APPEARS ATTRACTIVE BUT REQUIRES MAJOR R&D EFFORT IN WING AERODYNAMICS - DIFFICULT PROBLEM LEADING TO RECOMMENDATIONS FOR LARGE AIRCRAFT WITH HIGH FREEBOARD - MAJOR PROBLEM RESULTING IN RECOMMENDATIONS NOT TO PURSUE POWERED LIFT BUT CONCENTRATE ON STOPPED-ROTOR-TYPE SOLUTIONS

3.2 Parametric Analyses and Experiments

(U) The sea loiter aircraft has only one conceptual path, but many variations on that configuration are possible. For instance, the shape of the main fuselage hull can be designed to better assist the craft in riding the waves; the position of the floats on the wings provides different advantages, e.g., suspension from the wing tips (like conventional seaplanes) yields maximum moment whereas suspension close to the fuselage increases the compactness and reduces the weight. There were other considerations as well. The sea loiter aircraft can be large and operate from a land base or it can be small and operate close to or from a ship. If it is sufficiently reduced in size, the sea loiter aircraft can be a VTOL aircraft. As a VTOL, the sea

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loiter's descent to the water can be powered by a high-disc-loading fan or by a low-disc-loading helicopter rotor or similar device. The impact of disc loading on spray generation is of both technical and operational concern.

(U) Because so many possibilities exist, the problem had to be bounded in some way if tractable and practical solutions were to be found. Accordingly, three main designs were selected for evaluation as to the advantages of the sea loiter concept:

- large, sea loiter aircraft;
- small, sea loiter aircraft; and
- small, VTOL, sea loiter aircraft.

The first two craft were used to examine the size factor for a sea loiter aircraft with a conventional takeoff and landing capability. The third case as an examination of VTOL advantages.

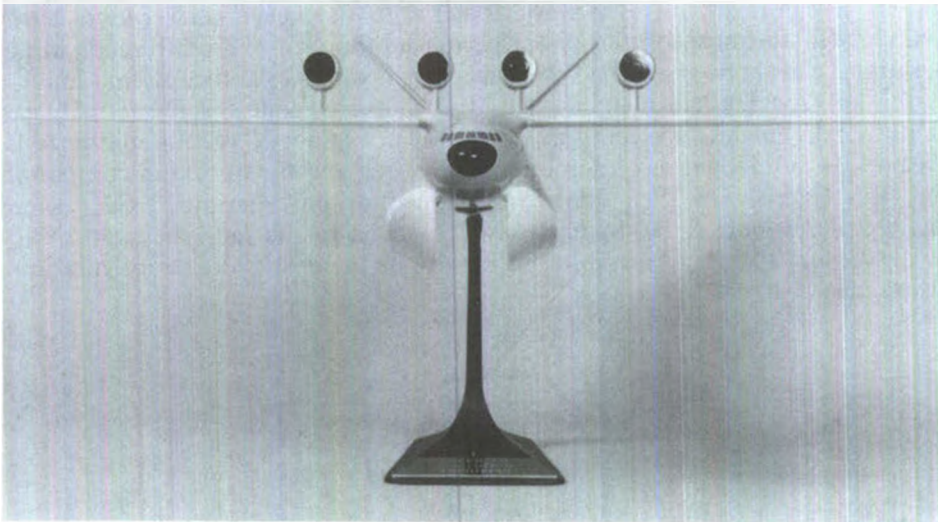
(U) Parametric analyses in each of these areas were pursued to identify the key parameters. Experiments were also performed on different hull forms and damping mechanisms to determine ride quality while sea sitting and on spray mechanisms. Since the parametric analyses and the experimental investigations were directed at solving particular problems that are unique to each of the three categories, the conclusions from these efforts are discussed jointly under these category headings.

3.2.1 Large, Sea Loiter Aircraft

(U) The large sea loiter aircraft would operate in open-ocean conditions and sea-state-6 seas. Such large waves acting in random fashion and having a high energy content are a problem for an aircraft with a wing/fuselage combination that is lightweight and relatively fragile (by surface ship standards) loitering on such a sea. The high-aspect-ratio wings needed for efficiency at cruise altitude are not capable of withstanding such wave action. Adding conventional, wingtip floats did not satisfactorily solve the problem. However, use of a catamaran-hulled fuselage instead of the wing-tip floats to provide lateral stability was promising. Large catamaran hulls with sufficiently wide beam and high freeboard enabled the wings to be kept high and out of the water. By mounting the engines on pylons above the wing, they can be protected from the spray and their life extended. This parametric analysis and the configurational form produced (Figure IV-14) are described in Reference 60.

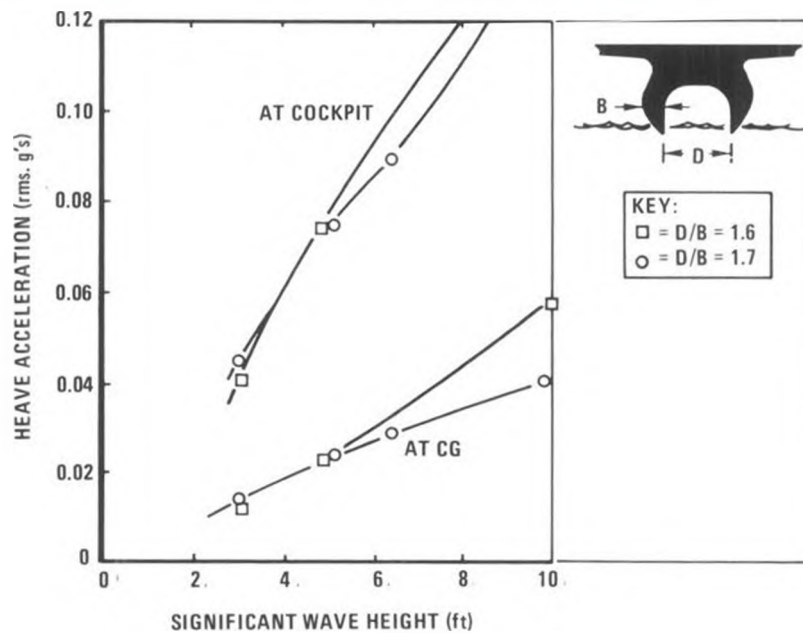
(U) The next problem was to determine the combination of all the pertinent geometric and mass properties that would provide the best sea loitering capability. Key parameters are the hull spacing and beam, the chine geometry, the wing height above the water, the L/B ratio of the hull/fuselage, the length of forebody and afterbody forward and aft of the step, and the relative positions of the CG and metacentric height. Many questions had to be addressed by the ANVCE Project because of the many possible combinations of variables and an almost total lack of representative data on such configurations (an ongoing R&D program on seaplane characteristics has not existed for the past 20 years).

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(U) Figure IV-14. MODEL OF THE CATAMARAN-HULLED,
SEA LOITER AIRCRAFT

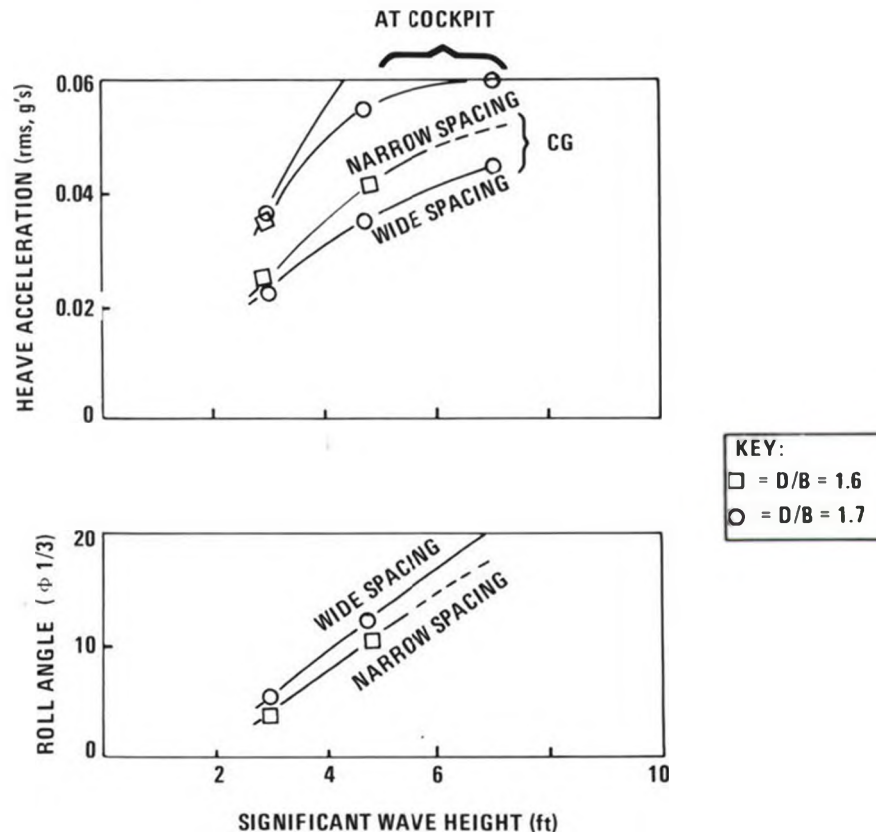
(U) Experimental data on the catamaran-type sea loiter concept are given in Reference 61. Figure IV-15 shows the effect of hull spacing on heave acceleration.



(U) Figure IV-15. CATAMARAN SEAKEEPING IN HEAD SEAS

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As shown, a significant difference exists between the heave acceleration levels at the cockpit (in the nose of the aircraft) and at the CG. The difference in heave acceleration levels between the two hull spacings is far less significant, and in low sea states the hull spacing had little impact. In beam seas, wide spacing actually gave a larger roll angle but less acceleration, as shown in Figure IV-16. In combined head and beam seas, more-complex interactions were seen and the optimum configuration became less clear. The best configuration cannot be determined by geometric parameters alone; consideration must also be given to the radii of gyration in the pitch, heave, and roll modes in order to determine the best overall configuration for operation in such seas.



(U) Figure IV-16. CATAMARAN SEAKEEPING (BEAM SEAS)

(U) Based on the results of these analyses and experiments (Reference 61), the findings pertaining to the use of a catamaran-type hull on the sea loiter aircraft are as follows:

- the weight and aerodynamic cruise drag are relatively high,
- heave acceleration and motions are somewhat alleviated if careful account is taken of the geometry and the mass properties for confused-sea operation,

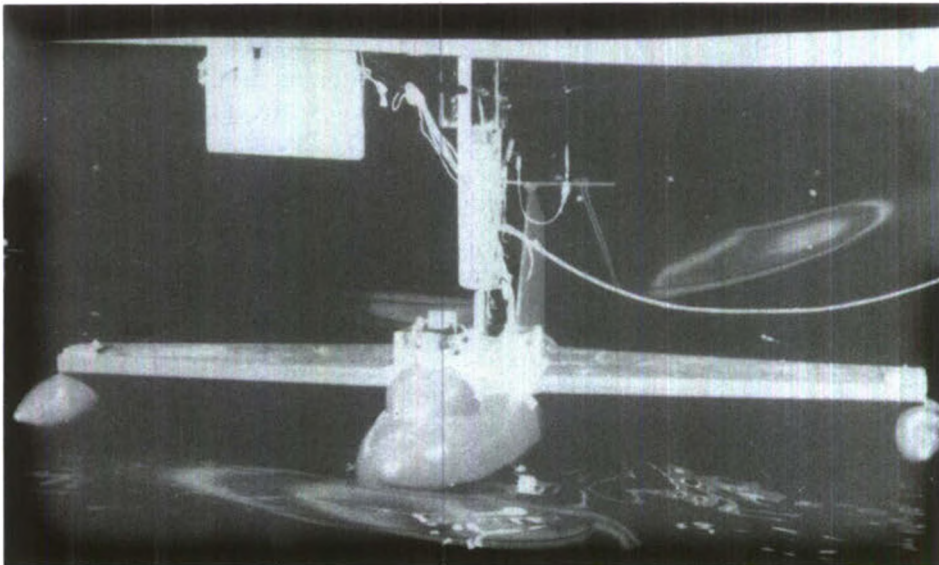
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- placing the work station at the aircraft CG while sea sitting does more for alleviating motions than hull shaping, and
- the inherent danger of “digging-in” that exists with a wing-tip float configuration are discussed in the description of the point designs (Section 3.3 of this chapter).

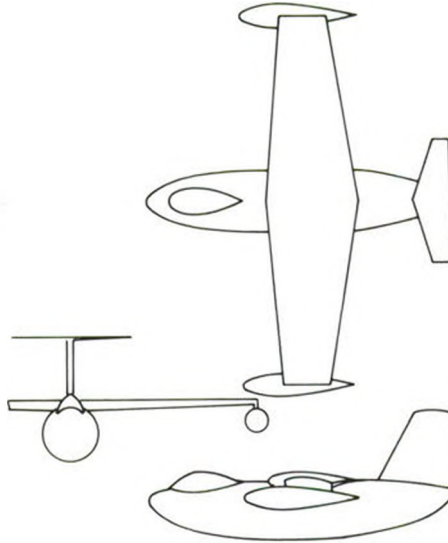
3.2.2 Small, Sea Loiter Aircraft

(U) An alternative seakeeping solution to that followed in the large, sea loiter configuration is to have the craft follow the waves. This approach allows the craft to follow the large (vertical) motions but at reduced acceleration levels. This technique of surface following appears to be most compatible with a small, sea loiter aircraft whose low mass reduces the forces imparted to the hull. Since the more-compact geometry of a small size is indicated, the use of wing-tip floats becomes more feasible as a means of providing stability.

(U) A series of model experiments was conducted on the basis of a preliminary analysis of shapes for a surface-following hull form for the sea loiter aircraft. Figure IV-17 shows the baseline model under test. Figure IV-18 shows three views of the model tested. The hull shape is unlike that of a conventional seaplane in that there is no chine and it is designed to have a constant pressure distribution over most of its length. The wing-tip floats are rotatable to the vertical position for spar-buoy-



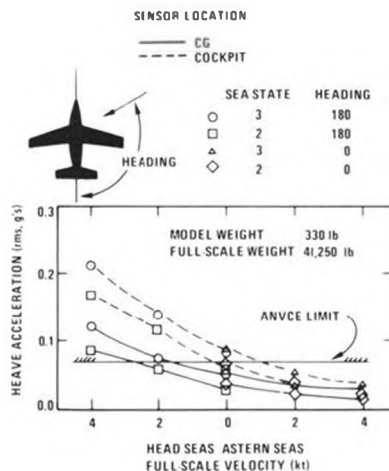
(U) Figure IV-17. SURFACE-FOLLOWING MODEL OF SEA LOITER



(U) Figure IV-18. HULL FORM OF SURFACE-FOLLOWING MODEL

type damping. In addition to the wing-tip floats, other damping mechanisms such as wing-tip damping plates (passive) were also tested. The model was tested in various sea states at various headings in both regular and random waves. The model was also tested both at rest and underway at slow speed.

(U) The results are given in detail in Reference 62; Figure IV-19 illustrates a key result of the tests. While the characteristic pitching motion seen in the large sea loiter tests is also evident here, again the effect is not large and a greater reduction in heave acceleration is available merely by keeping a little way on. As shown in the figures, heading the sea loiter into the waves and motoring at about 4 kt reduces the acceleration levels by a factor of four.



(U) Figure IV-19. SURFACE-FOLLOWING MODEL TEST RESULTS

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(U) Based on these tests, a slight change in operational technique (possibly the use of a small outboard) can significantly reduce the acceleration level and not have any detrimental effects on the configuration. The lack of chine in such a configuration has detrimental effects in beam seas and contributes to increased spray sheet height. The model test results also show that the use of damping plates does not reduce the motions by a significant amount.

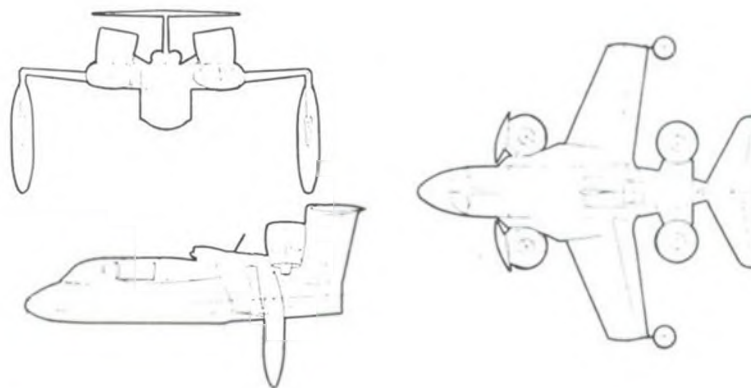
3.2.3 *Small, VTOL, Sea Loiter Aircraft*

(U) The third solution to the sea loiter configuration problem was to devise a geometry that would be optimum strictly for sea loitering. If the sea loiter vehicle could take off and land vertically, the hull would not have to be shaped for take-offs and landings and the motion problems incurred by such a hull in rough seas would be solved. In addition, an aircraft capable of both VTOL and sea loitering could be based on a ship and integrated with the surface fleet, which might be of value in terms of military usefulness.

(U) Two radically different configuration forms for the small, VTOL, sea loiter concept were studied parametrically:

- lift/cruise fan, and
- circulation-controlled, stopped-rotor.

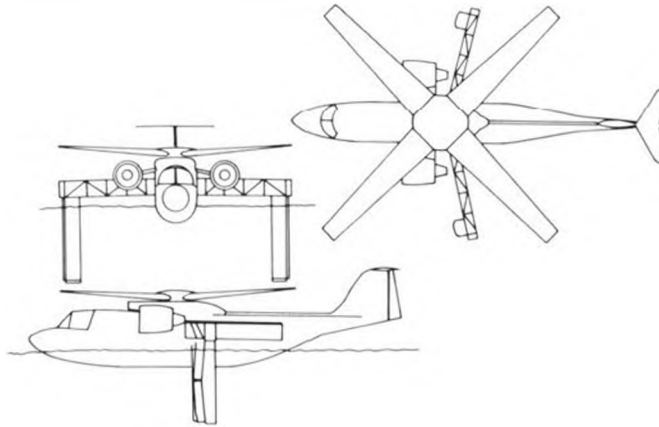
The lift/cruise fan configuration is shown in Figure IV-20. It represents the least departure from the current state of the art of such configurations and is characterized by high-disc-loading fans that force air downward at high pressure on the water. For the general size perceived for such an aircraft (about 50,000 lb TOGW), the disc loading is about 650 psf. The circulation-controlled, stopped-rotor configuration, shown in Figure IV-21, represents a significant technological advance in rotor development. It is characterized by a low-disc-loading rotor imparting an air



(U) Figure IV-20. LIFT/CRUISE FAN CONFIGURATION

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stream of much lower pressure on the water. As shown in Figure IV-21, the surface-following hull form investigated during the model tests of the small, sea loiter aircraft has been used. For the same size aircraft as that with the lift/cruise fan configuration, the circulation-controlled, stopped-rotor configuration would have a disc loading of about 20 psf (similar to that of a helicopter).



(U) Figure IV-21. CIRCULATION-CONTROLLED, STOPPED-ROTOR CONFIGURATION

(U) Experiments were conducted at high disc-loading (Reference 63). Because of known scaling problems for spray testing, the results are inconclusive except that high-disc-loading generates more spray than low disc loading. However, because lift/cruise fans are vulnerable to rapid erosion from salt spray and the brute-force, high-energy nature of this operation, the circulation-controlled rotor, if developed to the 1995 technology level, seems to be the best solution to the problem.

3.3 Point Designs

(U) Utilizing the findings of the parametric analyses and experiments, three point designs were prepared:

- Large, Sea Loiter Aircraft (Far Term)
S/L(L), 290 tonnes TOGW
- Small, Sea Loiter Aircraft (Far Term)
S/L(S), 61 tonnes TOGW
- Small, VTOL, Sea Loiter Aircraft (Far Term)
S/L(V), 21 tonnes TOGW.

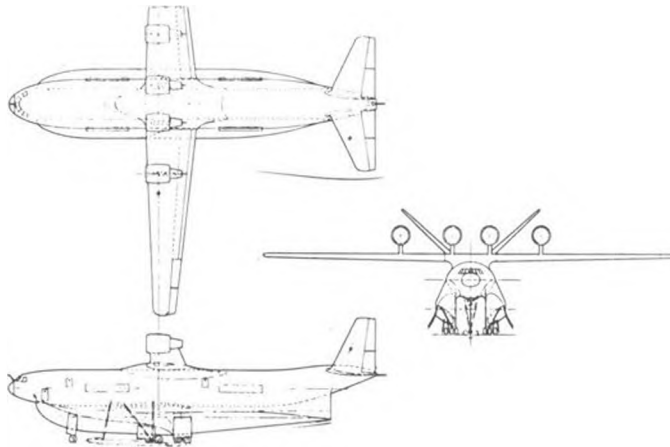
The large, sea loiter design, the S/L(L), represents a particular design wing and the catamaran-hull fuselage. The small, sea loiter design, S/L(S), uses upgraded, 1990 technology information on such subsystems as engine weight and fuel consumption

but is actually a near-term design based on current, Japanese seaplane, the SHIN-MEIWA PS 1. The VTOL, sea loiter design, the S/L(V), uses the circulation-controlled, stopped-rotor configuration.

(U) These designs are described in References 60 [S/L(L)], 64 [S/L(S)], and 65 [S/L(V)]. The final designs, as modified during the technical analysis, are presented in detail in Appendix B. and are summarized in the following subsections.

3.3.1 Large Sea Loiter Aircraft

(U) The S/L(L) is shown in Figure IV-22. The catamaran hulls and the (lowered) planing ski to assist in takeoff are shown. The high aspect ratio has a supercritical airfoil and lateral empennage and tail empennage flaps to mechanically increase the lift coefficient to values greater than 3.5. Advanced, composite materials are used in the wing and hull fuselage to offset the weight increment of the catamaran hull.



(U) Figure IV-22. S/L(L) POINT DESIGN

(U) Details of the basic S/L(L) are given in Reference 60; the final point design with modifications is presented in detail in Appendix B. The leading particulars are given in Table IV-9.

(U) Table IV-9. S/L(L) LEADING PARTICULARS

GROSS WEIGHT (TONNES)	290
PAYLOAD (TONNES)	37
MAXIMUM AND CRUISE SPEED (KT)	407
ALTITUDE (FT)	35,000
TIME ON STATION (HR)	19
RADIUS OF ACTION (NMI)	1,600

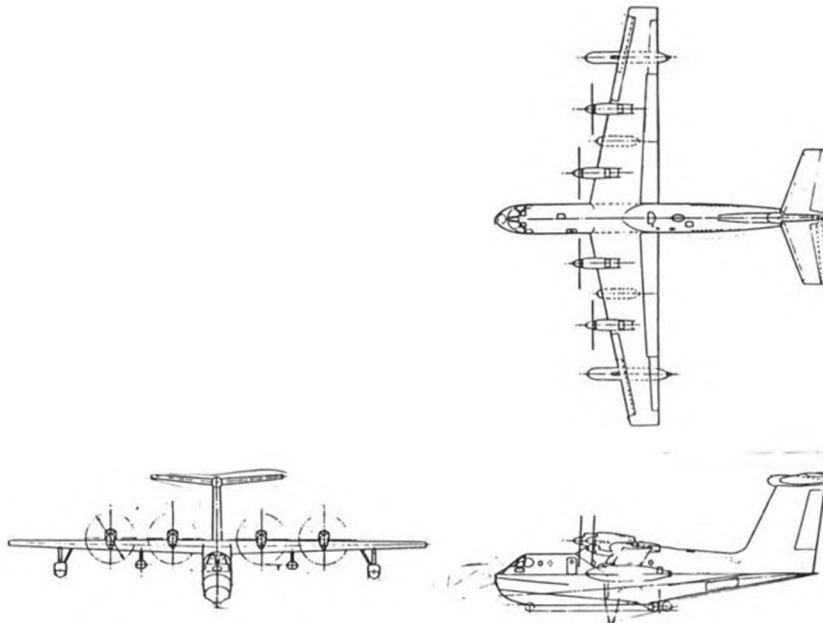
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(U) The S/L(L) point design is a multimission air vehicle with a combat suite that is common to the multimission, air combatant group (Appendix A). This group is made up of the S/L(L), A/L, A/L(N), FAB, and WIG(O). The mission durations vary between the various point designs; the time on station for the S/L(L) was reduced from 24 hr (Reference 60) to 19 hr (Appendix B and Table IV-9) as a result of the modifications needed to make the combat suite common to the other multimission, air vehicles.

(U) In comparing the S/L(L) leading particulars with those of the A/L (Table IV-2), the S/L(L) has a significantly greater weight (about 86 tonnes) than the A/L for the same payload, time on station, and radius of action. However, the speed of the S/L(L) is about 50 kt higher than that of the A/L. These differences are important in terms of cost/effectiveness.

3.3.2 Small, Sea Loiter Aircraft

(U) The turboprop-powered, small, sea loiter aircraft, the S/L(S), is shown in Figure IV-23. It strongly resembles the present-day SHIN-MEIWA PS 1. However, although the design of the S/L(L) is essentially that of the seaplane, its design includes advanced, composite materials in its structure; boundary-layer control (BLC) on the wing and empennage; and advanced, turboprop engines and propellers. Such advancements will require a considerable development effort; however, without such features the aircraft would be much larger than that of this point design.



(U) Figure IV-23. S/L(S) POINT DESIGN

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(U) Details of the point design development are given in Reference 64; the final, modified design used for the ANVCE Project analyses is presented in Appendix B. Table IV-10 gives the leading particulars of the S/L(S).

(U) Table IV-10. S/L(S) LEADING PARTICULARS

GROSS WEIGHT (TONNES)	61
PAYLOAD (TONNES)	8
MAXIMUM SUSTAINED SPEED (KT)	300
CRUISE SPEED (KT)	242
ALTITUDE (FT)	30,000
TIME ON STATION (HR)	5-1/2
RADIUS OF ACTION (NMI)	540

(U) The S/L(S) point design is part of the single-mission, air combatant group. This group is comprised of the S/L(S), S/L(V), SAB, and, for reference, an advanced VP aircraft (the AVP). These vehicles each have unique capabilities, precluding the use of a completely standard combat suite within the group. The details of these combat suites are given in Appendix A.

3.3.3 Small, VTOL, Sea Loiter Aircraft

(U) Figure IV-21 shows the circulation-controlled, stopped-rotor configuration of the S/L(V). The artist's rendering in Figure IV-24 gives a better indication of the nature of the extendable floats. The S/L(V), like the S/L(S), is part of the



(U) Figure IV-24. S/L(V) POINT DESIGN

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single-mission, air combatant group. Details on the development of this design are given in Reference 65; the final design used, including modifications made during the technical analysis, is presented in Appendix B. Table IV-11 gives the leading particulars of the S/L(V).

(U) Table IV-11. S/L(V) LEADING PARTICULARS

GROSS WEIGHT (TONNES)	21
PAYLOAD (TONNES)	4
CRUISE SPEED (KT)	430
ALTITUDE (FT)	32,000
TIME ON STATION (HR)	2
RADIUS OF ACTION (NMI)	350

3.4 Findings and Conclusions

(U) The high speed (350-450 kt) of a VP aircraft offers advantages in certain scenarios that even the fastest, surface platform envisioned (50-100 kt) cannot provide. A principal disadvantage of such aircraft, however, is that they are tied logistically to fixed bases, which are apt to be far from an area of conflict and could possibly be overrun during a conflict. Moreover, VP aircraft are severely limited in the time they can remain on station.

(U) The sea loiter aircraft is a concept designed to eliminate these disadvantages through the capability of sitting on the sea, a technique that conserves fuel and extends the aircraft time on station. The addition of this capability in a high-speed aircraft has definite operational advantages.

(U) Three versions of the sea loiter aircraft have been explored and found to be technically feasible. Specifically, the findings and conclusions related to the sea loiter concept are as follows:

- Unique configurations providing good sea sitting characteristics for both large and small versions of the sea loiter concept are technically feasible and offer promise. Because of the complexity of the multimodal character pitch, heave, and roll in confused seas, the correct geometrics could not be determined within the scope of the ANVCE Project.
- The catamaran-hull configuration considered for the large, sea loiter aircraft is feasible and eliminates the need for wing-tip floats, which are potentially dangerous. The increased weight and aerodynamic drag associated with this hull configuration, however, are a disadvantage in the airborne cruise mode. Thus, while technically feasible, its sea sitting capability must be weighed in terms of military worth and cost.

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- The concept of a VTOL, sea loiter aircraft with a circulation-controlled, stopped-rotor configuration is technically feasible and is an excellent solution to the problem of alighting on the water without generating large amounts of spray. Being ship-based (when folded, the particular point design studied will fit into a DD-963 flight deck hangar), the VTOL, sea loiter aircraft offers some improvement over the performance of future helicopters, as currently envisioned.

4. WIG VEHICLE

(U) Wing-in-ground-effect (WIG) technology extends into many areas, but those areas associated with both surface and air vehicles are of particular interest. Depending on the mode desired, a WIG vehicle can take any of several different forms. The ANVCE Project explored a limited number of these variations within the WIG concept. Therefore, in assessing the findings and conclusions derived from these analyses, model tests, and point designs, the cursory nature of this examination in terms of the full range of variations within the WIG vehicle concept must be considered.

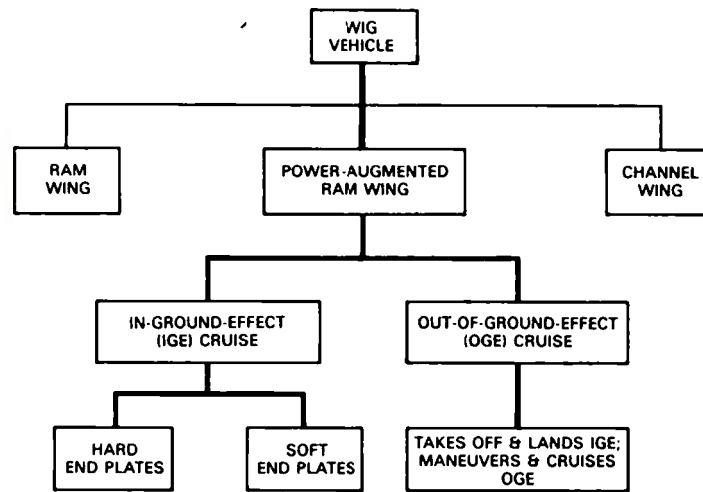
(U) In the preceding examination of surface and air concepts, the ANVCE Project categorized each concept within a particular operational group in order to bound the problem. Evaluation of concepts within a group permits a comparison of competitive concepts within a specific operational context and is not an examination of complementary concepts in a broader context. However, the WIG vehicle concept cannot easily be confined within a particular operational group because in one form it can border on becoming a high-speed, surface platform (with reduced drag); in another form it can be a version of a sea loiter platform; and in another form it can be considered to be an aircraft (with a particular form of takeoff-and-landing capability). Since many technical unknowns exist in each of the possible forms, only one basic, "pure" form was examined within a particular category in order to examine the technical issues in that area in as much depth as possible. (This approach highlights the essential difference between exploring the value of a *concept* and designing a *vehicle* to meet some specific mission requirements. During this investigation, problems arose because of the relatively shallow data base and the uncertainty as to where the WIG concept and various specific forms would be most effective. However, such an examination of *concepts* is the tasking of the ANVCE Project.)

4.1 Concept Tree

(U) The WIG vehicle concept tree is shown in Figure IV-25. The concepts examined in the ANVCE Project evaluation included WIG forms with

- hard end plate,
- soft end plate, and
- out-of-ground-effect flight capability.

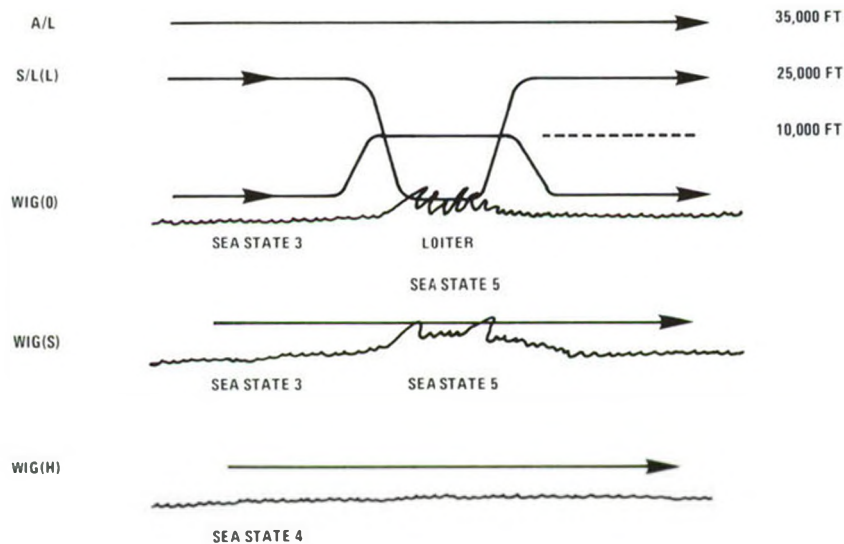
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NOTE: HEAVY LINES INDICATE ANVCE PROJECT EXAMINATION

(U) Figure IV-25. WIG VEHICLE CONCEPT TREE

These forms, designated by H, S, and O, respectively, are illustrated in Figure IV-26. The A/L and S/L(L) point designs are also included for comparison. Basically a WIG vehicle is grouped within one of two modes, or configurational forms: (a) it can operate totally in ground-effect (H and S forms) or (b) it can operate periodically out of ground-effect (O form). Both of these forms were examined only in terms of the power-augmented ramjet (PAR) approach to the WIG concept.



(U) Figure IV-26. COMPARISON OF WIG CONCEPT VARIATIONS WITH AIR AND SEA LOITER AIRCRAFT

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(U) In a conceptual sense, the sea loiter aircraft is the inverse of the WIG(O) in that it normally operates at altitude but, when the occasion demands, can operate at sea level. However, the sea loiter vehicle does not operate in ground effect while at sea level.

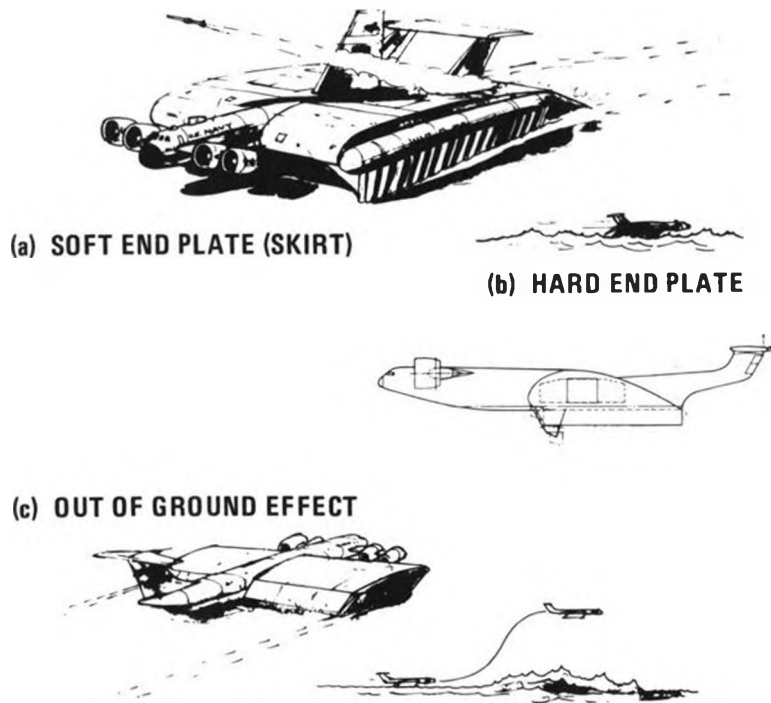
(U) The technical differences and the related R&D of the air and surface sea loiter concepts and the three configurational forms of the WIG concept are radically different. Because of this variation, the ANVCE Project tried to examine only "pure" forms, recognizing that once the data base was obtained, a particular vehicle could be designed that might have features taken from more than one of the "pure" forms analyzed. This purity was not completely maintained: where deviations occurred, areas needing further study are identified.

(U) For a WIG vehicle that always operates in ground-effect and is particularly affected by rough seas with random wave heights, special attention must be paid to the vehicle's mass and geometric properties. In general, the span of the platform is kept short so that the wing tip will not dip into the water. The ground-effect phenomenon compensates for the loss of aerodynamic efficiency of the resulting low aspect ratio. The platform is designed to be structurally compact, with the heavy mass concentrated near the centroid, in order to enhance the load-absorbing capability of the WIG vehicle against the inevitable wave contact.

(U) For the WIG vehicle that occasionally flies out of ground-effect the aspect ratio of the wing is increased slightly to gain aerodynamic efficiency for the short-duration airborne cruise. However, this increase in aspect ratio makes the WIG vehicle more susceptible to rough water damage and thus limits its use to the lower sea states. If the WIG vehicle spends a considerable amount of its mission duration at altitude, its aerodynamic configuration is more like that of an airplane and it becomes a seaplane rather than a WIG vehicle.

(U) The WIG vehicle that always operates in ground-effect was examined in two forms, the hard and soft end-plate (skirt) versions. The classical form of the WIG vehicle, known as a ram wing, used end plates at the wing tips to contain the pressurized air beneath the wing and to eliminate or reduce the incurred vortex or induced drag. This feature has been retained in many of the basic forms of WIG vehicle considered in this study. A fundamental problem with these end plates, experienced with many of the WIG vehicles tested in the 1960s, is that the end plates have a catastrophic effect when contacting the waves, especially at a heading other than dead ahead.

(U) As a possible solution to this problem, the ANVCE Project considered the concept of a WIG vehicle with a soft end plate, a skirt that would be compliant (like ACV skirts) in traversing rough seas. The soft end plate enables the WIG vehicle to operate in higher sea states than the WIG vehicle with a hard end plate, all else being equal. Figure IV-27 illustrates the differences among the S, H, and O forms of the WIG vehicle. The relative, sea-state capabilities inferred by such conceptual differences, assuming that the size and speed characteristics are the same, are shown in Figure IV-26.



(U) Figure IV-27. STRUCTURAL DIFFERENCES OF THREE
WIG VEHICLE FORMS

4.2 Features and Issues

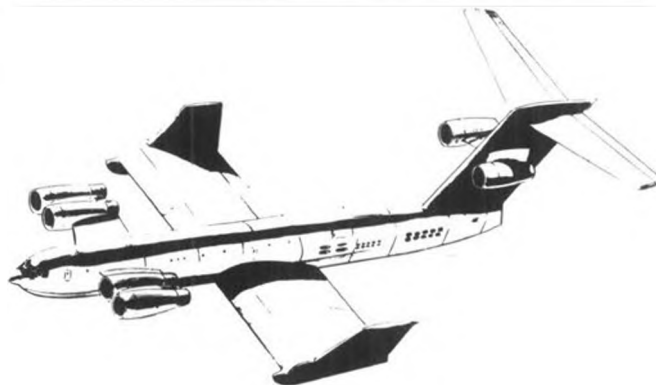
(U) Based on the assessment of the technological state of the art in WIG vehicles (Reference 14) and the conceptual capabilities discussed in the preceding section, the particular features and issues of the WIG concept are given in Table IV-12. The paths taken in resolving the particular issues (parametric analyses, experiments, and point designs) as well as the findings and conclusions of those efforts are discussed in the following subsections.

(U) A unique feature of a WIG vehicle is its ability to “jump up” and look over the horizon. Furthermore, if properly designed, a WIG vehicle has the ability to operate over a wide speed range. All of the WIG concepts described herein have the same form of propulsion, one that is patterned after the latest WIG vehicle developed by the USSR (referred to as the “Caspian Sea Monster”). This particular propulsion method uses a jet thrust from forward-mounted engines directed beneath the wing to augment lift. The United States has developed a similar system, the power augmented ramjet (PAR) feature, which is shown in Figure IV-28. As shown, such a vehicle essentially operates as a seaplane up to some nominal speed and the jet-deflected wake beneath the wing increases the lift (and lowers the take-off speed) until the vehicle eventually flies in ground effect at very high speed.

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(U) Table IV-12. WIG VEHICLE EXAMINATION

FEATURES	ISSUES	ANVCE ACTION	CONCLUSIONS
- JUMP-UP FEATURE IN WIG VEHICLE, CAPABLE OF OUT-OF-GROUND-EFFECT FLIGHT - MULTIMODE CAPABILITY FROM LOW TO HIGH SPEEDS	- HAS THE VULNERABILITY PROBLEM OF FLYING CLOSE TO ROUGH SEAS AT HIGH SPEEDS BEEN RESOLVED? - HAS THE "PITCH-UP" PROBLEM BEEN SOLVED? - GIVEN ITS PROXIMITY TO THE WATER, IS A HIGH-SPEED, WIG VEHICLE MANEUVERABLE?	- CONDUCTED MODEL TESTS OF WIG VEHICLES FLYING CLOSE TO WATER - ANALYZED AND CONDUCTED MODEL TESTS OF DIFFERENT CONFIGURATIONS - ANALYZED THE VARIOUS MANEUVERABILITY SOLUTIONS	- THIS NEW FEATURE SHOULD PROVIDE A UNIQUE CAPABILITY IN AN OPERATIONAL SENSE; OPERATIONAL RESEARCH NEEDS TO BE PURSUED TO DETERMINE ITS MILITARY USE - NOT FULLY EXPLOITED IN ANVCE BUT APPEARS FEASIBLE TO PROVIDE A VEHICLE CAPABLE OF OPERATING OVER A WIDE SPEED RANGE (EVEN WITHOUT ALTITUDE FLIGHT CAPABILITY) - GENERALLY NOT A PRACTICAL SOLUTION IF HARD STRUCTURE USED; INDICATIONS ARE THAT SKIRT-LIKE END PLATES MAY RESOLVE PROBLEM; R&D NEEDS TO BE PURSUED IN THIS POTENTIAL SOLUTION - THE GEOMETRY TO ACHIEVE STABLE CONFIGURATIONS WITH AERODYNAMIC DEVICES WAS NOT SATISFACTORILY DEMONSTRATED, AND MORE R&D IS REQUIRED TO RESOLVE THIS ISSUE - THE WIG VEHICLE IS NOT VERY MANEUVERABLE AT HIGH SPEED AND MUST CLIMB OUT OF GROUND EFFECT TO TURN (IN SHORT RADII); SOME POTENTIAL SOLUTIONS WERE POSTULATED BUT NOT EXPLORED; MORE R&D NEEDS TO BE PURSUED IN THIS AREA



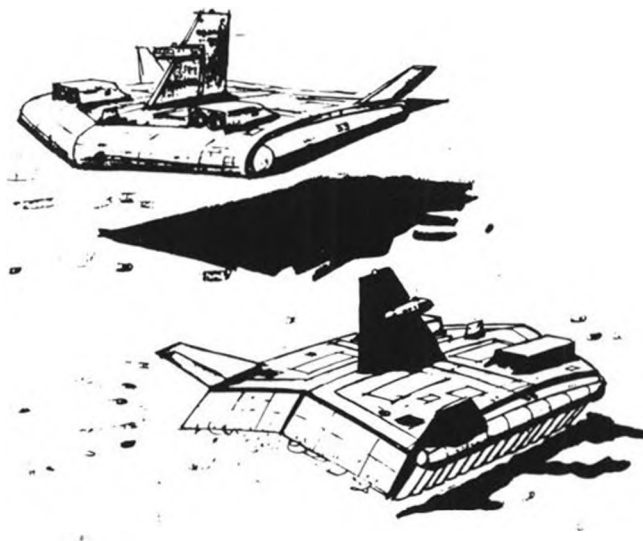
(U) Figure IV-28. PAR, OUT-OF-GROUND-EFFECT CONFIGURATION, WIG(O)

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(U) However, using other propulsion schemes, the WIG vehicle can operate at zero speed on a cushion of air (much like an ACV). Figure IV-29 shows this feature of the WIG concept. One propulsion scheme that could be used for such operation is to house the propulsion system on the wing itself and deflect the pressurized air beneath the wing (through ducting). This scheme gives the WIG vehicle a hovering capability, enabling it to operate over land as well as water. The same pressurized air can be used to inflate the soft (skirted) end plates (Figure IV-29), enabling the WIG vehicle to operate well at high speeds in rough water. By retracting the skirt, the WIG vehicle can operate at very high speed in relatively calm water. The wing geometry could also be designed to allow the WIG vehicle to occasionally fly out of ground-effect

(U) Although all of these features need to be explored in depth, they indicate some of the possibilities and potential within the WIG concept.

(U) The issues associated with the WIG concept have existed throughout its history. Despite the technological efforts devoted to the WIG vehicle in the 1960s, practical solutions have never been found. Accordingly, emphasis of the ANVCE Project was on finding solutions to these technical issues through analysis, experimentation, and point design activity. In its efforts, the ANVCE Project concentrated on the PAR propulsion scheme. Wherever possible, more-generalized conclusions will be drawn from the specific results using the PAR scheme.



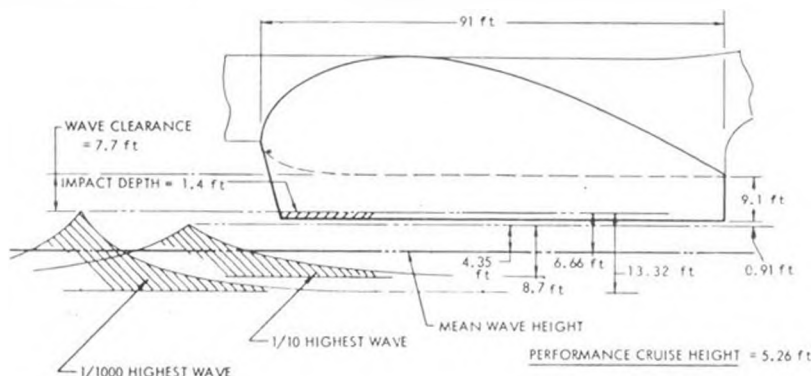
(U) Figure IV-29. MULTIMODE, VARIABLE-GEOMETRY, WIG VEHICLE

4.3 Analyses and Experiments

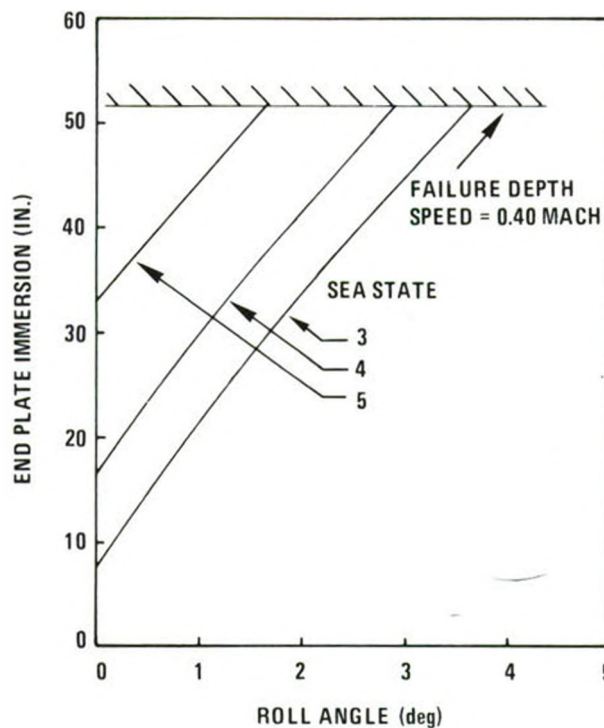
(U) Several analyses and experiments were conducted to extend the state of the art of WIG technology. The principal findings are summarized in the following paragraphs.

(U) Basic thrust, lift, and drag theory of the PAR, WIG vehicle in the zero-speed, forward mode is given in Reference 66. This theory was used to better understand the Soviet scheme and to guide the experiments on the PAR, WIG vehicle. The basic stability equations for the WIG vehicle are given in Reference 67; the PAR, WIG, jet-efflux parameters were further developed (Reference 68); and an analysis of water loads on a hard end plate was conducted (Reference 69).

(U) Although there were no conclusive findings on the vulnerability of a WIG vehicle flying very close to rough waves, the geometry involved provides some insight. Figure IV-30 shows the geometry of the WIG(H) over sea-state-4 waves. The WIG/water-interface geometry allows the desired aerodynamic efficiency at the minimum height deemed practical. The geometry is such that the lower edges of the hard end plates are clear of the highest 10 percent of the waves expected by almost a foot (actually 0.91 ft). In this cruise condition the end plates would impact the 1/1000 highest wave expected, with an immersion of approximately 1.4 ft. No pitching, heaving, or rolling of the WIG(H) was assumed to occur during this mode of operation. The analysis was not sufficient to determine if the flight control systems together with the mass and inertia characteristics of the WIG vehicle could cope with these forces and the frequency of contact. To gain some insight as to what might happen if the end plates were further immersed, some further analysis was performed (Reference 70). Figure IV-31, the WIG(H) is assumed to be flying straight and level with the initial immersion set at the values shown at zero roll angle. As the WIG(H) rolls, the end plate becomes more immersed until structural failure occurs, assuming no deformation. At 265 kt (Mach = 0.400 in sea state 4, the end plate will fail if the WIG vehicle rolls approximately 3 deg. In reality, structural failure would occur sooner since if failure is predicted to occur at 3 deg (assuming the end plate is normal to the wave), structural deformation would occur much earlier. Thus, the end plate would be bent so as to increase the angle of flow, which in turn would increase the load, causing structural failure.



(U) Figure IV-30. WIG(H) POINT DESIGN IN FLIGHT CLOSE TO WAVES



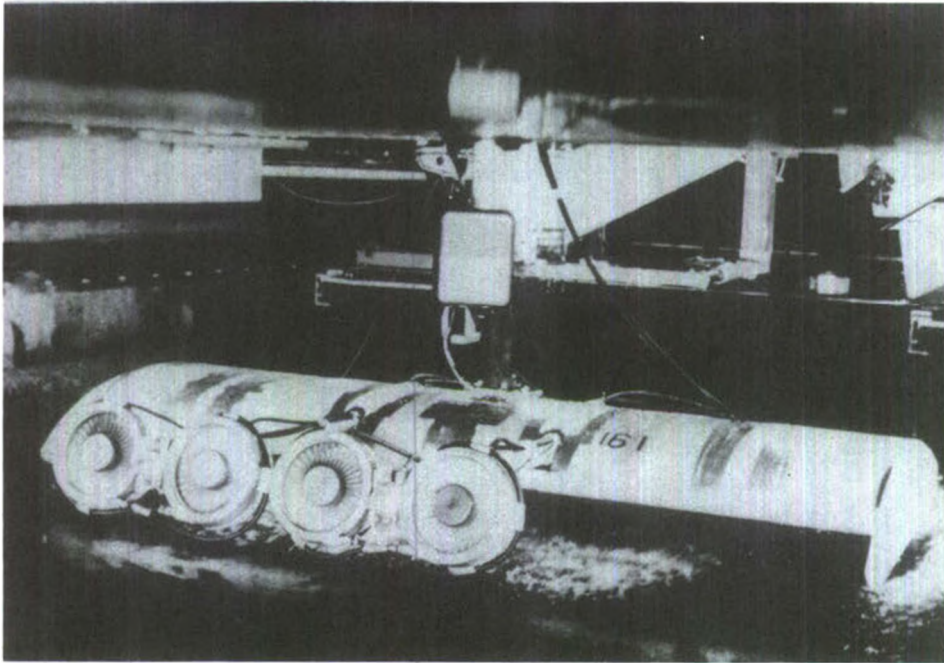
(U) Figure IV-31. EFFECT OF IMMERSING HARD END PLATE, WIG(H)

(U) Given the small angles and immersion depths involved and the fact that sea waves are not very predictable, the problem still exists and other solutions need to be sought. Another concern is that if structurally sound end plates were to be used, then the weight of the structure would increase (much like the penalty incurred by the seaplane) if it is to withstand the hydrodynamic impact loads. The analysis performed was not sufficient to project what the weight increase might be or its impact on the payload-carrying capability.

(U) All experiments conducted were restricted to the Soviet, PAR-type propulsion scheme. Several experiments were conducted to investigate wing geometries, end plate types, the number of propulsion engine jet effluxes, and other basic parameters. The results of testing hard end plates with various features such as leading-edge, load-alleviation springs are described in Reference 71; experimental observations of the spray patterns around a PAR WIG vehicle in connection with the performance of such a vehicle near the air/water interface are described in Reference 72.

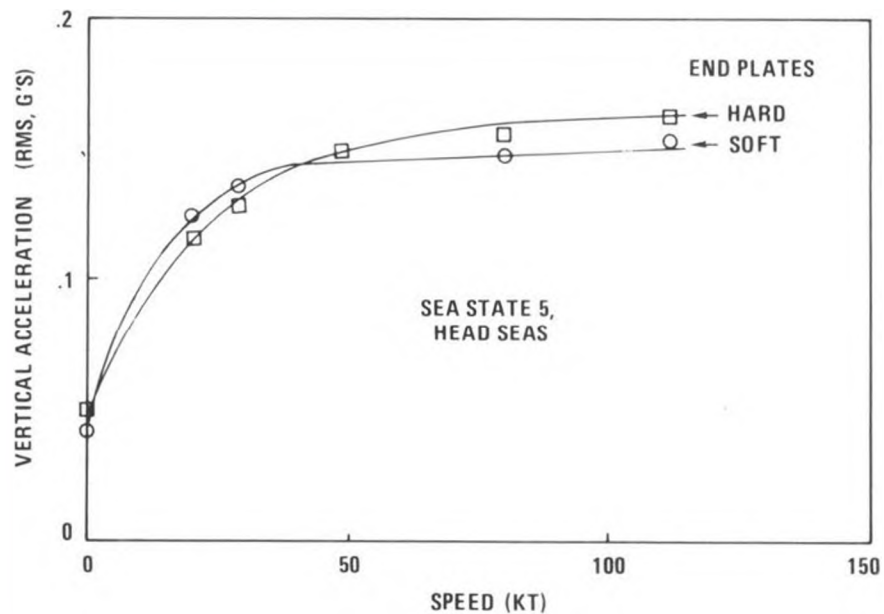
(U) Figure IV-32 shows a model of the PAR WIG vehicle under test. These model tests provided much-needed performance data on the many different configuration combinations of aspect ratio, number of propulsors, and end plate configurations for the PAR WIG vehicle.

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(U) Figure IV-32. MODEL OF THE PAR WIG VEHICLE UNDER TEST

(U) Some measurements were also made on the ride quality of the PAR WIG vehicle in cruising at high speed in rough seas. Both the hard end plate and a crude version of the soft end plate were tested; the results are shown in Figure IV-33. At high speed (100 kt or more), the vertical acceleration is about 0.15 g (rms), which is above the habitability standards (Appendix A) set for a long-duration cruise on surface platforms. Also, the soft end plate tested, unlike any ACV skirt,



(U) Figure IV-33. RIDE QUALITY OF PAR WIG(H) AND WIG(S) VEHICLES

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was made up of a set of inflated cones. Because there was no free-flowing air, it was much stiffer than a conventional ACV skirt. Therefore, motion similar to that of the hard end plate was experienced. Further experimentation utilizing the ACV technology and experience is needed on the soft (skirted) end plate concept.

(U) Details of the many experiments are given in the references cited.

4.4 Point Designs

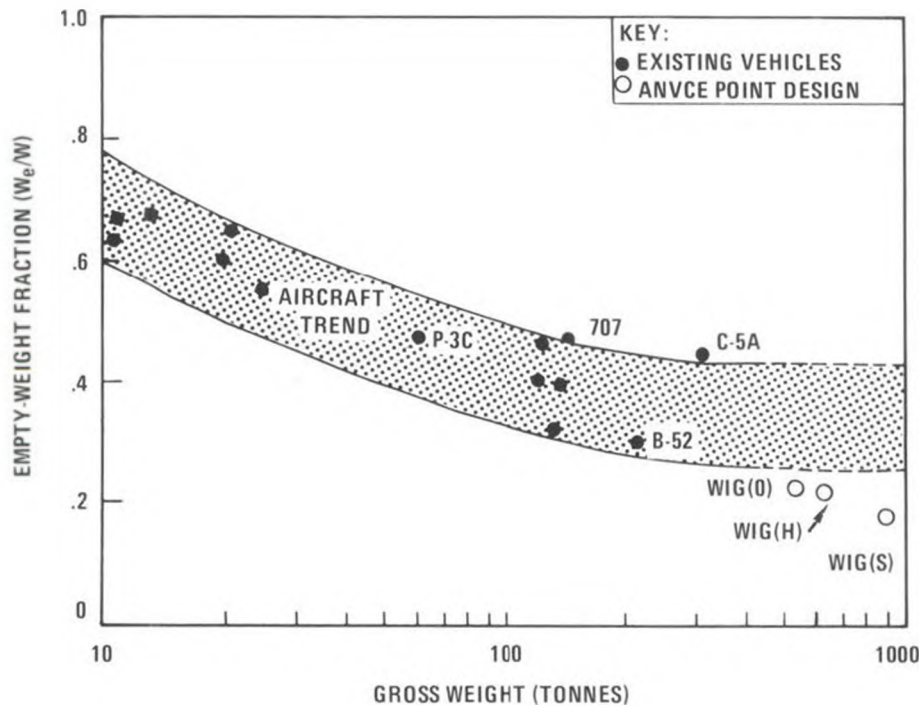
(U) In addition to the various technical analyses and model experiments, three point designs were developed to determine the technical feasibility of some aspects of the WIG concept and to provide quantitative vehicle information for the cost and mission analyses. These point designs are as follows:

- Logistics WIG Vehicle (Far Term)
WIG(H), 618 tonnes displacement
- Surface-Combatant WIG Vehicle (Far Term)
WIG(S), 907 tonnes displacement
- Multimission, Air Combatant (Far Term)
WIG(O), 536 tonnes displacement.

The wide disparity of sizes results from a consideration of possible military applications for the various WIG vehicles. Although many of the technical differences among configurational forms tend to be masked by the size effect, these differences must be considered during comparative analyses.

(U) Detailed descriptions of the development of these point designs are given in Reference 73 for WIG(H), 74 (for structural analysis), and 75 (for performance analysis) for WIG(S), and Reference 76 for WIG(O). The parametric studies conducted aided in the selection of key parameters for these point designs; these analyses are reported in Reference 70 for WIG(H), 74 for WIG(S), and 77 for WIG(O). The final point designs, including any modifications, are presented in Appendix B.

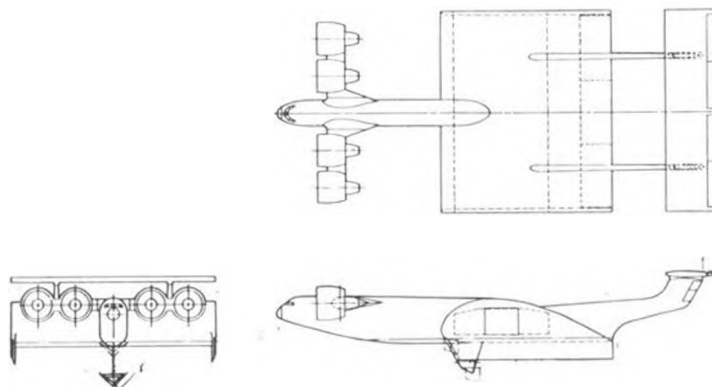
(U) Since WIG technology is still embryonic and very little is known about the characteristics of these vehicles, several questions arise regarding the point designs. The viability of designing lightweight structures that are flight-capable yet rugged enough to withstand the impact with the rough seas is debatable. As shown in Figure IV-34, the WIG concept point designs are lighter than conventional aircraft, which do not have to fly in such a rugged environment. The question remains whether the more-compact structures of the WIG point designs will be sufficient to combat the impact of rough seas. The WIG vehicle requires more power than an aircraft at the same design speed because of the PAR feature (Section 2.1.1 and Figure V-32 Chapter V). Thus, there is an additional weight penalty in the propulsion system also to be included in the empty weight. It has been suggested that the structural weights for all three WIG designs be doubled. Further investigations are needed on this issue.



(U) Figure IV-34. EMPTY-WEIGHT FRACTION OF WIG POINT DESIGNS

4.4.1 Logistics WIG Vehicle /WIG(H)/

(U) Figure IV-35 shows the logistics vehicle, WIG(H). Several hard-end-plated, WIG configurations were analyzed parametrically. Aerodynamically, higher-aspect-ratio wings ($AR \geq 2$) show greater efficiency, while structurally the lower-aspect-ratio wings ($AR \approx 1$) provide a more-compact, less-vulnerable wing structure for operation



(U) Figure IV-35. WIG(H) POINT DESIGN

in rough seas. The need to have such a compact, raft-like structure becomes even more important in considering that the WIG vehicle does not use the PAR feature when it is sitting on the ocean. To ensure that all such features were explored, the low-aspect-ratio solution was incorporated into the WIG(H) point design, while for the WIG(O) point design the aspect ratio was increased for out-of-ground-effect advantage. Operationally this choice of aspect ratio for each design was compatible with the use of that vehicle. The low aspect ratio implied a short span (108 ft); therefore, the surface-bound WIG(H) can transit the Panama Canal. The WIG(O), which can fly over the Panama Canal, has a higher aspect ratio and span than the WIG(H).

(U) The leading particulars of the WIG(H) are given in Table IV-13. Since this particular point design is considered as a logistics vehicle, it does not have a combat suite in common with any group of ANVs. This logistics WIG(H) is a high-speed, open-ocean transport and is evaluated as a large, air-capable transport. Although the WIG(H) has a higher aerodynamic (and possibly structural) efficiency than a conventional air transport, it is not as fast as a conventional airplane. [The advantage or disadvantage of this difference is not considered within this technical evaluation of the capabilities of the WIG(H).]

(U) Table IV-13. WIG(H) LEADING PARTICULARS

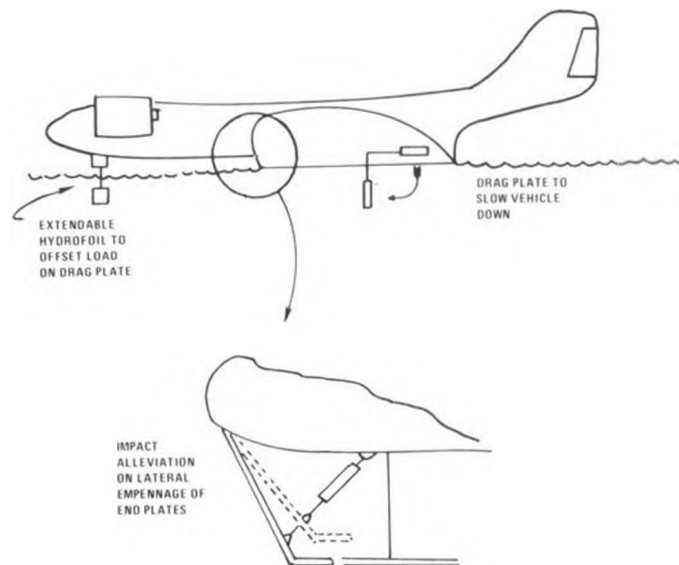
GROSS WEIGHT (TONNES)	618
PAYLOAD (TONNES)	201
RANGE AT 264 KT (NMI)	4,000
MAXIMUM SUSTAINED SPEED IN SEA STATE 3 (KT)	264

(U) A technical problem associated with high-speed vehicles is how to stop them in any reasonable distance when traveling at a high cruise speed. This problem was explored through this point design; several schemes were investigated, and Figure IV-36 shows the particular scheme used. As shown in the figure, a drag plate could slow the craft down and an extendable foil at the nose could prevent pitching-in. To lessen impact in waves, the lateral empennage of the end plates would be spring-loaded. The hydrofoil is immersed into the water at the vehicle CG to create a drag force without pitching moment. However, this scheme has not been investigated; it is simply one of many ideas that may have merit. Any such scheme must be thoroughly investigated.

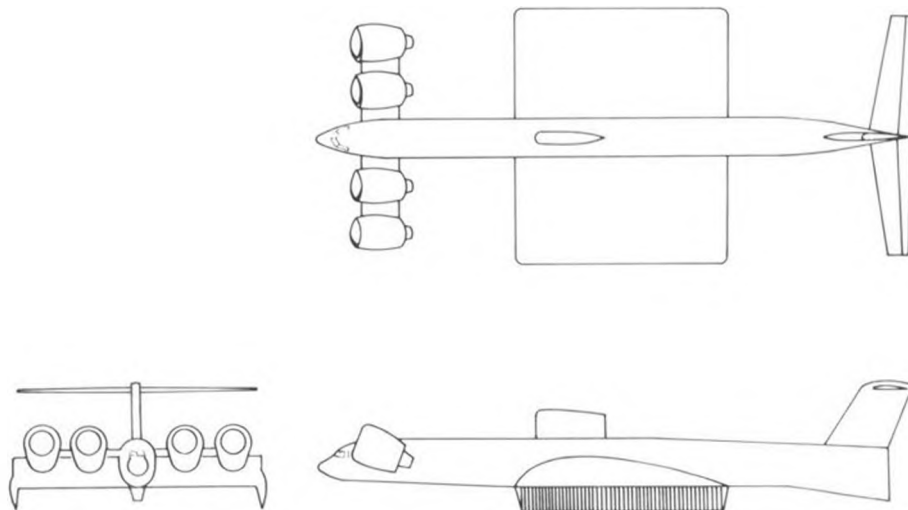
4.4.2 Surface Combatant Wig Vehicle [WIG(S)]

(U) Figure IV-37 shows the WIG(S) point design. The leading particulars for this point design are given in Table IV-14. Although WIG(S) is listed organizationally as an air vehicle, it overlaps into the surface vehicle category and carries the same combat suite as the ACV 1, a nonair-capable, surface combatant.

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(U) Figure IV-36. SCHEME TO STOP WIG(H) WITHIN REASONABLE DISTANCE



(U) Figure IV-37. WIG(S) POINT DESIGN

(U) Table IV-14. WIG(S) LEADING PARTICULARS

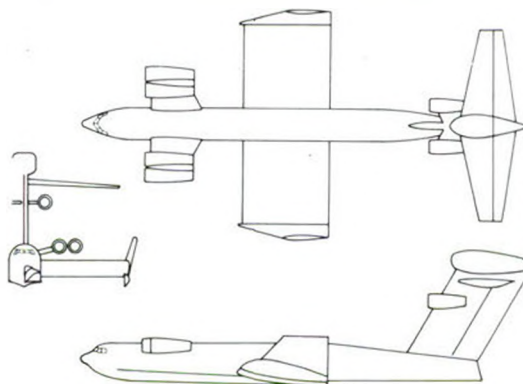
GROSS WEIGHT (TONNES)	907
PAYLOAD (TONNES)	107
RANGE AT 200 KT (NMI)	4,616
MAXIMUM SUSTAINED SPEED IN SEA STATE 3 (KT)	200

(U) This point design is basically a simple modification of the WIG(H) design with the hard end plates replaced by the soft end plates. These soft end plates are crudely designed, and as the model tests showed, a better design, based on ACV experience, is needed. The model tests also indicated that the pitch of the PAR WIG configuration is unstable and that the horizontal aerodynamic tail has insufficient volume to stabilize the craft. Accordingly, a ski-like tail that would provide the required stability was added; however, such a ski-like tail incurs much higher drag and can cause major problems both in rough water operations and during the transition mode.

(U) It is believed, however, that a much better configurations can be developed; for example, converting to an ACV-like skirt would be a major improvement. Furthermore, with a better understanding of the stability mechanisms, an effective aerodynamic tail could be developed, eliminating any need for such schemes as the hydrodynamic, ski-like tail.

4.4.3 Multimission, Air Combatant [WIG(O)]

(U) The WIG(O) point design as previously shown in Figure IV-28 is shown in Figure IV-38 in a three-view diagram. It closely resembles the "Caspian Sea Monster" of the USSR, which was the basic reason for studying this particular form

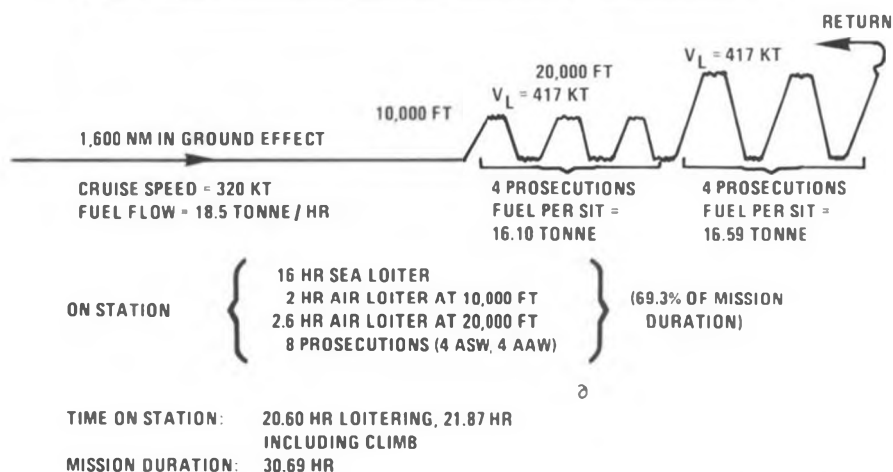


(U) Figure IV-38. WIG(O) POINT DESIGN

of WIG vehicle. The leading particulars of the WIG(O) are given in Table IV-15. The time that a WIG(O) can remain on station depends on the number of "jumps" it is required to make, e.g., for ASW and AAW prosecutions. [Although the WIG(O) has a time on station of 22 hr, a longer time on station (about 4 days)—comparable to the A/L(N) and FAB point designs—is conceivable; however, no point design was developed to test the feasibility of this concept.] During the technical evaluation, the weight of the WIG(O) point design was modified (previously discussed) and its combat suite was changed to be in common with the other "day-on-station" air vehicle concepts (the air and sea loiter aircraft). These changes were made because of the operations envisioned for the WIG(O). The mission profile analyzed is shown in Figure IV-39. In this particular profile, the WIG(O) climbs four times to about 10,000 ft for ASW prosecution. The combat suite and number of weapons are compatible with the number of prosecutions, which is a function of the vehicle's performance capability. This compatibility among combat suite, time on station, and vehicle performance was developed from information obtained from parameteric analysis (Reference 77) and point design development. Once the

(U) Table IV-15. WIG(O) LEADING PARTICULARS

GROSS WEIGHT (TONNES)	536
PAYLOAD (TONNES)	48
MAXIMUM SPEED (KT)	
AT 12,000 FT (SUSTAINED SPEED)	445
AT 20,505 FT (CRUISE SPEED)	417
AT SEA LEVEL (GROUND EFFECT) (LOITER SPEED)	285
TIME ON STATION (HR)	22
RADIUS OF ACTION (NMI)	1,000



(U) Figure IV-39. WIG(O) MISSION PROFILE FOR ONE DAY ON STATION

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requirements were determined, the preliminary point design (Reference 76) was modified for use in the cost and mission analyses. Details on the final point design, summarized here, are presented in Appendix B. (The preliminary designs are referenced here only for completeness of documentation.)

4.5 Findings and Conclusions

(U) During the ANVCE Project, an effort was made to extend the technological state of the art for WIG vehicles. However, although a considerable amount of data were obtained, satisfactory solutions were not found for many of the fundamental issues involved in this concept. Vulnerability and the likelihood of "digging-in" at high speed over rough water were explored and several solutions postulated. The pitch-up problem can be solved through the use of aerodynamic devices, but the design parameters still need to be clearly defined. The use of hydrodynamic, ski-like foil at speeds of 90-100 kt does not appear to be a practical solution.

(U) Maneuverability at high speed also presents a problem. A WIG vehicle that is constrained to operate close to the surface cannot bank into a turn to generate the necessary side force. Several schemes are available for generating such side forces. The dorsal-fin solutions shown in Figures IV-27 and IV-29 are examples of such schemes. However, the ANVCE Project did not verify the feasibility of any of the schemes.

(U) The best type of end plate sealing mechanism is still to be determined; sufficient analysis was conducted, however, to raise reasonable doubt as to whether a hard structure is a good means of sealing the air flow. The use of an ACV-type skirt appears to be the most promising solution, but requires further study and design development.

(U) In summary, the WIG vehicle, in both its ground-effect-only form and its out-of-ground-effect, air-capable form, is unique and has considerable military potential, assuming its technical problems can be resolved. Further research and development are needed before proceeding with a practical, large-scale vehicle program.

CHAPTER V

TECHNICAL ASPECTS OF OPERATIONAL ISSUES

(U) In conducting the technical evaluation of the advanced naval air and surface vehicle concepts, many detailed and separate analyses, experiments, and point design studies were undertaken. A listing of documents reporting this ANVCE-sponsored research is presented in Volume I. For the surface vehicle concepts the investigations explored such characteristics as power, ride quality, maneuverability, flexibility to varied-speed operation and load-out, and other technical features that determine whether the concept would be useful in the U.S. Navy at the turn of the next century. For the air vehicle concepts, analogous characteristics—with the added features of a long-endurance flight capability, compatibility with air-capable ships, and sea sitting where appropriate—were explored.

(U) In all cases, the technical evaluation included an assessment of the concepts in relation to the current state of the art so that a determination could be made as to the direction and composition of the R&D program that would be required to produce a vehicle with an IOC of about 2000. A concept is not evaluated by a single measure or figure of merit but by an aggregate of factors. Such factors include the physical characteristics of a vehicle and its capability compared to other vehicles as well as its related costs and usefulness, both of which are also compared with those of other vehicles. All of these factors are involved in the trade-offs made in developing an optimal design.

(U) Chapters III and IV presented the physical characteristics of the ANV concepts; this chapter presents a comparison of selected performance factors. The point designs developed to test feasibility (Chapters III and IV) are used as design points in these analytical assessments. Because this volume is only concerned with the technical evaluation of the ANV concepts, underlying questions of cost and usefulness are raised but not considered.

(U) How well a vehicle performs depends on its speed, maneuverability, range, endurance, and ride quality. Its military usefulness depends on its payload capacity, availability, and survivability. The characteristics of the various surface and air vehicle concepts are discussed in Chapters III and IV, respectively. However, in addition to determining the optimal design *within* a concept, an across-the-board comparison of some characteristics *among* the various surface and air concepts is needed. Section 1 of this chapter examines and compares the effect of characteristics on performance, while Section 2 examines and compares the effect of the characteristics on military usefulness.

1. VEHICLE OPERATIONAL PERFORMANCE CHARACTERISTICS

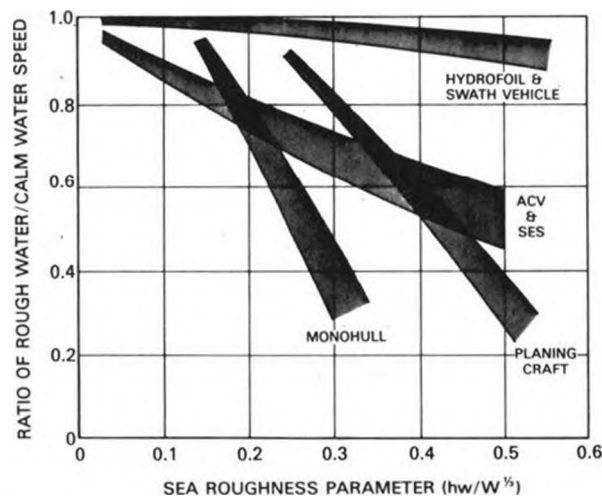
1.1 Speed at Sea

(U) The speed capability of a ship at sea is a function of several key factors. The significance of each of these factors varies from concept to concept, e.g.,

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dynamic vehicles behave differently from buoyant vehicles and are subject to different constraints, and merchant and military requirements differ. The key factors include the ship's size and displacement, its heading, and its "limiting" features (power, ride quality, hull slamming, and deck wetness). Hull slamming affects the fatigue life of the hull structure, and deck wetness is an important consideration in evaluating surface vehicles that will carry vertical takeoff and landing (VTOL) or vertical/short takeoff and landing (V/STOL) aircraft.

(U) While specific designs can be developed for special conditions, the general performance capabilities of the surface concepts fall into the groupings shown in Figure V-1. The broad curves in Figure V-1 cover most of the size ranges of the vehicles. They have been normalized to some extent in the sea roughness parameter by the ratio of the significant wave height (h_w) to the cube root of the displacement (W). When all other variables are held constant, the hydrofoil with fully submerged foils and the SWATH ship can maintain speed in rougher seas than can the ACV, SES, planing craft, or monohull displacement ships. What is not expressed in the normalized plot of Figure V-1 is that the calm-water speed capability for each concept is also quite different.

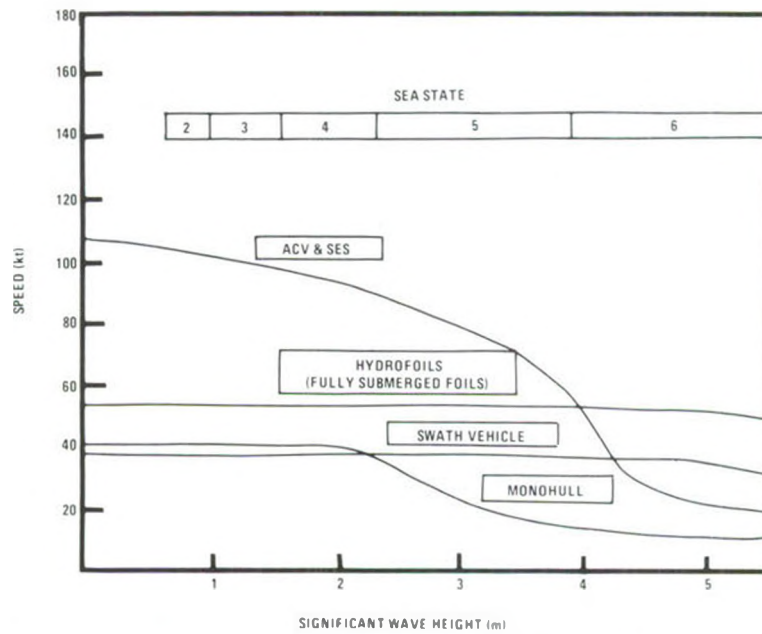


(U) Figure V-1. ROUGH WATER SPEED CAPABILITY OF SURFACE VEHICLE CONCEPTS

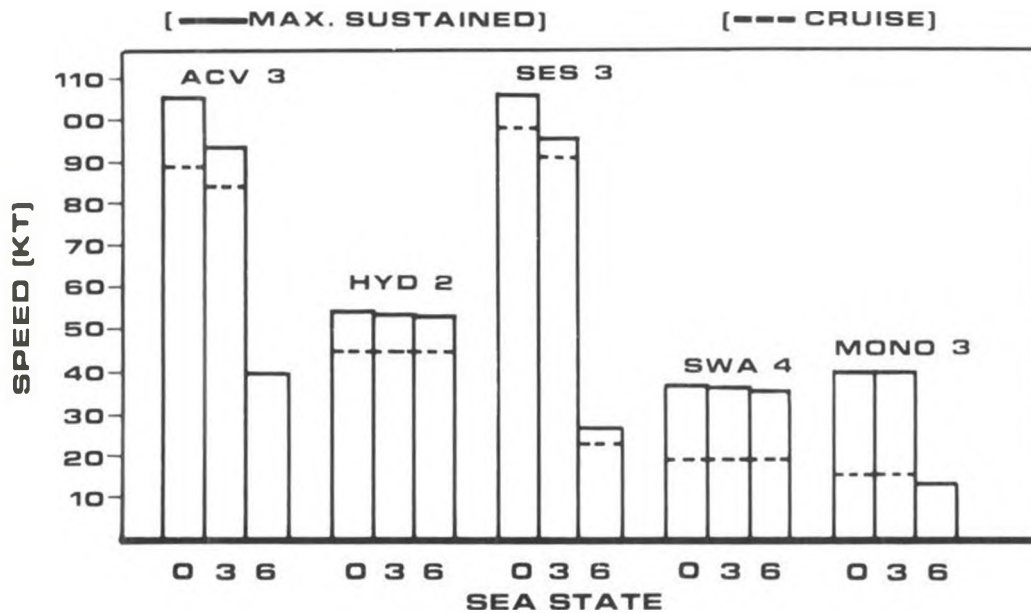
(U) Figures V-2 and V-3 compare the speed capabilities at sea of the surface vehicles within one displacement class (3000 tonnes) under full-load displacement (FLD) conditions and with head seas. These curves are based on the point designs but should not be read as absolutes because of the inability to predict rough sea performance precisely. They do, however, demonstrate the relative performance between concepts.

(U) The curves shown in Figure V-2 change when either the displacement or the direction of the seas are changed. For example, speed of the SES (using the SES 3 as typical of the concept) in rough seas can be improved by changing course and turning away from head seas. Furthermore, decreasing the load will improve the

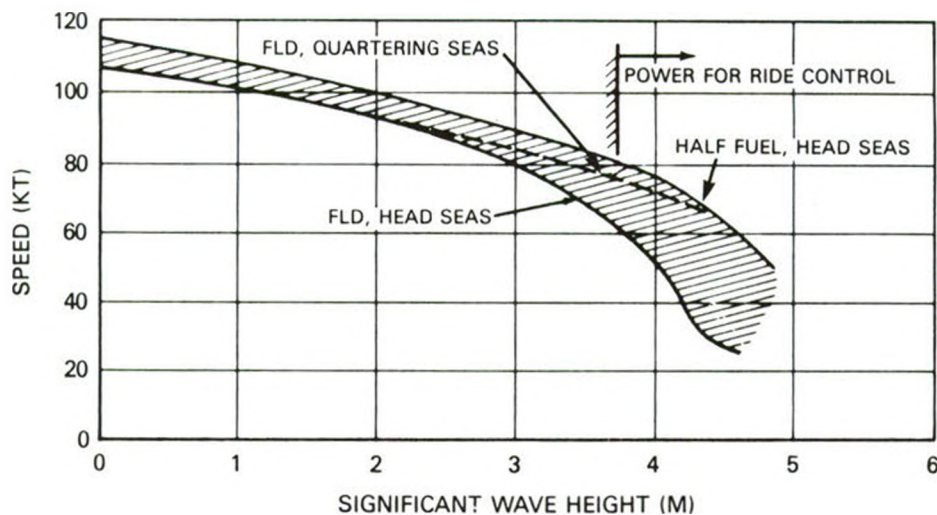
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(U) Figure V-2. SPEEDS OF SURFACE CONCEPTS IN 3000-TONNE DISPLACEMENT CLASS AT FULL-LOAD DISPLACEMENT IN HEAD SEAS



(U) Figure V-3. COMPARISON OF SPEED FOR 3000-TONNE CLASS



(U) Figure V-4. SES (SES 3) SPEED AT SEA UNDER VARIOUS CONDITIONS

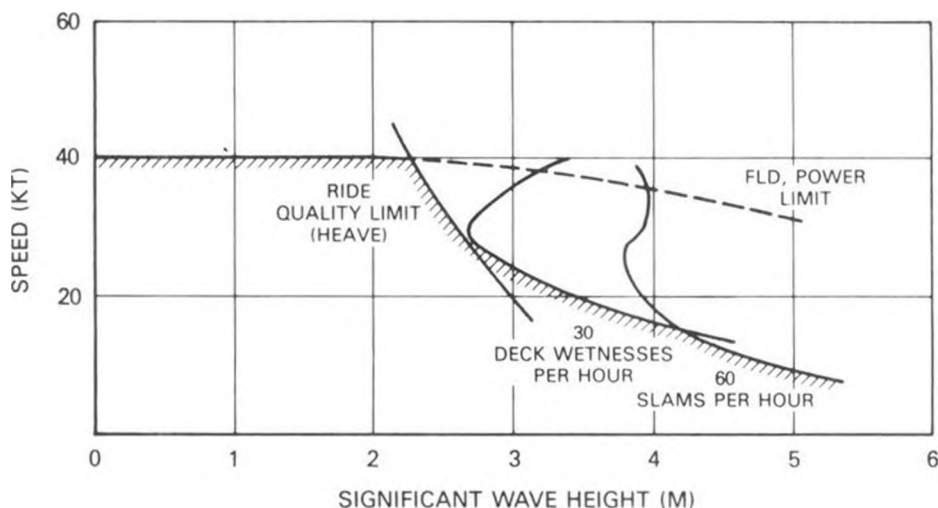
speed capability of the SES. These effects are illustrated in Figure V-4,* in which the shaded band covers all cases for the SES 3. The full-load displacement and head seas condition is represented at the lower edge of the band, and corresponds to the curve shown for the SES in Figure V-2; the conditions represented by the upper edge of the band are half-fuel displacement and head seas. A key consideration for all these conditions is the lift power requirements to pump sufficient cushion air back into the cushion to replace that pumped out by the wave action. This is a complex problem and insufficient definitive information is available to determine whether the ride quality (heave acceleration levels) is better with lighter loads. At a significant wave height of about 3 1/2 to 4 m, the question arises as to whether sufficient power is available to counteract the wave pumping while maintaining the desired low heave acceleration level for a lightly loaded SES.

(U) As shown, the speed of the SES in high sea states can be maintained better if the vehicle is allowed to steer off course and operate obliquely to the oncoming sea. However, such action has operational limitations since with its relatively higher speed (even in rough seas) such a maneuver could take the SES far off its originally prescribed course. The key point is that although speed is degraded in high sea states, even the degraded speeds of these vehicles are greater than that of the conventional displacement ship (monohull), as shown in Figures V-1 and V-2. To further emphasize this point, the speed-at-sea characteristics of the optimal, circa-2000 monohull, the MONO 3 point design, shown in Figure V-5 can be compared to the SES 3 shown in Figure V-4.

(U) The speed of the monohull displacement ship at sea is limited by different factors depending on the severity of the sea state. For wave heights between 2 and 3 m, the MONO 3 is limited in speed by its ride-quality limit, i.e., the point at which heave acceleration is still within acceptable limits. For wave heights between 3 and 4 m, the speed is limited by the criterion of 30 deck wetnesses per hour; for wave heights between 4 and 5 m, it is limited by hull slamming. The envelope

*Although the SES is used as the example, the ACV and SES are basically interchangeable in this discussion.

of all these curves, shown by the sawtooth line in Figure V-5, is the curve representing the monohull in Figure V-2.



(U) Figure V-5. MONO 3 SPEED-AT-SEA CHARACTERISTICS

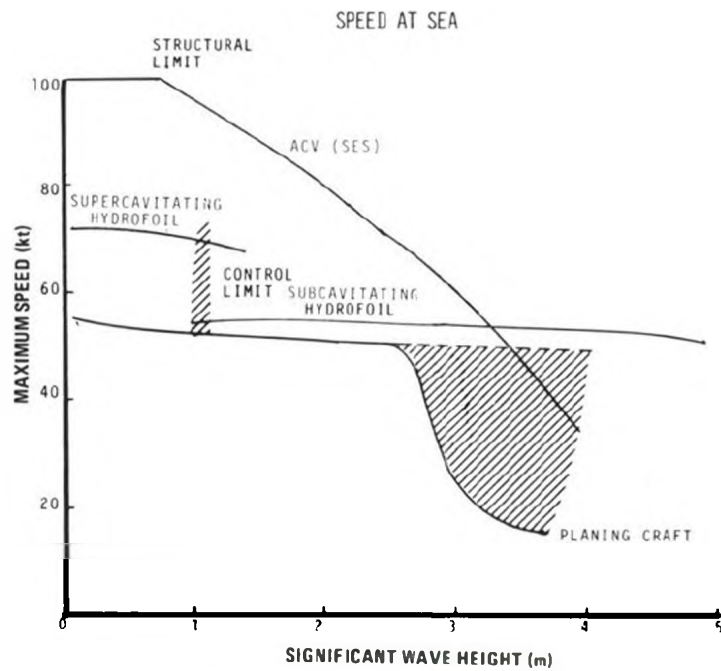
(U) If a hull form that does not have the hull slamming and deck-wetness problems of conventional ships can be developed, speeds of more than 30 kt could be achieved in 4- to 5-m seas by a ship (vehicle) of the 3000-tonne displacement class. Therefore, the ANVCE Project investigated the concept of a supercritical hull form (Chapter III, Section 3).

(U) The speed capabilities of the SWATH vehicle and hydrofoil concepts in the 3000-tonne class, shown in Figure V-2, are not degraded until wave heights are greater than those shown. Similarly, vehicles with smaller displacements have a greater speed degradation for the same sea conditions than do the vehicles with larger displacements, except for the hydrofoil. Figure V-6 shows this comparison for vehicles in the 1000-tonne displacement class. The high-speed hydrofoil (HYD 7) has a 70-kt capability and, conservatively, can maintain adequate control of the supercavitating foils in waves of about 1 m. The subcavitating speeds (up to 50 kt) can be maintained into extremely high seas. The large shaded region for the planing craft (PC 1) reflects the slamming and poor seakeeping of conventional planing hull forms. Again, the treatment of a supercritical hull form design for a craft of the 1000-tonne displacement class could well improve its speed capability in rough seas. (This issue is discussed in Chapter III, Section 3.3: no point design was developed to substantiate the conclusions of the analysis and model tests.)

1.2 Maneuverability

(U) Virtually all the advanced surface vehicle candidates have good maneuverability expressed in terms of tactical diameter per ship length. The relative maneuverability of these various concepts is compared in Figure V-7. The uncertainty shown for the SWATH concept results from incomplete data; however, there are indications that the SWATH vehicle maneuverability would be in the lower part of

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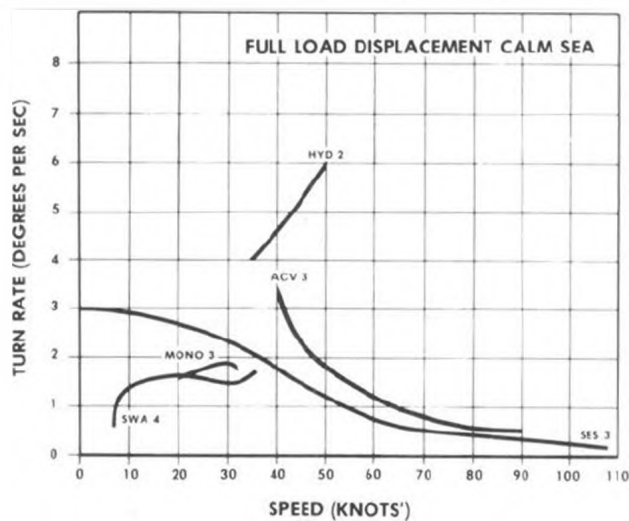
(U) Figure V-6. SPEED AT SEA FOR SURFACE CONCEPTS IN 1000-TONNE DISPLACEMENT CLASS

(b) (1)

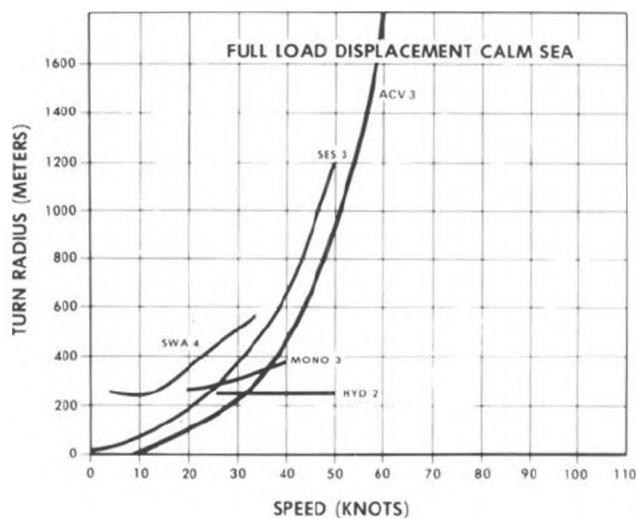
~~(C)~~ Figure V-7. MANEUVERABILITY OF SURFACE CONCEPTS (U)

the shaded region. As might be expected, as speed (reflected in the Froude number) is increased, maneuvering becomes increasingly difficult. Vehicles that cannot bank into a turn (ACV and SES) have larger turn radii than those that can (planing craft and hydrofoil). In terms of turn rate and radius (Figures V-8 and V-9), the point design concepts are comparable only at speeds of less than 40 kt and there are no remarkable differences. Above 40 kt, the hydrofoil is clearly superior to the aerostatic lift platforms. Insofar as acceleration and deceleration (Figures V-10 and V-11) are concerned, the aerostatic lift platforms have a definite advantage over the displacement vehicles.

(C) (b) (1)
(b) (1)

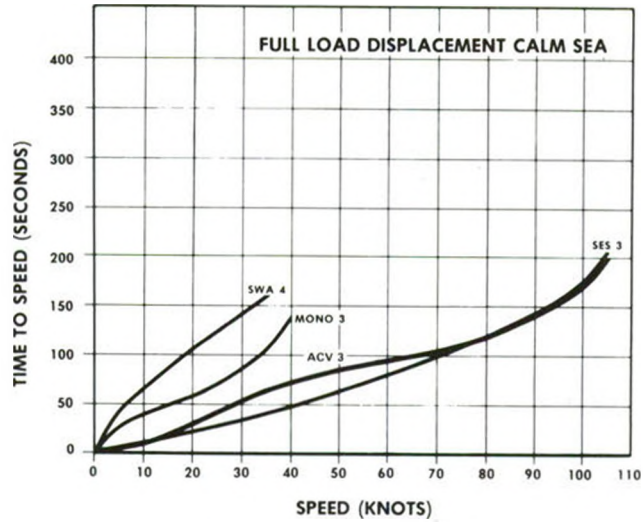


(U) Figure V-8. TURN RATE COMPARISON, 3000-TONNE CLASS

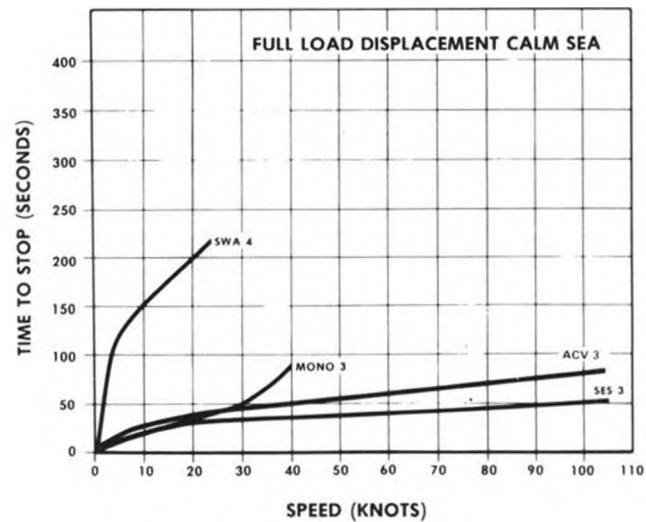


(U) Figure V-9. TURN RADIUS COMPARISON, 3000-TONNE CLASS

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(U) Figure V-10. ACCELERATION COMPARISON, 3000-TONNE CLASS



(U) Figure V-11. DECELERATION COMPARISON, 3000-TONNE CLASS

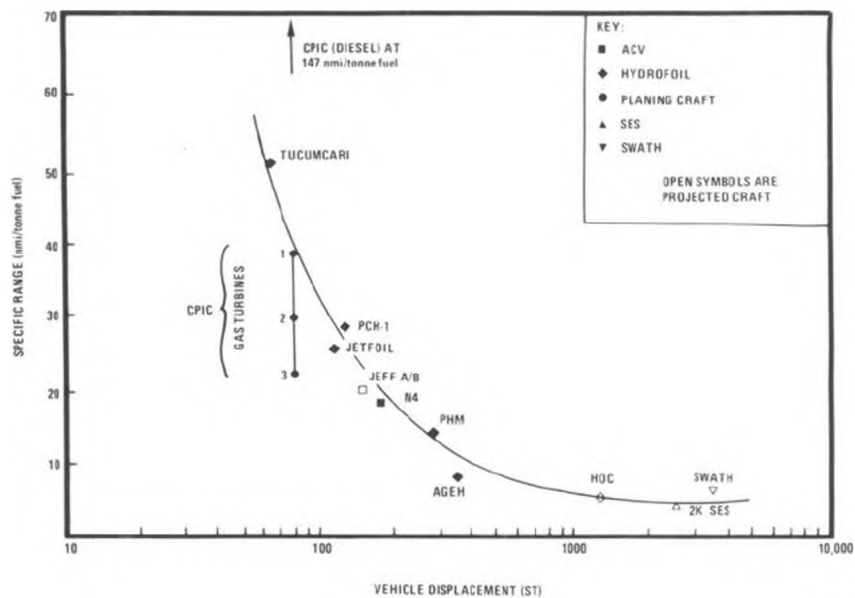
(b) (1)

1.3 Range Capability

(U) Each of the surface and air concepts has certain fundamental characteristics that affect its range capability. Based on these characteristics, reasonable assessments can be made of the state of the art. Fundamentally, the specific range capability (measured in nautical miles per tonne of fuel) of any vehicle decreases as size of the vehicle increases because of the proportional increase in power required to move the larger mass.

1.3.1 Surface Vehicle Concepts

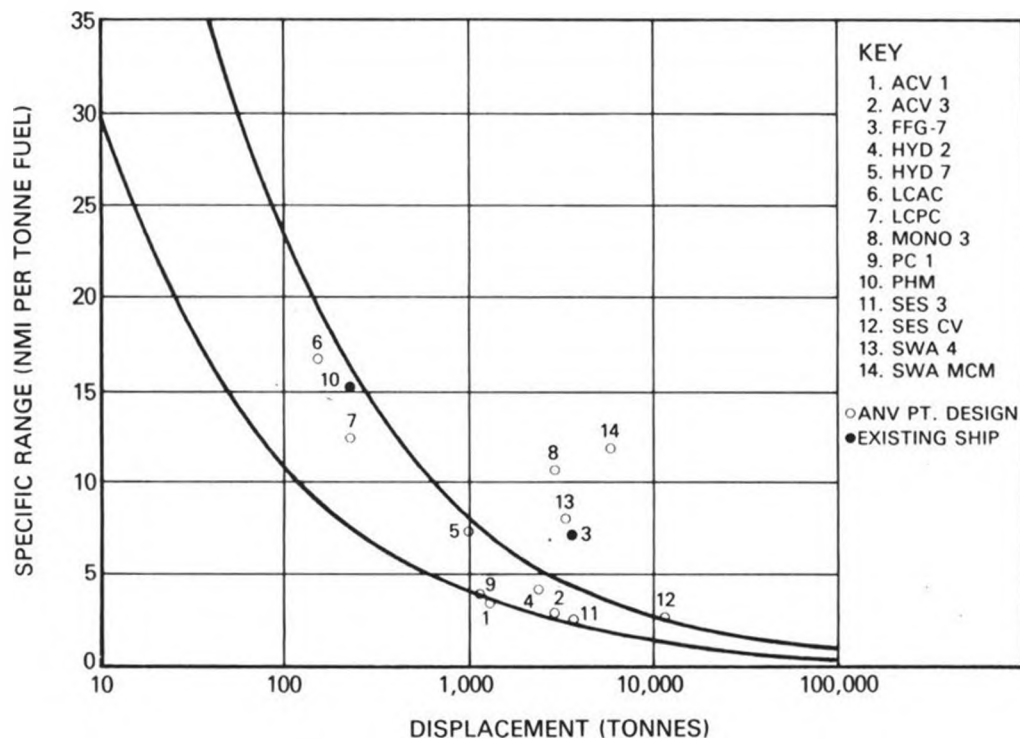
(U) Figure V-12 (prepared during the early stages of the ANVCE Project) shows the specific range of conceptual surface vehicles as a function of vehicle displacement. The specific range capability is primarily affected through changes in operating speed and propulsion system. As an example, in Figure V-12, the



(U) Figure V-12. SPECIFIC RANGE OF SURFACE VEHICLE CONCEPTS

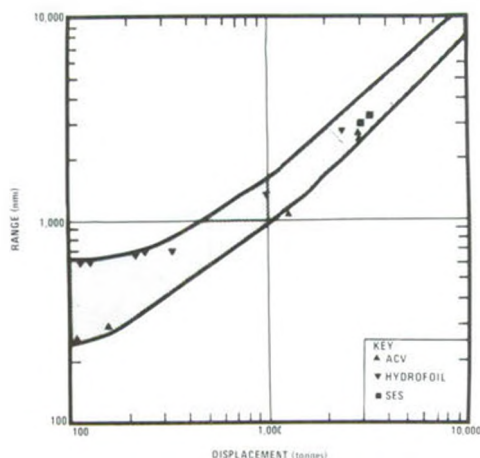
specific range for the CPIC is shown with one, two, or three turbines in operation and with diesel engines in operation (147 nmi/tonne). As size increases, however, these effects become increasingly more difficult to offset and the concept differences become less dominant.

(U) Figure V-13 is a plot similar to that of Figure V-12 except that it shows many of the point designs developed later in the project. Again, the characteristic trend may be seen. The slower-speed, displacement craft (SWATH concept and monohull) generally exhibit better specific range characteristics than the dynamic-lift vehicles (ACV and SES). As shown in Figure V-14, the actual ranges of the dynamic lift vehicles increase with size because of the larger fuel capacities. Again, the craft have proportionately greater range capabilities with smaller rather than larger displacements. In assessing the range capabilities of the conceptual vehicles, it was necessary that similar vehicles have common design standards. Thus, the groupings listed in Chapter II and referenced throughout Chapters III and IV were applied for this assessment.



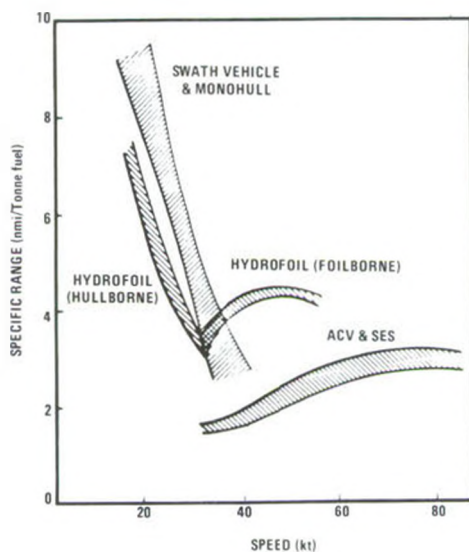
(U) Figure V-13. SPECIFIC RANGE OF SURFACE POINT DESIGNS

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(U) Figure V-14. ACTUAL RANGE OF DYNAMIC-LIFT CONCEPTS AS A FUNCTION OF DISPLACEMENT

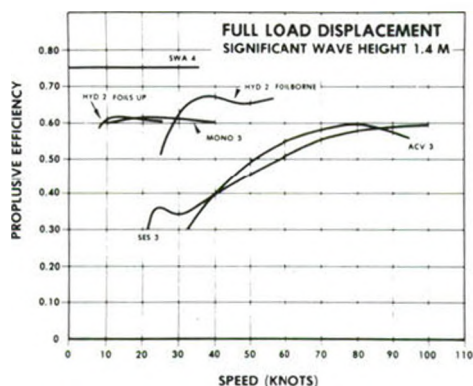
(U) Figure V-15 shows the specific range capabilities of the surface combatant group of the 3000-tonne displacement class. The broad bands cover the effects of operating at other than the nominal design weight and broaden the concept evaluation beyond specific vehicle characteristics. The displacement ships show the characteristic good fuel economy at low speeds (about 10-15 kt) but their fuel economy is degraded dramatically as speed is increased. The dynamic-lift vehicles



(U) Figure V-15. SPECIFIC RANGE CAPABILITIES OF SURFACE COMBATANTS OF 3000-TONNE-DISPLACEMENT CLASS

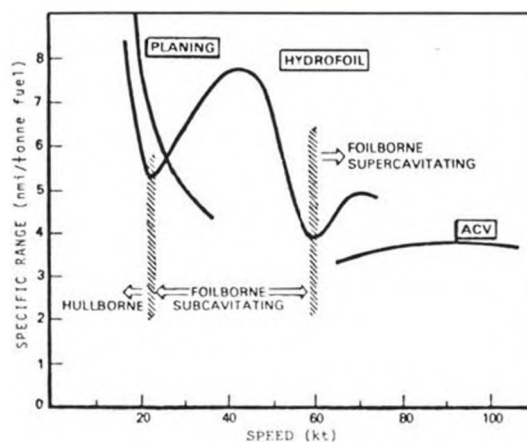
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as presently designed exhibit much lower fuel economy at low speeds but have much better fuel economy at their design speeds (about 60-80 kt). Figure V-16 shows the propulsive efficiency of the 3000-tonne group as a function of speed. Here again, the dynamic lift vehicles become more efficient with higher speeds.



(U) Figure V-16. PROPULSIVE EFFICIENCY OF 3000-TONNE SURFACE COMBATANT VEHICLES AS A FUNCTION OF SPEED

(U) The hydrofoil, whose specific range capabilities are shown in Figure V-15, is in reality a hybrid vehicle in that at low speeds it operates in its hullborne mode and has the economy of a displacement ship. Because its resistance is lower, at subcavitating foilborne speeds (up to 50 kt) the hydrofoil has better fuel economy than other conceptual vehicles. This particular feature was explored further in an examination of the 1000-tonne displacement class (Figure V-17). The features are

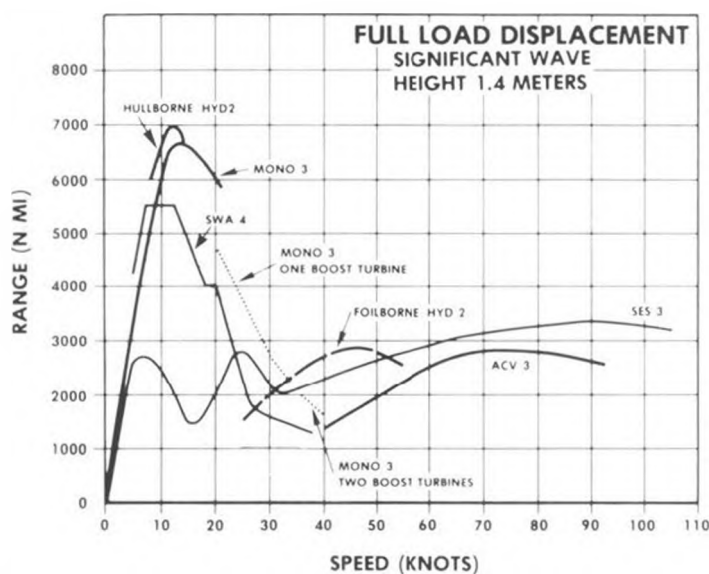


(U) Figure V-17. SPECIFIC RANGE CAPABILITY OF COMBATANTS OF THE 1000-TONNE DISPLACEMENT CLASS

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the same as those shown in Figure V-16, except that the hydrofoil supercavitating (above 60 kt) mode is added. In this mode, the hydrofoil exhibits even greater fuel economy. A hydrofoil that can move among the three modes (hullborne, subcavitating foilborne, and supercavitating foilborne) can operate with conventional ships in the fleet at high cruise speed (about 50 kt) or at very high dash speed (60-70 kt) and maintain good fuel economy in each mode. Figure V-17 indicates the need for R&D on the ACV and SES concepts in order that they can also provide good fuel economy in the lower speed range. Improvements in hull shaping could probably improve their fuel economy, but further research is needed.

(U) Figure V-18 shows the actual ranges of the 3000-tonne displacement class as a function of speed. This figure shows that displacement vehicles attain their best ranges at slow speeds; if, on the other hand, time is critical, the dynamic lift vehicles have the "sprint" range advantages in all but the most severe sea state as seen in Figure V-19. The hydrofoil is the most flexible vehicle in selection of ranges.



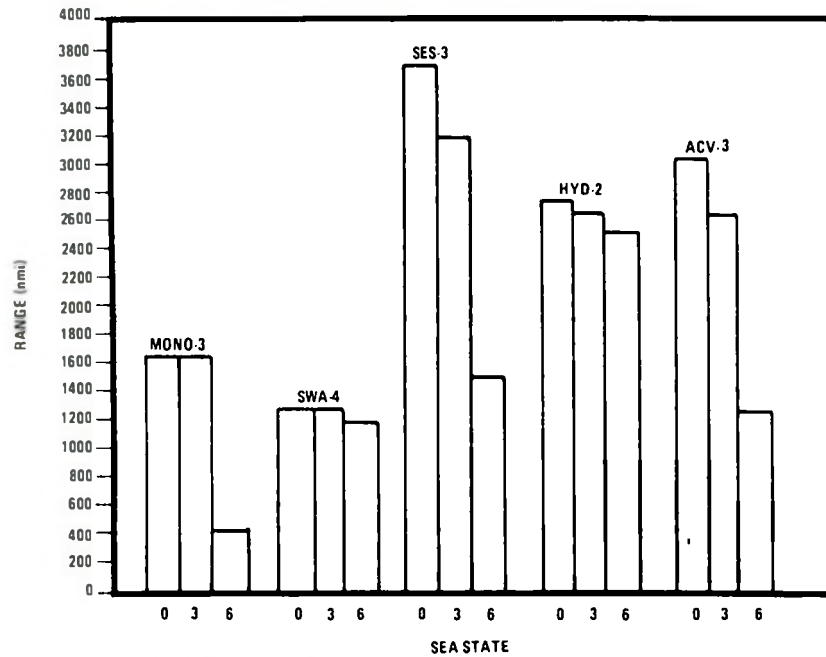
(U) Figure V-18. ACTUAL RANGE OF 3000-TONNE VEHICLES AS A FUNCTION OF SPEED

(U) In addition to the trade-off of range for speed and time on a ship with a fixed full-load displacement, range can be traded for payload as is shown in Figure V-20 for the 3000-tonne surface combat vehicles. Thus, while specific range is an excellent measure for comparisons across concepts, range capability is also mission dependent.

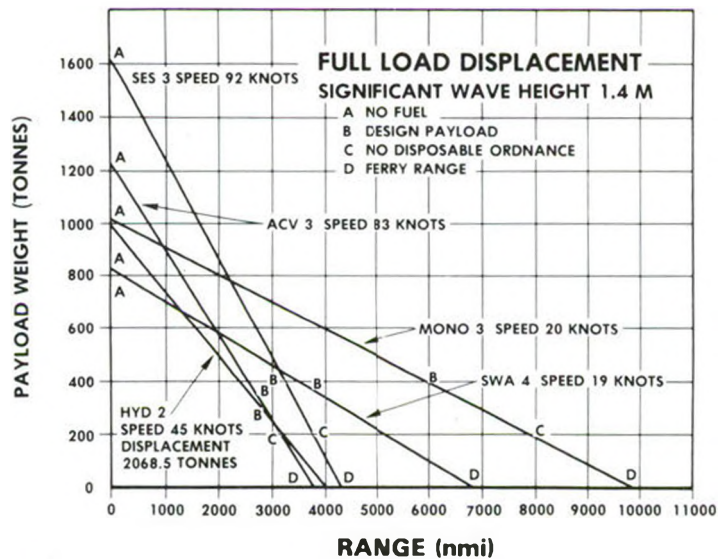
1.3.2 Air Vehicle Concepts

(U) A similar evaluation was made of the characteristic specific range capabilities of the air vehicle concepts (Figure V-21). The air vehicle concepts compared

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(U) Figure V-19. RANGE OF 3000-TONNE SURFACE COMBATANT VEHICLES AT MAXIMUM SPEED AS A FUNCTION OF SEA STATE

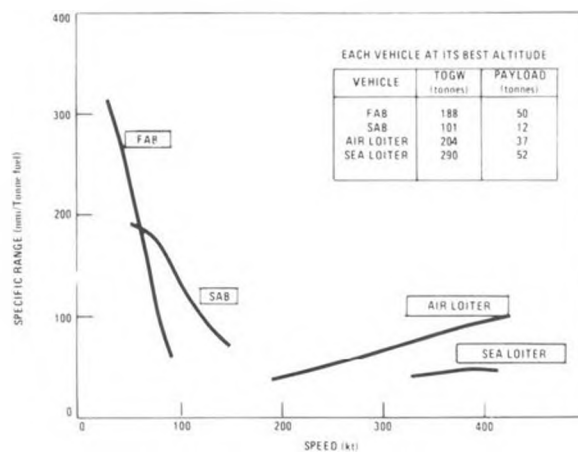


(U) Figure V-20. PAYLOAD WEIGHT AS A FUNCTION OF RANGE AND FOR 3000-TONNE SURFACE COMBATANT VEHICLES AT VARIOUS SPEEDS

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in Figure V-21 reflect the lack of a common payload among the early designs,* and since the specific range characteristic is dependent on the size of the vehicle, caution must be exercised in comparing these concepts. The box within the figure provides the size of the vehicles in terms of TOGW (takeoff gross weight) and the payload of each vehicle. However, with appropriate caution in comparing these concepts, the range curves are useful and informative.

(U) The FAB is extremely efficient at low air speeds (50-80 kt) but falls off in range capability as speed increases to just below 100 kt. In both the relative values of specific range for surface vehicles (Figure V-17) and air vehicles (Figure V-21), size has a strong impact. However, these plots are of vehicles that differ greatly in size. Yet, a small (236-tonne) PHM would be a comparably sized surface vehicle for comparison with the air concepts shown in Figure V-21, but it would have a specific range capability of only 10-20 nmi/tonne of fuel.

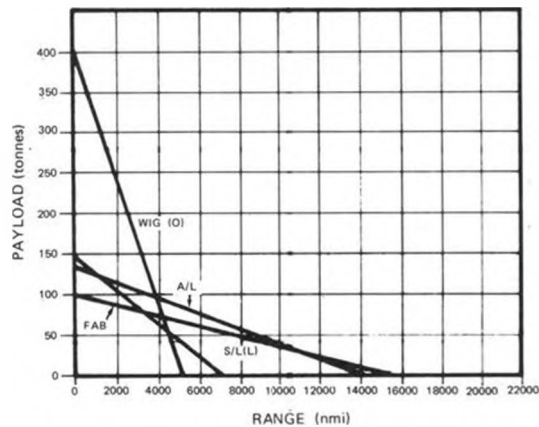


(U) Figure V-21. SPECIFIC RANGES OF AIR VEHICLE CONCEPTS AS A FUNCTION OF SPEED

(U) This discussion of the specific range characteristics of the air and surface concepts evaluated has concentrated on developing the basic *conceptual* differences and similarities. The range of a particular vehicle can vary depending on the fuel load and the amount of payload that can be sacrificed to increase the fuel load. Trade-offs such as that between payload and fuel are typical in the design process. Appendix B provides the normal payload/range charts for the final point designs used in the ANVCE Project analysis. A summary of the multimission air vehicles is given in Figure V-22.

*In evaluating the air vehicles, significant changes in both the composition of the combat suite and designs of the vehicles were necessary to give them a common comparative base.

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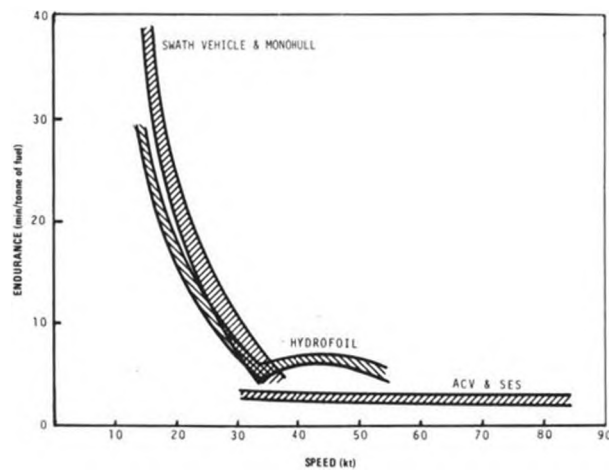
(U) Figure V-22. SUMMARY OF PAYLOAD CAPABILITY AS A FUNCTION OF RANGE FOR MULTIMISSION AIR VEHICLES

1.4 Endurance

(U) In order to be useful in a military operation a vehicle must have sufficient range without frequent refueling and endurance (the ability to loiter and spend time on station).

1.4.1 Surface Vehicle Concepts

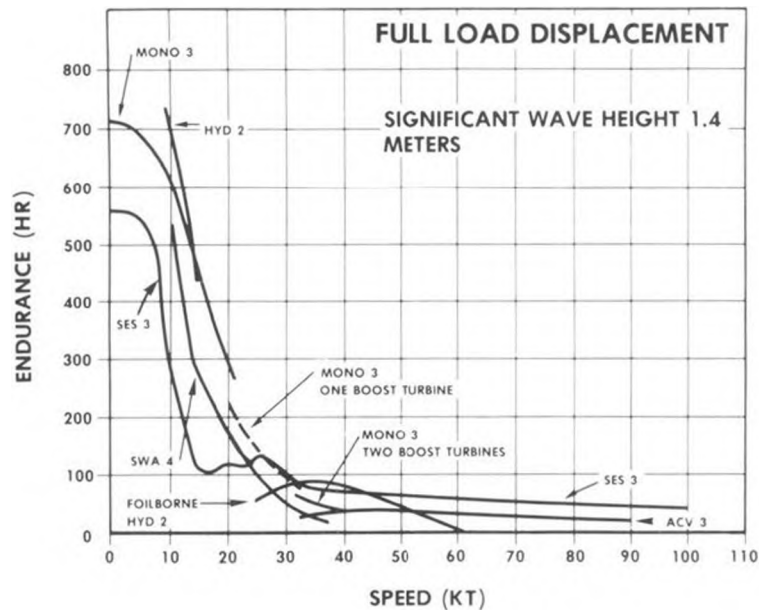
(U) For surface vehicles, endurance is relatively straightforward and is computed in a manner similar to range. Figure V-23 shows the endurance (in minutes per tonne of fuel) for the surface combatants in the 3000-tonne displacement class.



(U) Figure V-23. ENDURANCE OF SURFACE COMBATANTS IN THE 3000-TONNE DISPLACEMENT CLASS

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(U) Figure V-24 shows the same pattern for the 3000-tonne class as was seen for the range vs. speed graph. The same trade-offs can be made with endurance as with range. Figure V-24 displays the unique sprint-and-drift potential of the SES.



(U) Figure V-24. ABSOLUTE ENDURANCE OF 3000-TONNE CLASS SURFACE VEHICLES AS A FUNCTION OF SPEED

1.4.2 Air Vehicle Concepts

(U) For air vehicle concepts, the assessment of endurance or loiter capability becomes more complex when the air vehicle can loiter alternatively in the air or on the surface. In evaluating the air vehicles, significant changes in both the composition of the combat suite and the designs of the vehicles were necessary to give them to a common, comparative base. (These final designs used in the analyses are presented in Appendix B.) This need to standardize was particularly true within the multipurpose air combatant group, and these changes had a major impact on fuel and time on station (TOS). Table V-1 summarizes these revised designs. It was found that the multipurpose air vehicles could be best grouped within either a 1-day TOS or a 4-day TOS, as indicated in Table V-1. These modified point designs were matched to mission profiles that were compatible with the common combat suite (Appendix A). Obviously, the basic point design presented in Appendix B can be varied in many ways to change the payload weight, radius, and TOS.

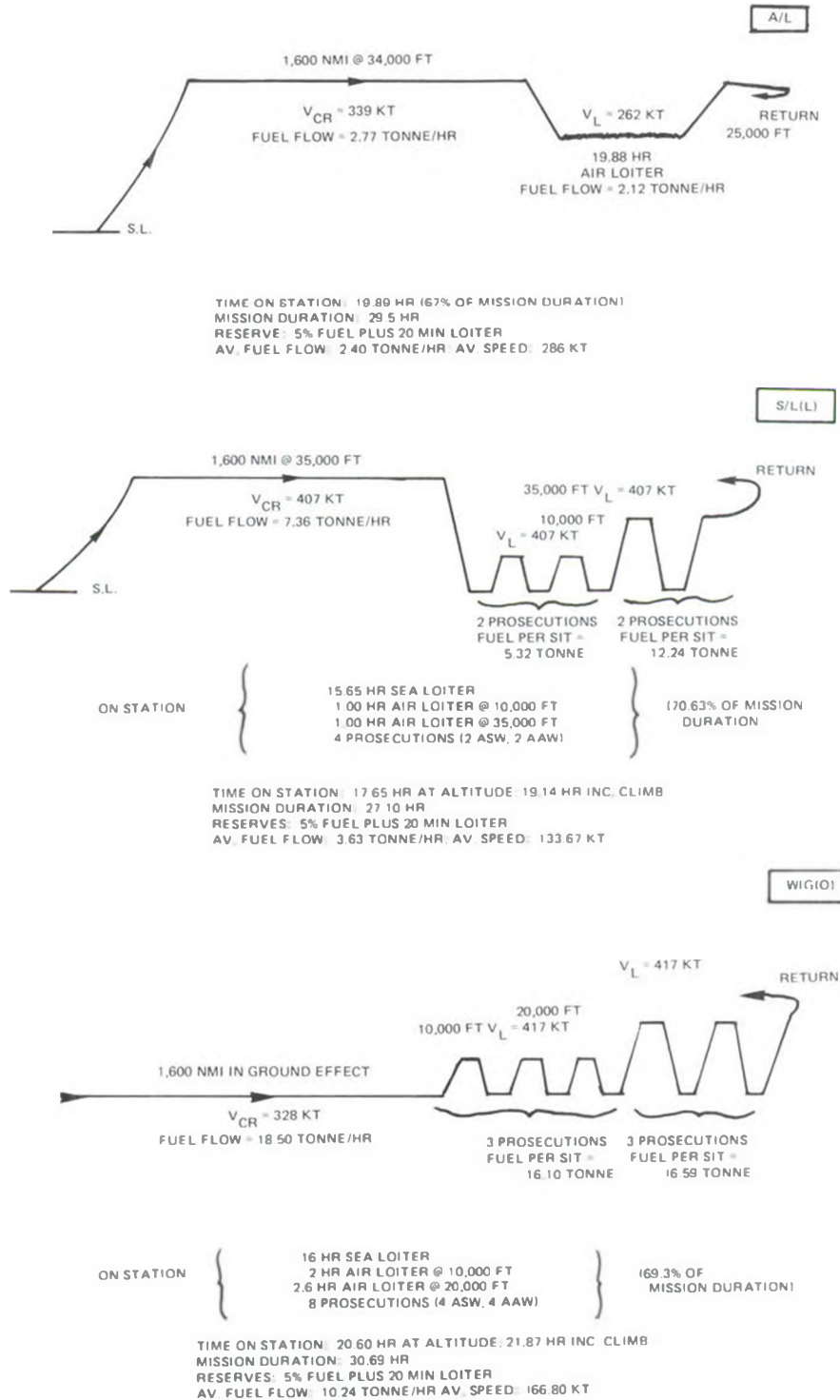
(U) The mission profiles for the 1-day TOS group are shown in Figure V-25. As shown, the S/L(L) and WIG(O) conceptual vehicles spend approximately the same percentage of time on station (70 percent of mission duration) as the A/L

(U) Table V-1. LEADING PARTICULARS OF FINAL, MODIFIED POINT DESIGNS

Leading Particulars	A/L (TOS = 1 day)	S/L(L) (TOS = 1 day)	WIG(O) (TOS = 1 day)	A/L(N) (TOS = 4 days)	FAB (TOS = 4 days)
TOGM	203.83 tonnes	209.86 tonnes	535.55 tonnes	559.83 tonnes	187.86 tonnes
SITE					
Overall length	174.08 ft	205.83 ft	288.33 ft	260.17 ft	783 ft
Overall beam/span	53.06 m	62.74 m	87.88 m	79.30 m	239 m
Volume	249.6	233.65	119.4	340.65	164
POWER					
Propulsion	4 STS-487A-12,500 shp	4 Fanjet/45,949 lb ^a	6 BPH 37,900 ^a Turbopan	4 BPR 13 76,500 lb ^a Turbopan	9.32 x 10 ⁶ ft ³ (263,900 m ³)
Engine/Power					4 QT/1,055 hp 1 Diesel/205 hp 1 Diesel/715 hp
Total Power	4 (12,500) - 50,000 shp	4 (45,949) = 183,796 lb ^a	6 (37,900) - 227,400 lb ^a	4 (76,500) - 306,000 lb ^a	4 (1,055) = 4,220 1 (715) = 715 1 (205) = 205 5,140 hp
SPEED					
Max./alt.	398.8 kt/20,500 ft ^b	406.7 kt/35,000 ft	445 kt/12,000 ft	411 kt/35,000 ft	80 kt/10,000 ft
Cruise/alt.	359 kt/14,000 ft ^b	406.7 kt/15,000 ft	417 kt/20,500 ft	407 kt/15,000 ft	50 kt/10,000 ft
Loiter/alt.	262 kt/36,000 ft ^b	330 kt/20,000 ft	285 kt/0 ft	407 kt/15,000 ft	30 kt/10,000 ft
PAYLOAD/RANGE ^c					
Payload/Weight	37.98 tonnes	16.51 tonnes	48.28 tonnes	74.02 tonnes	61.31 tonnes
Radius/TOGW	1,600 nmi/19.88 hr	1,600 nmi/19.14 hr	1,600 nmi/21.87 hr	1,600 nmi/96 hr	1,600 nmi/96 hr

^aSea level static thrust.^bTOW is less than 40 percent of the full load weight.^cIn sea state 3, M_{1/3} equals 1.4m.

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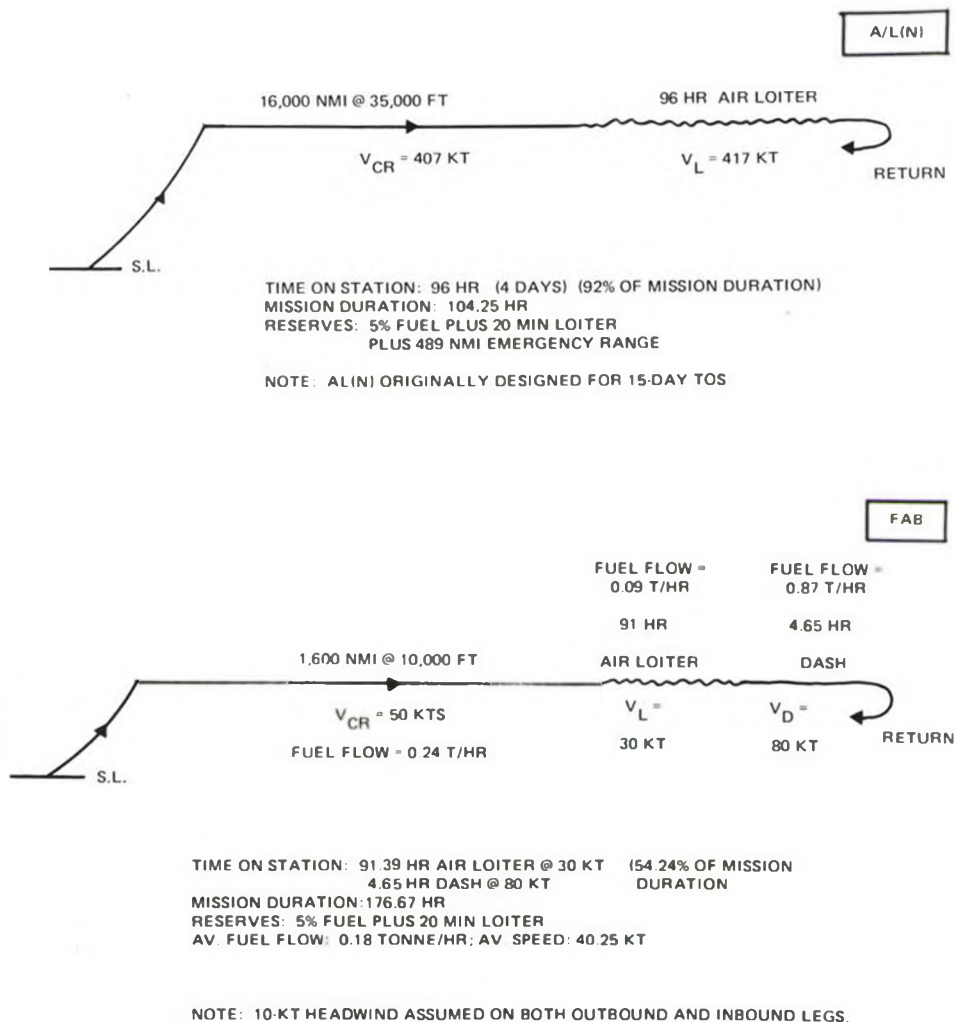


(U) Figure V-25. MISSION PROFILES FOR MULTIMISSION AIR VEHICLES
IN 1-DAY TOS GROUP

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but included in the TOS for the S/L(L) and WIG(O) are climbs to altitude (10,000 ft for ASW prosecutions and 20,000 ft for AAW prosecutions). A similar set of results for the 4-day TOS group is shown in Figure V-26.

(U) Figures V-25 and V-26 indicate a strong interdependence between the combat suite composition and the time on station. Although the fuel consumption of the "sea sitters" is minimal while loitering on the sea surface, considerable fuel is expended in climbing to altitude to take full advantage of the combat suite carried. Thus, the TOS capability of the sea-sitting concepts depends on the composition of the combat suite carried.

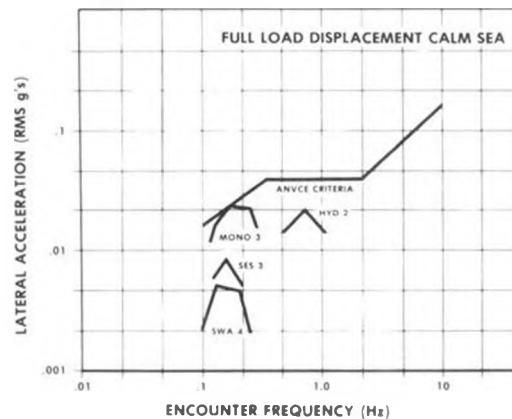


(U) Figure V-26. MISSION PROFILES FOR MULTIMISSION AIR VEHICLES OF 4-DAY TOS GROUP

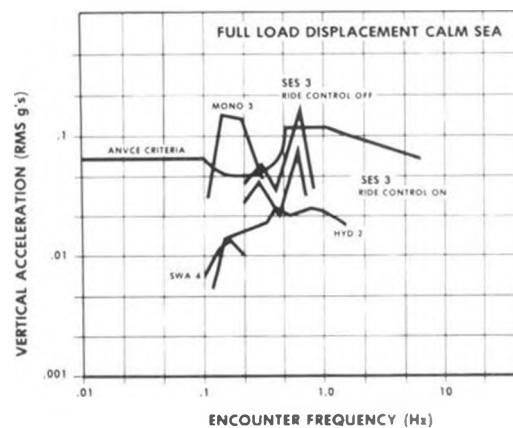
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1.5 Ride Quality

(U) With the introduction of such diverse concepts as ACV, hydrofoil, planing craft, SES, SWATH ship, sea loiter aircraft, and WIG vehicle, the ride quality of the conceptual vehicles varies greatly. As noted in Chapter III, the ANVCE Project developed ride-quality criteria based on crew acceptability. These criteria are shown in Figures V-27 and V-28 and compared with the ride quality of the 3000-tonne surface point designs.



(U) Figure V-27. LATERAL ACCELERATION AS A FUNCTION OF ENCOUNTER FREQUENCY



(U) Figure V-28. VERTICAL ACCELERATION AS A FUNCTION OF ENCOUNTER FREQUENCY

(U) Considerably more research is needed in this area, not only in the field of human tolerance but also on the subject of aircraft handling and fleet operations (see R&D Recommendations, Chapter VI).

2. VEHICLE OPERATIONAL USEFULNESS CHARACTERISTICS

2.1 Payload Capacity

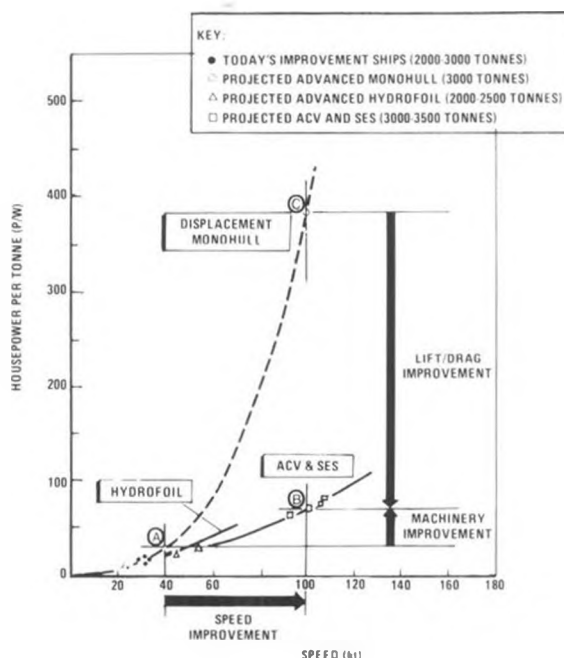
(U) The foremost requirement for a military vehicle is that it be able to carry the payload required for some mission. Its payload capability—the amount of payload it can carry—depends on the extent to which the weight of the vehicle can be reduced without jeopardizing other requirements and the fuel carried can be reduced without losses in range and power.

2.1.1 Power

(U) The power required to propel the conceptual surface or air vehicle is a principal design factor since it has an impact on the basic cost of the vehicle, its ability to carry a given payload, and its operating (fuel) costs.

(U) Technically, power is examined in terms of (a) the horsepower per tonne to attain a given speed and (b) the amount of power required to transport a given mass (vehicle) at a certain speed (efficiency). Reducing the power required (or increasing the transport efficiency) while not increasing other variables such as weight and cost is a major objective in any design and is frequently the reason for seeking new concepts. There is extreme reluctance to accept a design that forfeits some efficiency to provide or enhance some other capability.

(U) Figure V-29 shows the horsepower per tonne required to propel the displacement monohull (current and future), hydrofoil, and ACV and SES at their respective design speeds. This particular set of curves is for a common set of displacements (approximately 3000 tonnes), which eliminates the impact of size differences. Figure V-29 illustrates one of the main features of the dynamic lift concepts (hydrofoil, ACV, and SES)—a significant savings in the power that is required to propel a displacement ship through water. As shown, the power per tonne required for a conventional monohull displacement ship increases at a rate approximately proportional to the speed cubed. For the dynamic lift vehicles, the horsepower required per tonne is lower than that required by displacement ships although the difference becomes less pronounced for dynamic lift vehicle of more than 3000-4000 tonnes. For example, the best monohull that can be designed can achieve 40 kt with installed propulsion power at approximately 30 hp/tonne (Point A in Figure V-29). If, however, mission requirements dictate a 100-kt requirement, this need is best met by an ACV or SES, with an installed power plant at approximately 75 hp/tonne (Point B). This increase in speed from 40 to 100 kt is not the result of better machinery (providing 75 hp/tonne instead of 30 hp/tonne) because, as Figure V-29 shows, to propel a displacement hull at 100 kt would require approximately 375 hp/tonne (Point C in Figure V-29); even with lightweight, gas-turbine installations, the weight of the power plant would be greater than the displacement of the ship being propelled. On the other hand, if the ACV and SES concepts were restricted to the same conservative power plants used in displacement ships, the speed capability of these concepts would still be 60 kt.



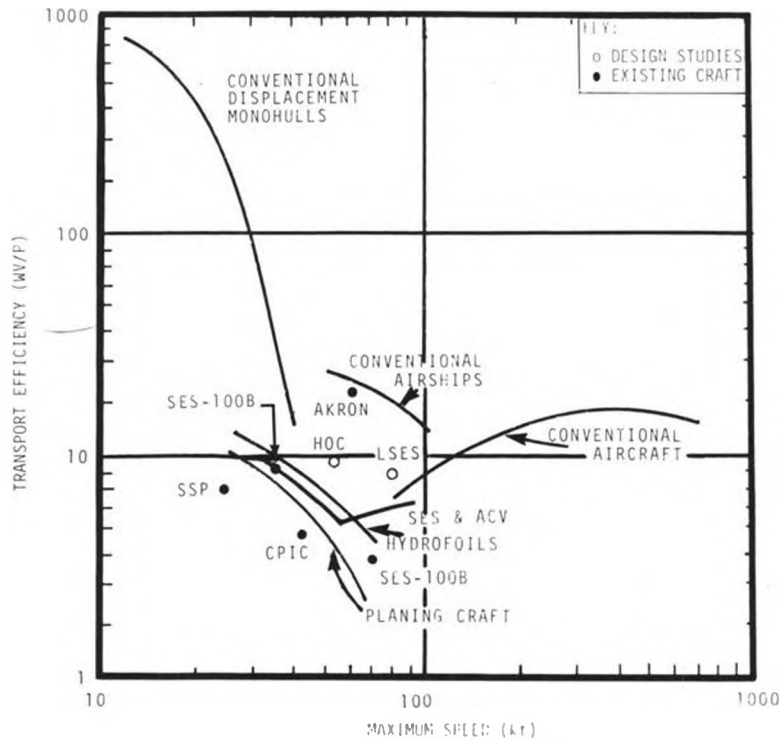
(U) Figure V-29. HORSEPOWER PER TONNE REQUIRED FOR SURFACE VEHICLE CONCEPTS

(U) Since the power requirements depend on both size (weight) and speed, it is more correct to establish parametrically the bounds of the combined parameter for each concept. The transport efficiency,

$$\frac{WV}{P}$$

is the ratio of the work done by a vehicle of weight (W) traveling at a given speed (V) to the total installed power (P) required to meet this condition. Each concept has characteristic state-of-the-art boundaries of the WV/P , against which new versions of the concept can be evaluated.

(U) Figure V-30 shows the transport efficiencies of the surface and air concepts under evaluation as well as the reference craft (past, present, and projected designs). The transport efficiency generally increases as size increases and as technological improvements are made, provide the improvement to the concept does not have an adverse effect on its economy.



(U) Figure V-30. TRANSPORT EFFICIENCIES OF SURFACE AND AIR CONCEPTS

(U) For example, in considering the range equation,

$$\text{Range} = \left(\frac{\text{constant}}{\text{specific fuel consumption}} \right) \left(\frac{WV}{P} \right) \ln \left(\frac{\text{initial weight}}{\text{final weight}} \right)$$

or

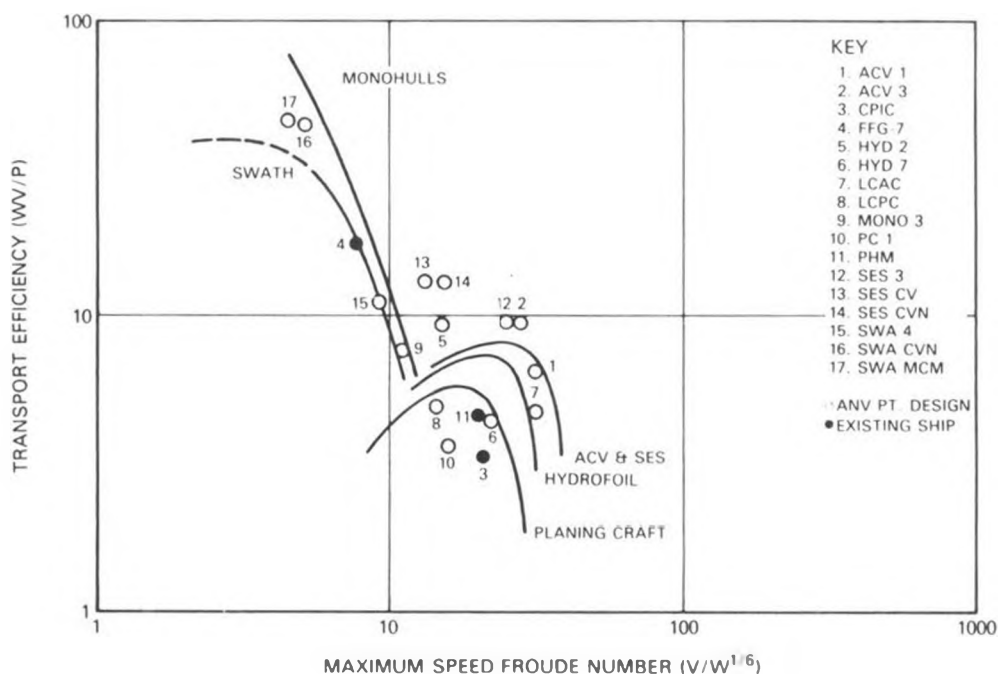
$$\text{Range} = \left(\text{constant} \right) W \left(\frac{\text{nautical miles}}{\text{tonnes of fuel}} \right)$$

If the concept is to be designed for long-range operation, solutions must be sought to the standard design problem of increasing WV/P and increasing the weight fraction (by lowering the ratio of final, empty weight to initial weight). The particular problem with a high-speed concept is how to increase speed without excessively increasing the power to the point of reducing the transport efficiency and increasing the empty-weight fraction. Figure V-29 and V-30 illustrate the trends and concept options in reducing the power requirements. Weight reduction is discussed in the next subsection.

(U) However, not all vehicle concepts are designed for long endurance; in some missions other characteristics such as speed and maneuverability take precedence over high values of WV/P or low power requirements. An example of this differentiation is the difference between bomber and fighter aircraft in terms of power, weight, speed, and range.

(U) For those concepts emphasizing such factors, the following figures show how well the proposed ANV concepts fare in terms of transport efficiency and power requirements, as indicated by the various point designs. From Figure V-31 the hydrofoil and ACV and SES concepts may be compared. To minimize the scale effect, the speed of each vehicle has been normalized into a pseudo-Froude number. As shown, the ACV 1 and LCAC would be considered conservative and within the current state of the art. The SES designs (SES 3, SES CV, and SES CVN) along with the large ACV (ACV 3) are regarded as technically feasible extensions of the state of the art. The increased power requirements of the supercavitating, variable-geometry, high-speed hydrofoil (HYD 7) is a degraded value from the state of the art of subcavitating (50-kt) hydrofoils. This degradation is not pronounced, however, and is not considered detrimental, especially if R&D improvements can improve the foil characteristics (Chapter III, Section 2). The large, subcavitating hydrofoil (HYD 2) is also seen to be technically feasible in terms of the power requirements; however, the associated weight of the subsystems is a problem, as discussed in Chapter III, Section 2.

(U) Figure V-31 also shows the transport efficiency values for the SWATH concept. While there are some differences in the powering requirements between SWATH ships and monohull ships (Chapter II), the functional variation with speed is very similar, and the SWATH designs (SWA 4, SWA CVN, and SWA MCM) are conservative designs technically feasible in terms of powering requirements. The high speed of the SWA 4 is obtained by adding power to the craft without any major conceptual change. It is not beyond today's state-of-the-art boundary and requires only a little more power than monohull ships of the same displacement and speed.



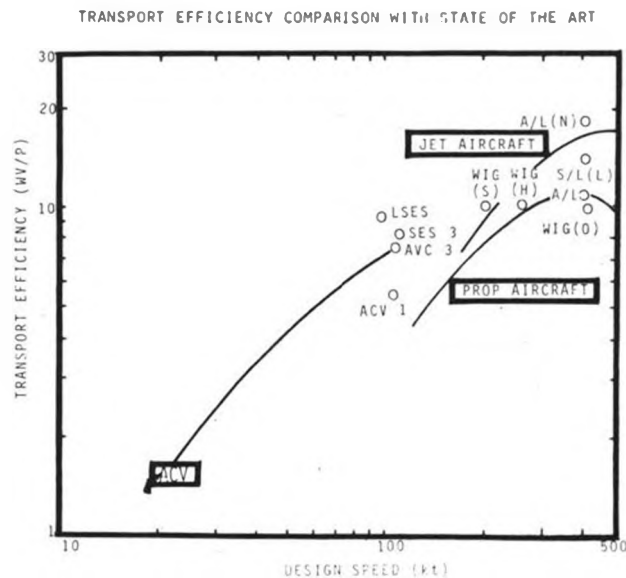
(U) Figure V-31. TRANSPORT EFFICIENCIES OF ADVANCED AND EXISTING NAVAL VEHICLES

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(U) For the advanced-technology monohull (MONO 3), the improvements in speed (40 kt compared to the 30 kt of current ships) are obtained by merely adding more power to the ship. The improvements in technology, therefore, have been directed at removing weight from the ship (for example, the use of an aluminum hull design) to offset the increased weight of the power plant.

(U) The transport efficiencies of planing craft concepts are also shown in comparison with a state-of-the-art craft (CPIC) in Figure V-31. The analysis of the power requirements for the planing craft has yielded a rather surprising result. Compared to the state of the art and the designs of small planing craft of Great Britain, Germany, and other European nations, U.S. planing craft designs are quite conservative. The normal scale advantage in power requirements was not gained in the case of the large planing craft (PC 1), with a displacement of 1127 tonnes, because of the offsetting effects of retaining planing characteristics for a craft of this size with a speed of 50 kt. Again, the analysis that could be conducted within the ANVCE Project was not sufficient to determine whether it is possible to design a hull form that could offset such large power requirements.

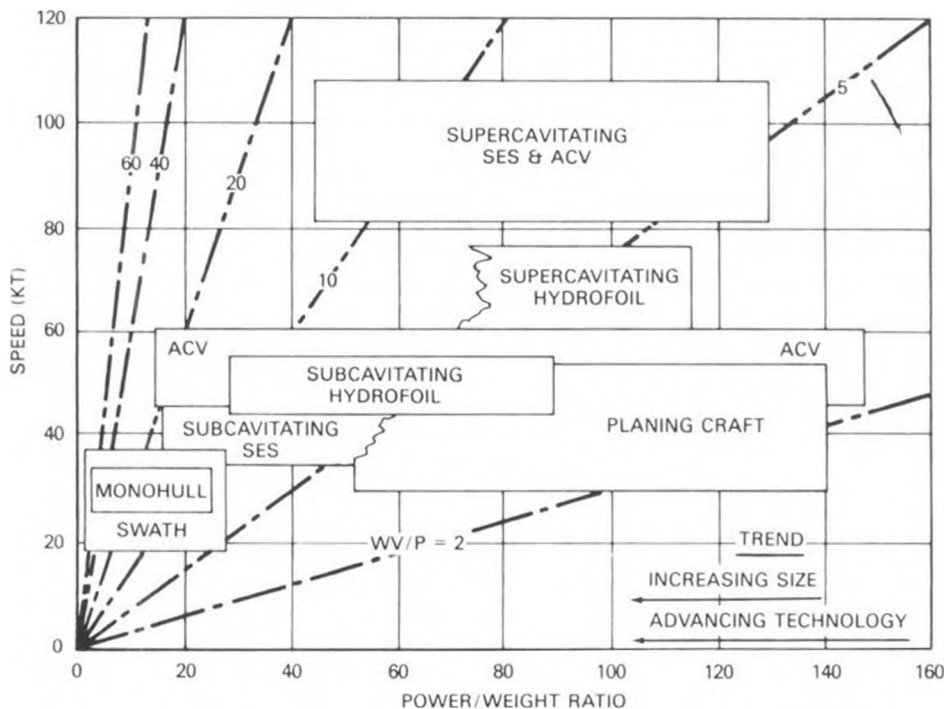
(U) Comparisons were also made among conceptual surface and air vehicles designed for long-range operations. Figure V-32 shows the transport efficiency of the air loiter vehicles (A/L and A/L (N)) and the three WIG vehicles [WIG(O), WIG(H), and WIG(S)] in comparison with the high-speed surface concept point designs (ACV 1, ACV 3, LSES, and SES 3). Aerodynamically, the two air loiter aircraft are straining the state of the art. The WIG vehicles, on the other hand, have very similar power requirements to conventional aircraft. The aerodynamic



(U) Figure V-32. AIR AND SURFACE VEHICLE TRANSPORT EFFICIENCY COMPARISONS

advantage of flying in ground effect has been offset by the power requirements for the power augmentation feature and by the need for structural compactness in order to survive in a seaway. While the compactness of the structure degrades the aerodynamic efficiency (lower-aspect wing designs), shown in Figure V-32 in terms of power requirements, hopefully it allows a lower structural and empty weight fraction such that a greater payload/range capability can be achieved. As discussed in Section 4 of Chapter IV and in the next subsection of this chapter, the highest risk in technical feasibility is in terms of weight rather than the high power requirements.

(U) In terms of the surface concepts, an assessment of the power requirements for the various concepts evaluated indicated definite trends. While the data points have been omitted for clarity, Figure V-33 shows the general boundaries of the power/weight ratio and speed for each of the major forms of concepts evaluated. The rectangular boundaries cover all vehicles built or projected to date. As technology improvements occur and size increases, the general trend is to collapse toward the ends of the boundaries on the left-hand side of the figure. The speeds shown are the calm-water speeds; the degradation of speed with sea state has been discussed in Section 1.1 of this chapter. Similar charts for the air vehicle concepts are not as illuminating because of the much more restrictive ranges in data sampling and performance.

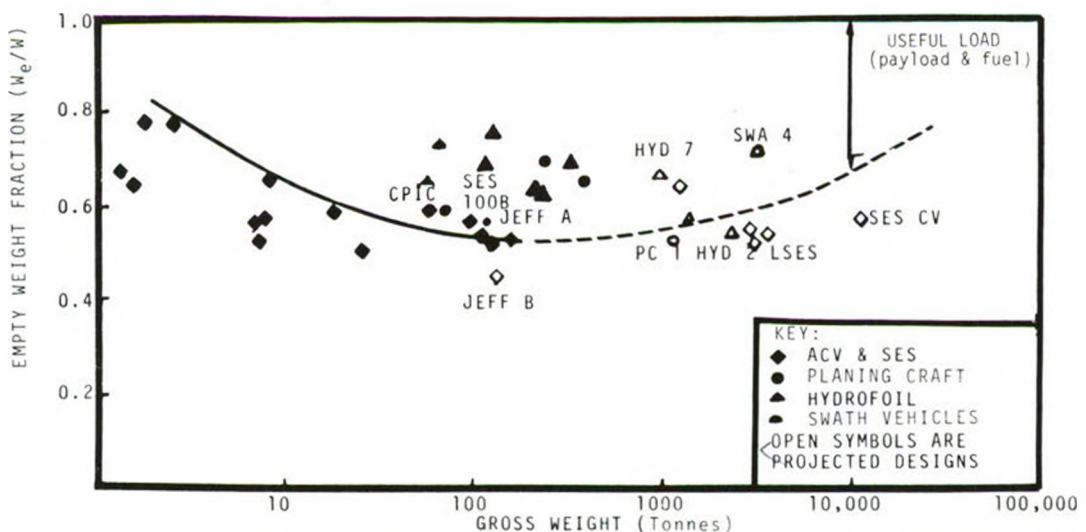


(U) Figure V-33. POWER/WEIGHT RATIO AND SPEED
OF SURFACE CONCEPTS

2.1.2 Weight

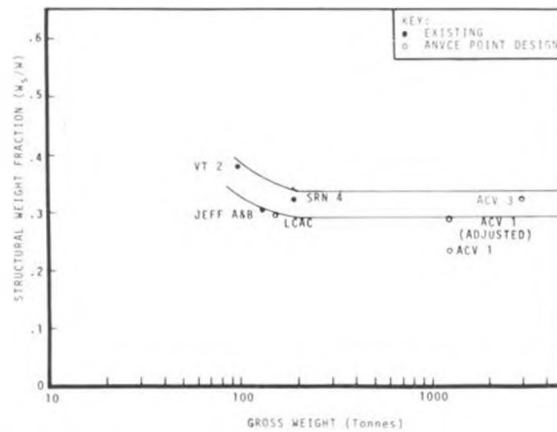
(U) The weight predictions for both surface and air vehicles were investigated during the point design feasibility studies. Projections of improvements in materials, power plants, and other systems elements were also taken into account in those investigations. Such advancements in technology were applied to all possible points so that the designs would all meet common standards for proper comparisons.

(U) The analysis of all of the seven subsystems of every concept showed some general trends in the findings. For example, Figure V-34 shows the empty weight fractions, where empty weight is the total gross weight minus useful load (payload and fuel),* for the surface vehicle concepts. The figure indicates that useful load capability is reduced as displacement is increased beyond about 500-1000 tonnes. However, each concept has its own characteristic curve and a detailed assessment of the seven subsystem elements comprising the empty weight (structure, propulsion, armament, etc.) was made to determine technical feasibility. This assessment of only the structural weight of the air cushion vehicles is shown in Figure V-35. In this particular case, the original ACV 1 point design developed was found to be far too optimistic in view of the state of the art and the lack of potential technological improvements. Accordingly, the value of the structural weight of the ACV 1 was adjusted. To avoid invalidating the point design process, the gross weights or full-load displacements (FLD) were retained and weight adjustments made "internally" to either subsystem weights or fuel as necessary. In the case of the ACV 1, a common payload (combat suite) was desired for the analyses performed; therefore, a trade-off was made in fuel load, reducing the range of the vehicle.



(U) Figure V-34. EMPTY WEIGHT OF SURFACE VEHICLE CONCEPTS

*Detailed accounting used in the analysis included crew and effects, potable water, etc.; however, for purposes of this discussion, only payload and fuel (the two major factors) are considered.



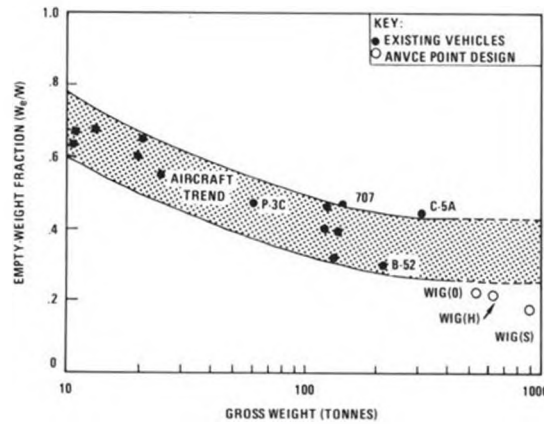
(U) Figure V-35. STRUCTURAL WEIGHTS OF AIR CUSHION VEHICLES

(U) A similar technique was used for the air vehicles; Figure V-36 shows the empty weight fraction of the WIG vehicles. Since there is no reliable data base on the WIG vehicles, a comparative technique was used. The state-of-the-art, conventional aircraft (and seaplane) weights were analyzed and compared with those of the WIG vehicles. Based on this comparison, the conceptual WIG vehicles tend to have a greater weights because the airframes must be strengthened to withstand wave impacts, but this weight tendency is offset by the more compact structure in using lower-aspect-ratio wings. The WIG(O), WIG(H), and WIG(S) point designs as shown in Figure V-36 imply that the two opposing weight factors result in a new weight fraction that is less than that of a conventional airframe constrained to fly at altitude. The Navy Program Office doubled the contractor-supplied values of structural weight to apply a more "realistic" value to the WIG structure estimates, and these increased values were used in the analysis. However, at present the structural weight of WIG vehicles cannot be estimated with any degree of accuracy, and because of the disagreement within the technical community further research is needed in this area.

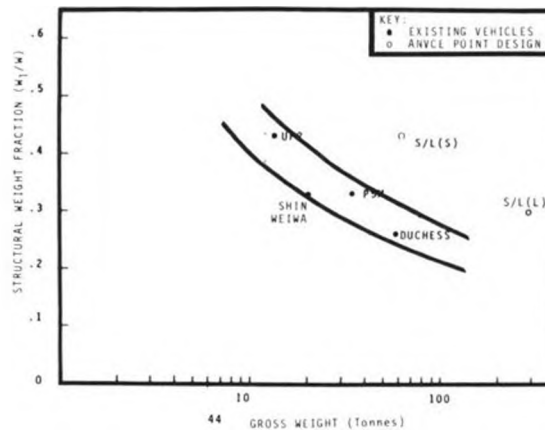
(U) Because of the high power requirements and fuel consumption of many of the high-performance vehicles, the empty weights of these vehicles tend to be high, limiting their payload capabilities. Payloads were typically 5-10 percent of the full gross weight of the vehicles; thus, critical review of the various weight groups or subsystem weights was necessary to evaluate the relative trade-off between an expensive but lightweight subsystem (with increased payload capability) and a lower cost but heavier subsystem (with a reduced payload capability). Accordingly, detailed reviews were made of all the subsystem weights of each of the point designs to assess whether, given their stated performance and technological advancements, the designs appeared feasible.

(U) Many of the weight trends have been shown throughout this volume in demonstrating various points and, therefore, will not be elaborated upon here. However, two examples have been selected to illustrate the technique used in the analysis. The first example is the sea loiter concept, in which both the S/L(S) and the S/L(L) are extensions of the familiar seaplane in terms of configuration. In comparing the structural weight of these two particular designs, it was found that they exhibited a higher weight fraction than their seaplane counterparts within the current state of the art, as shown in Figure V-37. An evaluation of the designs

revealed several reasons for why these concepts had the higher weights despite the use of improved (higher strength-to-weight ratio) structural materials. Because the sea loiter concepts are designed for sea states higher than those that can be safely encountered by seaplanes, they have higher structural loadings. In the case of the S/L(L), the catamaran configuration also contributes to a higher weight fraction, which more than offsets the weight savings gained through use of advanced structural materials. In the case of the S/L(S), conservatism in the design has contributed to the higher weight.



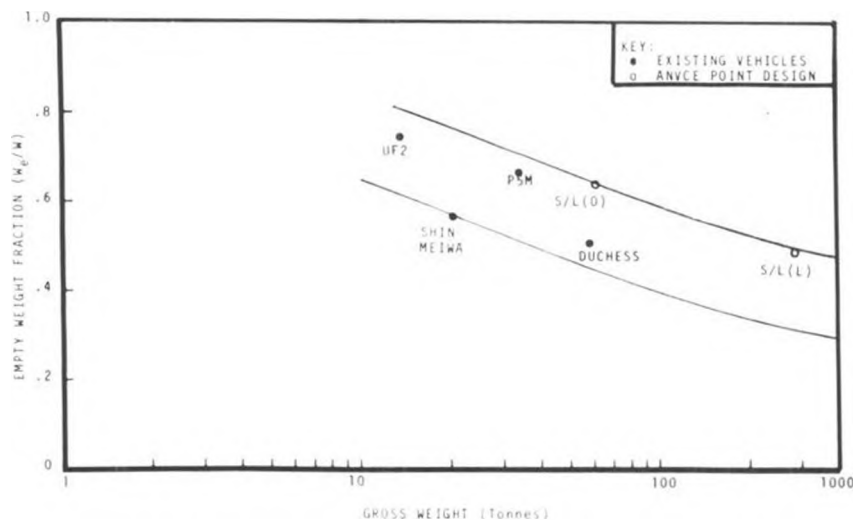
(U) Figure V-36. EMPTY WEIGHTS OF WIG VEHICLES
COMPARED WITH EXISTING AIRCRAFT



(U) Figure V-37. STRUCTURAL WEIGHT OF SEA LOITER AIRCRAFT

(U) The net result of the consideration of the other subsystems of the sea loiter concept is represented by the empty weight fraction in Figure V-38. As shown, the sea loiter concept (represented by the S/L(S) and S/L(L) point designs) generally follows the empty-weight trend within the seaplane state of the art,

despite the fact that the structural-weight trend (Figure V-37) within the concept is higher than that of the seaplane. By using advanced, lightweight engine characteristics and lowering the performance levels, lower installed propulsion system weights were obtained. Such evaluations using the state-of-the-art weight trends as baselines have served to establish the confidence levels in both the original point designs and in the modified point designs that resulted from such evaluations.

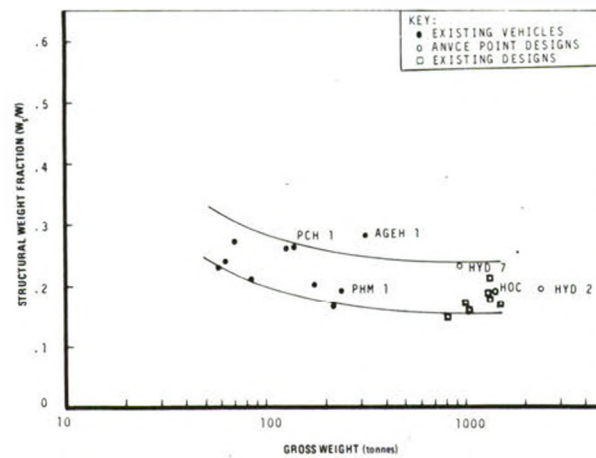


(U) Figure V-38. EMPTY WEIGHT OF SEA LOITER AIRCRAFT

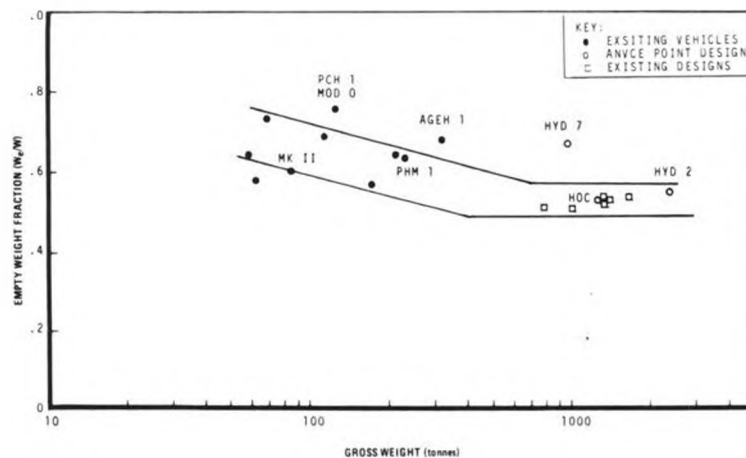
(U) The second example is the hydrofoil, the structural weight fraction of which is shown in Figure V-39. By definition, the structural weight of the hydrofoil does not include the weight of the struts and foils (which are included in the auxiliary system). Most of the data base pertains to subcavitating (up to 50 kt) hydrofoils with fully submerged struts. Based on these data, the large, subcavitating (50 kt) hydrofoil, HYD 2, is compatible with other similar designs. The high-speed (70 kt) hydrofoil, HYD 7, is also within this trend. On the HYD 7, the weight gain in hull structure caused by the fixed struts is offset to some extent by the higher loading used to attain the 70-kt speed. These factors together with the use of advanced structural materials maintain the general structural weight trend.

(U) The empty weight trend for the hydrofoil reveals the impact of the high speed of the HYD 7, as shown in Figure V-40. While the performance of the large hydrofoil (HYD 2) is comparable to that of existing hydrofoils because it generally is within the trend of state of the art, the strut and foil system will require a significant technological advancement. The value of empty weight for the HYD 2 shown in Figure V-40 is based on the belief that such an advancement is possible (Chapter III, Section 2).

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(U) Figure V-39. STRUCTURAL WEIGHT OF HYDROFOILS



(U) Figure V-40. EMPTY WEIGHT OF HYDROFOILS

(U) The high, empty-weight value for the HYD 7 reflects the large weight of the propulsion system required to achieve the supercavitating speed of 70 kt. The feature of the variable-geometry foil that provides this supercavitating speed capability also imposes a drag penalty during the transition from subcavitating to supercavitating flow (Chapter III, Section 2). Based on this penalty and the state of the art, the weight shown for the HYD 7 in Figure V-40, while high, is accurately represented. However, in evaluating this design it should be noted that improvements are likely and R&D in foil development would probably improve the value shown.

(U) The examples shown are typical of the analysis and evaluation conducted on all the point designs for use in assessing the concepts and indicating particular areas for further R&D.

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2.1.3 Productivity

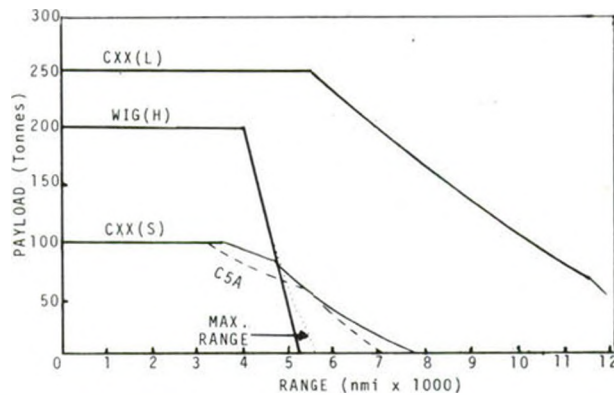
(U) Since most of the vehicle concepts were being evaluated for combatant missions, economic measures such as productivity, defined as payload multiplied by speed divided by tonnes of fuel, were not analyzed in detail. However, one particular point design, the WIG(H), was considered to have potential for the logistics mission. To determine whether the WIG(H) is competitive in the logistics mission, it was compared with projections for large aircraft (essentially variants of the C-5A), designated CXX(S) and CXX(L). The CXX(S), or small version, is comparable to the C-5A, and the CXX(L), or very large version, is more than double the C-5A in payload and gross weight. The comparison between the WIG(H) and the projected CXX schemes is presented in Table V-2. The variation of the payload with range for these three vehicles is shown in Figure V-41. As shown, the WIG(H) carries considerably more payload (and has a shorter range) than the CXX(S) or C-5A.

(U) Table V-2. LOGISTICS VEHICLE COMPARISON

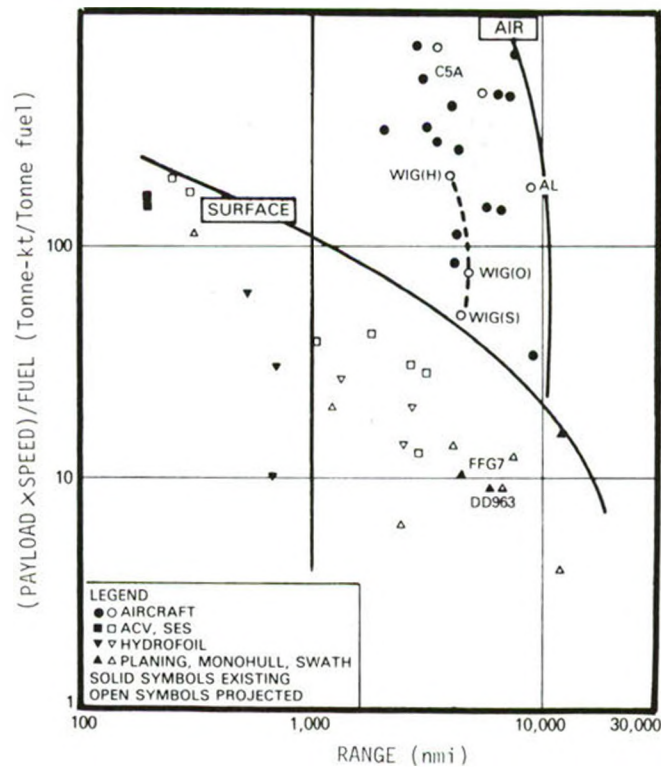
CHARACTERISTICS		CXX (S)	CXX (L)	WIG (H)
PAYLOAD	(LB)	220,000	550,000	441,000
	(TONNE)	100	250	200
RANGE (nmi) (FULL LOAD)		3,500	5,000	4,000
CRUISE SPEED	(MACH)	0.85	0.85	0.40
	(KT)	500	500	264
ALTITUDE (FT)		37,000	37,000	3.8
FLIGHT HOURS PER MONTH	PEACETIME	120	120	120
	WARTIME	300	300	300
	SURGE	375	375	375
TAKE OFF GROSS WEIGHT (LB)		577,058	1,733,841	1,362,000
OPERATING WEIGHT EMPTY (LB)		209,492	600,600	357,900
PAYLOAD (LB)		220,000	550,000	441,000
FUEL (LB)		147,566	583,241	563,100

(U) The values of productivity for the surface and air vehicles are compared with those of the WIG vehicles in Figure V-42. Envelopes have been drawn around both air and surface vehicles. Out to a range of about 10,000 nmi one way, the air vehicles are superior to surface vehicles because of their much higher speed. (The costs associated with this productivity are discussed in Volume 3.) The WIG designs that were evaluated show gains in productivity over surface vehicles but are limited to one-way ranges of about 4000-5000 nmi. Thus, the conventional air vehicles have greater productivity than the WIG vehicles. These and other results show the WIG

concept to be less competitive than it was believed to be; however, the analysis was not sufficient to determine whether this lower productivity is a basic shortcoming or the result of the particular designs examined. Further study and the examination of variety of designs are needed to resolve this issue.



(U) Figure V-41. PAYLOAD AS A FUNCTION OF RANGE OF LOGISTIC VEHICLES



(U) Figure V-42. PRODUCTIVITIES OF SURFACE AND AIR VEHICLES

2.2 Survivability

(U) In terms of platform characteristics, survivability is primarily a question of a vehicle's own detectability, its capability to detect a threat (a sensor issue), and its vulnerability to damage. This section presents only the material available on the survivability associated with the various point designs.

2.2.1 Detectability

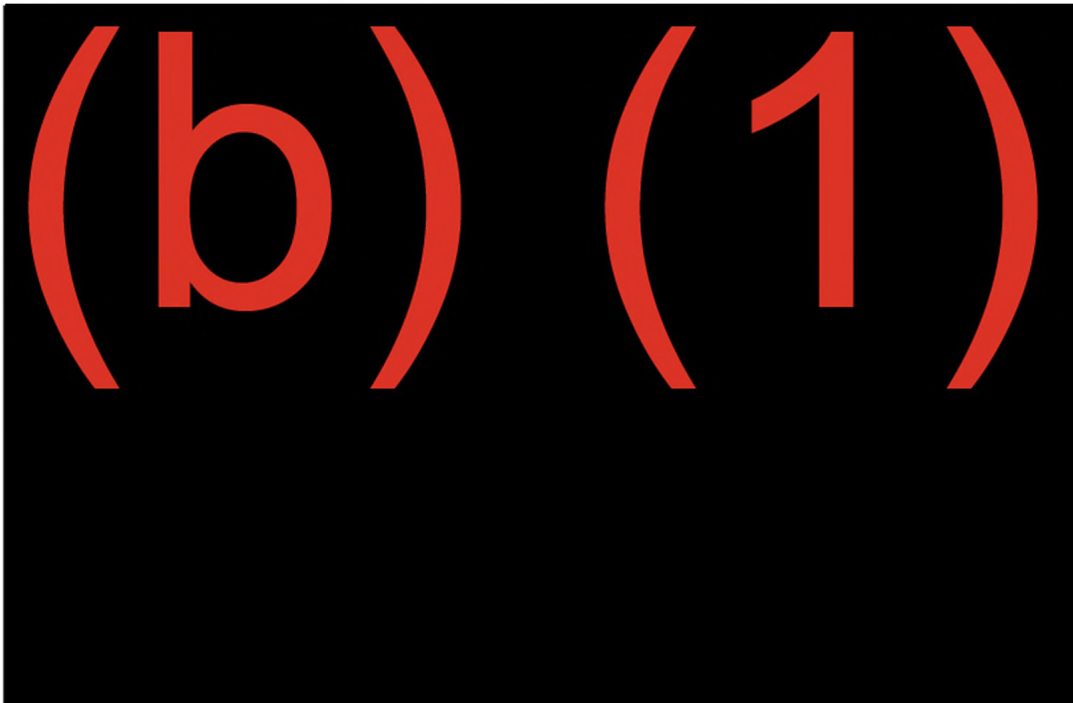
2.2.1.1 Surface Vehicle Signatures

(U) A detailed analysis of the signatures for all the surface vehicles is given in Reference 79. A brief summary of the findings for each of the signatures is given here.

2.2.1.2 Radar Cross-Section

(U) Table V-3 gives the radar cross-section (RCS) and beam aspect profile area (in square meters) for each of the point designs. The profile RCS is followed by the

~~(C)~~ Table V-3. BEAM ASPECT PROFILE AREAS, REDUCTION TECHNIQUES, AND RADAR CROSS-SECTION (U)



reduction techniques and deflecting and absorbing techniques that detract from it; the actual RCS (the profile RCS minus the reduction factors) is given in the far-right column.

~~(C)~~ (b) (1)

(b) (1)

(U) In projecting the capability of surveillance radars for circa 2000, a probability of detection (P_D) of 0.50 was assumed (Reference 80). Depending on weather, etc., an RCS of 1 m^2 can be detected at a range of approximately 30 to 215 nmi. The range values projected for future surface-to-air and surface-to-surface missiles are well beyond such requirements. Based on the RCS data in Table V-3, every point design vehicle can be detected, even in bad weather.

2.2.1.3 Acoustic Signature

(U) Empirical methods were used to estimate the acoustic signature of the surface vehicles or their radiated noise through the water. The primary signature is the noise radiated through the water by the propulsion system. Additional noise would be generated by such subsystem elements as gears, lift fans, and generators; however, such noise is usually in the form of tonals above the primary noise level, and no satisfactory method exists for predicting such tonal noise.

(U) The acoustic signatures are measures in the 1/3-octave frequency band level with a center frequency range of 1000 to 10,000 Hz. The signatures are relative noise levels with the reference noise level being $1 \mu\text{Pa}$ at 1 yd.

~~(C)~~ (b) (1)

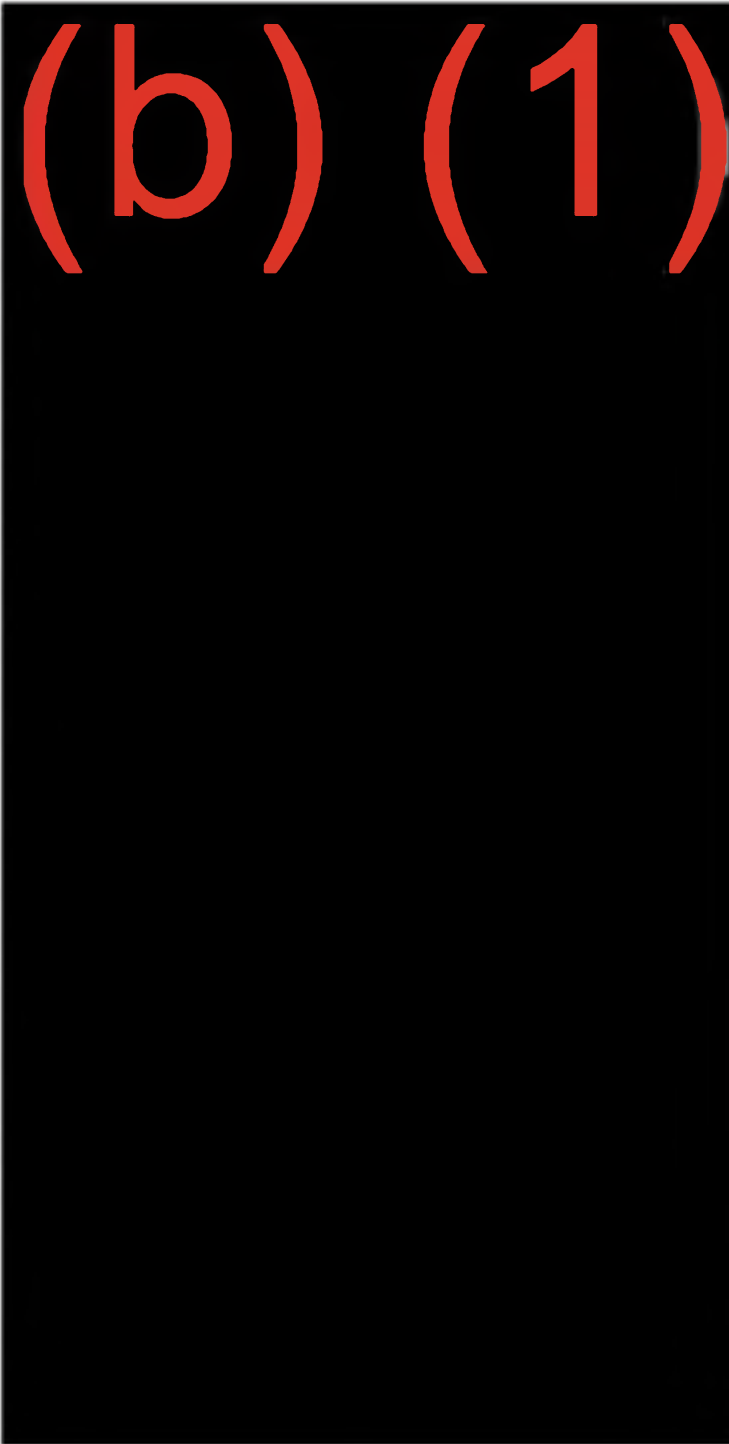
(b) (1)

2.2.1.4 Infrared

(U) Analytical techniques for computing the infrared (IR) signature of platforms are available and depend to a large extent on the temperature of the engine exhaust plume. The application of such techniques to the point designs proved to be too large a task for resolution within the ANVCE Project.

~~(C)~~ Table V-4. ACOUSTIC SIGNATURE PARAMETERS AND ESTIMATES (U)

(b) (1)



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2.2.1.5 Air Vehicle Signatures

(U) A similar set of signatures was obtained for the air vehicle point designs. The methodology and detailed results are given in Reference 81; the main signatures are summarized in Table V-5. For those air vehicles that spend part of their mission duration sea sitting, the RCS is assumed to be 90 percent of that when airborne. The IR signature is expressed as the ratio to the fourth power of the engine exhaust temperature of 798.61°K. The acoustic signature is the airborne noise level given that the air vehicle, with 60 percent fuel remaining, is cruising at the conditions for maximum range. When sea sitting, only the auxiliary power unit (APU) is running, at the maximum power. The visibility cross-section is simply the plan view area.

(U) Table V-5. AIR VEHICLE POINT DESIGN SIGNATURES

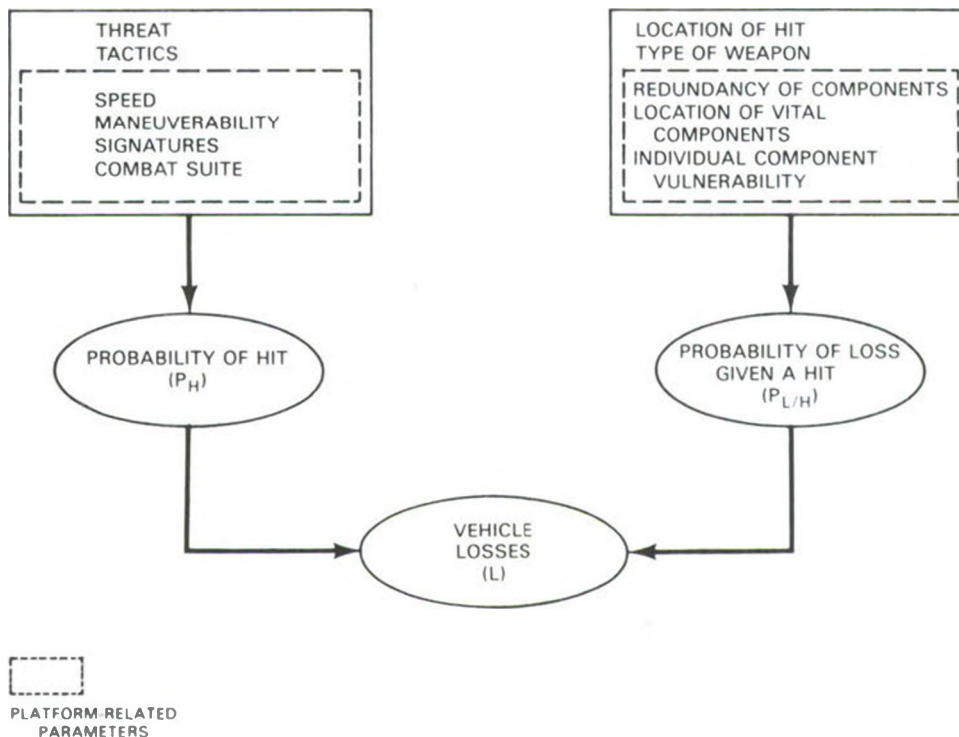
VEHICLE	RADAR CROSS-SECTION [dB (m ²)]		IR SIGNATURE	ACOUSTIC SOURCE		VISIBILITY CROSS-SECT. [dB (m ²)]
	AIRBORNE	SEA-SIT.		AIRBORNE (dB//1 KW)	SEA-SIT. (dB//1 KW)	
A/L	25.7	.....	.78	18.9	.....	28.9
A/L (N)	29.3	.....	.49	23.5	.....	32.2
AVP	22.5	.....	.49	16.3	.....	25.4
SAB	35.5	.....	2.68	9.47	.....	37.5
FAB	39.4	.....	.03	- 1.08	.....	39.5
ZPG	35.0	.....	2.69	- 1.26	.....	35.0
S/L (L)	28.5	28.1	.68	18.8	82.2	31.2
S/L (S)	24.2	23.6	.78	14.5	79.7	27.2
S/L (V)	19.4	19.0	.34	12.4	79.5	23.4
WIG (H)	26.6	.....	.68	23.0	85.0	32.0
WIG (S)	28.1	27.7	.68	24.2	84.7	31.6
WIG (O)	29.1	28.6	.68	24.4	84.7	31.1

2.2.2 Vulnerability

(U) From a purely technical standpoint, the vulnerability of a ship is determined by how easily it can be put out of action. It is a function of the scenario, operations, etc., as well as the platform characteristics as shown in Figure V-43. The number of vehicle losses (L) is affected by (a) such platform characteristics as its speed, maneuverability, and signatures, which are factors in the probability of being

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hit (P_H), and (b) its backup systems, systems locations, and system protections, which are factors in the probability of loss given a hit ($P_{L/H}$). The out-of-action probabilities ($P_{L/H}$) for the surface and air point designs are given in the following subsections.



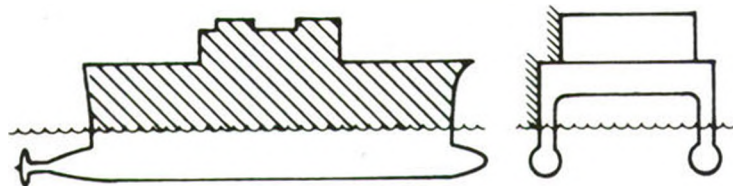
(U) Figure V-43. OUT-OF-ACTION FACTORS

2.2.2.1 Surface Vehicles

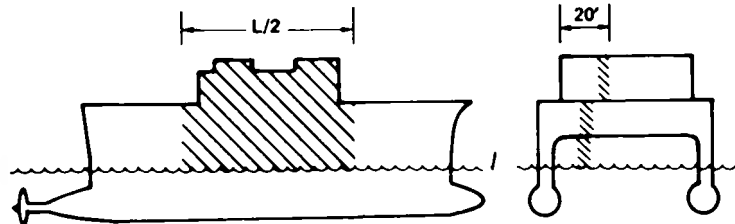
(U) The detailed analysis to determine the out-of-action probability estimates for direct attacks on the surface vehicle point designs is given in Reference 79. In the analysis, four threat weapons were considered: 0.30-caliber, armor-piercing (AP) projectiles; 500-lb, semi-armor-piercing (SAP) missile warheads; 5"/54, fragmenting projectiles; and 250-lb torpedoes. The assumed hit distribution areas for the four threat weapons are shown in Figure V-44, using the SWATH concept design as an example.

(U) The out-of-action probabilities were estimated for both the platform and the weapon system, and the probabilities were computed for three cases: less than 100 percent, 50 percent, and 10 percent of maximum design speed with maneuverability control. Complete charts are provided in Reference 79; the out-of-action probabilities for the 500-lb SAP missile are given in Table V-6 as an example. These probabilities are discussed in the following paragraphs for a 500-lb SAP missile and a 250-lb torpedo warhead (or any proximity-fuze underwater explosion of the same intensity).

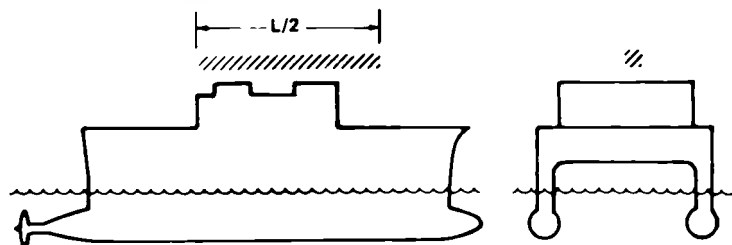
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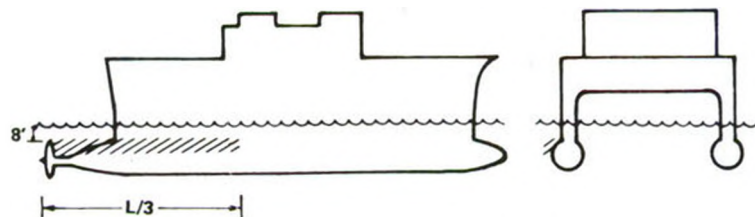
(A) 30-CAL AP PROJECTILE (CHEAP KILL)



(B) 500-LB SAP MISSILE WARHEAD



(C) 5"/54 - PROXIMITY FUZE



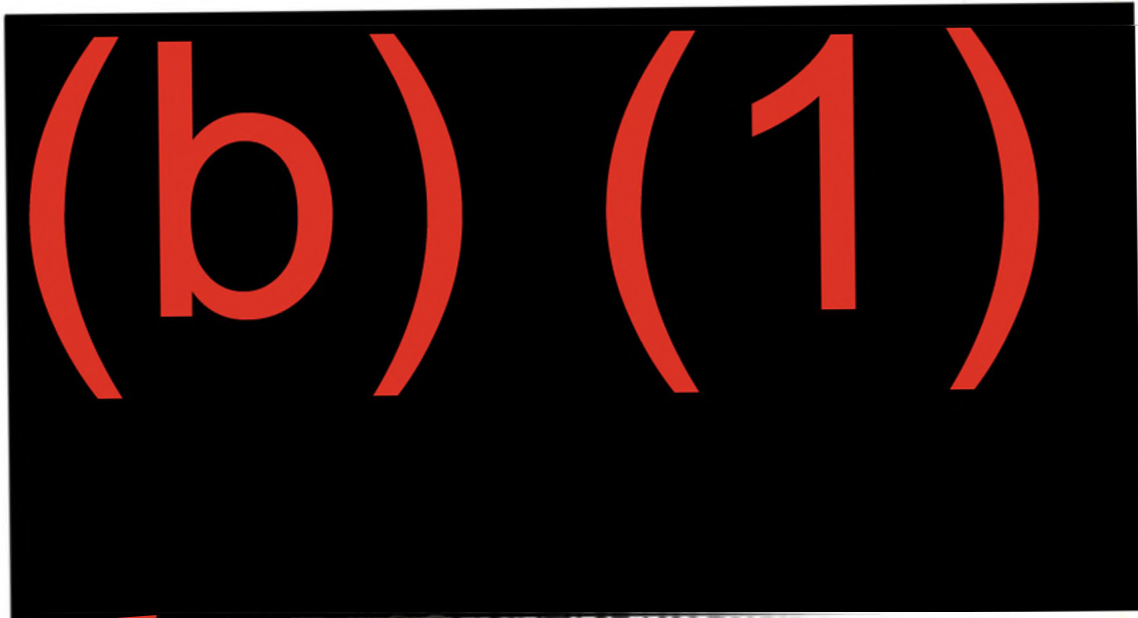
(D) 250-LB TORPEDO

(U) Figure V-44. WEAPON HIT LOCATIONS

(U) Figure V-45 shows the vulnerability of the surface vehicle point designs of the 1000-tonne displacement class to the SAP missile with a 500-lb warhead. The ACV is less vulnerable than either the planing craft or the hydrofoil because of the dispersal of its main power plants. While the vital components in the other conceptual vehicles could be similarly dispersed, it has not been the practice to do this. However, these results suggest that alternative (nontypical) configurations would be useful in reducing the vulnerability of such designs.

~~(C)~~ Table V-6. OUT-OF-ACTION PROBABILITIES WITH 500-lb
SEMI-ARMOR-PIERCING (SAP) MISSILE AT

(b) (1)



(C) Figure V-45. VULNERABILITY OF 1000-TONNE CLASS ANV TO
SAP MISSILES WITH 500-lb WARHEADS (U)

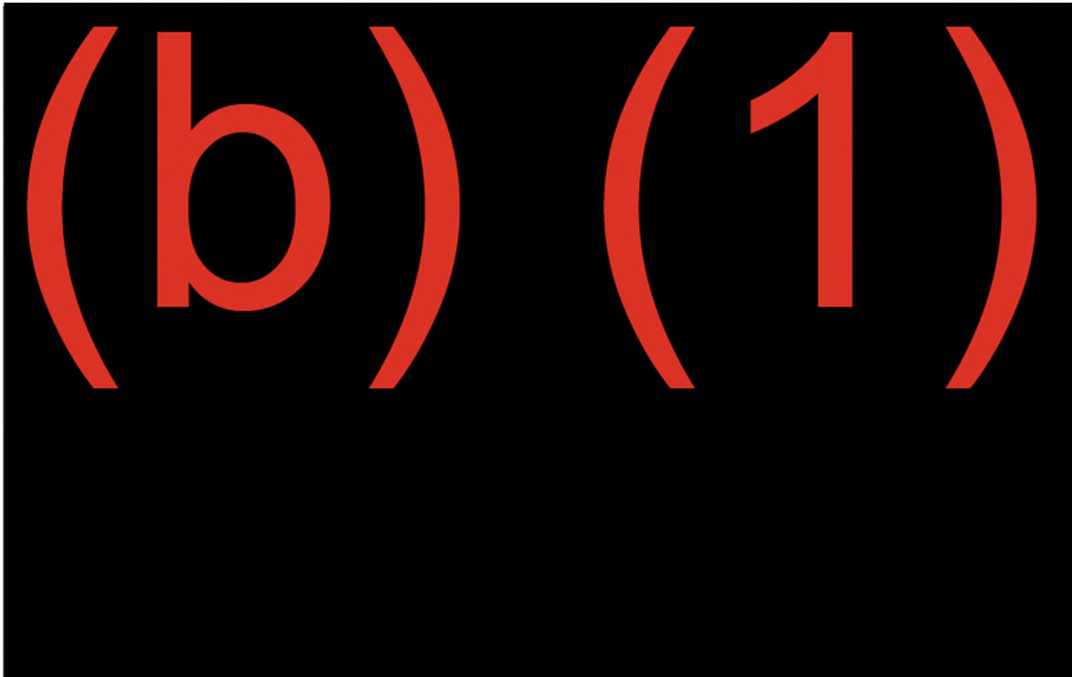
(U) The vulnerability of surface vehicle point designs of the 1000-tonne displacement class to torpedoes is shown in Figure V-46. The ACV shows an advantage here; since it is amphibious and nothing protrudes into the water, it is considered "invulnerable" to torpedo attack. Various tests, particularly those by the Royal Navy with the SR.N3 hovercraft, have also shown that the ACV is relatively invulnerable to underwater explosions (proximity-fuze explosions).

(U) The vulnerability of the 3000-tonne displacement surface vehicle point designs to a 500-lb SAP missile is summarized in Figure V-47. Again, the differences among the various designs have an impact on the probability of performance loss. In this case, the ACV 3 is nonamphibious, with a waterscrew propulsion system housed amidships. The SES 3 has its main propulsion plant in the after part of the ship, which reduces the probability that its full performance capability will be lost with a single hit. Careful attention to such factors can reduce the vulnerability of many of the concepts.

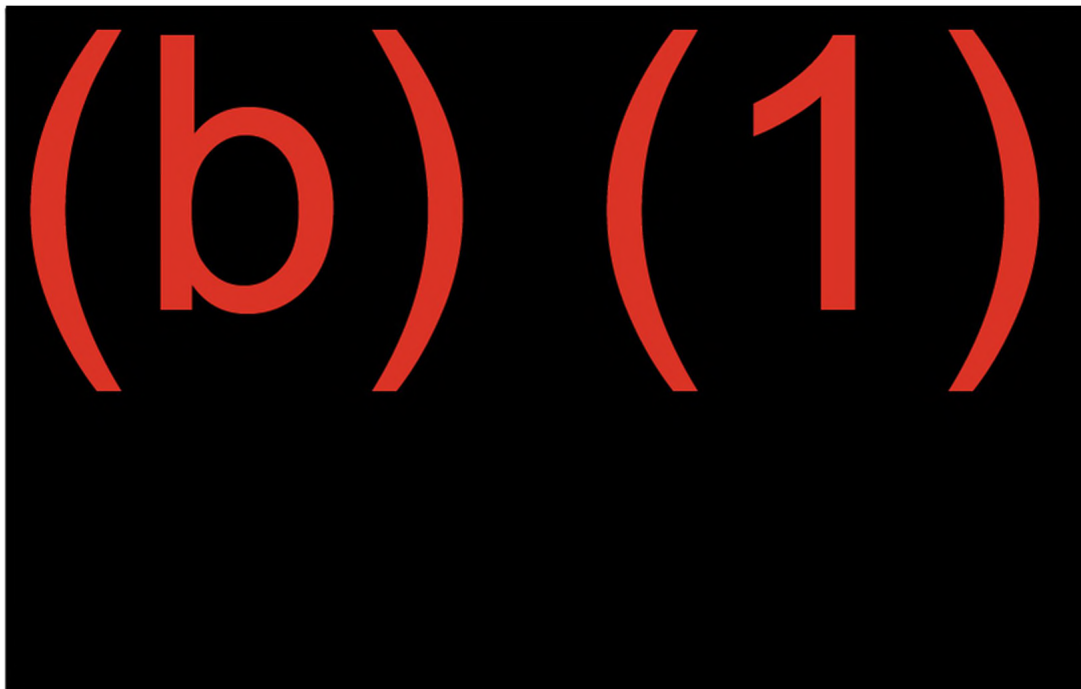
(U) Figure V-48 shows the vulnerability of surface vehicle point designs of the 3000-tonne displacement class to a torpedo with a 250-lb warhead.

(U) The results shown in Figures V-45 through V-48 are drawn as continuous curves for display purposes. The tables in Reference 79 should be consulted for complete data on vulnerability.

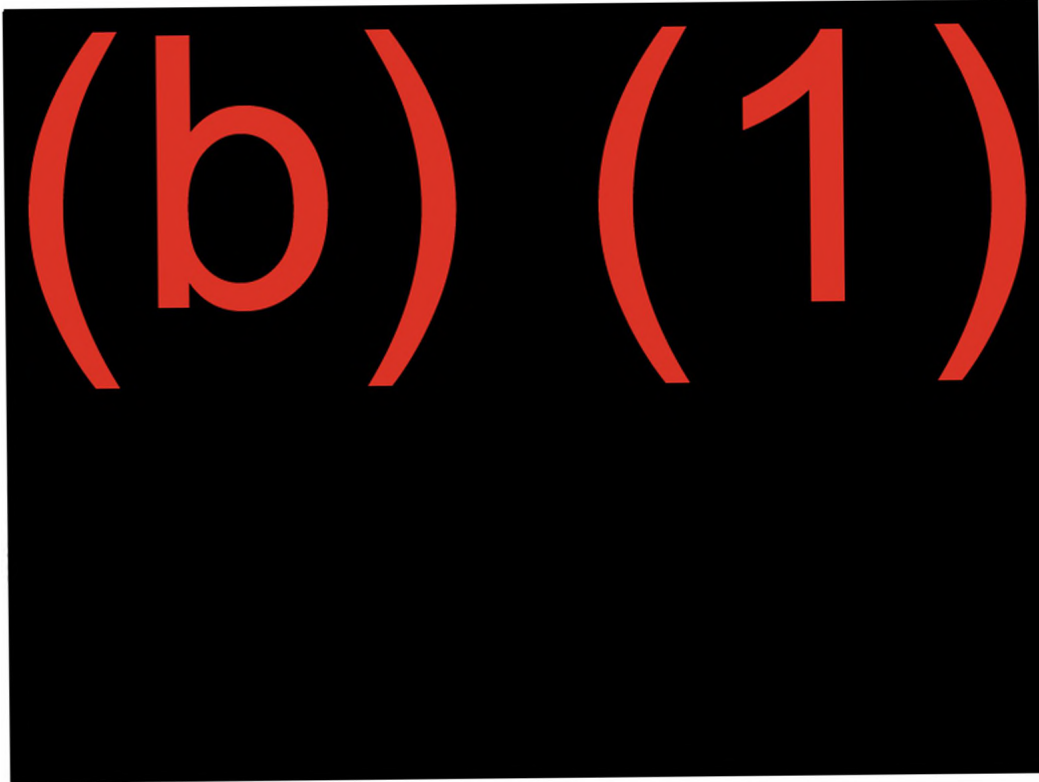
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~~(C)~~ Figure V-46. VULNERABILITY OF 1000-TONNE CLASS ANV TO
TORPEDOES WITH 250-lb WARHEADS (U)



~~(C)~~ Figure V-47. VULNERABILITY OF POINT DESIGN VEHICLES IN
3000-TONNE DESIGN VEHICLES IN 3000-TONNE
CLASS TO SAP MISSILES WITH 500-lb WARHEADS (U)



(C) Figure V-48. VULNERABILITY OF POINT DESIGN VEHICLES IN
3000-TONNE CLASS TO TORPEDOES
WITH 250-lb WARHEADS (U)

2.2.2.2 Air Vehicles

(U) Estimates of the out-of-action probabilities for the air vehicle point designs were made, but in less detail. The analysis and results are presented in Reference 81.

2.3 Availability

(U) As with survivability and vulnerability, availability is determined by scenario, operation, etc., as well as the platform characteristics. In availability, these factors can be divided into consideration of the vehicle's service-life availability (SLA), which is largely platform-related, and its wartime availability, which is largely scenario-dependent. This discussion deals primarily with the SLA of the various point design vehicles, but also relates SLA to the factors that must be considered in regard to operational use: maintenance, reliability, transit, and underway replenishment (UNREP).

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2.3.1 Service-Life Availability

(U) Basically, SLA is defined as the fraction of calendar time that the vehicle is expected to be underway or flying. Although SLA is computed differently for the surface and air vehicles, the definitions are equivalent.

2.3.1.1 Surface Vehicles

(U) For the surface vehicle, SLA is calculated from (a) a 10-yr operating profile for large point designs and a 5-yr profile for small vehicles and (b) a division or percentage of time at sea and in port according to the breakdown shown in Table V-7. The "other" category includes such items as intermediate and depot maintenance activities, postshakedown availability, preparation for overseas movement, leave and upkeep, and modernization. Based on Table V-7, therefore, SLA for the surface vehicles is 0.28 for large surface vehicles (all surface vehicles except CPIC, PHM, LCAC, and LCPC) and 0.25 for small surface vehicles (CPIC, PHM, LCAC, and LCPC).

(U) Table 4-7. OPERATIONAL EMPLOYMENT OF SURFACE VEHICLES

OPERATION	PERCENTAGE OF TIME AT SEA	PERCENTAGE OF TIME IN PORT
LARGE SURFACE VEHICLES (10-YR)		
DEPLOYMENT	23	23
TYPE TRAINING	4	9
REFRESHER TRAINING	1	2
OTHER		38
TOTAL	28	72
SMALL SURFACE VEHICLES (5-YR)		
TOTAL	25	75

(U) References 82 and 83 present descriptive material on the time lines and other pertinent information on availability. However, during the evaluation process, detailed analyses for each point design were conducted; information was obtained on similar vehicles (although it was limited and inconsistent); and adjustments were made to account for the particular concept. Thus, the final values used in the evaluation presented here differ accordingly from the values cited in the references.

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2.3.1.2 Air Vehicles

(U) For air vehicles SLA is determined differently because of the difference in operational doctrine. It is derived by dividing the flight hours per month by the number of hours per month. This difference is basically caused by the relatively short mission durations of aircraft (measured in hours rather than days). Essentially, this difference means that most maintenance for air vehicles is conducted at the base and has a faster turnaround.

(U) To simplify the problem of predicting the availabilities of advanced air concepts, a comparative method based on the P-3 patrol aircraft was used. Background data and methodology for the planned flight hours per month for the air vehicles is provided in Reference 81. Table V-8 presents the availability of the aircraft as determined through a review and evaluation of the designs and analysis, and used for computation of life-cycle cost (LCC) in the cost analysis (Volume 3).

(U) Table V-8. AIR VEHICLE AVAILABILITY

AIR VEHICLE POINT DESIGN	FLIGHT HOURS PER MONTH	SLA
A/L	120	0.167
A/L(N)	120	0.167
AVP	85	0.118
FAB	120	0.167
SAB	85	0.118
ZPG	85	0.118
S/L(S)	60	0.083
S/L(V)	60	0.083
S/L(L)	120	0.167
WIG(S)	204	0.283*
WIG(O)	120	0.167
WIG(H)	120	0.167
P-3 (REFERENCE POINT)	85	0.118
*TREATED AS A SURFACE VEHICLE.		

2.3.2 Wartime Availability

(U) For a given scenario situation, the mission factors related to availability become critical, and maintenance and training doctrines change. Availability becomes only the fraction of time in the operational cycle that the vehicle is on station and in ready status. As in previous considerations, only the platform-related aspects will be discussed here.

(U) The operational cycle for advanced vehicles is shown in Figure V-49. It is comprised of four factors—maintenance (MF), reliability (RF), transit (TF), and UNREP. The general formulation used in determining the availability (A) of the vehicle point designs is

$$A = (MF) (TF) (UF) (RF).$$

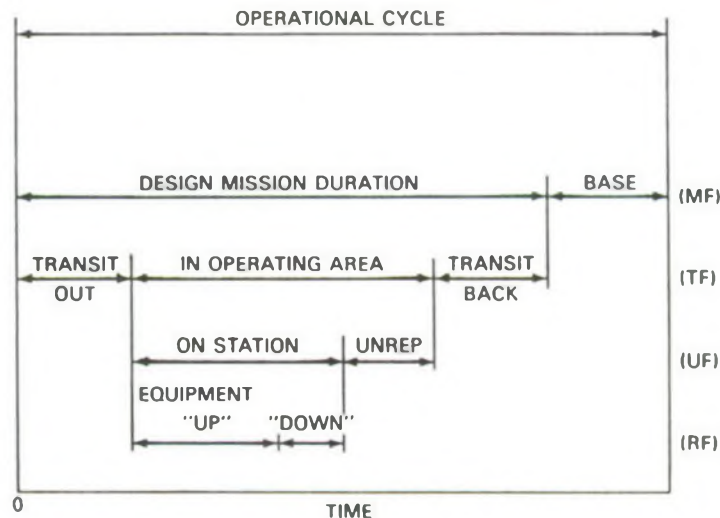
For air vehicles, the maintenance and reliability factors combine to form the utilization rate (UR), where

$$UR = \frac{\text{flight hours/month}}{\text{hours/month}}.$$

Because no airborne refueling of aircraft was considered in this discussion, the UNREP factor is equal to unity and the transit factor is the time on station divided by the mission duration. Thus, for aircraft, availability is

$$A = UR (TF).$$

(U) Thus, there is a commonality in the definitions for surface and air vehicle availability. The methodology and numerical values used for these factors are discussed in the following subsections.



(U) Figure V-49. OPERATIONAL CYCLE FOR ADVANCED VEHICLES

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2.3.2.1 Maintenance Factor (MF)

(U) The MF is that component of availability which accounts for, in a given operational cycle, the turnaround time at base for required or scheduled maintenance, rearming, taking on stores, or crew change. It accounts for actions that are required at a land base between operating periods or flights. The MF, shown in Figure V-49 is

$$MF = \frac{\text{mission duration}}{\text{mission duration} + \text{base time}},$$

where the mission duration plus base time is equal to the operational cycle time.

(U) In the point designs, mission duration was extended as far as possible. This mission duration is referred to as design mission duration. However, at times a lesser capability was more appropriate to a given operation; these mission durations were referred to as off-design mission durations.

(U) The basic methodology and preliminary results are given in References 82 and 83 for surface vehicles and in Reference 81 for air vehicles. However, modifications were made during the evaluation. The final values are presented in this report.

(U) Table V-9. MAINTENANCE FACTORS OF SURFACE VEHICLE POINT DESIGNS

VEHICLE	DESIGN MISSION DURATION (DAYS)	BASE TIME (DAYS)	MF
ACV 1	15	4	.79
HYD 7	15	4	.79
PC 1	15	4	.79
ACV 3	15	5	.75
HYD 2	30	6	.83
MONO 3	30	6	.83
SES 3	15	5	.75
SWA 4	30	6	.83
SES CV	30	7	.81
SES CVN	30	7	.81
SWA CVN	60	8	.88
SWA MCM	45	7	.87
ACV SK-5 CLASS			.08
FF-1052 CLASS			.74
DDG-2 CLASS			.69
CVAN-65			.82

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(U) The amount of time that a surface vehicle must spend in port or at base depends largely on the size and complexity of the vehicle, and to a lesser extent on the method of operation. The MF for each surface vehicle point design is presented in Table V-9. For reference purposes, MF data on the ACV SK-5 class experience in Vietnam as well as data on the FF-1052 and DDG-2 classes and the CVAN-65 are also given in Table V-9. The low ACV MF values are principally the result of the method of operation, not the platform characteristics of the ACV.

(U) A similar set of calculations was performed for the air vehicle point designs, with the additional criterion of requiring that the air vehicle be in varying degrees of operational readiness. This additional criterion was necessary since traditionally aircraft spend more time at base in different states of readiness than ships but can be deployed more quickly when needed. The operational use of aircraft differs from that of ships in that their high-speed capability permits them to reach a location quickly.

(U) The air vehicles were analyzed in terms of four MF conditions (Reference 81):

- *Condition I: 3-day maximum effort, launch when ready.* In Condition I, every "up" aircraft (not downed for flight safety discrepancy) can be expected to be launched as soon as the ground servicing has been completed.
- *Condition II: 10-day maximum effort, launch when ready.* For Condition II, aircraft will require corrective maintenance at the end of each flight to ensure operable aircraft for the full 10 days.
- *Condition III: 3-month, wartime environment, extended operations.*
- *Condition IV: 6-month, wartime environment, extended operations.*

For Conditions III and IV, each aircraft will be operated in a routine wartime environment. The aircraft will not be required for a launch-when-ready operation and will be available for preventive maintenance and standard scheduling delays, etc.

The results of these analyses are summarized in Table V-10.

(U) In the case of the air vehicle designs, utilization rate (expressed in flight hours per month) is used as a general planning factor that combines the various considerations involved in the reliability and maintenance factors as used by the ANVCE Project.

2.3.2.2 Reliability Factor (RF)

(U) The second component in availability is the RF,* which accounts for mission-essential equipment that is inoperative while a vehicle is on the line, thus preventing the vehicle from performing its assigned mission. It is defined as

*At the beginning of the ANVCE Project and in many of the references, RF was called mission availability (MA).

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(U) Table V-10. MAINTENANCE FACTORS OF AIR VEHICLE POINT DESIGNS

VEHICLE	CONDITIONS			
	I 0.3 DAYS (72 HR)	II 10 DAYS (240 HR)	III 3 MONTHS (2160 HR)	IV 6 MONTHS (4320 HR)
A/L	.69	.51	.25	.25
A/L (N)	1.00	1.00	.47	.47
AVP	.68	.48	.21	.21
FAB	1.00	1.00	.47	.47
SAB	1.00	.70	.21	.21
ZPG-X	.88	.71	.21	.21
S/L (S)	.63	.51	.15	.15
S/L (V)	.60	.56	.11	.11
S/L (L)	.81	.70	.36	.36
WIG (S)	1.00	1.00	.58	.58
WIG (O)	.74	.63	.51	.51
WIG (H)	.63	.53	.42	.42

$$RF = \frac{\text{vehicle "up" time on station}}{\text{total time on station}}$$

as shown in Figure V-49. RF considers both platform-essential equipment and combat equipment. Furthermore, two types of equipment failure are considered in this computation:

- those pieces of equipment that are repairable on board and while underway; in which case the RF is computed by

$$RF = \frac{MTBF}{MTBF + MTTR}$$

where MTBF is the mean time between failures and MTTR is the mean time to repair; and

- those pieces of equipment that are not repairable on board; in which case the RF is computed by

$$RF = e^{-\frac{t}{MTBF}}$$

where t is mission duration. In the point designs account was taken of those systems that were repairable on board and those that were not in order to produce a composite RF for the entire vehicle.

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(U) Details of the RF analyses are given in References 82 and 83 for surface vehicles and in Reference 81 for air vehicles. Again, modifications were made during the evaluation; the final values are presented in this report.

(U) The RF for each point design concept is a combination of the estimates of platform subsystem reliability and combat system reliability. In the initial work (References 81-83) it was assumed that all components in the subsystem had to be 100 percent functional before the subsystem could be declared functional, i.e., there was no allowance for graceful degradation of subsystem functioning as the mission proceeded. Furthermore, the reliability of the point designs was computed for the design mission duration. Although an ideal case, this maximum test provided a good basis for analysis. The results are summarized in Table V-11. As shown in the table, the propulsion subsystem is the greatest contributor to the platform system RF, which is the greatest contributor to vehicle RF.

(U) Table V-11. RELIABILITY FACTORS OF SURFACE VEHICLE POINT DESIGNS USING DESIGN MISSION DURATIONS

VEHICLE	DESIGN MISSION DURATION (DAYS)	PLATFORM SYSTEM RF						COMBAT SYSTEM RF	VEHICLE RF
		PROP.	ELECT.	AUX.	LIFT	SHIP CONTROL	TOTAL RF		
ACV 1	15	.525	.999	.999	.998	.999	.523	.962	.503
HYD 7	15	.765	.999	.999	.....	.990	.756	.962	.727
PC 1	15	.888	.999	.999	.....	.991	.878	.962	.845
ACV 3	15	.652	.998	.999	.840	.999	.546	.964	.521
HYD 2	30	.719	.999	.999	.....	.956	.686	.954	.654
MONO 3	30	.840	.999	.999	.....	.965	.809	.954	.772
SES 3	15	.752	.999	.999	.779	.999	.586	.954	.559
SWA 4	30	.910	.999	.999	.....	.979	.889	.954	.848
SES CV	30	.481	.986	.987	.864	.999	.404	.947	.383
SES CVN	30	.948	.986	.987	.864	.999	.797	.947	.755
SWA CVN	60	.999	.999	.992	.....	.912	.904	.947	.856
SWA MCN	45	.805	.999	.999	.....	.973	.782	.955	.747

(U) Since it would be necessary to evaluate the vehicle at other mission durations when considering various scenarios, the RF was also computed for various off-design mission durations, ranging from 1 to 90 days. The results are given in Table V-12. As shown, the vehicle is considered "up and operational" on Day 0 and, depending on the types of equipment failure, is gradually degraded as the mission proceeds, passing through the design point at its appropriate mission duration.

(U) Those concepts that require a relatively large amount of power and a relatively large number of engines have low reliability for any but very short mission durations. On the one hand, having many engines (and propulsors) provides a high degree of redundancy, which keeps the vehicle operating; on the other hand, this

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(U) Table V-12. RELIABILITY FACTORS OF SURFACE VEHICLE POINT DESIGNS FOR VARIOUS MISSION DURATIONS

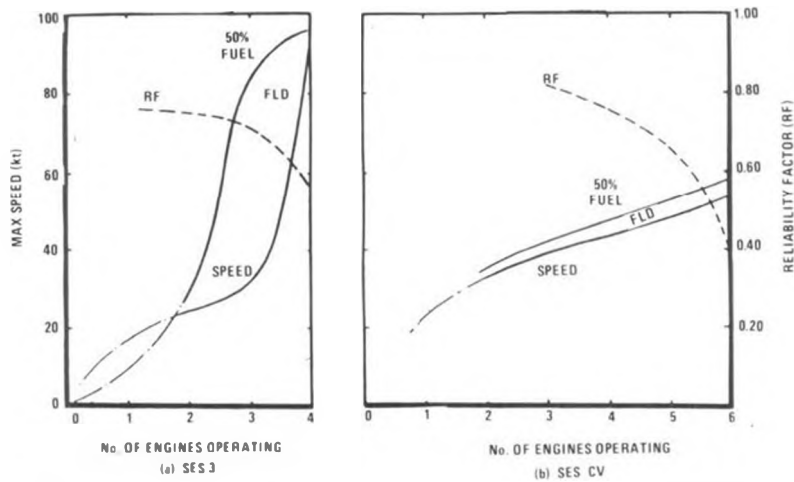
VEHICLE	RF/MISSION DURATION (DAYS)							
	0	5	10	15	30	45	60	90
ACV 1	1	.784	.642	.503	.287	.156	.084	.024
ACV 3	1	.774	.634	.521	.282	.152	.081	.022
CPIC	1	.117	.010	.001	.000	---	---	---
FFG 7	1	.943	.914	.885	.805	.733	.667	.552
HYD 7	1	.877	.798	.727	.528	.376	.262	.121
HYD 2	1	.883	.820	.759	.654	.457	.345	.189
HOC	1	.908	.841	.776	.605	.463	.350	.193
LCAC A	1	.362	.108	.029	.000	---	---	---
LCAC B	1	.340	.099	.026	.000	---	---	---
LCPC	1	.320	.097	.029	.001	.000	---	---
LSES (R)	1	.759	.591	.458	.207	.091	.039	.007
MONO 3	1	.909	.863	.809	.772	.461	.323	.145
PC 1	1	.924	.889	.845	.763	.680	.606	.481
PHM	1	.667	.444	.288	.071	.016	.003	.000
SES 3	1	.786	.664	.559	.330	.193	.111	.036
SES CV	1	.793	.688	.596	.383	.243	.152	.006
SES CVN	1	.892	.866	.840	.755	.670	.587	.437
SWA 4	1	.926	.909	.891	.848	.792	.748	.665
SWA CVN	1	.923	.916	.909	.889	.868	.856	.810

redundancy is no longer an advantage if the primary military requirement of such a vehicle is high speed. An analysis was performed on the SES 3 and the SES CV, which has very high speed and is in the 3000-tonne displacement class. Each engine was allowed to "drop off the line" according to its reliability mode without penalizing the rest of the system. When this mechanism is used, the vehicle RF increases as each engine comes off the line; however, the speed of the vehicle decreases in accordance with the thrust, drag, and speed relationship.

(U) The results of this analysis are shown in Figure V-50. As discussed in Chapter III, the low length-to-beam (L/B) SES 3 and the high-L/B SES CV reflect quite different craft-speed relationships. The impact of this effect is quite dramatic in the case of the SES 3, as shown in Figure V-50. For the condition of full-load displacement (FLD), the SES 3 has a speed of 97 kt in sea state 3 and an RF of 0.559 at the corresponding condition when all four propulsion engines are operating. For the same FLD condition, if one propulsion engine is allowed to drop off the line, the RF improves to about 0.68 but the ship speed falls to 30 kt because of the existence of the high hump drag. This situation has a considerable impact on the performance capability of the ship. The change is significantly different if the fuel level is also taken into account. For example, with 50 percent of its fuel remaining, the speed loss is much less dramatic, falling from 97 kt to only about 82 kt

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(Figure V-50). The corollary to this situation in any particular scenario, however, is that to keep the performance level high, the fuel allowed on board must be significantly reduced. (For the current example, this reduction would mean one-half the range capability or twice as many refuelings.)



(U) Figure V-50. SES SPEED AND RELIABILITY FACTOR IN SEA STATE 3

(U) Conversely, for the high-L/B SES CV, where the hump drag problem is greatly diminished, the number of engines operating and fuel remaining are much less critical. As shown, at FLD the SES CV has a speed of 58 kt in sea state 3 and an RF of 0.383. If one engine is allowed to drop off the line, the RF increases appreciably, to about 0.65, and the speed loss is only about 3-5 kt.

(U) The impact of reliability on the performance of a craft is demonstrated by such results. The need to integrate such considerations into the design process early in the conceptual stages is emphasized since reversals or changes made after the design becomes firm can be extremely expensive.

(U) Following a similar method to that used for the surface vehicle point designs, the RFs of the air vehicle point designs computed for the design mission duration are given in Table V-13. For the long-endurance air vehicles, serious degradations in reliability occur even with the redundancy in their design. This problem needs further, detailed study.

(U) To assess the impact of operating for other than the design mission durations, a range of duration was considered, and the results are summarized in Table V-14. Again, a significant improvement in reliability can be achieved by shortening the mission duration.

(U) For example, during the initial design studies the FAB was designed for a mission duration of 8 days and the A/L(N) was designed for a mission duration of 15 days. However, the long mission duration of these point designs lowered their reliability to the point where their usefulness became questionable (Table V-14).

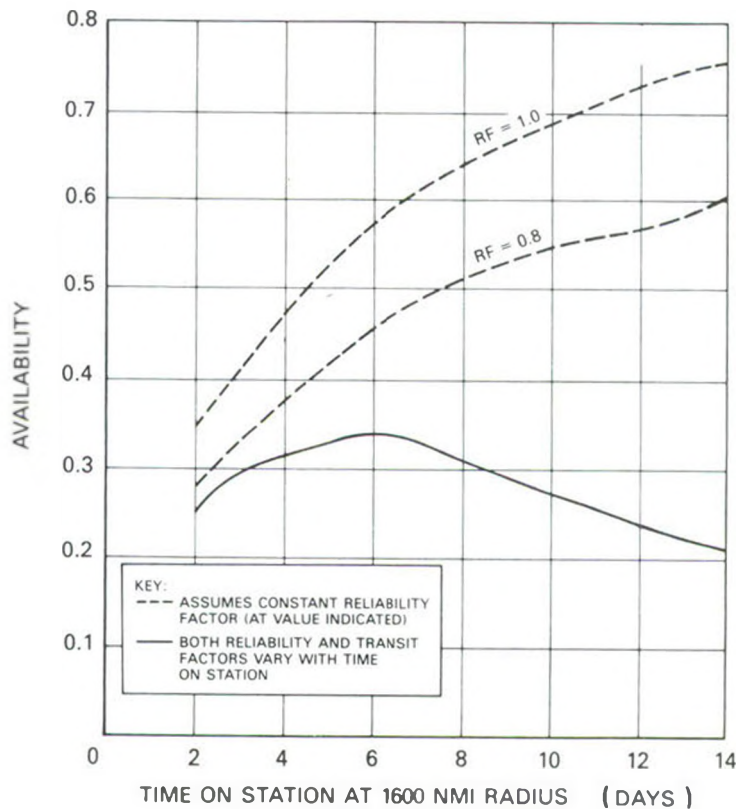
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**(U) Table V-13. RELIABILITY FACTORS OF AIR VEHICLE POINT DESIGNS
USING DESIGN MISSION DURATIONS**

VEHICLE	DESIGN MISSION DURATION (HR)	PLATFORM RF	COMBAT SYSTEM RF	VEHICLE RF
A/L	33	0.940	0.867	0.815
A/L (N)	369	0.155	0.258	0.040
AVP	14	0.986	0.918	0.905
FAB	282	0.912	0.345	0.315
SAB	240	0.989	0.344	0.340
ZPG	38	0.958	0.826	0.792
S/L (S)	15	0.992	0.934	0.927
S/L (V)	9	0.910	0.676	0.615
S/L (L)	62	0.971	0.777	0.754
WIG (S)	360	0.760	0.276	0.210
WIG (O)	52	0.973	0.817	0.795
WIG (H)	17	0.944	0.987	0.932

**(U) Table V-14. RELIABILITY FACTORS OF AIR VEHICLE POINT
DESIGNS FOR VARIOUS MISSION DURATIONS**

VEHICLE	RF/MISSION DURATION (HR)							
	0	2	4	10	24 (1 DAY)	96 (4 DAYS)	192 (8 DAYS)	360 (15 DAYS)
A/L	1	0.985	0.954	0.920	0.856	0.600	.....	.....
A/L (N)	1	0.975	0.925	0.872	0.780	0.500	0.260	0.040
AVP	1	0.963	0.949	0.930	.....	.....	.....	.....
FAB	1	0.990	0.980	0.940	0.865	0.670	0.465	0.190
SAB	1	0.990	0.975	0.930	0.858	0.638	0.430	0.120
ZPG	1	0.990	0.975	0.930	0.858	0.638	0.430	0.120
S/L (S)	1	0.977	0.959	0.940	0.886	.....	.....	.....
S/L (V)	1	0.900	0.800	0.550	.....	.....	.....	.....
S/L (L)	1	0.990	0.980	0.940	0.875	0.680	.....	.....
WIG (S)	1	0.990	0.980	0.940	0.865	0.670	0.465	0.210
WIG (O)	1	0.990	0.980	0.940	0.875	0.680	.....	.....
WIG (H)	1	0.982	0.965	0.950	0.915	.....	.....	.....



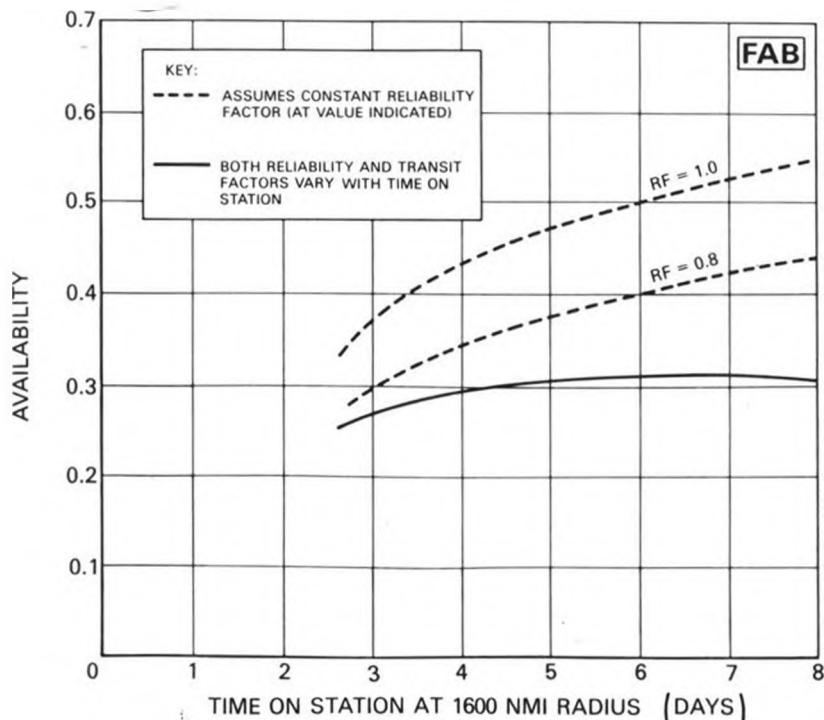
(U) Figure V-51. A/L(N) AVAILABILITY IN TERMS OF TIME ON STATION

(U) Figure V-51 shows the combined effect on all the components of availability as a function of time on station for the particular case of a constant (99-hr), turnaround time. The impact of the reliability factor is also shown. The lower curves assume mid-mission RF values compatible with those in Table V-14. As shown, a more "available" A/L(N) would be one with a TOS of about 6 days (corresponding to a mission duration of less than 6 1/2 days).

(U) Similar results (Figure V-52) were obtained for the FAB although they were not quite as striking. Again, the longer the mission duration and TOS, the lower the reliability and the less available the aircraft. For better availability, the FAB should be designed for a TOS of less than 8 days, with 6 days being about the same value as that for the A/L(N).

2.3.2.3 Transit Factor (TF)

(U) The third component in considering wartime availability is the transit factor (TF). This factor involves the effects of radius of action, time on station, and tactics. TF for surface vehicles is calculated by



(U) Figure V-52. FAB AVAILABILITY IN TERMS OF TIME ON STATION

$$TF = \frac{\text{time in area}}{\text{time in area} + \text{transit time}} = \frac{\text{time in area}}{\text{mission duration}}$$

TF represents that portion of a vehicle's nonproductive operational time that is spent in transit to and from the designated operating area and the base. It is a function of the vehicle's performance capability in terms of speed in a seaway, fuel capacity, fuel consumption, and range.

(U) For the air vehicles, the vehicle is assumed to be functional while in the general area; thus, time in the area is equivalent to time on station.

(U) The surface vehicles were evaluated in many different scenarios where the TF would not be used; thus, a meaningful summary of TF for the surface vehicles cannot be obtained. For the particular case of patrol aircraft, transit factors, using design mission durations, are summarized in Table V-15.

2.3.2.4 UNREP Factor (UF)

(U) The fourth component in considering wartime availability accounts for the time off station during an operational cycle for UNREP of fuel, ordnance, or stores. Since air vehicles are considered to be of short mission duration and are not refueled during the mission (i.e., for air vehicles $UF = 1$), only surface vehicles are considered in the UNREP factor.

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(U) Table V-15. TRANSIT FACTORS OF MULTIMISSION AIR VEHICLE POINT DESIGNS USING DESIGN MISSION DURATIONS

VEHICLE	RADIUS OF ACTION (NMI)	TIME ON STATION (HR)	DESIGN MISSION DURATION (HR)	TRANSIT FACTOR
A/L	1600	19.9	29.5	0.674
A/L (N)	1600	96	104.2	0.921
FAB	1600	96	176.7	0.543
S/L (L)	1600	19.1	27.1	0.706
WIG (O)	1600	33.0	41.8	0.789

(U) For the surface vehicles,

$$UF = \frac{\text{time on station}}{\text{time on station} + \text{UNREP time}}$$

UF is a function of distance (to and from the refueling area), speed, specific fuel consumption, fuel tank capacity, fuel transfer rate and reserve policy, sea state, and tactics. The numerical values used for these parameters depend on the mission and operation.

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CHAPTER VI CONCLUSIONS AND RECOMMENDATIONS

(U) This chapter presents some general conclusions from the technical evaluation and recommendations for a balanced R&D program based on the technical evaluation of the nine concepts of advanced naval vehicles for circa 2000. The recommendations are divided into those related to the development of the concepts and those related to general performance (power requirements, seakeeping, etc.), that cross concept lines and are more related to basic R&D efforts.

1. CONCLUSIONS

1.1 Basic Limitations and Assumptions

(U) Specific findings and conclusions regarding the concepts, issues, and point designs have been presented throughout this volume. However, some general conclusions and comments based on the technical examination must also be stated.

(U) As discussed in Chapter I, limitations restricted the scope of the study. For example, hybrid vehicles using a combination of features from different concepts to optimize the vehicle designs were not explored. Whether any of the vehicle concepts could have been enhanced through such a hybrid design remains unanswered.

(U) Furthermore, because of the assumption within the ANVCE Project that the Navy of the future would require multimission vehicles, the point designs were developed and evaluated within that context. Thus, no vehicle was optimized for a specific, single mission for which it might be particularly well-suited and in which the uniqueness of the vehicle could be fully exploited. However, in many ways, because of their high performance, the ANVs are more akin to airplanes, which are typically designed for single missions (e.g., high-altitude interceptors, high-speed penetrators, long-endurance bombers, etc.), than they are to the traditional, multi-purpose, surface ships of the Navy.

(U) Because of the multimission requirement, a large combat suite was assigned to each ANV point design. This requirement had an effect not only on the design but on the size, performance, and cost as well. The large payload required by multimission operations results in a larger and more expensive vehicle that may not always have an increase in performance and effectiveness commensurate with the cost increase.

(U) The often misused phrase "economy of scale" has led to the tendency to always assume that bigger is better and, thus, once having postulated a concept to emphasize the ability to increase the size and economy of a vehicle. A smaller,

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high-performance vehicle can often accomplish a task with greater efficiency and at lower cost than can a larger vehicle while at the same time maintaining the same level of performance. For example, in rough seas, the SWATH ship can maintain the calm-water speed of a conventional, displacement ship, thus providing a small ship that has the rough-sea capability of a big ship. This capability is particularly useful in a situation such as escorting an aircraft carrier. A current aircraft carrier must sometimes slow down in rough seas because its escorts cannot keep up, not because of any performance limitations of its own. A SWATH escort ship, however, while smaller than a conventional, monohull displacement ship, would not have to slow down, thus allowing the aircraft carrier to better conduct its mission in higher seas.

1.2 Platform/Combat Suite Interface

(U) The ANVCE Project found significant uncertainty and misinformation about helicopter deck-handling limits, 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 the dynamic ANVs, the platform 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 passing design information on capabilities and limitations of developing systems.

1.3 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 significantly 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 0.5 percent.

(U) The ANVCE Project sought to develop common cost-estimating relationships over a wide spectrum of air and surface vehicles for which no common standards existed in the Navy or industry (Volume III). It became evident that with such

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a wide range of technology, different costing methods and philosophy would affect the end design product and make comparisons more difficult. This issue is mentioned here to emphasize the point that cost and design must be done in tandem.

2. RECOMMENDATIONS

2.1 Concepts

(U) The U.S. Navy faces continuing requirements for increased levels of performance against the expanding threat that is quantitatively superior and improving in quality. For many years it has been a stated intention of the United States that it will not engage in a "numbers race" with the USSR but will instead exploit superior technology to develop and maintain a qualitative edge in military strength. Considerable debate has ensued on how best to exploit the technology and maintain superior quality. As discussed in Section 1 of this chapter, increasing platform performance and size may not always be the best solution. The rapidly increasing combat systems capability is tending to overshadow many of the differences in performance capability among the different platform concepts.

(U) Therefore, each concept must be further evaluated not only in terms of the current emphasis on multimission capabilities but also in terms of the unique, unquantifiable, intangible features of the concept and how they might best be applied to naval warfare.

(U) Thus, the following subsections present the recommendations for each of the concepts in light of their specific features, issues, and technical risks.

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.
- 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



(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 relative 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. Greater technical risk and higher costs are found to be associated with hydrofoil development within the 2000- to 3000-tonne class.*

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
- developmental 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 halved.*

2.1.5 SWATH Ship

(U) The SWATH concept represents in its simplest form 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.

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(U) The steady platform feature of the small SWATH ship provides it with the seakeeping characteristics of a large 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 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 in defining specific missions and defining 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 (fully air-buoyant) 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 but applied to much smaller vehicles (about 1 million to 3 million ft³ of internal volume) for use in ASW surveillance missions.*

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(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 ft³) with a payload approaching that of the S/L(V). Based on these analyses, *investigation of the technical feasibility of a small, ship-supporting SAB LTA should be pursued.*

2.1.8 Sea Loiter Aircraft

(U) The overriding advantage 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 light-weight 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 during the WIG concept investigations because of the relatively shallow data base and the uncertainty as to where the WIG vehicle in its overall concept sense and various forms would be most effective.

(U) The WIG vehicle is one that either

- stays in ground effect or
- *occasionally* flies out of ground effect.

Occasionally is a key word since if a WIG vehicle spends any appreciable time at altitude, then it is more an aircraft or seaplane than a WIG vehicle.

(U) The WIG vehicle did not compare favorably in the logistics role as a WIG vehicle operating only in ground effect because 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 to perform a task were not fully explored.

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(U) The technical examination of the WIG vehicle focused on one path, the PAR-wing approach, favored by the Navy technical community. This approach did not permit the resolution of issues as well as desired. Technical solutions were sought to the problems of

- pitch instability and
- avoidance of a crash into rough seas.

Solutions examined for stability involved water skis, hydrofoils, and similar devices but all lacked a degree of practicality for operation in rough water. Thus, these issues remain unresolved.

(U) Similarly, hard end plates for the WIG vehicle were shown to be structurally unsound in any practical operation. The use of skirt-like appendages to alleviate the dynamic loading was explored. While the models tested were crude, the use of an ACV-like skirt seems to have potential.

(U) The WIG vehicle remains in R&D Category 6.2 (Exploratory Development) until the technical issues are resolved. Foreign technology was examined in the technical areas of concern, and German and Soviet approaches were found to "avoid the problem," essentially making the craft either a calm-water platform or an aircraft with a WIG-vehicle takeoff and landing aid. In this context, it becomes difficult to distinguish between the WIG vehicle and the sea loiter aircraft.

(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 a continuing R&D base in many technical areas and disciplines that is developed in R&D Categories 6.1 (Research) and 6.2. This data base covers 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. The technical evaluation of the ANV concepts found several key areas in which R&D is required on a broad front to supplement the more-specific R&D items given for each particular concept. All of these functional areas apply to both surface and air concepts. However, the majority of the function-related area recommendations pertain to the surface ANV concepts because they have the combined problem of operating at high speed in rough seas and being weight-sensitive vehicles.

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(U) The eight key areas (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 recommended R&D in each of these eight areas are discussed in the following subsections.

2.2.1 Seakeeping

(U) The recommended R&D activities on seakeeping apply to ACV, hydro-foil, planing craft, SES, SWATH ship, sea loiter aircraft, and WIG vehicle. 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; and
- 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.

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(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 on marine propulsion apply to the ACV, SES, planing craft, hydrofoil, high-performance displacement ships, sea loiter aircraft, and WIG vehicle. 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 long life in a salt-laden atmosphere.*
- *Develop improved filtration systems to protect the marine gas-turbine engines developed 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 life 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. This development includes all related components of the propulsor (propeller blades, waterjet pumps, pitch control mechanisms, and waterjet inlet design). 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 on structural design apply to the ACV, SES, planing craft, hydrofoil, sea loiter aircraft, and WIG vehicle. 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 50-250 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 on 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 1.0) and at high speeds (Froude numbers greater than 1.0 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 foils 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 hull is depressed below the free water level by the presence of the pressurized air cushion.

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2.2.5 Skirts and Seals Development

(U) The recommended R&D activities on 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 10,000-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 on 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 on 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 maintaining their properties in a marine environment, (b) being used in construction for low cost (limited special tooling), and (c) being 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 at-

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tention 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 on 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.

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characteristics of the advanced vehicles in Chapter V, the conclusions and recommendations of the study are given in Chapter VI. The appendices cover design standards, details of the point designs, and references.

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ADVANCED NAVAL VEHICLES
CONCEPTS EVALUATION (ANVCE) PROJECT

Volume 2

TECHNICAL EVALUATION
APPENDICES A and B

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APPENDIX A
DESIGN CONSIDERATIONS

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(All Tables and Table Titles in this appendix are Unclassified)

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I. INTRODUCTION

(U) This appendix presents the methodology used to develop a set of vehicles that could be compared effectively. As part of this methodology, to ensure common design standards, the ANVCE Project Office developed common terminology; common technological projections of engine performances, material capabilities, etc.; and a common combat suite for each class (1,000 tonne, 3,000 tonne, CVs, etc.).

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II. ANVCE DEFINITIONS

I. INTRODUCTION

(U) Different programs, projects, and studies within the U.S. Navy have followed different systems for identifying the terms used. "Payload," for example, in one program may not include the same items as in another program. Furthermore, one program may describe ship or aircraft motion by "peak-to-peak" amplitudes while another program may use "standard-deviation" amplitudes. All too frequently it becomes virtually impossible to make valid comparisons between the vehicles capabilities, and much misinformation and confusion results from such different definitions.

(U) For the ANVCE Project, charged with comparing vehicles coming from many different branches of the U.S. Navy within both the Naval Air Systems Command (NAVAIR) and the Naval Sea Systems Command (NAVSEA), it is imperative that a consistent set of definitions be used in comparing technical data on these vehicles. However, it was not the intent of the ANVCE Project to develop an exhaustive glossary of all possible terms that were likely to be used in the project. It was important to standardize, for example, the presentations of "power" from an engine since this has a direct bearing on comparative performance and cost, but it was not considered important to standardize the definition of the torque coefficient for the engine that produces the power. Such detailed information was presented, if needed, in the existing format. This procedure avoided replotting of existing information and helped focus concentration on the key elements of vehicle and weapon system characteristics.

2. INTERNATIONAL SYSTEM OF UNITS

(U) The International System of Units (SI)* is a combination of the customary units, English and metric. This system includes the following quantity of units:

Quantity	Units	Symbol
Length	Centimeters, meters, kilometers nautical miles	cm, m, km, nm
Area	Centimeters, meters, kilometers	cm^2 , m^2 , km^2
Volume	Liter, cubic meter	l , m^3

* A complete description of the SI system is given in "The Metric Practice Guide" published by the American Society for Testing and Materials, 29 Nov 1973, Standardization Document (ASTM E 380-72e).

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Quantity	Units	Symbol
Mass	Kilograms	kg
Density	Kilogram per cubic meter	kg/m ³
Force	Newton (kg.m/s ²)	N
Pressure	Pascal (N/m)	Pa
Speed	meter per second, knot	m/s, knot
Acceleration	meter per second squared	m/s ²
Frequency	Hertz (cycle/s)	Hz
Power	Watt, metric horsepower	W, mhp
Temperature	Degrees Kelvin	°K
Time	seconds	s

(U) Whenever more than one unit is given, the choice was a matter of convenience, e.g., one would quote the wing span in “meters” but the aircraft range in “kilometers.” The SI unit for time is the second and was used when technical calculations were involved. Minutes, hours, or days were used in obvious instances such as for quoting endurance. The range of a vehicle may be given in nautical miles and speed in knots. For convenience, some of the more common quantities are given in terms of their conversion from English units to SI units in Table A-1.

(U) While the SI terminology was selected for use by the ANVCE Project, it could not be adhered to in all cases because of the many contractors, Navy Laboratories, and data sources involved.

TABLE A-1

CONVERSION OF SOME COMMONLY USED TERMS

English	SI (Metric)
100 ft	30.48 m
100 nm	185,200 m or 185.2 km
100 kt	51.44 m/s
100 ST (weight)	90,710 kg or 90.71 t
100 lb (force)	444.822 N
100 psf (pressure)	4,788.026 Pa
100 hp	74,570 W or 101.38 mhp*

* Although watts is used in the SI system, metric horsepower was preferred for the ANVCE Project.

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3. DEFINITION OF TERMS

(U) The definitions of terms used in the ANVCE documentation, listed alphabetically, are as follows:

<u>TERM</u>	<u>DEFINITION</u>	<u>NOTES</u>
Lift-Drag Ratio (L/D)	L/D indicates the ratio of the equilibrium aerodynamic or hydrodynamic lift to the full load condition (W_T) of the vehicle. The drag (D) is the total aerodynamic or hydrodynamic resistance of the vehicle.	As a ratio, L/D is dimensionless and should always be accompanied by corresponding speed (i.e., 15 at 25 m/s).
Payload	Payload consists of those items carried by the vehicle to enable it to discharge its mission. Specifically, payload consists of those items listed in Table A-2.	
Sea Condition	All sea conditions are expressed in terms of significant wave height (m), not sea state.	
Speed	Nondimensional speed is expressed as $\text{Froude No.} = \frac{V}{\sqrt{gL}}$ where V = vehicle speed (m/s), g = gravitational constant (m/s^2), and L = waterline length (m). The dimensional speed is expressed in m/s. Maximum sustained speed is the speed attainable at full-load displacement for surface vehicles and takeoff gross weight for air vehicles at maximum continuous power.	This term is applicable to surface vehicles only. Mach No. is used for air vehicle speed nondimensionalization. Same for air vehicles.

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Maximum speed is the speed attainable at full-load displacement for surface vehicles and take-off gross weight for air vehicles at maximum intermittent power.

Loiter speed is the speed corresponding to maximum endurance.

Cruise speed is the speed corresponding to 99 percent maximum range.

Transport
Efficiency
 $\frac{WV}{P}$

Parameter that appears in range equation and relates "horsepower" per ton" (P/W) with vehicle speed (V),

where

W = full load weight of vehicle,

V = vehicle speed, and

P = total power installed to both propel and lift the vehicle at speed V.

1. Is non-dimensional ratio of work done by vehicles (WxV) to total power (P) expended.
2. In the simple case of no lift, power is product of propulsive efficiency (η) and L/D ratio i.e.,

$$\frac{WV}{P} = \eta \frac{L}{D}$$

Useful Load

Useful load consists of those items carried by the vehicle to enable it to operate. Specifically, useful load consists of those items listed in Table A-3.

Empty
Weight

Empty weight is the weight of the basic vehicle as follows:

Empty Weight = Total Gross Weight - Useful Load,

where

Total Gross Weight = Full load displacement for ships, takeoff gross weight for aircraft.

Specifically, empty weight consists of those items listed in Table A-4.

TABLE A-2

DEFINITION OF PAYLOAD

ITEM	SHIP		AIRCRAFT	
	DESCRIPTION	SWBS ^a	DESCRIPTION	MIL-STD-1374 ^b
Mission Electronics	Command and surveillance minus navigation and interior communications	400 - (420+430)	Avionics minus navigation and interior communications	II 31
Armament	Armament	700	Armament minus passive protection ^{c,d}	II 32 and 33
Ordnance plus Ordnance Delivery Systems	Ordnance plus ordnance delivery systems	F21-F27	Disposable ordnance and sensors (not already included)	I 4. Items 24-25
Fuel for Onboard Aviation Equipment	Fuel for helicopters and remotely piloted vehicles (RPV)	F42, F43, F46	RPV fuel	
Cargo ^e	Cargo	F60	Cargo	I 4. Item 22

^a Numbers are from Ship Work Breakdown Structure (SWBS) NAVSHIPS 0900-039-9010.

^b Numbers refer to page and item number from MIL-STD-1374 "Weight and Balance Data Reporting Forms for Aircraft," 31 March 1972.

^c Includes repair parts for avionics and armament.

^d Includes passive protection (armor) with structure.

^e For logistics mission.

TABLE A-3
DEFINITION OF USEFUL LOAD

ITEM	SHIP		AIRCRAFT	
	DESCRIPTION	SWBS	DESCRIPTION	MIL-STD-1374
Payload	See Table A-2		See Table A-2	
Liquids	Ship endurance fuel, lubricants, water, other fluids.	F40, F50	Aircraft endurance fuel,, lubricants, water, other fluids ^a .	I 4, Items 5-20
Crew and Effects	Ships complement and effects.	F11, F12 F13	Crew and effects ^b	I 4, Items 3 and 4
Stores	Stores	F30	Stores ^c	I 4, Items 21, 48-54

^a Does not include fuel tanks or plumbing (internal or external).

^b Includes entire crew (flight crew, sensor operators, and support personnel) and their effects (clothing, toilet articles, etc.).

^c Includes provisions and personnel stores. Does not include repair parts.

TABLE A-4
DEFINITION OF EMPTY WEIGHT

ITEM	SHIP		AIRCRAFT	
	DESCRIPTION	SWBS	DESCRIPTION	MIL-STD-1374
Structure	Hull structure	100	Structure ^a	II 2-17
Propulsion	Propulsion plant	200	Propulsion group ^b	II 18-21
Electrical Plant	Electrical plant	300	Electrical group	II 30
Navigation and Interior Communications	Navigation and Interior communications	420+430	Navigation and Interior communications ^{b,c}	II 35, Item 32-37
Auxiliary	Auxiliary systems	500	Auxiliary systems	II 22-29, 37-40
Outfit and Furnishings	Outfit and furnishings	600	Furnishings and equipment group ^d	II 34-36 II 34-36

^a Passive protection (i.e., armor included).

^b Each group includes repair parts.

^c Navigation and internal communication equipment are reported separately.

^d Flight control group, auxiliary power group, instrument group, hydraulic and pneumatic group, air-conditioning group, anti-icing group, photographic group, load and handling group included.

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III. STANDARD POWER PLANT CHARACTERISTICS (1980-2000)

1. INTRODUCTION

(U) This section provides a single set of standardized characteristics to describe the power plants expected to be available by the year 2000. This standardization is considered necessary to avoid the inconsistencies that have resulted from otherwise independent extrapolations of technological trends.

(U) For convenience, all principal characteristics have been presented graphically as a function of required continuous shaft horsepower. In each case at least two curves representing the characteristics of power plants expected to be available in quantity production are shown – one for 1980 and the other for 2000. For all ANVCE far-term point designs [(initial operational capability (IOC) 1995)], the curves marked 1980 should be used. The rationale for this statement is as follows:

Vehicle IOC - 1995

Vehicle design, construction, testing - 8 to 10 years

Subsystem technology base - 1985-87.

(U) For the ANVCE near-term air vehicle point design (ZPG), candidate propulsion systems are restricted to those systems currently in production or those currently in final stages of development with an IOC prior to 1982 (such as the T700-GE-700).

(U) For all ANVCE far-term air vehicle point designs (IOC, 1995), curves for 1990 should be interpolated and used except as noted below. Where engine sizes fall within the scalable ranges of the Pratt & Whitney STS-487 or STF-477, these should be used. Where required engine sizes are below those ranges, the procedure used is as follows: (1) any existing or study engine of the proper size is used, (2) the specific weight of the engine is adjusted to reflect the value shown in WP-011 for a 1990 technology engine of the same power rating, (3) the SLS (sea level static) SFC (specific fuel consumption) at maximum continuous rating of the existing or study engine is adjusted to reflect the value shown in WP-011 for a 1990 technology engine of the same power rating, and (4) the SFC's at other Mach number, altitude, power setting conditions are adjusted by the ratio of the WP-011 SLS SFC to the existing or study engine SLS SFC.

(U) Propulsors associated with nuclear power plants are limited to the component technology (e.g., materials characteristics) of the Pratt & Whitney STS-487 and the STF-477.

(U) The selection of the 1980 data base is slightly on the conservative side but far more realistic than the use of the data extrapolated to the year 2000.

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(U) Characteristics for eight distinct types of power plants are presented in Table A-5. Table A-5 also identifies the parameters selected for power plant characterization along with an index for figures and/or sections in this chapter that present the data. Wherever applicable, the data are presented for sea level, international standard atmospheric (ISA) conditions (59°F, 15°C, etc.). The performance requirements for the ANVCE point designs are specified at 80°F (26.7°C) at sea level. The thrust and resultant speed of the vehicle is computed and reported in the final design report at both 59°F (15°C) and 80°F (26.7°C). Appropriate corrections to the data are made to take these temperature differences into account. Where curves are shown as a function of maximum power that can be sustained continuously* within acceptable time between overhauls or with normal inspection intervals and maintenance cycles. Some engine manufacturers distinguish between maximum continuous power and continuous power ratings, where the maximum continuous rating is only applicable to, for example, 4 hr of continuous operation. In such cases, this continuous power rating is equivalent to the maximum continuous rating defined herein.

(U) In all cases, it is assumed that maximum intermittent (reserve, stand-by or take-off) ratings are 15 percent greater than maximum continuous ratings.

(U) All extrapolations to 2000 are based on technological trends that have been evident up to 1976, including both in-service, demonstrated performance, and the results of design studies, experimental investigations, and advanced development programs. The projections have been made and justified essentially on the basis of "A Review of Power Plants Likely to be Available for Advanced Naval Vehicles in the 1980-2000 Time Period," by Payne, Inc., March 1976. Additional data are presented in Figures A-1 through A-7.

* Power available for propulsion and accessory drives, etc., with engine installed having specific inlet and exhaust duct pressure losses; does not include transmission power losses.

TABLE A-5

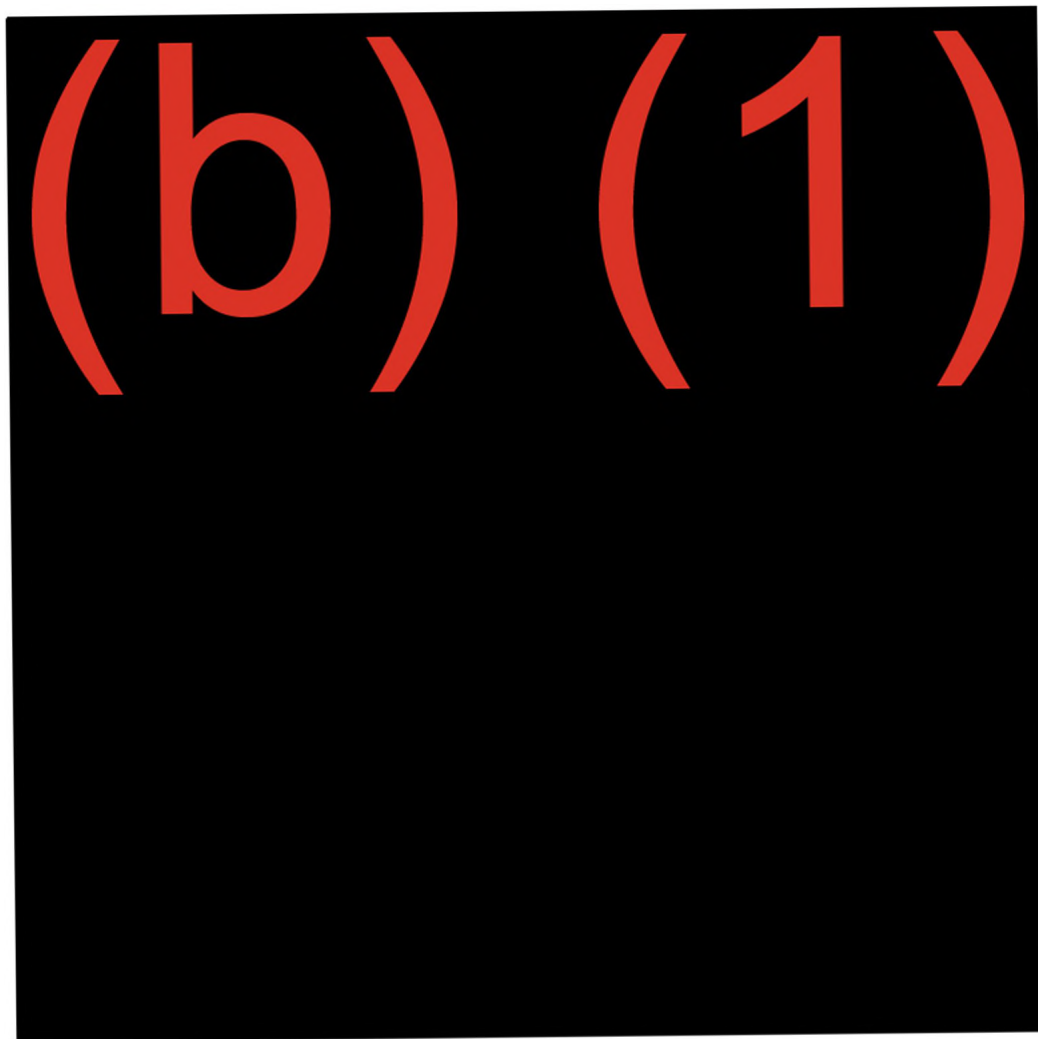
POWER PLANT TYPES, CHARACTERISTIC PARAMETERS
AND INDEX FIGURE NUMBERS

POWER PLANT TYPE	SPECIFIC WEIGHT	ON-DESIGN OR MAX. CONT. SFC	SPECIFIC FUEL CONSUMPTION AT PARTIAL POWER	POWER DENSITY	SPECIFIC COST
Reciprocating Marine Diesels	Fig. A-1	Fig. A-2	Fig. A-3	Fig. A-5	Fig. A-6
Rotary Marine Diesels	Fig. A-1	Fig. A-2	Fig. A-3	Fig. A-5	Fig. A-6
Open-Cycle Marine Gas- Turbines	Fig. A-1	Fig. A-2	Figs. A-3 & A-4	Fig. A-5	Fig. A-6
Closed-Cycle Marine Gas- Turbines	Fig. A-1	Fig. A-2	Fig. A-3	Fig. A-5	Fig. A-6
Regenerative Cycle Marine Gas-Turbines	Fig. A-1	Fig. A-2	Sect. 4	Fig. A-5	Fig. A-6
Aircraft Gas-Turbines	Fig. A-1	Fig. A-3	Fig. A-3	Fig. A-5	Fig. A-6
Marine Nuclear Power Plants	Fig. A-7	Sect. 3	Sect. 4	Sect. 5	Sect. 6
Free-Piston Engines	Sect. 2	Sect. 3	Sect. 4	Sect. 5	Sect. 6

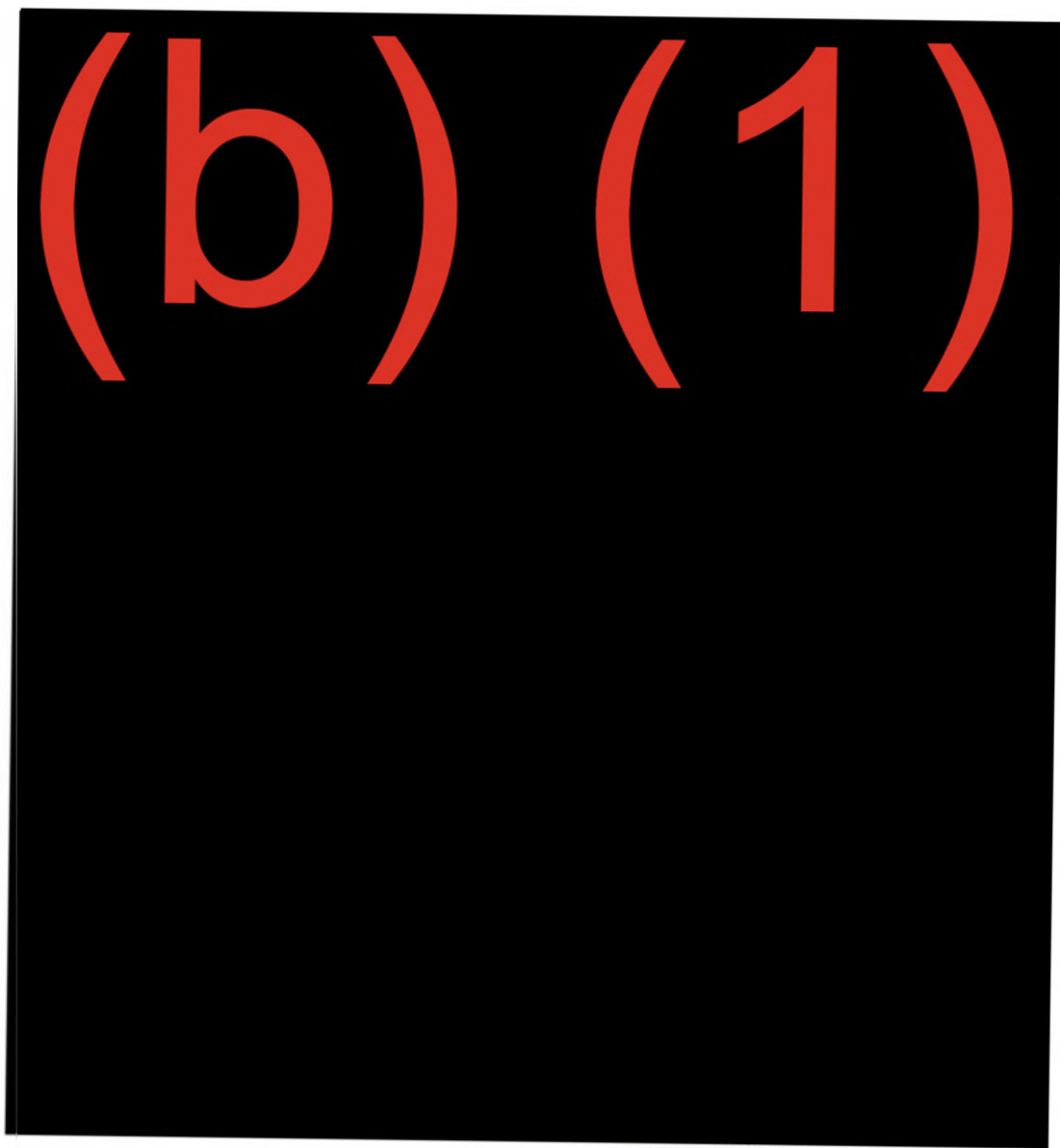
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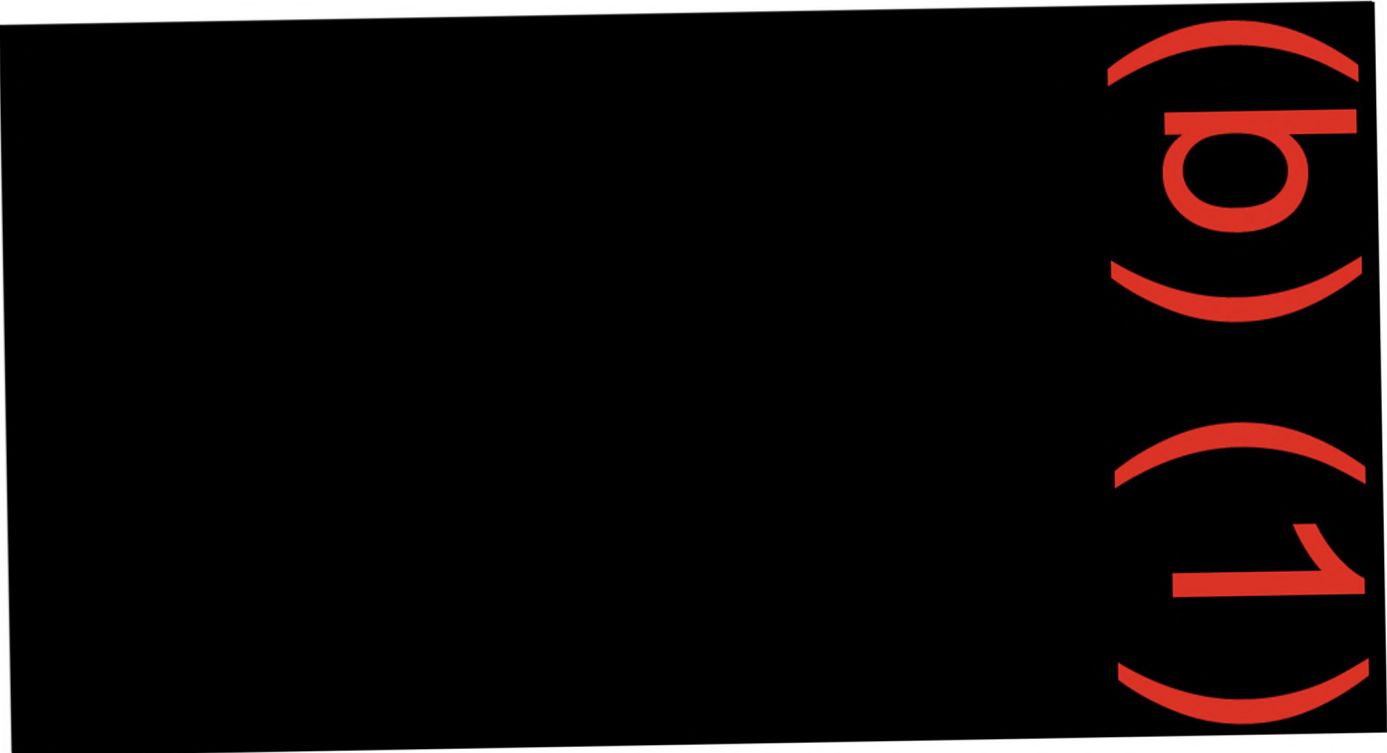


(C) Figure A-1. SPECIFIC WEIGHT PROJECTED FOR VARIOUS ENGINES
IN QUANTITY PRODUCTION BY THE YEAR SHOWN (U)

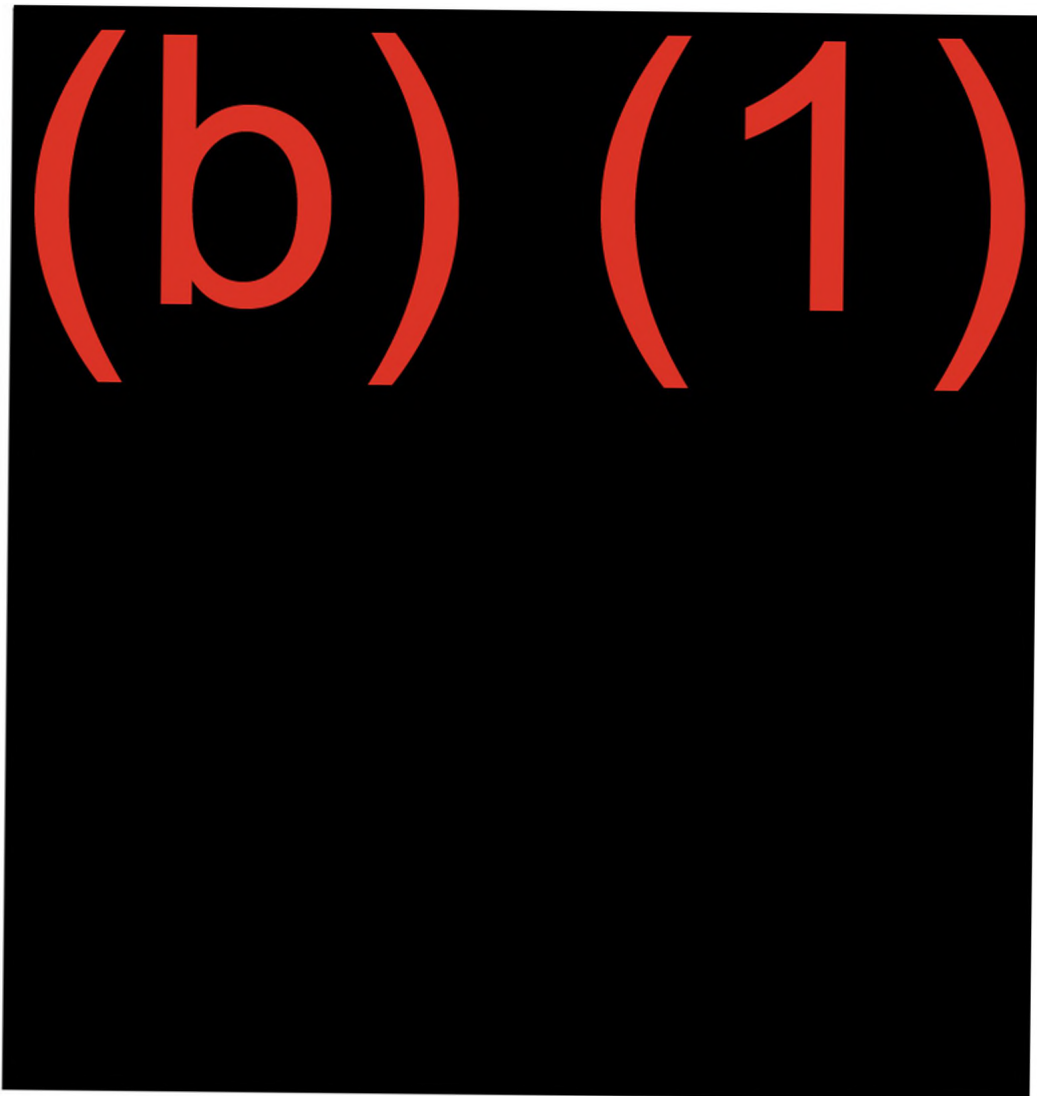


~~(C)~~ Figure A-2. SPECIFIC WEIGHT OF MARINE
NUCLEAR POWER PLANTS (U)

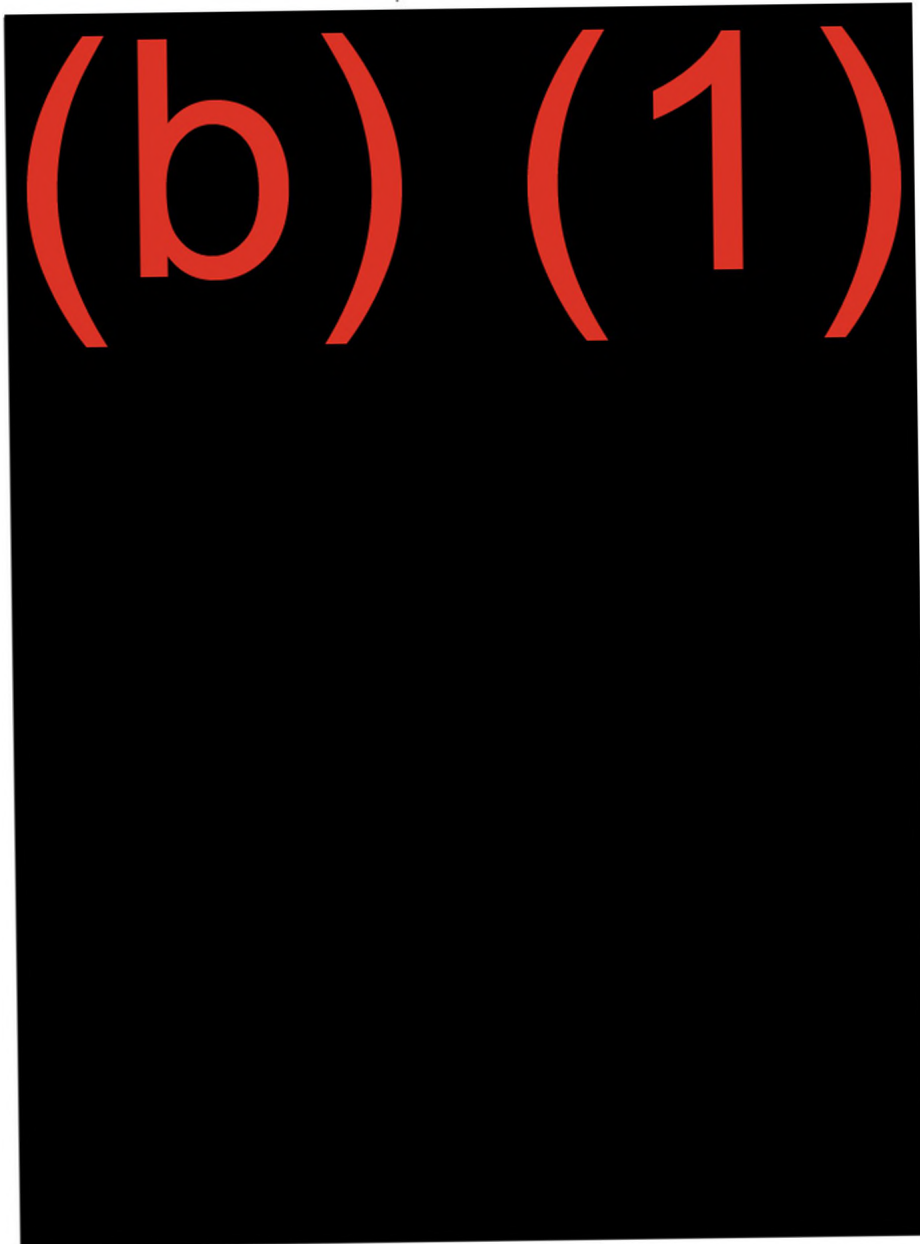
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(C) Figure A-3. SPECIFIC FUEL CONSUMPTION PROJECTED FOR VARIOUS ENGINES
IN QUANTITY PRODUCTION BY THE YEAR SHOWN (U)

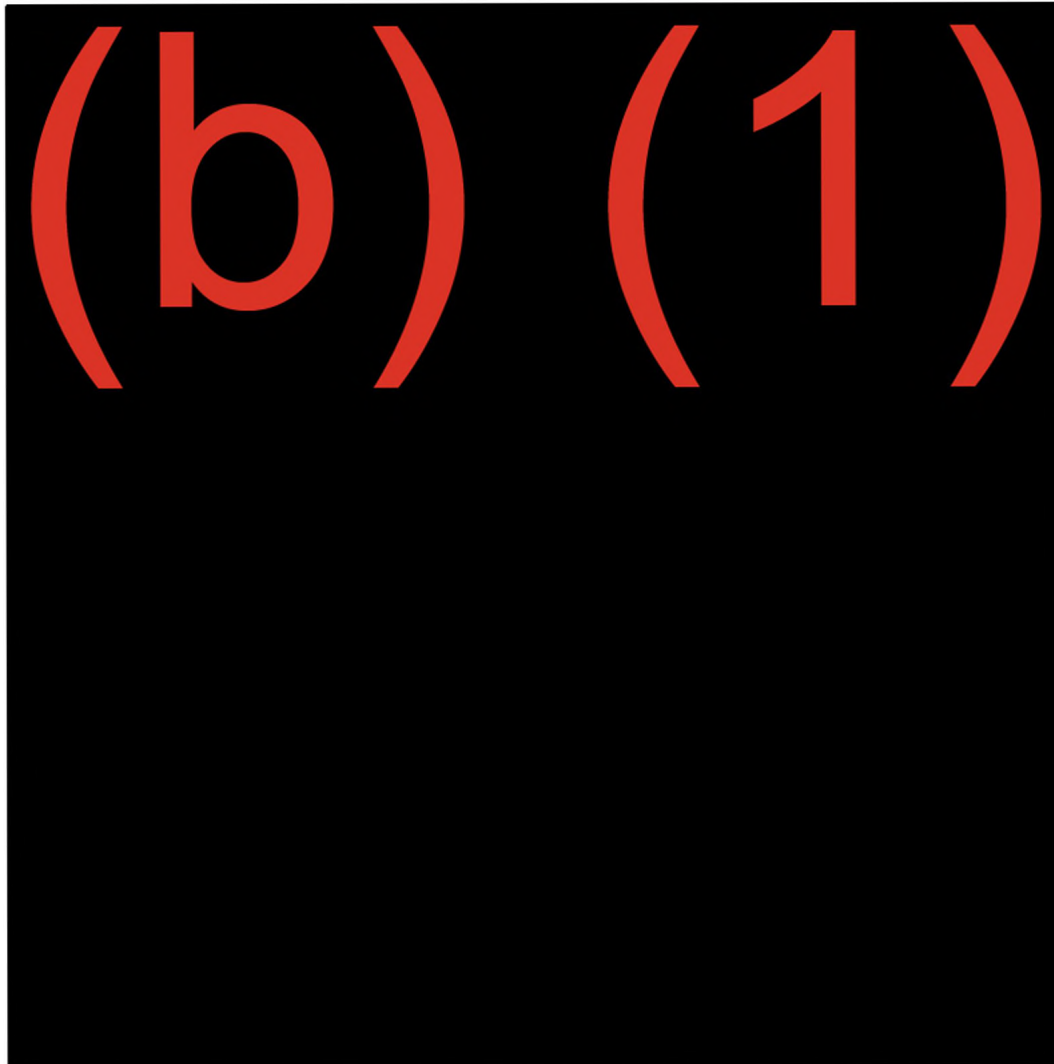


~~(C)~~ Figure A-4. SPECIFIC FUEL CONSUMPTION RATIO
FOR 1980 GAS TURBINES AND DIESEL
ENGINES DURING PARTIAL POWER OPERATION (U)



(C) Figure A-5. SPECIFIC FUEL CONSUMPTION RATIO FOR MARINE
GAS TURBINES AS A FUNCTION OF MAXIMUM
CONTINUOUS POWER AND PERCENT PARTIAL POWER (U)

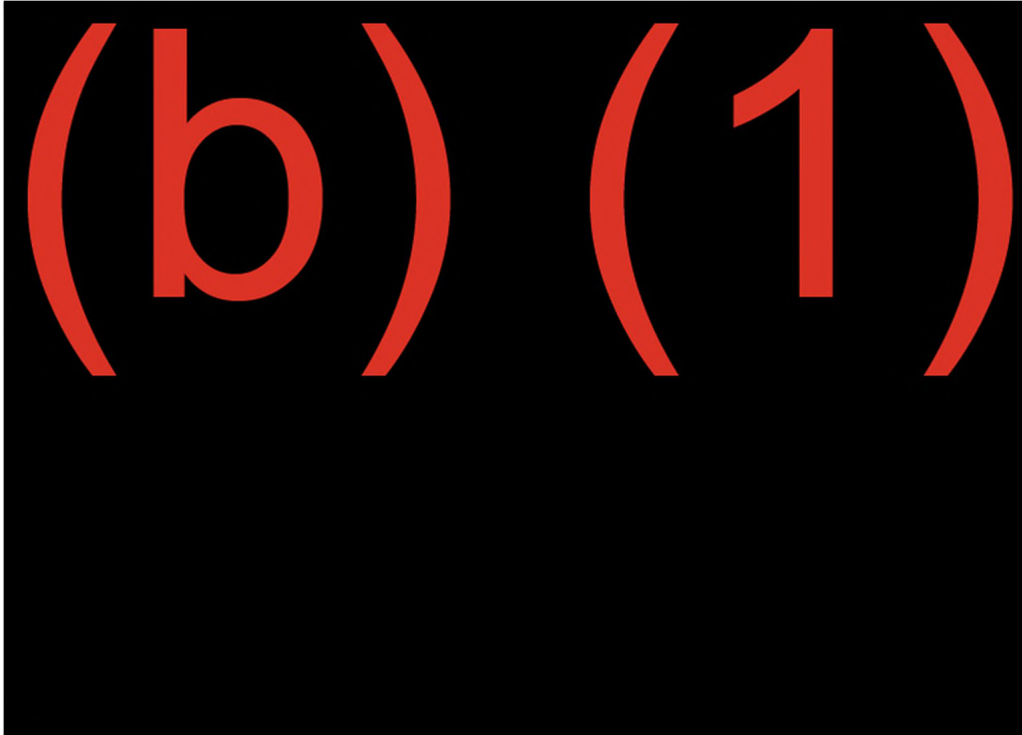
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~~(C)~~ Figure A-6. POWER DENSITY (POWER/VOLUME) VS. POWER,
PROJECTED FOR VARIOUS ENGINES IN QUANTITY
PRODUCTION BY THE YEAR SHOWN (U)

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~~(C)~~ Figure A-7. RELATIVE PROCUREMENT COST OF
VARIOUS MARINE ENGINES (U)

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2. SPECIFIC WEIGHT

(U) Figures A-1 and A-2 present dry-engine specific weights (weights per maximum continuous horsepower) for various power plants as a function of maximum continuous power rating. All engine weights used are complete, dry (no fuel and lubricant) engine weights with standard accessories and minimum inlet and exhaust ducts, excluding gear boxes and transmission (i.e., WBS group 230). In the case of the nuclear power plants, the weights include all power plant and reactor components and shielding, controls, auxiliaries, and reduction gearings up to the connection to transmission shafting (i.e., WBS group 210 and 230).

(U) Free-piston engines, not shown in Figure A-1 are projected to have specific weights of 0.7 lb/shp (0.313 kg/mshp) for maximum continuous power in the 1,000- to 10,000-shp range.*

3. ON-DESIGN SPECIFIC FUEL CONSUMPTION (SFC)

(U) On-design SFC, or SFC based on maximum continuous power operation, is shown in Figure A-3. ISA sea-level conditions are again assumed. Corrections necessary for other environmental operating conditions must be determined and justified independently. Fuel consumption or fuel cost for nuclear power plants must also be determined independently.

(U) The specific fuel consumption of free-piston engines, projected for the year 2000 in the maximum continuous power range of 1,000 to 10,000 shp, may be taken as 0.24 lb/shp-hr (0.107 kg/mshp-hr).*

4. PARTIAL POWER SPECIFIC FUEL CONSUMPTION

(U) Figure A-4 shows the ratio (R) of partial-power SFC to maximum continuous SFC as a function of the percentage of maximum continuous power. For open-cycle gas-turbines, it has also been necessary to show this relationship as a function of actual maximum continuous power. In this case, Figure A-5 is provided to assist in interpolating for specific power requirements.

(U) Since, for specific engines, SFC is a function of both shaft speed and percentage of horsepower, a $P \propto N^3$ propulsor power law has been assumed throughout.

(U) The off-design performance of free-piston engines is assumed to follow a trend equivalent to that of the diesel engine. The off-design performance of regenerative-cycle, marine, gas-turbine engines is assumed to follow a trend equivalent to that of the open-cycle, marine, gas-turbine engine.

* "A Review of Power Plants Likely to be Available for Advanced Naval Vehicles in the 1980-2000 Time Period," Payne, Inc., March 1976.

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(U) The curves plotted in Figures A-4 and A-5 are those projected for engines in quantity production by 1980. For engines in quantity production by 2000, the following corrections are required:

Assume $(R)_{2000} = [(R)_{1980} - 1.0] 0.7 + 1.0$ for open-cycle gas-turbine engines
and $(R)_{2000} = (R)_{1980} - (100 - x)/1800$ for diesel and closed-cycle gas-turbine engines,

where $(R)_{1980}$ is the SFC ratio projected for 1980 and $(R)_{2000}$ is the SFC ratio projected for 2000.

5. POWER DENSITY

(U) Power density, in terms of maximum continuous power per cubic volume of an equivalent rectangular box, is shown as a function of required power in Figure A-6. It is assumed that in all cases the volume does not include the volume required for inlet and exhaust ducting even if some ducting may normally be considered as an integral part of the engine.

(U) Difficulty was experienced in developing a consistent density trend for marine, gas-turbine engines. Up to 4300 shp, present-day, maximum, power densities for marine, gas-turbine engines can be represented by the AVCO/Lycoming TF series* of production and projected engines. For power in excess of 4300 shp, power density trends of marine, gas-turbine engines have been influenced less by volume minimization incentives. By 2000, however, a significant improvement of large-engine power density could (and will be assumed to) be made possible with a density trend mid-way between that of current day aircraft and marine, gas-turbine engines. The curve to be used is that which is labeled "open- and closed-cycle marine gas-turbine" shown in Figure A-6.

(U) For the purpose of marine, gas-turbine power plant installation layout, the following dimensional proportions will be assumed:

* Derived from the T53 and T55 helicopter engines for which volume minimization was a particularly high incentive.

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Max. Cont. Power ≤ 4300 shp > 4300 shp

$$\frac{\text{LENGTH}}{\text{WIDTH}} \left(\frac{L}{W} \right) = \quad \quad \quad 1.7 \quad \quad \quad 3.0$$

$$\frac{\text{DEPTH}}{\text{WIDTH}} \left(\frac{D}{W} \right) = \quad \quad \quad 1.3 \quad \quad \quad 1.0$$

where $w = \left[\frac{(\text{Max. Cont. Power})}{\left(\frac{L}{W} \right) \left(\frac{D}{W} \right) (\text{Power Density})} \right]$

The equivalent rectangular box, defined above, does not include the additional special requirements for accessories and maintenance, etc.

(U) The proportions, defined above, can also be assumed to apply to closed-cycle and regenerative-cycle, gas-turbine engines. For reciprocating marine diesels, assume

$$\left(\frac{L}{W} \right) = 2.5 \quad \text{and} \quad \left(\frac{D}{W} \right) = 1.2.$$

For rotary marine diesels, assume

$$\left(\frac{L}{W} \right) = 1.8 \quad \text{and} \quad \left(\frac{D}{W} \right) = 1.0.$$

(U) For free-piston engines assume a constant power density of 70 shp/ft³ (2496.5 mshp/m³) and proportions the same as reciprocating marine diesels. The volume and proportions of nuclear propulsion plant installations must be determined and justified independently.

6. SPECIFIC COST

(U) Specific cost of various marine engines is given in Figure A-7. The specific cost of free-piston engines may be assumed equal to that of reciprocating, marine diesel engines. The cost of a nuclear power plant installation must be determined and justified independently.

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IV. SURFACE VEHICLE MANNING

1. INTRODUCTION

(U) Surface vehicle manning has a direct impact on the size, performance, and life-cycle cost of the point designs. A manning policy ensures consistency in estimating the manning requirements for the surface point designs.

(U) From considerations of supportability/availability, the surface point designs have been grouped into three categories (A, B, and C). The far-term (i.e., post-1985) surface point designs have been placed in these categories as follows:

<u>Category</u>	<u>Approximate Endurance (days)</u>	<u>Far-Term Surface Point Designs</u>
A	30	SWA CVN, SES CVN, SES CV
B	15-30	MONO, HYD 2, SWA 4, SES 3, ACV 3
C	5-15	ACV 1, HYD 7, PC 1

2. MANNING POLICY

(U) The required capability and standards for Condition I (battle readiness) and Condition III manning are presented in Tables A-6 and A-7. The Condition I manning policy governs if a conflict develops. The objective is to have Condition I and Condition III manning be as efficient and balanced as possible.

(U) The manning levels for ANVCE far-term, surface point designs are specified in Tables A-8 and A-9.

TABLE A-6

CONDITION I MANNING POLICY

Class	Bridge Capability	COC Capability	ENG/DC Capability	Battle Messing/ Medical Capability
A	Standard plus Flag, AIR-OP	Fully control all air OPS and flag support. Able to take on bridge func- tions in emergency. Standard electronic repair/casualty con- trol capability.	Central and local control of all mis- sion-essential systems. Three repair parties.	Standard battle messing; extensive medical capability.
B	Minimum of OOD, ship controlman, lookouts. Capable of safety/visual navigation/visual formation man- euvering func- tions.	Fully control all systems and own- ship's air assets. Limited air control capability, no flag support. Limited electronic casualty control capability.	Same as Class A	Standard battle messing, one hos- pital corpsman.
C	Same as Class B	Fully control all systems. Very limited air control capability. No flag support. Very limited electronic casualty control capa- bility integrated with repair parties.	Central and local control of all mobility-essential systems. Two repair parties that include elec- tronic repair capa- bilities	Same as Class B.

TABLE A-7

ORGANIZATIONAL MANNING POLICY

Class	Condition III Capability	Maintenance Capability	Administrative Capability	Supply Capability	Food Service Standard
A	Standard, able to use all antiship missile defense (ASMD) systems; limited use of offensive weapons; routine OPS.	Capable of performing all preventive maintenance (PM) and corrective maintenance (CM) not requiring depot facilities.	Self-supporting.	Self-supporting. All supply department functions.	Minimum of 7 percent of crew.
B	Fast reaction time required; able to use all weapons in ready load. Reload requires Condition I.	Capable of performing all daily, weekly, monthly PM, CM on mission-essential equipment not requiring depot facilities; limited CM on non-essential equipment.	Limited; requires shore, tender, or flagship support.	Limited; requires shore, tender, or flagship support.	Maximum of 7 percent of crew.
C	Same as B	Capable of performing only daily and weekly PM and emergency CM on mission-essential equipment.	None	Very limited to support emergency repair/replacement.	Maximum of 7 percent of crew.

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TABLE A-8

MANNING LEVEL FOR SURFACE POINT DESIGNS, CATEGORY B

Function/Station	Condition I (Off/CPO/Enlisted)	Condition III (Off/CPO/Enlisted)
Bridge	2/0/2	6/0/6
COC	4/3/32	5/3/33
Lamps	4/1/12	4/1/12
Eng/DC	4/4/49	0/2/7
Admin/Supply/ Food Service	1/2/8	1/3/15
Maintenance		
Deck	—	0/1/8
C.S.	1/1/10	0/1/10
Eng	—	0/0/22
Total	16/11/113 (140)	16/11/113 (140)

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TABLE A-9

MANNING LEVEL FOR SURFACE POINT DESIGNS, CATEGORY C

Function/Station	Condition I (Off/CPO/Enlisted)	Condition III (Off/CPO/Enlisted)
Bridge	1/0/3	3/0/9
COC	3/2/25	2/1/24
Eng/DC	1/2/36	0/0/12
Admin/Supply/ Food Service	0/0/6	0/0/8
Maintenance	—	0/3/17
Total	5/4/70 (79)	5/4/70 (79)

V. TOP LEVEL REQUIREMENTS (TLRs)

1. INTRODUCTION

1.1 Purpose and Scope of Point Design

(U) It is both unnecessary and infeasible to produce an "optimum" point design in order to evaluate vehicle concepts. First, the evaluation models will probably not be sensitive to the changes in a point design realized by extreme design refinements and optimization. Second, the specification of the design requirements will be by no means optimum for each vehicle concept. (Analysis of the parametrics contained in the state-of-the-art summaries and the operational requirements projected for the 1980-2000 time frame would be too time consuming). The point designs are, therefore, baseline designs representing a "point" in the range of feasible design alternatives for the particular vehicle concept. A sensitivity analysis uses the point designs and related parametrics to check the impact on the risk and cost evaluation of design perturbations.

1.2 Purpose and Scope of Top Level Requirements

(U) This section on TLRs is similar in format to that specified in OPNAV Instruction 9010.3 of 4 January 1974 and the Top Level Requirements Model of April 1975. There are, however, two important differences:

- The intent of OPNAV INST 9010.3 is to produce a Draft TLR at the completion of the feasibility design and an Approved TLR at the completion of preliminary design. Because of time and budget constraints, the ANVCE point designs are only given to the approximate level of detail of a feasibility design. Therefore, the ANVCE TLR must be produced *before* the feasibility design begins.
- Again, time and budget limitations and the requirements for consistency among the point designs require that the ANVCE TLR specify design requirements to a greater level of detail than is normally desirable at the beginning of a feasibility design. These restrictions do not permit an exploration of the complete range of design alternatives. Therefore, the TLR will provide the designers with direction to "zero-in" very rapidly on a feasible point design. Furthermore, to enhance the risk and cost evaluation, consistency in specifying certain design standards and criteria is required.

(U) In Annex A to this appendix, the TLRs for two ANVCE point designs – the 1000-tonne Air Cushion Vehicle (ACV 1) and the Air Loiter (A/L) aircraft are presented.

2. OPERATIONAL CAPABILITIES

2.1 Mission and Tasks

2.1.1 Mission

(U) The mission of the ANVs is to operate offensively in the presence of an air, surface, or subsurface threat, independently or with strike, antisubmarine, or amphibious forces; to provide protection to those forces, underway replenishment groups, and military or mercantile convoys against air, surface or subsurface threats; and to provide effective self-defense.

2.1.2 Operations

(U) The operations of the ANVs include:

- barrier,
- sea-launched ballistic missile (SLBM) defense,
- surveillance and reconnaissance,
- ocean area,
- naval force protection,
- shipping protection, and
- offensive strikes.

2.2 Mission Warfare Areas

(U) Ships will have capabilities in following warfare areas:

- antisubmarine warfare (ASW),
- anti-air warfare (AAW),
- surface strike warfare (SSW), and
- command, control, and communications (C³).

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(U) The ANVs must be able to control these operations, to participate in independent operations, and to support and operate a single embarked helicopter configured for each of these operations. Table A-10 is a listing of the elements of the combat system used to support the mission warfare areas.

2.3 Mobility Area

- Ship size: nominal full-load displacement = 2200 - 4400 tonnes. Ship Characteristics to be determined.
- Speed: max sustained speed in seas with significant wave heights of 1.5m = 25m/s; max sustained speed as a function of wave height – to be determined.
- Range: @ 10m/s = 8000km (significant wave height 1.5m); @ 25m/s = 3000km (significant wave height 1.5m).
- Propulsion system: to be determined.
- Navigation: accuracy within 4km anywhere in world continuously.
- Miscellaneous: UNREP/VERTREP: receipt of fuel, ordnance, and provisions port and starboard; one VERTREP drop zone; towing: capability to tow another ship of similar size at 5m/s; small boats: one 10-m motor whale boat.

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TABLE A-10

COMBAT SYSTEM CHARACTERISTICS

Capability	Configuration	Remarks
Missile Battery	(1) MK 26	(64) SM-2 and HARPOON
Secondary Battery	(1) 5"/54 LWG	(600) rounds
Antiair	(2) Close-In Weapon System (CIWS)	(16,000) rounds off mount
Antisubmarine Battery	(2) MK 32/9	(50) MK 46 torpedoes, including aviation allowance
Surface Fire Control System	MK 92/STIR	or an equivalent
U/W Fire Control System	To be determined	
Electronic Countermeasures	Design-to-Price Suite No. 2	or an equivalent
Acoustic Countermeasures	NIXIE	
L.R. Air Search Radar	AN/SPS-43	or an equivalent
3-D Air Search Radar	To be determined	
Surface Search Radar	AN/SPS-55	or an equivalent
Active Sonar	AN/SQQ-23	or an equivalent
Passive Sonar	TACTASS	or an equivalent
IFF MK XII	To be determined	
Combat Direction System	UYK 7, UYK-20 computers; video processor; Link 11; Link 14 (transmit only); Class 3 air control.	or equivalent

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2.4 Survivability and Vulnerability

- Signature: no specific requirements; to be determined.
- Stability: IAW Sarchin and Goldberg
- Ballistic protection: to be determined.
- Shock factor: to be determined.
- Blast overpressure: to be determined.
- NBC protection: to be determined.
- Damage control: must provide for fire prevention and fighting, dewatering, and flooding control similar in capability to that of FFG-7.

3. PLANNED USE

3.1 Environment

(U) ANVs shall be designed to operate on any navigable ocean. They will not be designed for cold weather operations (ice hardening) or for Arctic operation.

3.1.1 Wave Heights

(U) Wave heights for various operations are:

<u>Operations</u>	<u>Maximum Wave Height</u>
Helicopter operations	3 m
UNREP	3 m
Continuous operation	4 m
Limited operation	10 m
Survive without damage	15 m

3.1.2 Pollution Control

(U) IAW OPNAVINST 6240.3

(Collection, holding, and transfer of sewage)

(Clean ballast tanks)

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3.2 Operational Availability and Ship Utilization

- (U)
- Life of Ship: 25 year
 - Operational Profile: Underway, 40 percent; in port, 60 percent.

● <u>Speed (m/s)</u>	<u>Percent of Underway Time</u>
Over 20	3
15 - 20	36
8 - 15	34
5 - 8	22
0 - 5	4
Astern	1

3.3 Maintenance, Overhaul, and Supply Support

3.3.1 General

(U) No personnel on board for maintenance not needed for Condition I watchstanding. Maintenance by replacement and off-ship repair concept shall be emphasized.

3.3.2 Organizational Level Maintenance

(U) Condition monitoring of selected equipment. Corrective maintenance as necessary to maintain equipment in an operational state.

3.3.3 Intermediate Level Maintenance

(U) Intermediate level maintenance facility shall serve as a stock or repair point and will accomplish special tests and inspection. At least one Intermediate Maintenance Availability of up to 30 days will be scheduled annually.

3.3.4 Depot Level Maintenance

(U) Depot level maintenance periods of 4 to 6 weeks in alternate years with a major overhaul of 10 to 12 weeks scheduled after 5 years.

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3.3.5 Supply Support - Stowage Requirements

<u>Supply Item</u>	<u>Stowage Requirement (days)</u>
Dry Provisions	60
Chilled Provisions	15
Frozen Provisions	30
Repair Parts	75
Medical Stores	180

3.4 Manning

- (U)
- General: essential manning concept should be emphasized.
 - Complement: to be determined.
 - Habitability standards: IAW OPNAVINST 9330.5 applies.
 - Personnel safety: LAW MIL STD 882 applies.

3.5 Future Growth Capability (Margins)

- (U) The following growth margins will be provided:

<u>Area</u>	<u>Margin (percentage)</u>
Light Ship Weight	10
Vertical Center of Gravity	2½
Space	0
Accommodations	0
Drag	10
Endurance Power	10
Sustained Power	25
Fuel Rate	9

Note: These margins will be divided among design and builders margin, future growth margin, and service life margin at the end of the point design.

4. DESIGN PHILOSOPHY

- (U) Design teams are guided by the following design philosophy in making trade-off decisions.

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4.1 Cost/Performance Tradeoff

(U) The ANV will be designed to meet minimum required performance specified in this TLR. Performance greatly in excess of specified requirements is to be avoided. Although no cost constraint has been specified, cost and performance should be considered equally important.

4.2 Cost Tradeoff

(U) The ANVs will be designed to minimize life-cycle cost. Increases in development and acquisition costs are permissible if there is a resultant decrease in overall life-cycle cost to the Navy.

4.3 Manning Tradeoff

(U) An “essential manning” concept should be emphasized. Reduced manning concepts should be considered not only to reduce life-cycle cost but also to reduce overall manning requirements of the Navy.

4.4 Operability Tradeoff

(U) The ANVs should be designed so that they can be operated by Navy crews in realistic Navy environments. At-sea operability and maintainability should receive design attention.

4.5 Performance Feature Tradeoff

(U) The ANV’s design should be balanced in accordance with priority of operations and mission warfare areas specified in this TLR.

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VI. COMMON COMBAT SUITES

1. INTRODUCTION

(U) An essential part of comparing different vehicle concepts in terms of their payload capability and military worth is ensuring that any differences in capability are due only to the platform concept differences and not to any differences in a combat system capability that could be installed in any of the platforms. It was necessary, therefore, at the beginning of the point design process to select sets of specific suites for particular missions. These common combat suites would then be installed equally on each of the platforms.

(U) Because this procedure was unfamiliar to the platform and the combat systems technical communities, frequently different weights, volumes, and performance information was used by the various communities for presumably the same piece of combat suite.

(U) The variances that occurred amounted to more than 100 tonnes of payload weight in the case of the surface vehicles, which, when translated to the effect on gross weight, could change the gross weight by as much as 1000 tonnes. This large discrepancy highlights the need for a much closer liaison between the ship design community and the weapons design community if reliable comparisons are to be made in the future. Experience with air vehicle combat system comparisons was the same.

(U) Much of the confusion centered around describing where and how the various parts of the combat system are accounted for, e.g., in accounting for the disposable ordnance, the canisters for the ordnance and the weight allocation in the (centralized) launcher are treated differently by different groups. Sometimes a particular item will be considered as a part of the empty weight of the ship and sometimes as disposable payload.

(U) The normalization of the weight and performance of the combat systems was not resolved to the degree of satisfaction that the ANVCE project office would have liked and differences still exist. However, the modified point designs, correcting these differences, have been documented and a summary is provided in this appendix, which may be used as a format for future use in normalization of the combat suites when comparing vehicles of any concept.

2. SURFACE VEHICLE COMBAT SUITES

(U) Several adjustments were made to the point designs to normalize the combat suites. Using the SWBS format, the combat suite (payload) is made up as follows:

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$$\text{payload} = \text{fixed payload} + \text{disposable payload}, \quad (\text{A-1})$$

where

$$\text{fixed payload} = \text{Group 400} + \text{Group 700}, \quad (\text{A-2})$$

where

$$\text{Group 400} = \text{sensors and fire control* and} \quad (\text{A-3})$$

$$\text{Group 700} = \text{launchers and associated systems.} \quad (\text{A-4})$$

(U) The weight breakdowns for each of the line items in the combat suites are provided in the ANVCE compiled combat systems data sheets.** The far-term surface combatant group will be used as an example of how the weights of the combat system payload, both fixed and disposable, combine to make up the common combat suite for the group.

(U) A certain amount of flexibility was given in the point design process to accommodate the common combat system. For example, different launchers were possible depending on the configuration; above deck, below deck, or special light-weight launchers are possible. Each has different weights and installation requirements. Also, certain differences were allowed depending on the basic nature of the concept. For example, the high-speed concepts (ACV, hydrofoil, and SES) incorporated the active-passive reliable acoustic path (APRAP) sensor as part of the ASW sensor suite, but it was not included on the slower-speed concepts such as the monohull and SWATH on which it would provide no advantage. The monohull and the SWATH vehicles, on the other hand, incorporated the NIXIE system to offset the noise problem of their own water propulsion systems. Table A-11 summarizes the sensors and fire control (Group 400) for the far-term, surface combatant group including the options of sensors. The remainder of the fixed payload items are those in Group 700, and they are summarized in Table A-12.

(U) The disposable payload items for the same combat system are summarized in Table A-13.

* Does not include ship's navigation and intercom.

** Naval Sea Systems Command Headquarters (NAVSEA 6512) "Combat System Data Sheets for AAW, ASW, and SSW (U)," Volumes I, II, III, 30 June 1976, SECRET.

TABLE A-11

GROUP 400: SENSORS AND FIRE CONTROL

ITEM	WEIGHT (lb/unit)	NO. OF UNITS	TOTAL WEIGHT		REFERENCES
			(lb)	(TONNES)	
Dual-Band 3-D Radar	11,000	1	11,000	4.99	3-108-1 ^a
Rotating Phased Radar	26,000	1	26,000	11.79	3-117 ^a
Light TWS FCS	1,700	1	1,700	0.77	3-92 ^a
Mk 74 MOD XX FCS	20,000	1	20,000	9.07	3-96 ^a
ASDM EW Mk XX	2,426	1	2,426	1.10	3-84 ^{a,b}
APS 116 Radar	443	1	443	0.20	2-353 ^c
Sonobuoy (Type B)	220.04	1	220.04	0.10	3-362 ^{a,b}
ASW Electronics	15,365	1	15,365	6.97	3-301 ^a
NIXIE	1,374.5	1	1,374.5	0.62	3-601 ^a
AWS	1,400	1	1,400	0.64	3-592 ^a
ASTD	2,240	1	2,240	1.02	
C ³ and Navigation	26,000	1	26,000	11.79	
HARPOON Control	766	1	766	0.35	3-254 ^a

^a ANVCE Combat Data Sheets, Volume III, Serial No. S760653, 30 June 1976.

^b MONO 3 Final Point Design Report, page 146.

^c ANVCE Combat Data Sheets, Volume II, Serial No. S760653, 30 June 1976.

TABLE A-12

GROUP 700: LAUNCHERS AND ASSOCIATED WEIGHT

ITEM	LAUNCHER WEIGHT (tonnes)	ASSOCIATED SYSTEM WEIGHT (tonnes)	TOTAL (tonnes)	REFERENCE
Vertical Launch System (VLF) with 72 Cells				
40 Cells for AMRM (below deck design)	36.29		36.29	3-152 ^a
40 Cells for AMRM (above deck design)	21.77		21.77	3-152 ^b
16 Cells for ALWT (S.O.) (below deck design)	29.03		29.03	3-152 ^b
16 Cells for ALWT (S.O.) (above deck design)	17.42		17.42	3-152 ^a
16 Cells for HARPOON (below deck design)	14.52		14.52	3-152 ^b
16 Cells for HARPOON (above deck design)	8.71		8.71	3-132 ^a
Light WT HARPOON Launcher 16 Cells	5.01		5.01	3-254 ^a
ASDM Launcher with 24 Cells	4.35		4.35	3-147 ^a
ERAPS Launcher	1.67		1.67	3-501 ^b
AWS Countermeasures Launcher	0.99		0.99	3-592 ^a
ASTD Launcher	2.54		2.54	
NIXIE		2.33	2.33	3-601 ^a
Sonobuoy (Type S) Launcher	0.40		0.40	3-362 ^{a,c}
ASMD EW Mk XX Launcher	0.40		0.40	3-44 ^{a,d}
APRAPS		5.81	5.81	3-464 ^{a,d}
Deployed Linear Array (DLA)		4.15	4.15	3-348 ^a
RPV Launch/Recovery	0.5		0.5	3-242 ^a
Mk 25 Launcher (Mk 48 Launch on MONO 3)	3.4		3.4	3-566 ^a
Towed Array with Depressor		4.94	4.94	3-400 ^a

^a ANVCE Combat Data Sheets, Volume III, Serial No. 5760653, 30 June 1976.

^b ANV's Combat System Performance and Effectiveness in AAW and SSW from NAVSEA-4112 Memo, Serial No. WD 139, 14 January 1977.

^c MONO 3 Final Point Design Report, Page 146.

^d MONO 3 Final Point Design Report, Page 145.

TABLE A-13
DISPOSABLE PAYLOAD

ITEM	MISSILE OR TORPEDO 1			CANISTER 2			TOTAL 1 + 2	
	LB/UNIT	NO. OF	TOTAL	LB/UNIT	NO. OF	TOTAL	LB	TONNES
		UNITS	(LB)		UNITS	(LB)		
MAIN VEHICLE:								
AAW								
AMRM	2,115	40	34,600	1,000	40	40,000	124,600	34.52
ASDM	300	24	7,200	50	24		8,400	3.81
SSW								
HARPOON	1,450	16	23,200				23,200	10.52
ASW								
Mk 48	3,415	4	13,660	1,000	4	4,000	17,650	8.01
ALWT (standoff)	3,000	16	48,000	2,000	16	32,000	80,000	36.29
SENSORS AND DECOYS								
ASMD EW Mk XX Decoys	36.78	18	662				662	0.3
ERAPS (RP) MONO & SWA 4	500	46	23,000				23,000	10.43
ERAPS (RP) ACV, SES, HYD	500	46	13,000				13,000	5.90
AWS Jammer	37	20	740				740	0.34
ASTD Countermeasures	448	4	1,792				1,792	0.81
SECONDARY VEHICLES:								
LAMPS Mk XX	Two Helicopters at 20,000 lb each Helicopter Fuel Spare						40,000 61,729 3,368.3 <u>105,697.3</u>	18.14 28.00 1.80 47.94
	Optimiser: 36 ALWT at 700 lb/unit						25,200	11.32
	Sensors: 200 Sonobuoy (Type A) at 39 lb/unit 10 Sonobuoy (Type B) at 110.23 lb/unit 10 ERAPS at 100 lb/unit						7,800 1,103.2 1,800	3.54 0.50 0.82
RPV	12 RFV at 250 lb/unit Spare						3,000 3,000	1.36 0.91

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(U) To recapitulate, the common combat suites (reflecting the difference in APRAP, NIXIE, and launchers) for the far-term, surface combatant (3000-tonne) group, Tables A-14 and A-15, have been prepared. Table A-14 is for the high-speed concepts. A similar set of values of weights and costs was prepared for the MONO 3 and SWA 4 point designs. The difference in weight between the values given in Table A-14 (approximately 341 tonnes) and those values given in the modified point designs in Volume 2 is attributed to the weight of installation. A complete listing for far-term air-capsule surface combatants is shown in Table A-15. A compilation of the combat suites for each of the remaining surface vehicle groups is given in Tables A-16 through A-19.

TABLE A-14

COMMON COMBAT SUITES FOR ACV 3, HYD 2 and SES 3
HIGH-SPEED CANDIDATES

	NO.	WEIGHT (tonnes)
GROUP 400: SENSORS AND FIRE CONTROL		
Dual-Band 2D Radar	1	4.99
Rotating Phased Array	1	11.79
Light TWS FCS	1	0.77
Mk 74 MOD XX FCS	1	9.07
ASDM EW Mk XX	1	1.10
APS 116 Radar	1	0.20
Sonobuoy (Type B)	1	220.04
ASW Electronics	—	6.97
C ³ and Navigation	—	11.79
HARPOON Control	—	0.35
SUBTOTAL	47.03	71.72
GROUP 700: LAUNCHERS AND ASSOCIATED SYSTEMS		
72 Cell VLS (below deck)	1	79.84
ASDM Launcher (24 cells)	1	4.35
ERAPS Launcher (6 cells)	1	1.67
Mk 25 Launcher	4	3.40
APRAPS	1	5.81
DLA	6	4.15
Towed Array with Depressor	1	4.94
RPV Launcher/Recovery	1	0.50
SUBTOTAL		104.66

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TABLE A-14 (continued)

	NO.	WEIGHT (tonnes)
DISPOSABLE PAYLOAD		
Main Vehicle Ordnance and Sensors		
AMRM	40	56.52
ASDM	24	3.81
HARPOON	16	10.52
Mk 48	4	8.01
ALWT (Standoff)	16	36.29
ASDM EW Mk XX Decoys	18	0.30
ERAPS (Rocket Projected)	26	5.90
AWS Jammer	20	0.34
ASTD Countermeasures	4	0.81
SUBTOTAL		122.50
Secondary Vehicles, Ordnance and Sensors		
LAMPS Mk XX	2	18.14
Helicopter Fuel	—	28.00
Spares	—	1.80
ALWT	36	11.32
ERAPS	10	0.82
Sonobuoys: Type A	200	3.54
Type B	10	0.50
RPV (Standard Ship-Launched)	12	1.36
Spares	—	0.91
SUBTOTAL		66.50
Total Payload (Combatants)		340.69

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TABLE A-15

FAR TERM, AIR-CAPABLE SURFACE COMBATANT
GROUP COMBAT SUITES

SES 3	ACV 3	SWA 4	HYD 2	MONO 3
<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>
AAW 40 ASAR (MR) (Multi-mode Missiles) 24 ASDM	Same as SES 3	Same as SES 3	Same as SES 3	Same as SES 3
SSW 16 HARPOON Mk XX Missiles				
AAW 4 Mk 48 Torpedoes 36 ALWT 16 Standoff Weapon/ ALWT 2 LAMPS Mk XX Helos				
<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>
1 ADV Dual Band 2D Radar 1 Rotating Phased Array 1 ADV Lightweight TWS FCS 1 Mk 74 MOD XX FCS 1 ASMD EW Mk XX 1 APS-116 Radar 6 Deployed Linear Arrays 1 Towed Array w/ Depressor 1 APRAP 10 ERAPS 26 ERAPS Rocket Projected 200 Sonobuoys (Type A) 10 Sonobuoys (Dropline) 12 RPVs	Same as SES 3	Same as SES 3 except: No APRAP 1 NIXIE/ASW/ASTD 46 ERAPS Rocket Projected	Same as SES 3	Same as SES 3 except: No APRAP 1 NIXIE/AWS/ASTD 46 ERAPS Rocket Projected

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(U) TABLE A-16

AMPHIBIOUS SURFACE VEHICLE PAYLOADS

LCAC	LCPC
ARMAMENT	ARMAMENT
1 GAU 8A Gun	1 GAU 8A Gun
SENSORS AND FIRE CONTROL	SENSORS AND FIRE CONTROL
1 VEOS FCS 1 APS 116 Radar	1 SEA FIPE FCS 1 APS 116 Radar
PAYLOAD	PAYLOAD
1 Main Battle Tank	2 Main Battle Tanks

(U) TABLE A-17
SPECIAL PURPOSE VEHICLE COMBAT SUITES

CPIC	PHM	SWA MCM	EPG
<u>ARMAMENT</u> 1 Twin 30mm Gun 2 Twin 7.62mm M60 Machine Gun 2 40mm Grenade Launchers <u>SENSORS AND FIRE CONTROL</u> 1 LN66/HP Radar 1 FCS 2 Optical Directors	<u>ARMAMENT</u> 8 HARPOON Missiles 1 MK 75 76mm Gun and 330 rounds <u>SENSORS AND FIRE CONTROL</u> 1 AN/SPS 63 Radar 1 MK 94 FCS 1 AN/SLR20 ESM	<u>ARMAMENT</u> 2 30mm MK 16 Machine Gun w/12,000 rounds Mine Warfare 6 RH53D Helos <u>SENSORS AND FIRE CONTROL</u> 1 An/SQQ14 Deep and Minehunting Sonar 1 Shipboard Minehunting Sonar System 1 Mine Neutralization Vehicle 1 S ⁴ p System 2 AN/ALQ141 Surface Double Alpha Sweeps 1 AN/SSN-2 Precise Navigation System 1 AN6UQN4 Depth Sounder 1 SPS55 Radar 3 MK 105 AMCM Magnetic Sweep Sleds	<u>ARMAMENT</u> 2 HARPOONS ASW 6 MK 46 Torpedoes <u>SENSORS AND FIRE CONTROL</u> 1 APS116 Radar 1 ESM/ECK Set 1 MADAIR 1 ORICS 1 FLIR 1 Photo 1 IRF 6 ADAS 30 VLA/DIFAR 20 DICASS 3 ERAPS 1 Proteus Signal Processor

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ACV 1	HYD 7	PC 1	WIG(S)
<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>
AAW 24 ADV Self-defense Missiles	Same as ACV 1	Same as ACV 1	Same as ACV 1
SSW 8 HARPOON MK XX			
ASW 6 MK 48 Torpedo 12 Standoff Weapon/ALWT			
<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>
1 TAS MK XX Radar 1 ADV Lightweight WS FCS	Same as ACV 1 except:	Same as ACV 1 except:	Same as ACV 1
1 ASMD FW MK XX 1 APG 116 Radar 10 Sonobuoys (Dropline) 1 APRAP 6 Deployed Linear Arrays 20 ERAPS 26 ERAPS Rocket Projected 12 RPV	1 Towed Array w/ depressor No Dropline Sonobuoys	1 Towed Array w/ depressor No Dropline Sonobuoys	

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(U) TABLE A-19

AIRCRAFT CARRIER COMBAT SUITES

SWA CVN	SES CV	SES CVN	VSS
<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>
AAW 100 AMRM (multi-mode)	Same as SWA CVN except:	Same as SWA CVN except:	AAW 2 CIWS
100 ASDM	3 Type A V/STOL Subsonic	3 Type A V/STOL Subsonic	
SSW	(AEW)	(AEW)	
20 HARPOON MK XX	4 Type A V/STOL Subsonic	4 Type A V/STOL Subsonic	SSW
20 ASCM MK XX	(ASW/SSW)	(ASW/SSW)	
ASW	6 Type B V/STOL Subsonic	6 Type B V/STOL Subsonic	8 HARPOON Missiles
40 MK 48 Torpedoes	(AAW/SSW)	(AAW/SSW)	
100 ALWT	4 LAMPS MK XX Helos	4 LAMPS MK XX Helos	ASW 100 MK 46
16 Standoff Weapons/ALWT			
Aircraft			Aircraft
4 Type A V/STOL Subsonic			4 AV 8A HARRIERS
5 Type A V/STOL Subsonic (ASW/SSW)			16 SH 53 Helos
10 Type B V/STOL Subsonic (AAW/SSW)			6 LAMPS Helos
10 LAMPS MK XX Helos			
24 RPVs			
<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>
1 AEGIS MK XX Radar	Same as SWA CVN except:	Same as SWA CVN except:	1 AN/SPS
1 ADV Dual Band 2-D Radar	No NIXIE	No NIXIE	52 Radar
1 ASMD WE MK XX			1 AN/SPS 55 Radar
2 ADV Lightweight TWS FCS			400 Sonobuoys
1 APS 116 Radar			
8 Deployed Linear Arrays			
30 ERAPS			
26 ERAPS Rocket Projected			
800 Sonobuoys			
1 NIXIE/AWS/ASTD			

3. FAR TERM, MULTIPURPOSE AIR COMBATANT GROUP

(U) Several significant changes were made to the original point designs because of differences in weight margins and in the make-up of the combat suites. The main paper of Volume 2 presents a detailed discussion of the availability and mission duration analyses on the multipurpose air vehicles (among other designs), and modifications were made in the flight profiles and missions durations to give the maximum benefit to the concepts. This necessitated changes in the consumables and combat suites to be compatible with the flight profiles. The conventional air loiter, A/L, is representative of this group, and Table A-20 summarizes the weight and cost of the fixed and disposable payload items of the combat suite. A similar set of values of weights and costs was prepared for the other air vehicle point designs, and a compilation of the make-up of the combat suites for each of the remaining air vehicle groups is given in Tables A-21 through A-23.

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(U) TABLE A-20

COMBAT SUITE FOR AIR LOITER A/L, S/L(L) & WIG (O)

GROUP 400: SENSORS AND FIRE CONTROL

	NO.	WEIGHT (TONNES)
ADV Sonobuoy Link	2	0.04
PROTEUS ASP (AN/VYS 1)	2	0.14
Phased Array Antenna	1	0.02
Miscellaneous Acoustic	—	0.14
ESM Set	1	0.12
ORICS	1	0.16
FLIR/IRSS Set	1	0.14
PHOTO	1	0.05
IFF	1	0.02
ECM Sets/Pods	1	0.27
Miscellaneous Non-Acoustic	—	0.05
Displays/Controls/Tactical	—	1.08
Correlation		
C ³ and Navigation	—	0.79
Conformal Array	1	2.54
ADV TWS FCS	2	1.26
AAW Controls/Displays	4	0.49
Data Processing	1	0.41
Passive Detection System	1	0.01
ECM Sets/Pods	2	0.54
Spares	—	0.82
SUBTOTAL		9.19
GROUP 700. LAUNCHERS AND ASSOCIATED SYSTEMS		
RPV Support/Launchers	—	1.81
DISPOSABLE PAYLOAD		
<u>Main Vehicle Ordnance and Sensors</u>		
ALRAAM	20	9.07
ASDM	12	0.95
HARPOON	4	2.09
ALWT	6	2.18
ADAS	6	1.09
VLA/DIFAR	30	0.20
DICASS	20	0.36
ERAPS	6	0.41
SUBTOTAL		16.35
<u>Secondary Vehicles</u>		
RPV	2	1.36
SUBTOTAL		1.36
Total Payload (Combatants)		28.71

(U) TABLE A-21

MULTIPURPOSE, AIR VEHICLE COMBAT SUITES

<u>A/L</u>	<u>S/L(L)</u>	<u>A/L(N)</u>	<u>WIG(O)</u>	<u>FAB</u>
<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>
AAW 20 ALRAM 12 SDM	Same as A/L	Same as A/L except: AAW 40 ALRAAM	Same as A/L	Same as A/L except: AAW 40 ALRAM 24 SDM
SSW 4 HARPOONS		SSW 4 HARPOONS		SSW 2 HARPOONS
ASW 6 ALWT 2 RPVs		ASW 12 ALWT 4 RPVs		ASW 12 ALWT 4 RPVs
<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>
6 ADAS 10 VLA/DIFAR 20 DICASS 6 ERAPS 1 ESM/ECM 1 ORICS 1 FLIR 1 Photo 1 IFF 1 Proteus Signal Processor 1 Phased Array Radar	Same as A/L	Same as A/L except: 30 ADAS 120 VLA/DIFAR 80 DICASS 24 ERAPS	Same as A/L	Same as A/L except: 4 ADAS 60 VLA/DIFAR 40 DICASS 12 ERAPS 1 Towed Array

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(U) TABLE A-22

SINGLE PURPOSE AIR VEHICLE COMBAT SUITES

SL(V)	AVP	SL(S)	SAB
<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>	<u>ARMAMENT</u>
2 ALWT	4 ALWT or 2 HARPOONS	Same as SL(V) except: 4 ALWT	Same as SL(V) except: 4 ALWT 12 SDM 2 HARPOONS
<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>	<u>SENSORS AND FIRE CONTROL</u>
1 APS 116 Radar 1 ESM 1 IFF 1 MAD 1 Proteus Signal Processor 2 Sonobuoy Links 3 ADAS 16 VLA/DIFAR 10 DICASS	2 PROTEUS Signal Processors 1 APS 116 Radar 1 MAD 1 FLIR 1 ESM/ECM/RHAW 100 Sonobuoys	Same as SL(V) except: 26 VLA/DIFAR 20 DICASS	Same as SL(V) except: No ADAS 20 VLA/DIFAR 60 SVLA/DIFAR 3 ERAPS

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(U) TABLE A-23

LOGISTICS AIR VEHICLE PAYLOADS

WIG (H)	
<u>Quantity</u>	<u>Description</u>
30	ISO Containers 8 ft x 915 ft x 20 ft

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ANNEX A
EXEMPLARY TOP LEVEL REQUIREMENTS (TLRs)

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1. ANVCE POINT DESIGN FOR A
1000-TON AIR CUSHION VEHICLE (ACV 1)

1. INTRODUCTION

1.1 Purpose and Scope of ANVCE Point Design

(U) An ANVCE point design represents a specific design of a vehicle concept to permit a meaningful evaluation of military worth, cost, and technical risk. To provide such an evaluation, design data at the approximate level of detail of a feasibility design is required.

1.2 Purpose and Scope of Top Level Requirements

(U) This top level requirements document is similar in format to that specified in OPNAV Instruction 9010.3 of 4 January 1974 and the top level requirements model of April 1975, the format of which was presented in Chapter V of Appendix A.

2. OPERATIONAL CAPABILITIES

2.1 Mission and Tasks

2.1.1 Mission

(U) The mission of ACV 1 is to operate offensively in the presence of air, surface, or subsurface threat, independently or with strike, antisubmarine or amphibious forces; to provide protection to those forces, underway replenishment groups and military or mercantile convoys against air, surface, or subsurface threats; and to provide effective self-defense.

2.1.2 Operations

(U) For the ACVs, design emphasis will be placed on the following operations:

2.1.2.1 Naval Force Protection

(U) Principal emphasis is on ASW and SSW. In ASW, complete job (detection through prosecution) is done by the ACV. In SSW, the ACV will follow-up and attack surface transitors prior to their coming within its surface-to-surface missile (SSM) range of the naval unit being protected (initial detection of the surface transitor must come from a source external to ACV 1). AAW capability is limited to self-defense and interdiction of aircraft transiting within acquisition cone of its surface-to-air missile (SAM) system; therefore, the ACV must work in concert with other forces (e.g., conventional escorts, land- or carrier-based air) in providing protection against an air threat. Replenishment of fuel, armament, missiles, and other expendables will be provided by UNREP ships.

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2.1.2.2 Shipping Protection

(U) This operation is similar to that of Naval Force Protection.

2.1.2.3 Ocean Area

(U) The principal emphasis in this operation is placed on ASW and SSW. In ASW, the complete job is done by the ACV. In SSW, the initial detection of targets is provided by external sources (e.g., land or carrier-based air, satellites), with final targeting and prosecution done with equipment on the ACV. AAW involvement is limited self-defense. Under high threat conditions, support may be required from land or carrier-based air. Replenishment will be provided by UNREP ships or at friendly ports.

2.1.2.4 Barrier (ASW/AAW)

(U) Principal emphasis in this operation is placed on ASW where the complete job is done (detection through prosecution). AAW involvement is limited to self-defense and interdiction of aircraft transiting within the acquisition cone of the SAM system. Most transiting aircraft interdiction will be accomplished by land- or carrier-based air. Replenishment will be provided by UNREP ships.

2.1.2.5 Barrier (ASUW)

(U) This task is basically an SSW one with limited need for external support other than UNREP.

2.1.2.6 Surveillance and Reconnaissance

(U) This task is basically an SSW one with limited need for external support other than UNREP.

2.1.2.7 Mine Warfare

(U) The ACV is involved in both minelaying and mine countermeasures. For minelaying, the concept would involve offloading all nonintegral equipment to increase total payload. For mine countermeasures, sweeping would be accomplished using the ACV as towing body; minehunting does not apply to this concept. Minimal self-defense is available in either case. Replenishment, especially of fuel, would be required.

2.1.2.8 Inshore Warfare

(U) Use of the ACV would be restricted to coastal interdiction, basically an SSW task. Limited external support would be required except for replenishment of fuel and other expendables.

2.2 Mission Warfare Areas

(U) This ship will have capability in the following mission warfare areas: *

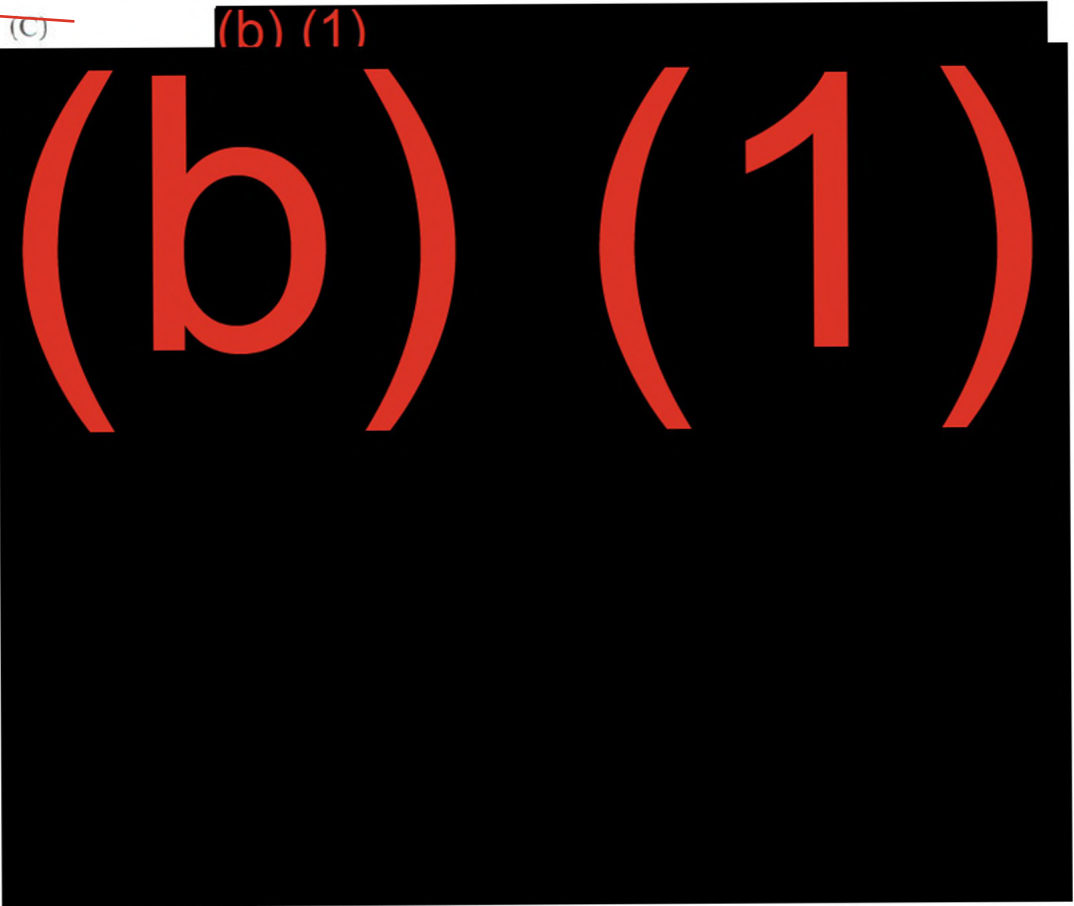
- ASW
- AAW
- SSW, and
- mine warfare (MIW).

(U) The following sections outline the scope of the ship's capabilities within each of the above mission warfare areas. The combat suite necessary to support these activities is listed in Table AA-1.

2.2.1 ASW

~~(C)~~

(b) (1)



(b) (1)

Certain warfare areas, such as command and control (when limited to command and control of own ship), special warfare, fleet support operations, and noncombat operations, have been excluded since they are basically required of all naval vehicles.

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TABLE AA-1

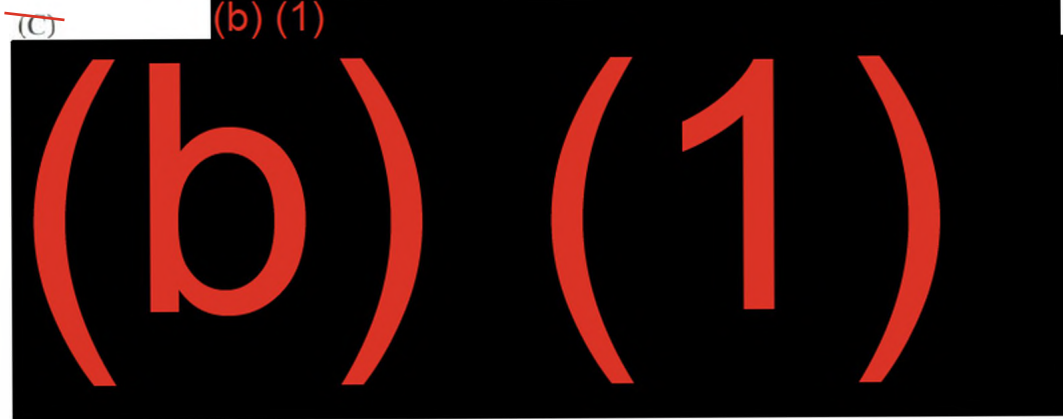
SURFACE COMBAT SUITE

System	Number	Weight	
		(klb)	(MT)
AAW			
TAS MK XX	1	11.0	5.0
Advanced Lightweight TWS FCS	1	1.7	0.8
ASMD EW MK XX	1	4.0	1.8
ADV Self-Defense Missile with Launcher	24	18.8	8.2
Total AAW		34.7	15.8
Additional for SSW			
APS 116	1	0.3	0.1
HARPOON MK XX with Lightweight Launcher ^a	8	17.9	8.0
Total SSW (Additional)		18.2	8.2
Additional for ASW			
Sonobuoys (Dropline)	10	2.3	1.0
APRAP	1	12.8	5.8
Deployed Linear Array	6	9.1	4.1
ERAPS	20	3.6	1.6
ERAPS Rocket Projected	26	13.0	5.9
ERAPS Launcher (6 cells)	1	3.7	1.7
MK 48 Improved Torpedo	6	20.5	9.3
Ejection Launch Container for MK 48 ^a	6	6.0	2.7
Standoff Weapon/ALWT with Launcher ^b	12	50.4	22.9
ASW Electronic	X	11.0	5.0
Total ASW (Additional)		132.4	60.0
C³ and N			
Command, Control, Communications and Navigation	X	25.0	11.3
Total C³ and N		25.0	11.3
Subvehicles			
Standard Ship-Launched RPV	12	3.0	1.4
RPV Launch/Recovery/Support	X	2.1	1.0
Total Sub Vehicles		5.1	2.4
Platform Total		215.4	97.7

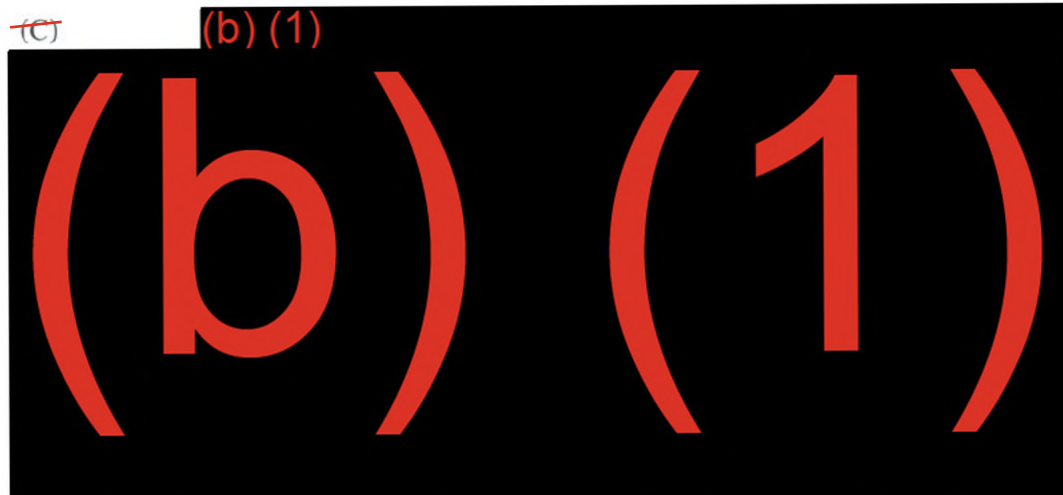
^a Selection of launcher is at the discretion of advocate. No weapons-handling equipment has been included; selection of handling equipment is dependent on launcher and requirement to rearm at sea.

^b Could be launched from vertical launcher used for HARPOON.

2.2.2 AAW

~~(C)~~ (b) (1)


2.2.3 SSW

~~(C)~~ (b) (1)


2.2.4 MIW*

~~(C)~~ (b) (1)


2.3 Design Standards

2.3.1 Ship Size

(U) Ship size is given in metric tons (1000 tonnes).

* The ACV configuration for mine warfare was specified during point design development.

2.3.2 Speed

(U) Speed requirement is 100 kt at the following conditions:

- significant wave height
(average of 1/3 highest; head seas): 1.4m
- air temperature: 26.7°C

2.3.3 Range

(U) Range requirement is stated at following condition:

- significant wave height
(average of 1/3 highest; head seas): 1.4m
- air temperature: 26.7°C

(U) Range for the 1000-tonne ACV is 1450 nmi at a speed of 100 knots.

2.3.4 Maneuverability

(U) Maneuverability requirement for the 1000-tonne ACV 1 is specified as a 0.1g steady turn at 110 kt in calm water. The turn radius is 3,725 m.

2.3.5 Propulsion Systems

(U) Fuel load necessary to meet the range requirements is based on the following conditions:

- fuel load = $\frac{\text{Range}}{\text{Speed}} (\text{BHP SFC} + \text{BHP}_L \text{ SFC}_L + \text{Auxiliary Fuel Rate}) (1 + \text{TP});$
- brake horsepower (BHP) of propulsion plant and of lift system (BHP_L) is computed at significant wave height of 1.4m;
- drag is computed at displacement at half-fuel condition (SWATH in normal ballasted condition);

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- fouling on ACV is not considered a factor that would affect the range of the vehicle*;
- auxiliary fuel rate for 24-hour average loads including lift system;
- propulsion prime mover fuel rate at standard conditions (14,696 psia, 26.7°C, 100 percent humidity inlet air, installed duct losses of 18,400 Btu/lb LHV);
- tailpipe allowance (TP) of 2 percent for narrow and deep bottom tanks and 5 percent for broad bottom tanks;
- no plant deterioration factor for endurance and fuel calculations.

(U)

Power margins are computed as follows:

- drag is computed at full-load displacement;
- fouling on an ACV is not considered a factor that would affect the power margin of the vehicle*;
- thrust at standard conditions (14,696 psia, 27.7°C inlet air temperature, 100 percent of installed duct losses of 18,400 Btu/lb LHV);
- 25 percent hump thrust margin over calm water drag in deep water (see Figure AA-1);
- maximum sustained speed in significant wave height of 1.4m at maximum continuous power. (see Figure AA-1).

2.4 Survivability and Vulnerability

2.4.1 Structural Strength

(U) The "Material Information Profile" NSRDC Report MAT-74-18, January 1975, by A.G. Morton and J.T. Kelly is used to determine properties (e.g., welded yield and ultimate stress) of structural materials. The following factors of safety are used to take into account uncertainties in predicting structural loads:

* Drag is computed assuming clean bottom (no fouling).

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- for yield stress: 1.15 and
- for ultimate stress: 1.50.

2.4.2 Stability and Buoyancy

(U) The applicable stability and buoyance criteria are as defined in NAVSEC DDS 079-1, "Stability and Buoyancy of U.S. Naval Surface Ships." Part III of that DDS deals with advanced marine vehicles (in waterborne displacement mode).

2.4.3 Protection Features

2.4.3.1 General

(U) This section specifies the type of ship features to consider for enhancement of the capability of the ship to function after exposure to weapon effects.

2.4.3.2 Design Threats for Protection Features

(U) The weapon threats to be used as guidance for the survivability design are given in Table AA-2.

TABLE AA-2

DESIGN THREATS CONVENTIONAL WEAPONS

Weapon Type	Warhead Size (HE) & Type	Design Threat
Antiship Missiles	Shaped charge 1000 lb; semi-armor-piercing 500 lb	1
Naval Guns	40-180mm shells, HC & AP	2
Aircraft Cannon	23-37mm projectiles, HE	3
Aircraft Rockets	50-150mm HE, AP	4
Small Arms	.30 caliber ball & AP	5
Shore Rockets	Covered by aircraft rockets	6
Torpedoes	300 and 600 lb HE	7
Mines	500 lb HE, bottom & contact	8
Limpets	50 lb bulk & shaped charge	9

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2.4.3.3 Arrangements for Survivability

(U) The major system and components of the vessel are arranged and located so that survivability to weapon effects is maximized. Considered here is redundancy with adequate separation, minimization of exposure, and taking advantage of shielding by other components or structures.

2.4.3.4 Structural Protection Against HE Weapons

(U) Ballistic protection is provided for the key components and threats listed in Table AA-3. The armor is suitable for shipboard environments and use; this includes acceptability with respect to fire hazard and fire toxicity. The specific extent of the armor shall be established during the point design, with the objective being to maximize the benefits for a given amount of armor.

TABLE AA-3

BALLISTIC PROTECTION

Compartment or Component Protected	Threats Protected Against (Table AA-1)
Magazines (prevention of mass detonation)	Projectile Threat 5 and fragments from near-misses; Threats 2, 3, and 4
Propulsion and fuel systems (vital parts only)	Same as above
Weapon system components (vital parts only)	Same as above
CIC (vital parts only)	Same as above

2.4.4 Shock Resistance of Equipment

(U) Near-miss underwater explosion attacks resulting in a keel shock factor of 0.3 or less will not inactivate components required for performance of:

- propulsion, ship control, navigation, and replenishment at sea;
- C^3 ;

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- surface, air, and underwater surveillance, countermeasures, fire control, firing or launching, and guidance of weapons;
- stowage, handling, and reloading of weapons (also applicable to expendable ordnance while in stowage);
- launching, retrieving, fueling, defueling, rearming, handling, checkout, and maintenance of helicopters; and
- casualty and damage control.

(U) Determination of the above performance is based on Grade A shock tests (MIL-S-901), tests on Floating Shock Platform or analysis using DDS 072-1. Above performance to be determined in cushion mode.

2.4.5 Damage Control Systems After Damage

(U) The firefighting system will be at least 75 percent effective after the ship suffers a single hit from which the ship can otherwise survive. Cutoff valves and emergency pumps will be installed in such a way that if the firefighting system is ruptured by the hit, the remainder of the firefighting system can be operated.

2.4.6 Fire Protection

(U) Passive fire protection insulation shall be provided on all load bearing surfaces, all nonload-bearing bulkheads around critical spaces, and on all surfaces where acoustical insulation and/or heating, ventilation, and air conditioning (HVAC) thermal insulation is required. It is anticipated that the fire protection insulation will have sufficient acoustical insulation characteristics that the passive fire protection insulation will replace the acoustical and HVAC thermal insulation.

(U) The passive fire protection should:

- provide thermal protection for aluminum ship structure such that the temperature of the structure does not exceed 204° F above ambient when subjected to a fire for 30 minutes;
- weigh 1.0 lb/ft (47.88 Pa) of insulated surface area;
- contain no material subject to combustion in the standard atmosphere at temperature up to but not exceed 925°C when fully cured and in normal service condition;

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- be constructed so as to preclude excessive emission of toxic gases and smoke when exposed to conflagration conditions;
- contain no materials that produce a corrosive reaction, with aluminum alloy structural materials in the normal service environment; and
- provide a finished surface of such quality as to effectively withstand the abrasion and remain functionally effective in the thermal/vibratory conditions resulting from the normal shipboard operational environment.

2.4.7 Signature Characteristics

(U) Consideration should be given to reduction of the following ship signatures:

- radar cross-section,
- infrared,
- acoustic, and
- visibility.

(U) To minimize signatures, efforts should be made to incorporate existing signature-reduction techniques in each ship design wherever possible and practicable.

3. PLANNED USE

3.1 Environmental Degradation

3.1.1 Unassisted Aircraft Operations

(U) The upper limit on pitch and roll amplitude for aircraft operation is:

- 6-degree significant roll amplitude and
- 3-degree significant pitch amplitude.

3.1.2 Personnel Performance

(U) Personnel performance degradation as a function of exposure to ship motion and acceleration is not well-defined, especially for encounter frequen-

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cies below 0.10 Hz. Differences occur among criteria issued by various program offices. Furthermore, the use of RMSg as a criterion is currently being revised by the International Standard Organization (ISO) and the new criterion will be issued sometime in the next 1-3 years. For consistency, however, and pending any subsequent revision of ISO criteria, personnel performance degradation shall be measured against the vertical and lateral accelerations shown on Figure AA-2. These curves represent a consolidation of the SES, hydrofoil, ACV, and SWATH program office curves.

(U) The constraints on the design of ships, systems, and equipment that are exposed to or affected by the weather environmental conditions are given in MIL-STD-1399 (Navy) Section 302. The maximum and minimum limits of the weather environment are stated in Table 1 of MIL-STD-1399. The design criteria for HVAC systems are also stated here.

3.2 Pollution Control

3.2.1 Sewage Treatment

(U) No sewage may be discharged from the vehicle. A minimum weight allowance of 40 lb (178N) per man is used for estimation of sewage plant weight, including:

- commode and valve assembly,
- urinal and valve assembly,
- macerator/transfer pump,
- evaporator (full of sludge),
- sludge pump,
- vapor treatment system, and
- electrical controls.

The above weight allowance is based on a 1600 lb (7120N) total system weight for 40 persons. The validity of any significant deviation from this weight allowance is demonstrated by the point design.

3.2.2 Oil Waste

(U) No oil waste may be discharged from the vehicle. If water ballast must be used, all ballast tanks will be clean. Clean integral (e.g., membrane type) fuel/ballast tanks are permissible.

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3.3 Operability/Availability

3.3.1 Availability

(U) The availability goal for at-sea missions is 0.90; the minimum availability is 0.75.

(U) The operating profile for the ACV 1 between modernization periods is set forth in Figure AA-3; the profile encompasses operating, training, leave, and upkeep and maintenance availability periods; a 15-day "Time Line" is shown in Figure AA-4; and Table AA-4 is a speed-time profile for ACV 1. Service life is 20 years.

TABLE AA-4

ACV 1 SPEED TIME PROFILE

OPERATING TIME (percent)	SPEED (kt)
5	110
20	100
50	80
10	20
15	0-10

3.3.2 Maintenance Concept

(U) The ACV 1 (medium endurance 15 days) will be manned to Condition 1 (Battle Readiness) watch standard requirements. When at-sea, underway maintenance both preventive (PM) and corrective (CM) will be minimal – limited to those activities necessary to the upkeep of mission-essential equipments and to those underway periods when inordinate ship motions are not expected to be encountered. The ship system design will, therefore, incorporate provisions that will maximize system utilization and will minimize requirements for at-sea maintenance. This should be accomplished by providing (a) high-reliability components, or (b) a combination of conditions monitoring and PM, or (c) redundancy of components. The design of the craft must consider the above options in order to provide not only a 15-day endurance without external support, but a 6/7-month period of deployment with minimal support resources. The design will incorporate provisions for condition monitoring of all mission-essential systems; will provide for rapidity and ease of module and component replacement with equipments in place; and will ensure accessibility to equipments for repair, removal, or test purposes.

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(U) Since ACVs utilize flexible skirts or seals for containment of the air cushion, consideration must be given to their proper maintenance. Although skirts are highly tolerant to failure, they require periodic maintenance and replacement. Since the maintenance and replacement time intervals are predictable, maintenance activities can be adequately planned in advance. The expected skirt life for the 1990 time period will permit deployment of ACVs for 6/7 months without skirt replacement.

(U) At-sea maintenance provisions will be made for repairs required because of exceptional operating conditions.

(U) Ship systems will be designed to permit incremental overhaul of subsystems, subsystems accessories, and related auxiliaries. Preventive, corrective and restorative maintenance will be performed by the Intermediate Maintenance Facility (IMF) while in port or alongside the tender or repair ship. Major maintenance actions will be accomplished by intermediate and depot activities during periodic upkeep and maintenance availabilities in accordance with ship utilization schedules.

(U) The following maintenance philosophy will govern the three levels of maintenance support to be provided by appropriate maintenance levels:

Organizational Level

Organization maintenance performed by the ship's crew will consist of the essential scheduled maintenance actions, restoration of function and performance after failure by replacement of modules or assemblies, and performance monitoring and fault isolation. Component and modules substitution will be performed with equipments in place. Arrangement designs will ensure adequate accessibility to equipments for maintenance without necessitating secondary equipment removals or structure rip-out.

Intermediate Level

(U) Intermediate maintenance (IM) will be performed by assigned tenders, repair ships, or advance base facilities when deployed and by tenders and designated shore facilities when in CONUS. Seal (skirt) system overhaul/replacement will be an IM responsibility and will be scheduled for accomplishment at 2000-hr intervals (during IM availabilities). The IM facility will serve as a stock and repair point and will, assisted by the ship's crew, accomplish all special tests, inspections, and equipment removal and replacement, and on-board repair while the ship is alongside. It will provide for installation of designated SHIPALT and ORDALT packages, rigging and lifting services,

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and packaging, handling, storage and transportation services for all retrograde repairables.

Depot Level

(U) Drydocking facilities and special tools and equipment will be provided by the shore-based IM facility. For embarked aviation elements the ship will provide the necessary intermediate maintenance capability for aircraft maintenance. An aviation detachment will be embarked to provide for aircraft [helicopter and vertical/short takeoff and landing (VSTOL)] maintenance activities.

3.3.3 Overhaul Concept

(U) The ship will be designed to permit increment overhaul of its subsystems, accessories and related auxiliaries by intensive use of scheduled upkeep and maintenance availability periods. The progressive maintenance activity will be scheduled to achieve equipment replacement before failure based upon observed or calculated performance degradation and will include the extensive use of rotatable pool equipments for system restoration by equipment removal and replacement. Condition monitoring equipment will be used to detect incipient equipment degradation in combat, propulsion, electrical, hydraulic, and other mission-essential systems and will be incorporated into systems designs. Operational usage of supporting equipment and its replacement during availabilities will be consistent with major item replacement schedules. Intermediate and depot level maintenance activities will perform the progressive overhaul in accordance with the ships Plan for Maintenance and will perform rotatable pool equipment repair and refurbishment as designated. The plan will provide for initial determination of level of repair, equipment replacement, and overhaul schedules on an analytical basis but will provide for subsequent schedule revision based upon actual failure rate of performance data as they become available and are appropriate. Modernization periods will occur every 10 years and will require 9 months based upon an estimated service life of 20 years.

3.3.4 Supply Support Concept

3.3.4.1 General

(U) Supply support will provide an adequate allowance of on-board material to support the operational and organizational maintenance needs of the ship. Allowance lists will provide for the subassemblies and modules required to support the most demanding ship mission. The second echelon of supply will be the IMF for spare equipments and modules. At-sea replenishment for expendable ordnance, consumables, and provisions will be provided by Underway Replenishment Groups using vertical replenishment (VERTREP) and/or underway replenishment (UNREP) methods.

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3.3.4.2 Stockage Criteria

(U) The following is a list of specific requirements for provisioning and stowage spaces:

<u>Type</u>	<u>Endurance (days)</u>
Dry Provision	
Chilled Provisions	
Frozen Provisions	As required by
Repair Parts/Equipment- Related Consumables	mission
Non-Equipment-Related Consumables	
Ships Store Stocks	
Medical Stores	

3.3.4.3 Ordnance Stowage

(U) The following missile, ammunition, and torpedo stowage shall be provided:

Missile Stowage: A standard reload requirement will be determined based upon the most demanding 15-day AAW/SSW engagement (mission) scenario and the capability for at-sea replenishment of those missiles. Magazine space and missile testing and handling facilities will be determined on the basis of the derived requirement.

Ammunition Stowage: Expendable ordnance and small arms ammunition requirements will be determined based upon the 15-day scenario and in consonance with NAVORD OD, Weapon Equipment List. Magazine space and ammunition handling facilities will be provided compatible with those requirements.

Torpedo Stowage: Magazine handling and testing facilities requirements for ship usage will be determined by evaluation of the most demanding ASW scenario requirements for torpedo expenditures.

3.3.4.4 Operating Logistics

(U) Resupply of provisions, consumables, spares, and expendable ordnance will be a schedule function performed by Mobile Logistic Support Forces (underway replenishment groups) and will be dictated by operational readiness requirements set forth in Fleet Commander OPLANs and OPORDERS. The size of the ship will limit weapons assembly, preparation, and testing capability such that

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expendable ordnance received must be in a fully prepared status for launcher re-loading. Ship design will provide for the rapid receipt, strike down, and stowage of replenishment items, the rapid reload of launchers and torpedo tubes, and for the rapid movement off-ship of retrograde material using VERTREP and UNREP methods. To this end, appropriate handling equipment (monorails, chain hoists, conveyors, davits, dollies, loading equipment, etc.) and access hatches, passageways, and doors must be designed and provided to accommodate material transfer and movement with minimum delay and disruption to the ships operational on-line commitments.

3.3.5 Off-Ship Repair

(U) Employment of the replace-before-failure maintenance strategy in conjunction with a minimum manning philosophy requires that a significant number of equipments be removed for rotatable pool replacement and off-ship repair/refurbishment. Equipments are to be designated, with the identification of specific intermediate or depot maintenance activity provided through level of repair analysis. All unique (to this ship) equipments requiring specific maintenance activity (intermediate, depot, or contractor) will be specifically identified.

3.4 Manning and Habitability

3.4.1 Manning

3.4.1.1 General

(U) The manning level in both skills and numbers of men must be adequate to meet the operational and maintenance requirements of the ship. Automation concepts that do not increase maintenance requirements, granted functional design of system, centralization of hotel and housekeeping facilities, and design work study analyses of operational and maintenance tasks, will be used to the maximum extent possible to minimize the size of the crew required.

3.4.1.2 Automation

(U) Reliable automated systems are well within the state-of-the-art, and they should be considered in every instance where safety, reliability, and maintainability are not adversely affected. Procurement costs of such systems will be evaluated against the life-cycle savings resulting from the reduction in manning attained. Among the systems that can be considered for automation are:

- ship control,
- propulsion,
- ammunition handling,

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- replenishment,
- strikedown, and
- certain data-processing and transmission functions.

(U) Each operating station will have its decision or action responsibility defined, and the controls needed for executing the responsibility should be positive and simple. Proper design will prevent duplication of decision or action by two or more persons with resulting manpower savings.

3.4.1.3 Centralization of Facilities

(U) Messing facilities, food storage, and scullery services will be designed and positioned for manpower and man-hour savings. Workshops and administrative facilities will, where possible, be similarly centralized in the ship, thereby permitting greater utilization of skills in the ship's company.

3.4.1.4 Design Work Study Analysis

(U) Any design work study analysis made should assume the "Navy Standard Workweek Afloat," i.e., a maximum of 74 hours per week for watch standers and 66 hours per week for nonwatch standers.

3.4.2 Habitability

(U) The ship will be designed to habitability standards in accordance with OPNAV INST 9330.7A. For ships of extremely short duration and unique operational concept, deviation from this instruction is acceptable but must be fully described and the trade-offs discussed in the point design report.

<u>Ships</u>	<u>Space/Man* (m³)</u>	<u>Weight/Man** (tons)</u>
With less than 15-day mission duration	14.9	0.5
With 30 days or greater mission duration	18.0	1.2

* Includes all spaces directly related to personnel, e.g., berthing, food preparation and handling, sanitary, personnel administrative offices, medical and dental, laundry, post office, ships store, recreation, and personnel storerooms.

** Includes outfit and furnishings directly related to personnel (approximately 30 percent of total outfit and furnishing weight), provisions, personnel stores, crew and effects, potable water, and general stores.

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3.5 Margins

(U) The ACV 1 is designed with the following margins:

Space:	0
Accommodations:	0
Electrical load:	30 percent growth margin on generating capacity with one unit out of commission.
Weight:	Preliminary, contract, detailed design and construction margin of 15 percent of light-ship displacement.
KG:	Preliminary, contract, detailed design and construction margin of 15 percent of light-ship KG.
Service Life:	0

4. DESIGN PHILOSOPHY

(U) The design team was guided by the following design philosophy in making tradeoff decisions.

4.1 Cost/Performance Tradeoff

(U) The ACV 1 is to be designed to meet the performance requirements specified in this TLR. Performance greatly in excess of specified requirements is to be avoided. Although no cost constraint is specified, cost is considered of equal importance with performance.

(U) The Navy must be willing to pay a price for the attainment of the unique performance advantages of advanced marine vehicles. However, if the cost of these vehicles is permitted to escalate significantly beyond conventional vehicles already in the U.S. Navy inventory, it is doubtful that many advanced marine vehicles will be developed. It is, therefore, important to take a realistic approach at making cost/performance tradeoffs and not to specify unnecessary performance requirements.

4.2 Cost Tradeoff

(U) The vehicle is to be designed to minimize life-cycle cost. Increases in development acquisition costs are permissible only if there is a resultant decrease in overall life-cycle cost to the Navy. All direct and indirect costs related to the vehicle are to be considered.

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4.3 Performance Tradeoff

(U) The vehicle should be a balanced design in accordance with the operational capabilities listed in this annex. The vehicle should be designed and innovative operational concepts developed to take advantage of the unique performance advantages and minimize the weaknesses of the vehicle. The vehicle should not be designed to optimize a particular measure of effectiveness to be utilized in the mission assessment.

4.4 Operability Tradeoff

(U) The vehicle is to be designed so that it can be operated by a Navy crew in actual operational conditions and not just as an R&D prototype. Accordingly, operability, and maintainability should be considered of equal importance with basic vehicle performance.

4.5 Technical Risk Tradeoff

(U) It is expected that technology will have to be developed in certain areas in order to realize the far-term (1995-2000 time frame) vehicles. Thus, a degree of technical risk is expected. However, a realistic design approach should be followed to preclude specifying unattainable technical levels.

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II. ANVCE POINT DESIGN FOR AN
AIR LOITER (A/L) AIRCRAFT

1. INTRODUCTION

1.1 Purpose and Scope of ANVCE Point Design

(U) An ANVCE point design represents a specific design of a vehicle concept to permit a meaningful evaluation of military worth, cost, and technical risk. To provide such an evaluation, design data at the approximate level of detail of a feasibility design is required.

1.2 Purpose and Scope of Top Level Requirements

(U) This top level requirements document is similar in format to that specified in OPNAV Instruction 9010.3 of 3 January 1974 and the top level requirements model of April 1975, the format of which was presented in Chapter V of Appendix A.

2. OPERATIONAL CAPABILITIES

2.1 Mission and Tasks

2.1.1 Mission

(U) The mission of the A/L vehicle is to operate offensively in the presence of air, surface, or subsurface threat, independently or with strike, anti-submarine or amphibious forces; to provide protection to those forces, underway replenishment groups, and military or mercantile convoys against air, surface or subsurface threats; and to provide effective self-defense.

2.1.2 Operations

(U) For the A/L vehicle, design emphasis will be placed on the following operations. It is recognized that different loadouts might be required for each operation:

2.1.2.1 Naval Force Protection

(U) Principal emphasis is on ASW, AAW, and air warfare (ARW). In ASW, detection through prosecution is done by the A/L vehicle. AAW capability includes area defense (both aircraft and missiles are potential targets) in addition to self-defense capability. In ARW, surface transitors will be detected and attacked prior to their coming within SSM range of the naval unit being protected. The A/L vehicle will also work in concert with other forces (e.g., conventional surface ships, land- or carrier-based air) in providing naval force protection, especially against the air threat. In-flight refueling is permissible.

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2.1.2.2 Shipping Protection

(U) This operation is similar to that of Naval Force Protection.

2.1.2.3 Ocean Area

(U) The principal emphasis in this operation is placed on ASW and ARW. In ASW, detection through prosecution is done by this vehicle. In ARW, initial detection of targets is provided by this vehicle or other sources (e.g., land- or carrier-based air, satellites) with final targeting and prosecution done with equipment on own vehicle. AAW involvement is limited to self-defense; under high threat conditions support may be required from land- or carrier-based air. In-flight refueling is permissible.

2.1.2.4 Barrier (ASW/AAW)

(U) In this operation, emphasis is on ASW and AAW where the complete job is done (detection through prosecution). AAW involvement includes working in concert with other forces (e.g., AEW aircraft or OTH land-based radar). In-flight refueling is permissible.

2.1.2.5 SLBM Defense

(U) Defense against submarine-launched ballistic missiles (SLBMs) is basically an ASW and AAW task with limited need for extensive supplies of armament or resupply of armament. Task includes continuous tracking of ballistic missile submarines (SSBNs) and the capability to intercept SLBMs during powered flight. In-flight refueling is permissible.

2.1.2.6 Surveillance and Reconnaissance

(U) One case deals with the conduct of the airborne reconnaissance task with the ability to attack surface ships. A second case makes use of the ability to provide airborne early warning of an impending air attack. In-flight refueling is permissible.

2.1.2.7 Mine Warfare

(U) Only minelaying applies to the A/L vehicle. The concept would involve offloading all nonintegral equipment to increase total payload. Minimal self-defense is available in either case, and in-flight refueling is permissible.

2.1.2.8 Inshore Warfare

(U) Use of the A/L vehicle would be restricted to coastal interdiction of surface ships. Limited external support would be required, and in-flight refueling is permissible.

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2.1.2.9 Offensive Strikes Against Land Targets

(U) Offensive strikes will be limited to attacks against fixed targets. The basic concept is to use ASMs with targeting provided by own vehicle, sub-vehicles launched from own vehicle, or other manned aircraft (land or carrier-based). In-flight refueling is permissible.

2.2 Mission Warfare Areas

(U) The A/L vehicle will have capability in the following mission warfare areas:*

- ASW,
- AAW,
- ARW, and
- MIW.

(U) The following sections outline the scope of the vehicle's capabilities within each of the above mission warfare areas. The combat suite necessary to support these activities is listed in Table AA-5.

* Certain warfare areas, such as command and control (when limited to command and control of own ship), special warfare, fleet support operations, and noncombat operation, have been excluded since they are basically required of all naval vehicles.

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TABLE AA-5

AIR LOITER VEHICLE COMBAT SUITE

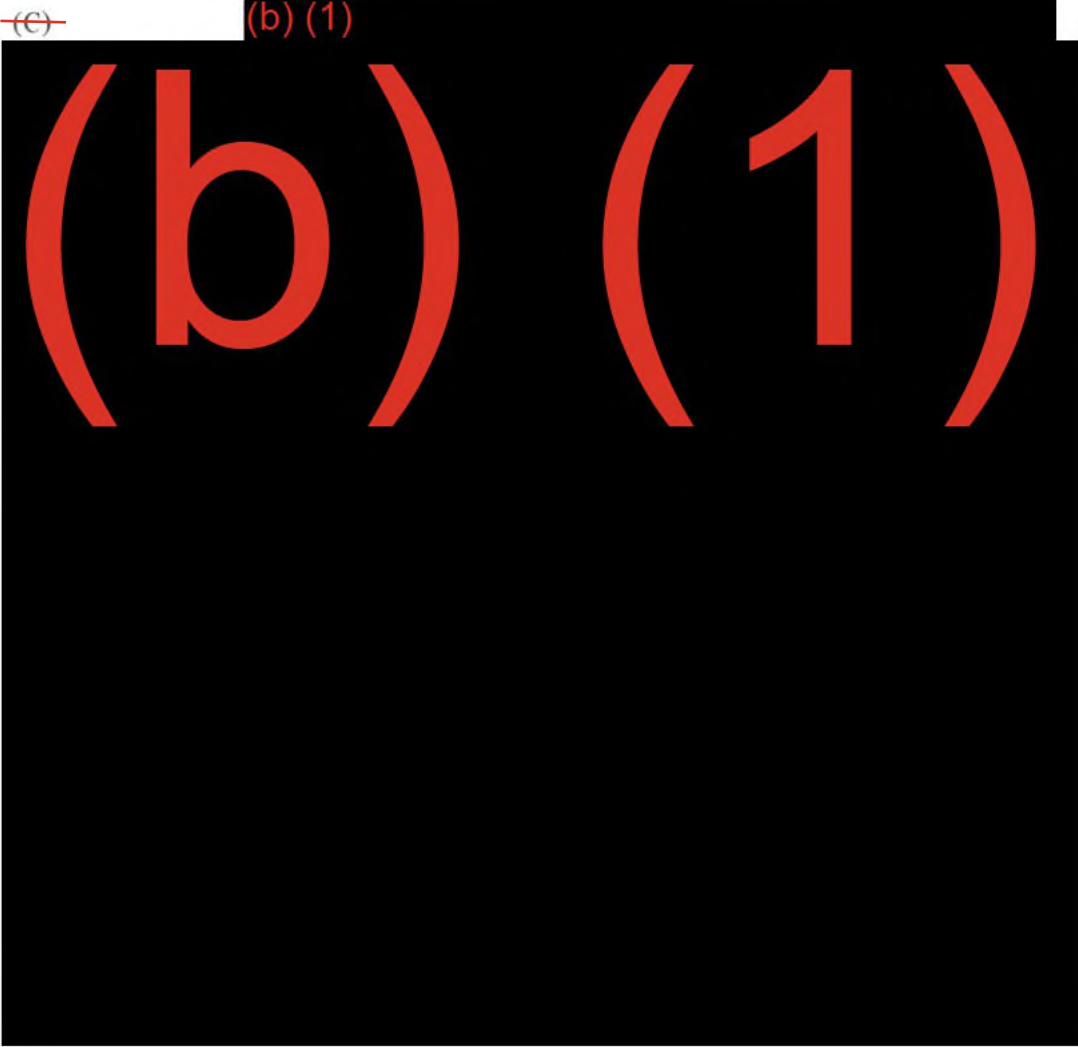
System	Prime Power (KVA)	Number	Weight (klb)
Command, Control, Communications and Navigation	14	X	1.8
ASW			
Acoustic Subsystem	6	X	.8
Sonobuoy Communication links (2), PROTEUS, AN/UYS-1 (2)			
Nonacoustic Subsystem	20	X	1.8
FSM/E/C/M Sets		(1)	
ORICS		(1)	
FLIR		(1)	
PHOTO		(1)	
IFF		(1)	
Displays, Controls, and Tactical Correlation	10	X	2.4
AAW/ARW			
Solid State, Phased Array Radar, and TWS Fire Control System	100	X	10.0
Additional			
ESC/FCM/Communications	3	X	.0
Displays and Process	3	X	1.0
Uninstalled Total	156		17.8
Install (23%): Racks (12%)			6.3
Spares (10%)			1.9
Subtotal (Fixed)	156		26.0
Variable Loads (Barrier)			
3 Stations - TOS = 1-1.5 days			
Subvehicles		2	
RPVs (Surface Control ID)			3.0
Fuel			1.0
Launch/Recovery/Support			4.0
			8.0
AAW			
SDMs	12		2.4
ALRAAM	20		20.0
ARW			
HARPOON MK XX	4		4.6
ASW			
SPRAY	6		2.4
ALWT (Glide, controlled)	6		6.0
VLA/DIFAR (Dwarf)	30		4
DICASS	20		.8
ERAPS	3		.5
Markers, BT, AN			4
			37.5
Provisions (10%)			3.8
			41.3
Subtotal (variable)	---		49.3
Platform Total	156		75.3

2.2.1

ASW

~~(C)~~

(b) (1)



(b) (1)

2.2.2

AAW

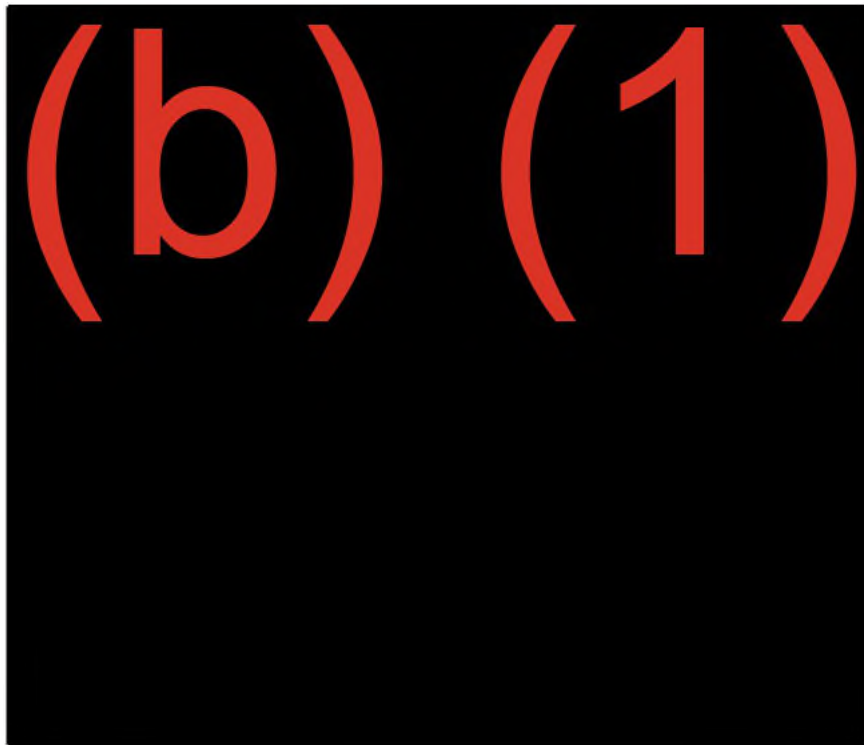
~~(C)~~

(b) (1)



(b) (1)

(b) (1)

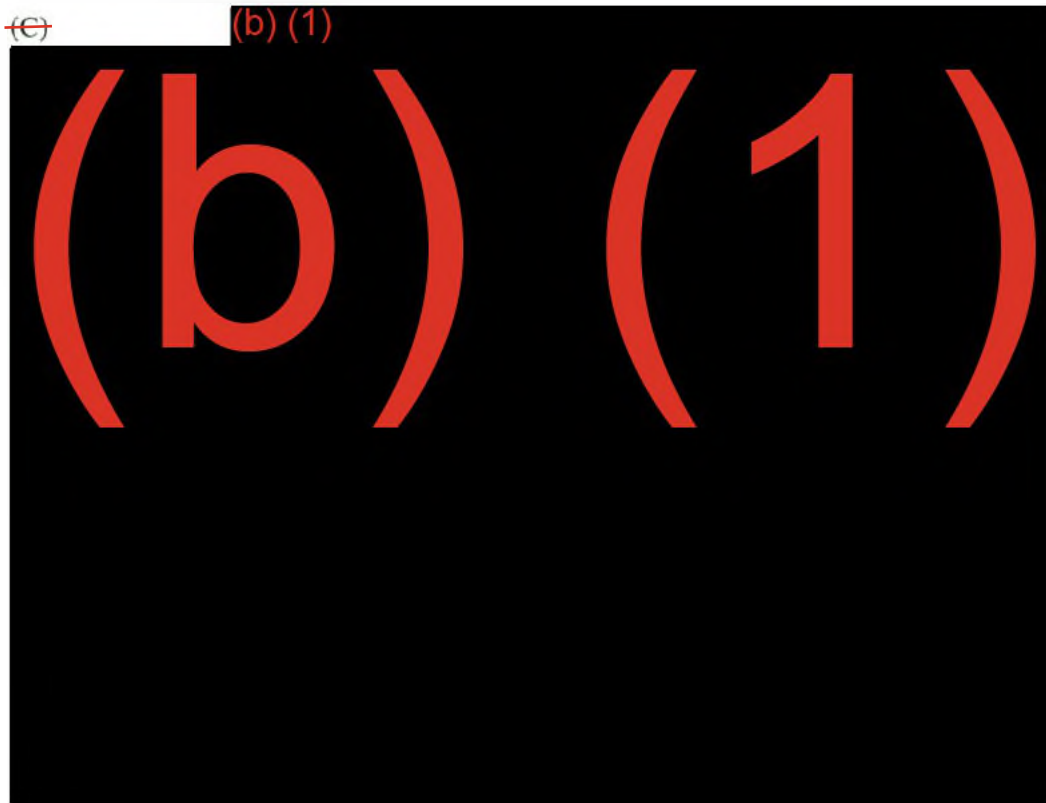


2.2.3

ARW

~~(c)~~

(b) (1)



2.2.4 MIW

(b) (1)
(b) (1)

2.3 Mobility Area

2.3.1 Vehicle Size

(U) The A/L vehicle size is dictated by the requirements to carry the payload over the design flight profile. The following considerations apply:

- nominal gross takeoff weight (TOGW):
500-600,000 lb and
- size and configuration constraints are
 - advanced turboprop (prop-fan), JP 5 fuel;
 - maximum interchangeability of expendable weapons; and
 - in-flight refueling capability is required (JP 5 fuel).

2.3.2 Design Flight Profile

(U) The A/L vehicle speed, range, altitude, and endurance are delineated by means of the governing design flight profile provided in Figure AA-5. The vehicle must be able to carry its full payload throughout this flight profile.

(U) The following normal environmental conditions apply to this flight profile:

- temperature at sea level: 26.8°C
- wind speed at sea level: 10 kt
(always headwind)
- sea-state condition:
 - average of 1/3 highest wave: 1.4m
 - head seas

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(U) FIGURE AA-5

DESIGN FLIGHT PROFILE FOR A/L VEHICLE

KEY

- 1 — Takeoff and climb.
- 2 — Cruise out @ BCAV, 1600 nmi.
- 3 — Loiter @ BEV, altitude $\geq 25,000$ ft for 1.0 day.
- 4 — Cruise back @ BCAV, 100 nmi (Assume: use ASW expendable sensors and RPV fuel).
- 5 — Descend and land (IAC 2.3.3.2).

NOTE: Maximum sustained speed $\geq 0.6M$

• Altitude above
sea level (ft)

0
1000
2000
3000
4000
5000
10,000
15,000
20,000
25,000

Temperature ($^{\circ}C$)

26.7
24.7
22.7
20.8
18.8
16.8
6.9
-3.0
-12.9
-22.8

• Wind speed variation
with altitude

0-100

5000
10,000
15,000
20,000
25,000
30,000
35,000

Wind Speed (kt)

Figure AA-6

14
20
25
31
42
53
62

- Gust Conditions: Noted in Figure AA-7.

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2.3.3 Propulsion/Fuel/Performance Calculations

(U) The propulsion/fuel/performance calculations are shown in the following paragraphs:

2.3.3.1 Takeoff/Landing/Hover

- Critical field length: 10,000 ft or less. Rules for computing critical field length shall be in accordance with MIL-M-7700B.
- Loss of one engine while airborne shall not prevent safe landing of vehicle.

2.3.3.2 Fuel Calculations

- Reserve fuel is 5 percent of design takeoff fuel plus 20-minute loiter in accordance with MIL-C-5011A.
- Auxiliary fuel rate for 24-hr average loads is included.
- Tailpipe allowance will be
 - 2 percent for narrow, deep tanks and
 - 5 percent for broad-bottom tanks.

2.3.3.3 Speed Definitions

- "Loiter speed" is the speed corresponding to maximum endurance.
- "Cruise speed" is the speed corresponding to 99 percent maximum range.
- "Maximum sustained speed" is the speed attainable at TOGW at maximum continuous power (Figure AA-8).
- "Maximum speed" is the speed attainable at TOGW at maximum intermittent power (Figure AA-8).

2.3.3.4 Range/Payload Trade-Offs

- All A/L vehicles are equipped with sufficient fuel tankage volume to permit trade of all disposable military payload for additional fuel on an equal weight basis.

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2.3.4 Maneuverability/Stability and Control/Buoyancy

(U) The maneuverability/stability and the control/buoyancy calculations are given in the following paragraphs.

2.3.4.1 Turning Radius

(U) The turning radius in calm air/calm water is as follows:

- $\min \leq 10,000$ ft as speed $M = M_{\text{loiter}}$ at altitude
 $h = h_{\text{loiter}}$.

2.3.4.2 Rate of Climb

(U) The minimum rate of climb from sea level (without ground effect) in cruise configuration is

- 500 ft/min with full power available and
- 300 ft/min with one engine out.

2.3.4.3 Airborne Stability

(U) Natural airborne stability (i.e., control surfaces fixed) is not required for the A/L vehicle. It is assumed that a full-time, quadredundant, fail operational SAS will be used in all vehicles, and SAS-off flying qualities will not be investigated. SAS-on flying qualities should comply with the "spirit" of MIL-F-8785 or 83300, as appropriate. No limits will be placed on static margin since the control surfaces will probably be sized by other considerations (e.g., iced tail maneuvering, outboard engine out, crosswind landing, takeoff rotation).

2.4 Survivability and Vulnerability (S/V)

2.4.1 Structural Strength

(U) MIL-HDBK-5B (1 Sept 1971) is used to determine properties (e.g., welded yield and ultimate stress) of structural materials other than composites. The following factors of safety are used to take into account uncertainties in predicting structural loads:

- for yield stress: 1.15 and
- for ultimate stress: 1.50.

(U) Vehicle strength levels should be those necessary for performance of design flight profile but in no case less than:

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$$n_z = +2.5, -1.0g.$$

where “ n_z ” is normal acceleration load factor.

2.4.2 S/V Features

2.4.2.1 Design Threats

(U) The weapon threats used as guidance in the design of survivability and vulnerability features of the A/L vehicle are given in Table AA-6.

TABLE AA-6

CONVENTIONAL-WEAPON DESIGN THREATS

Weapon Type	Warhead Size (HE) & Type	Design Threat
Antiship Missiles	Shaped charge 1000 lb; semi-armor-piercing 500 lb	1
Naval Guns	40 - 180mm shells, HC & AP	2
Aircraft Cannon	23 - 37mm projectiles, HE	3
Aircraft Rockets	50 - 150mm HE, AP	4
Small Arms	.30 caliber ball & AP	5
Shore Rockets	Same as aircraft rockets	6
Torpedoes	300 and 600 lb HE	7
Mines	500 lb HE, bottom and contact	8
Limpets	50 lb, bulk and shaped charge	9
Surface-to-air Missiles (SAMs)	200 lb HE	10
Air-to-air Missiles (AAMs)	100 lb HE	11

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2.4.2.2 General S/V Considerations

(U)

In the A/L vehicle design care was taken to

- minimize radar cross-section by judicious configuration selection and reduce corner reflectors to minimize homing points;
- minimize IR signature by judicious selection and placement of engines and shielding of exhaust ports;
- separate engines sufficiently to minimize multiple engine damage by a single projectile;
- provide engines with engine compartment or nacelle fire extinguishing system;
- provide redundant hydraulic systems, redundant aerodynamic control surfaces and/or excess aerodynamic power and to use fly-by-wire systems with redundant and separated wiring;
- provide redundant transfer system to drain fuel from most-vulnerable tanks first, and to provide fuel tanks with sealing protection up to 14.5mm projectiles;
- bury (in principal structure) or armor the most critical components; and
- provide five boundaries for large (over 50 tons TOGW) vehicles, to provide active fire extinguishing systems, to ensure that all insulation (including sound proofing and thermal) are live damping agents, nonflammable in presence of fuel fires, and do not give off noxious gases under any circumstances.

3. PLANNED USE

3.1 Environment

(U)

The vehicle shall be designed to operate in the following environmental conditions:

- day/night and
- all weather, except that takeoffs and landings from land base are not required in winds exceeding 50 kt.

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3.2 Pollution Control

(U)

The following pollution control conditions were imposed:

- the vehicle shall not dump fuel or oil in the air or water except in emergencies;
- a fuel-dumping system is provided so that the design landing weight can be achieved within ½ hour after takeoff at design TOGW; and
- the vehicle shall not dump sewage into the air or water.

3.3 Operability Availability

3.3.1 Availability

(U)

The A/L vehicle availability is as follows:

- Net reliability of flight-critical systems are such that the anticipated attrition rate from system failure does not exceed 10^{-7} aircraft/year.
- The mission availability is as follows:
 - goal: 0.90 and
 - minimum acceptable: 0.75,

where mission availability is defined

$$\text{as MA} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

MTBF is the cumulative mean time between failure for any mission-critical system.

MTTR is the mean time to repair (in-flight or while sea sitting) the failed system. For nonrepairable systems, the mission duration is used.

- The service life availability shall be 0.34 where service life availability is defined as

$$\text{SLA} = \frac{\text{Planned flight and sea sitting hours per year}}{8770}$$

- The A/L vehicle has a service life of 20 yr.

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3.3.2 Maintenance Concept

3.3.2.1 General

(U) In general, all A/L vehicles

- are equipped with maintenance condition monitoring systems automatically providing diagnostic information and
- make maximum use of “on-condition” maintenance as opposed to “fixed interval” maintenance.

3.3.2.2 Organizational Level

(U) At the organizational level

- corrective maintenance consists of in-flight removal replacement for accessible, mission-critical modules with no preventative maintenance required in-flight and
- removal/replacement capability at base for all components subject to frequent failure, including engines if feasible. In addition, all preventative maintenance activity is provided.

3.3.2.3 Intermediate Level

(U) At the intermediate level, maintenance consists of repair of components removed at the organizational level.

3.3.2.4 Depot Level

(U) At the depot level, maintenance consists of vehicle overhaul when its condition dictates.

3.4 Manning

(U) The number of crew rotations will depend on the mission duration as follows:

<u>Mission Duration</u>	<u>Number of Watch Sections</u>
12-72 hr	2

The required crew skill levels shall not exceed contemporary Navy aircrew standards. The crew complement is that specified in Table AA-7.

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(U) TABLE AA-7

CREW AIR LOITER VEHICLE COMPLEMENT

Crew Member	Stations	Personnel
Pilot/Co-pilot	2	4
Flight Engineer	1	1
NAV/COM	1	2
TACCO	1	2
Assistant TACCO	1	2
Acoustic SENSO	2	4
Non-acoustic SENSO	1	2
Radar	3	4
Missile Control	1	2
Technician	1	1
Total	—	24

3.5 Human Factors/Habitability

(U) Habitability standards within the A/L vehicle depend on mission duration as follows:

Mission Duration

Habitability Standards

12-72 hr

Similar to E-4 aircraft

- The following environmental conditions within the vehicle are designed into the vehicle:
 - Temperature levels must be maintained between 20^o and 26^oC in all spaces regularly occupied by crew, whether work or personal spaces.
 - Cabin pressure altitude shall not exceed 8,000 ft (isobaric pressure altitude) at any aircraft altitude intended for sustained operation. Unpressurized intermittent operation up to 10,000 ft altitude is permissible only if an oxygen mask system is provided. No vehicle is designed for operation above 45,000 ft altitude.

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- Maximum permissible noise levels in cruising flight (or sea-sitting) occupied spaces are

Design Total Mission Time: less than 4 days

Noise Level: 75 dbA

Work areas requiring occasional crew presence of short duration are limited to 90 dbA noise level. An exception is made for SLV which will be constrained only by MIL-A-88806.

- All inhabited crew spaces are provided with adequate ventilation with due regard for prevention of accumulation of toxic atmospheric components. Ventilation rate of 30 ft³/min/man (15 percent outside air) is desirable.

(U) The standard crew input/output for sizing of food/water/sewage systems will be in accordance with that shown in Figure AA-9. Personnel performance degradation as a function of exposure to ship motion and acceleration is not well-defined especially for encounter frequencies below 0.10 Hz. Differences occur between criteria issued by various program offices. Furthermore, the use of RMSg as a criterion is currently being revised by the International Standard Organization (ISO) based on continued research and will be issued sometime in the next 1-3 years. For consistency, however, and pending any subsequent revision of ISO criteria, personnel performance degradation shall be measured against the vertical and lateral accelerations shown in Figure AA-10.

3.6 Margins

(U) The vehicle should be designed with the following margins:

- Electrical load: 30 percent growth margin on generating capacity with one unit out of commission.
- Weight: 10 percent of the "operating weight empty" as calculated without use of any margins other than those specified in this TLR.

4. DESIGN PHILOSOPHY

(U) The design team is to be guided by the following design philosophy in making tradeoff decisions.

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4.1 Cost/Performance Tradeoff

(U) The A/L vehicle is to be designed to meet the performance requirements specified in this TLR. Performance greatly in excess of specified requirements is to be avoided. Although no cost constraint is specified, cost is considered of equal importance with performance.

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4.3 Performance Tradeoff

(U) The vehicle should be a balanced design in accordance with the operational capabilities listed in Section 2 of this annex. The vehicle should be designed and innovative operational concepts developed to take advantage of the unique performance advantages and minimize the weaknesses of the vehicle. The vehicle should not be designed to optimize a particular measure of effectiveness to be utilized in the mission analysis.

4.4 Operability Tradeoff

(U) The vehicle is to be designed so that it can be operated by a Navy crew in actual operational conditions and not just as an R&D prototype. Accordingly, operability and maintainability should be considered of equal importance with basic vehicle performance.

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APPENDIX B

POINT DESIGNS

APPENDIX B

POINT DESIGNS

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I. INTRODUCTION

(U) In order to analyze the nine basic concepts under evaluation, specific point designs, representing analytical reference points, were developed by the Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project Office through private industry and government engineering centers. These point designs provide specific characteristics and parameters to be used in the analyses. They also provide an indication of the technical feasibility of the concepts in the various size ranges in order to assess technical risks.

(U) Specifically, 13 surface vehicle and 10 air vehicle point designs were developed to demonstrate the capabilities of the nine generic vehicle concepts. These 23 point designs were all configured to a common set of design standards so that meaningful comparisons would be possible (Appendix A). Common technological levels were established for the point designs so that any differences in technical performance could be attributed to differences in concepts rather than assumptions of technology levels, e.g., the assumption of projected power levels for a given engine in the same time frame. In addition, to ensure compliance with the basic ANVCE charter to evaluate platform differences, the combat suites were standardized within class groups (Appendix A). In this way, the ANVCE effort could isolate the differences in concepts from differences resulting from various combat suite elements.

(U) In this appendix, Chapter II provides a summary of the major characteristics of the 13 surface vehicle point designs. These designs are as follows :

- | | |
|-----------|---|
| o ACV 1 | an air cushion vehicle of approximately 1000 tonnes; |
| o ACV 3 | an air cushion vehicle of approximately 3000 tonnes; |
| o LCAC | an air cushion vehicle landing craft; |
| o HYD 7 | a high-speed hydrofoil of approximately 900 tonnes (originally 700 tonnes before design modifications were incorporated); |
| o LCPC | a planing vehicle landing craft; |
| o SES 3 | a surface effect ship of approximately 3000 tonnes; |
| o SES CV | a aircraft carrier surface effect ship; |
| o SES CVN | a nuclear-powered aircraft carrier surface effect ship; |
| o SWA 4 | a small waterplane-area, twin-hull (SWATH) frigate of approximately 4000 tonnes; |
| o SWA MCM | a mine countermeasures SWATH ship; and |
| o SWA CVN | a nuclear-powered SWATH aircraft carrier. |

(U) Eleven of these point designs were configured to a technology level projected for 1985, which is compatible with a 1995 initial operational capability (IOC). Two point designs, the planing craft (LCPC) and the air cushion vehicle landing craft (LCAC), were designed to the current technology level, which is compatible with a 1985 IOC.

(U) Each of these point designs was provided either by industry or a government engineering center in response to the specific requirements provided by the ANVCE project office. These requirements were the result of an analysis of the technology assessment and the military requirements. Contractually, the point designs were conducted in response to a specific set of common requirements described for convenience and consistency in the form of a Top Level Requirements (TLR) document. An example of such a TLR and the design standards to which the point designs are to adhere may be found in Appendix A. For convenience, a summary of each surface vehicle point design follows, in alphabetical sequence, expressed in a format similar to that formerly used NAVWEPS Form 13100, "Standard Aircraft Characteristics." To a large degree these summary descriptions are extracted from the detailed point design description reports prepared by either industry or a government engineering center. In certain cases, however, it has been found necessary to modify the projected point design performance values given in the detailed design reports to more properly reflect the technology capability of the time frame of interest. By way of example, if, say, the projected structural weight fraction of a given point design from the detailed report appears unduly optimistic and unsupportable by technology projections than an appropriate modification is incorporated in the summary descriptions provided in this Appendix. It should be noted that the intent of this appendix is to provide a succinct summary of all the point designs used in the ANVCE project. For complete details of any one design, the appropriate reference cited in Volume II must be studied.

(U) Chapter III provides a summary of the major characteristics of the ten air vehicle point designs. These designs are as follows:

- | | |
|----------|---|
| o A/L | an air loiter aircraft; |
| o A/L(N) | a nuclear-powered air loiter aircraft; |
| o FAB | a fully air-buoyant, lighter-than-air (LTA) vehicle; |
| o SAB | a semi-air-buoyant, LTA vehicle; |
| o S/L(L) | a large sea loiter aircraft; |
| o S/L(S) | a small sea loiter aircraft; |
| o S/L(V) | a ship-based, vertical/short takeoff and landing (V/STOL), sea loiter aircraft; |
| o WIG(H) | a hard-end-plate, wing-in-ground-effect (WIG) vehicle; |
| o WIG(O) | a WIG vehicle that can also operate out of ground effect; and |
| o WIG(S) | a soft-end-plate, WIG vehicle. |

(U) Wherever possible these existing designs have been expressed in the ANVCE standard requirements format; however, they represent different time frames (and, therefore, different technology levels), different missions, and different combat suites. Taken in proper context, however, comparisons involving these designs can be informative.

(U) Table I provides a complete list of all point designs considered in the project.

(U) All of these air vehicle designs were designed specifically to a technology level projected for 1985, which is compatible with a 1995 IOC.

(U) In similar vein to the discussion above for the surface vehicle point designs, each of these point designs was provided either by industry or a government engineering center in response to the specific requirements provided by the ANVCE project office. In the case of the air vehicles, however, since they were all “far term” and thus relatively immature technologically compared to the surface vehicles, parametric analyses were embarked upon first to further guide the selection of the point designs.

(U) Again, like the surface vehicles it was found in certain cases that the performance projections of the point designs were not always in accordance with realistic technology projections.

(U) In addition to these point designs, it was considered informative to compare these designs with some recognizable “baseline” designs where appropriate. Thus, the following four baseline designs were selected:

- o AVP a typical, advanced fixed-wing, land-based patrol aircraft;
- o CXX a long-range cargo aircraft (USAF);
- o MONO 3 an advanced-technology monohull of approximately 3000 tonnes; and
- o VSS a V/STOL support ship.

(U) The MONO 3 represents a displacement ship designed to the same technology level (1985) as all of the surface vehicle concepts. The AVP is representative of a projected land-based patrol aircraft; the VSS is a projected V/STOL support ship; and the CXX is representative of current projections of strategic airlift logistics aircraft. While these baseline designs are not consistent with the standards and requirements established by the ANVCE project, they do provide reasonable baselines for comparisons. A summary of their characteristics is provided in Chapter IV.

(U) Finally, to provide a reference point with other designs conducted during early design studies and in some cases to representative hardware, the characteristics of existing designs are summarized in Chapter V. These designs are as follows:

- o CPIC a coastal patrol interdiction craft;
- o FFG-7 a USS PERRY class, guided-missile frigate;
- o HOC a ocean combatant hydrofoil;
- o LSES a large surface effect ship;
- o PHM a guided-missile, patrol hydrofoil; and
- o ZPG a LTA patrol vehicle.

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(U) TABLE 1. POINT DESIGN LISTINGS

<u>ACRONYM</u>	<u>DESCRIPTION</u>	<u>ADVCS POINT DESIGN (CHAP I, II)</u>	<u>BASELINE (CHAP III)</u>	<u>EXISTING DESIGN (CHAP IV)</u>
ACV 1	Nominal 1000-Ton ACV	X		
ACV 3	Nominal 3000-Ton ACV	X		
A/L	Air Loiter Aircraft	X		
A/L (N)	Nuclear Powered Air Loiter Aircraft	X		
AVP	Typical Advanced Patrol Aircraft		X	
CPIC	Coastal Patrol Interdiction Craft			X
CRX	Long Range Cargo Aircraft (USAF)		X	
PAB	Fully Air Buoyant LTA Vehicle	X		
PTC-7	"Perry" Class Guided Missile Frigate			X
HYD 7	Nominal 700-Ton High Speed Hydrofoil	X		
HYD 2	Nominal 2000-Ton Hydrofoil	X		
HOC	Hydrofoil Ocean Combatant			X
LCAC	Landing Craft Air Cushion Vehicle	X		
LCPC	Landing Craft Planing Craft	X		
LSBS	Large SBS			X
MONO 3	Nominal 3000-Ton Advanced Technology Monohull		X	
PC 1	Nominal 1000-Ton Planing Craft	X		
PRM	Guided Missile Patrol Hydrofoil			X
SAB	Semi-Air-Buoyant LTA Vehicle	X		
SES 3	Nominal 3000-Ton SES	X		
SES CV	SES Carrier	X		
SES CVN	SES Nuclear Powered Carrier	X		
S/L(L)	Large Sea Loiter Aircraft	X		
S/L(S)	Small Sea Loiter Aircraft	X		
S/L(V)	Ship-Based V/STOL Sea Loiter Aircraft	X		
SWA 4	Nominal 4000-Ton SWATH Frigate	X		
SWA MCN	Mine Countermeasures SWATH	X		
SWA CVN	Nuclear Powered SWATH Carrier	X		
VSS	V/STOL Support Ship		X	
WIG(N)	Hard End Plate Wing-in-Ground Effect Vehicle	X		
WIG(O)	Out of Ground Effect Wing-in-Ground Effect Vehicle	X		
WIG(S)	Soft End Plate Wing-in-Ground Effect Vehicle	X		
EPG	Patrol LTA Vehicle			X

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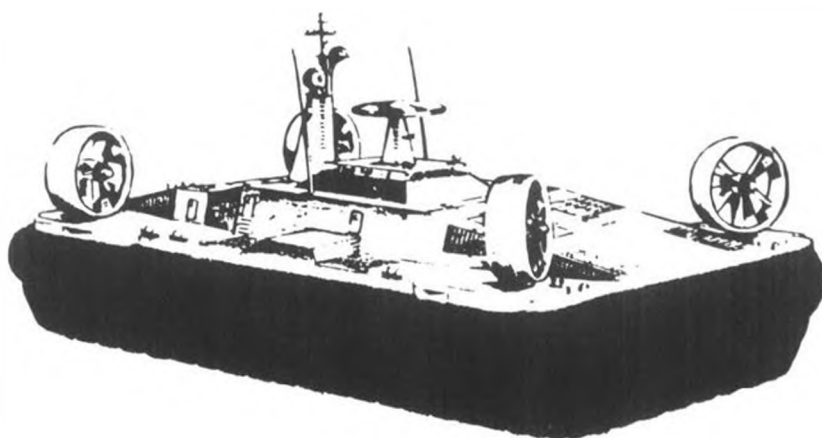
B-5

UNCLASSIFIED

II. SURFACE VEHICLE POINT DESIGNS

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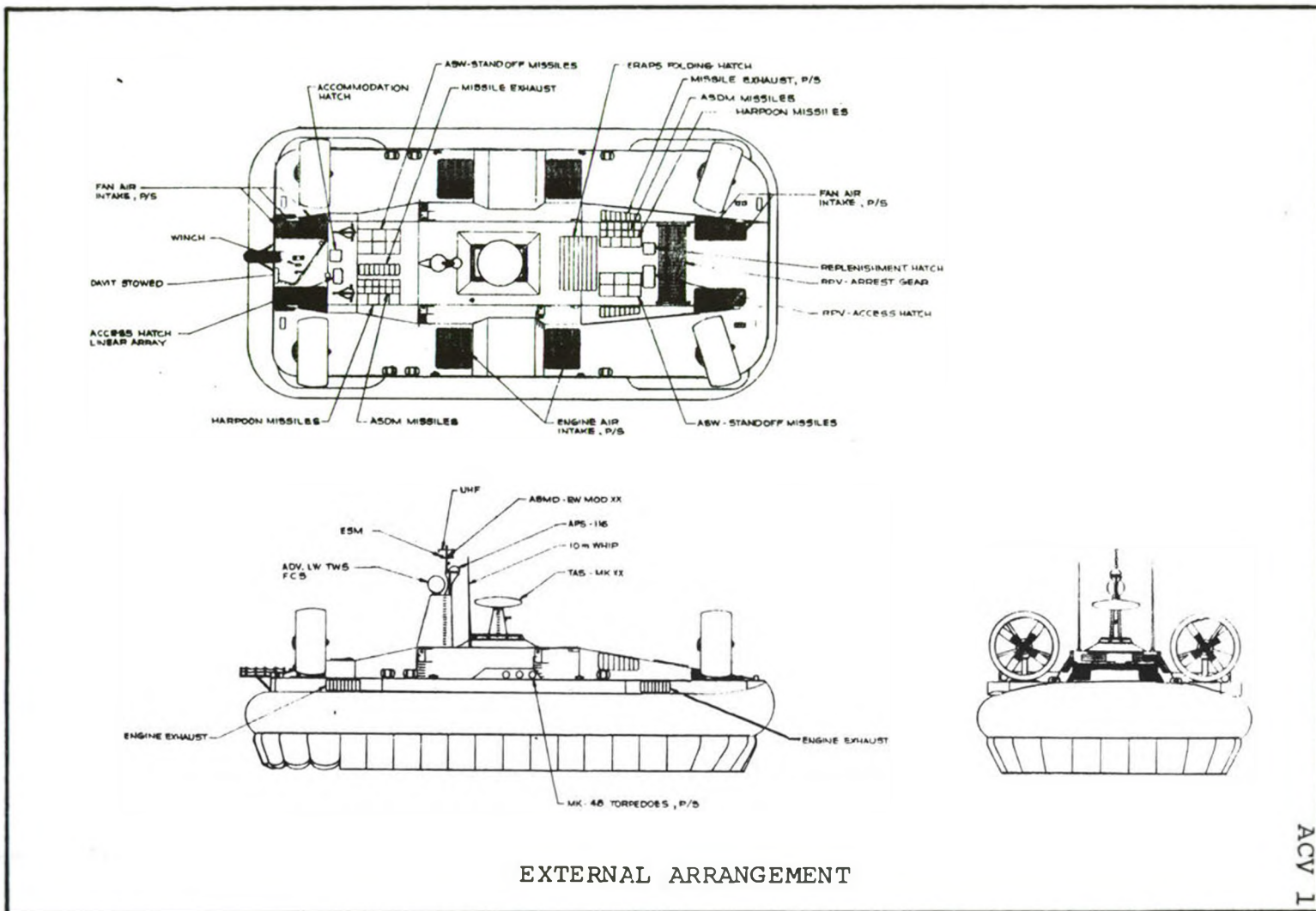
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NOMINAL 1000 TON ACV

POINT DESIGN SUMMARY

UNCLASSIFIED



EXTERNAL ARRANGEMENT

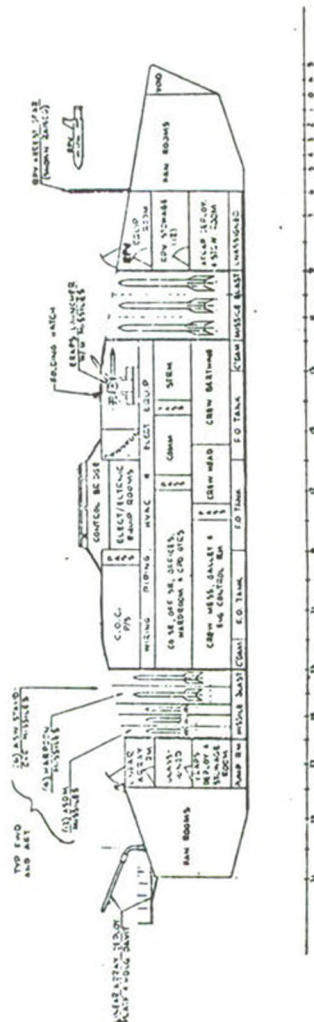
ACV 1

B-10

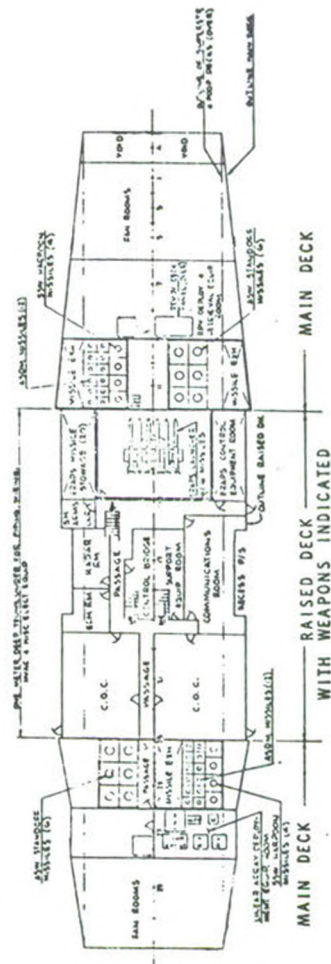
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ACV 1



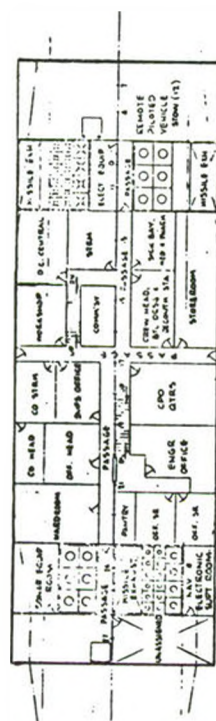
INBOARD PROFILE
WITH WEAPONS INDICATED



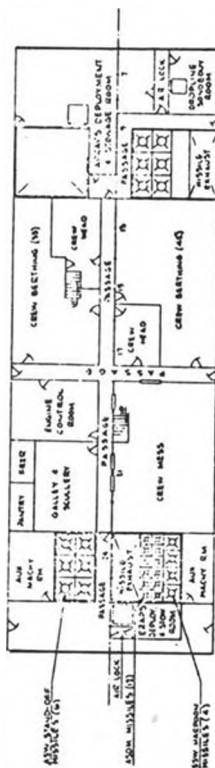
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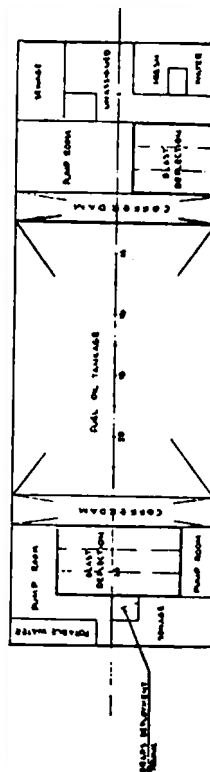
ACV 1



SECOND DECK



INNER BOTTOM



HOLD

INTERNAL ARRANGEMENT

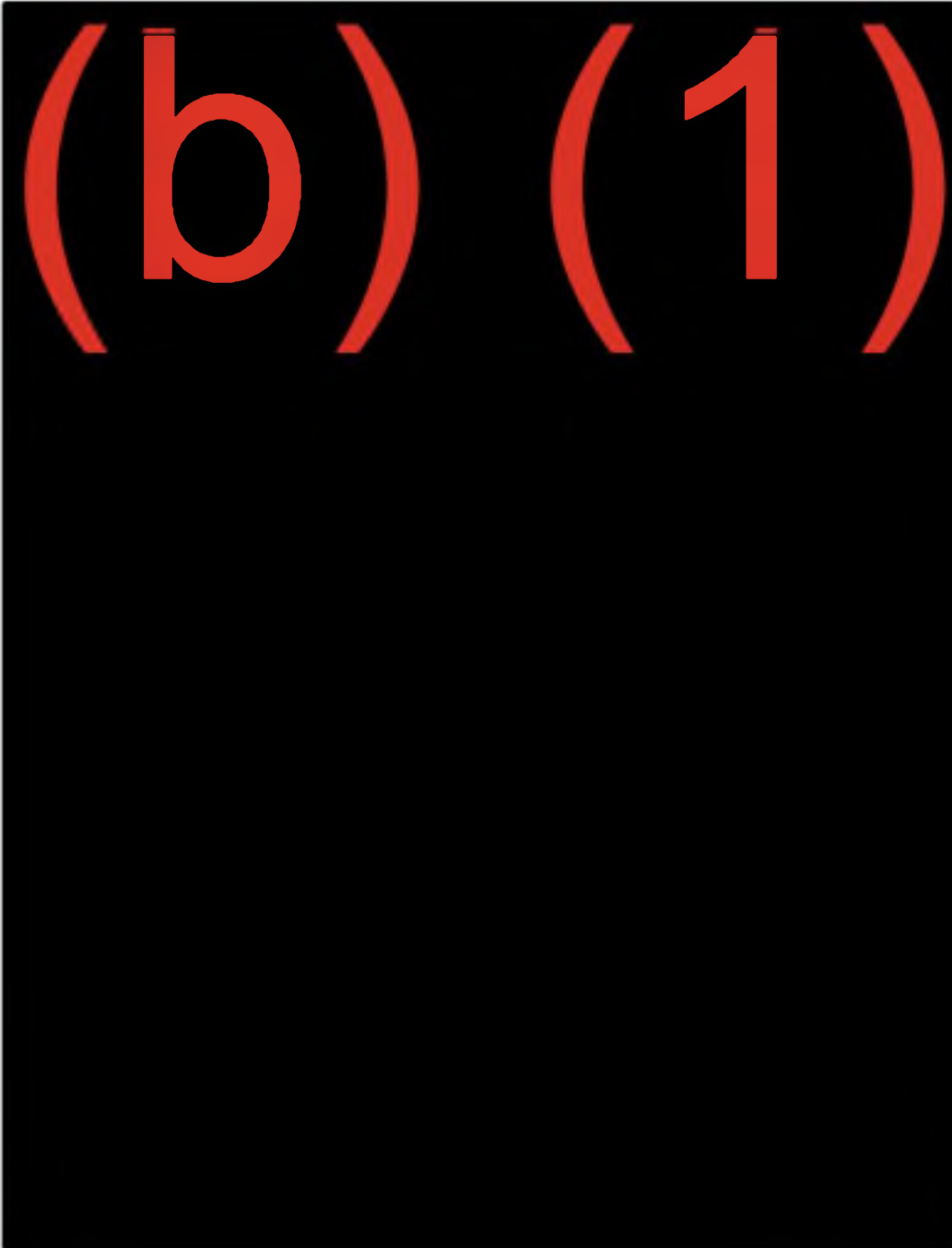
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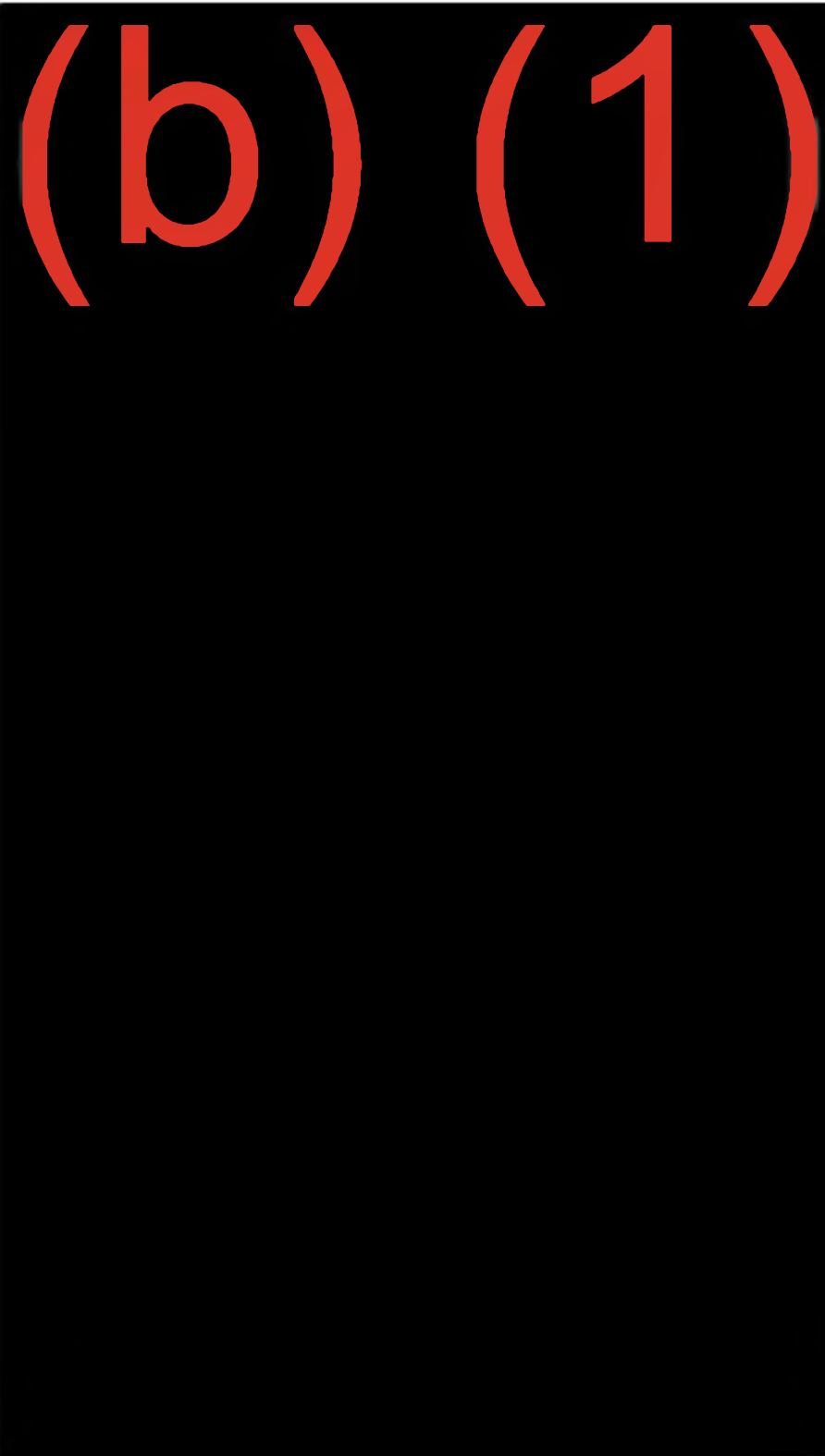


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ACV 1

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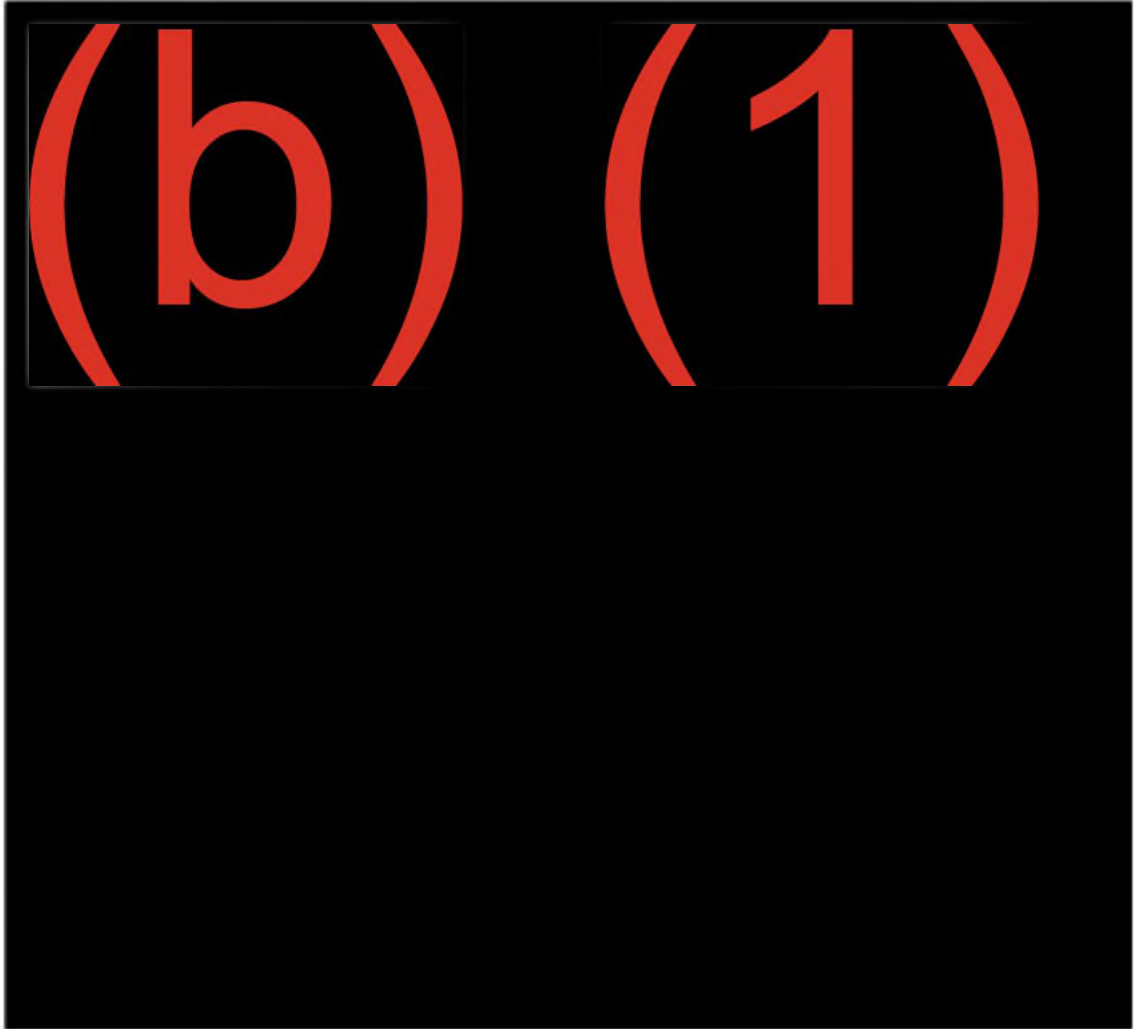
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ACV 1

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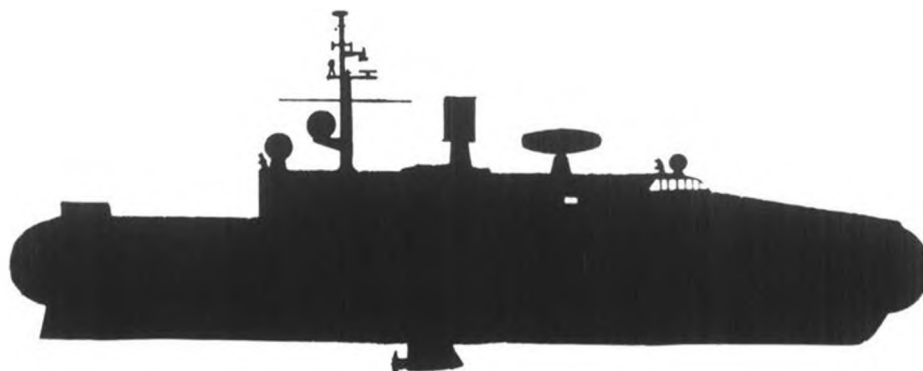
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ACV 3

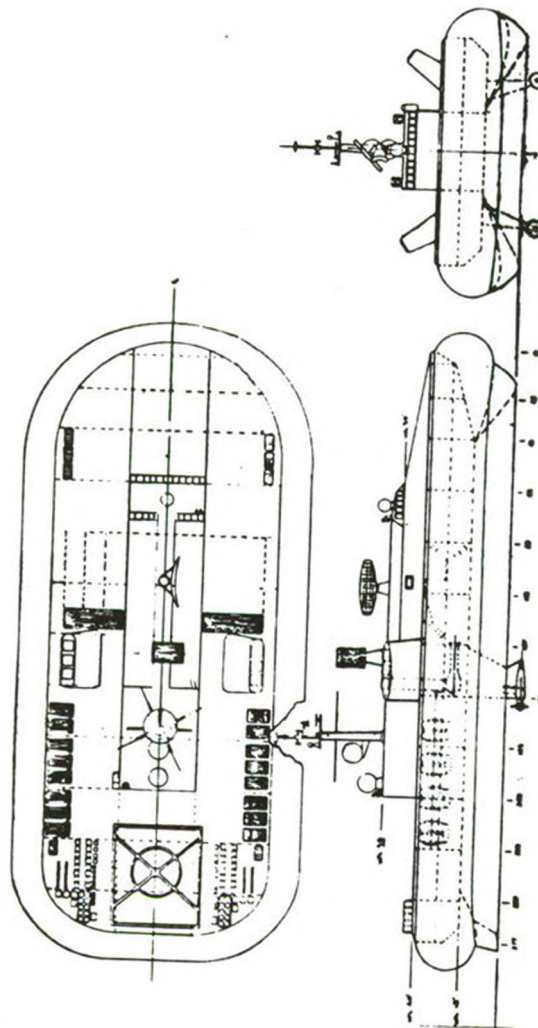


NOMINAL 3000 TON ACV

POINT DESIGN SUMMARY

UNCLASSIFIED

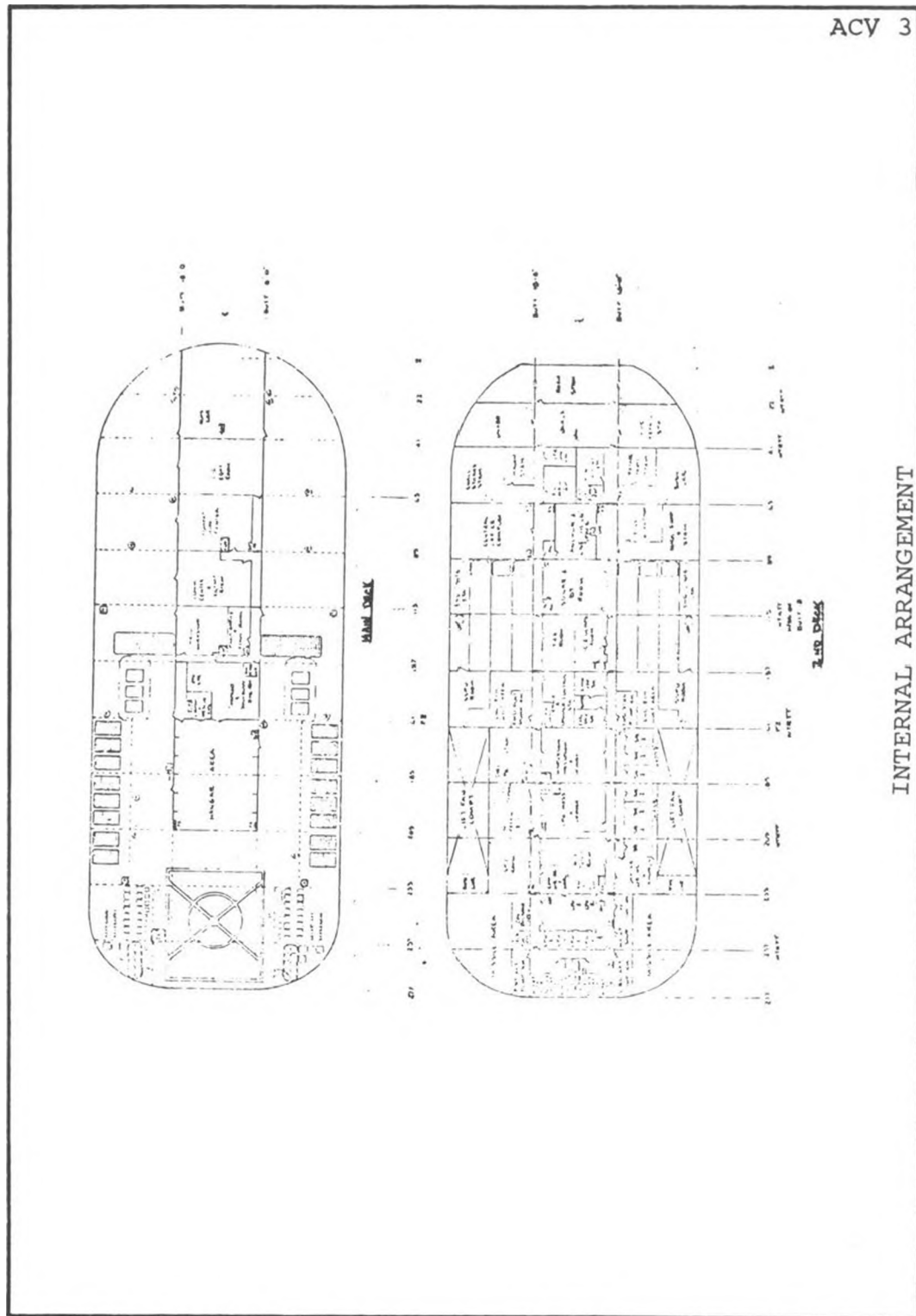
ACV 3



EXTERNAL ARRANGEMENT

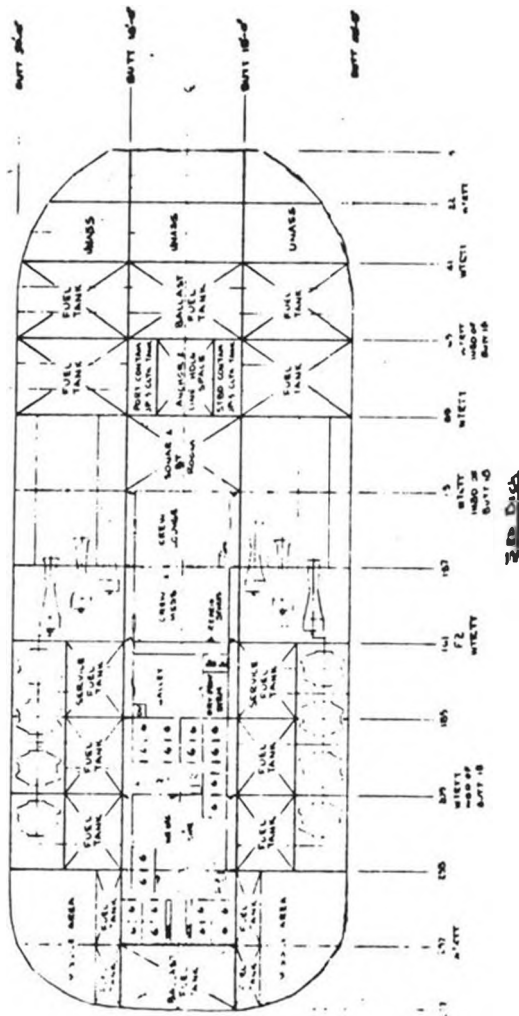
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ACV 3



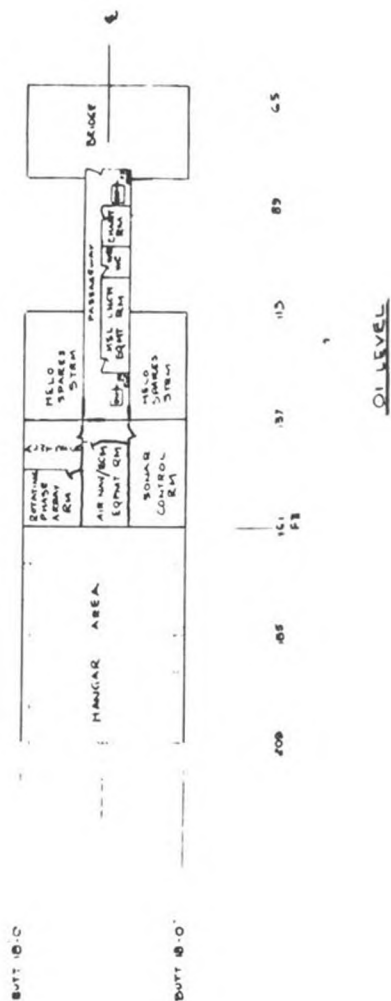
INTERNAL ARRANGEMENT

B-22

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ACV 3

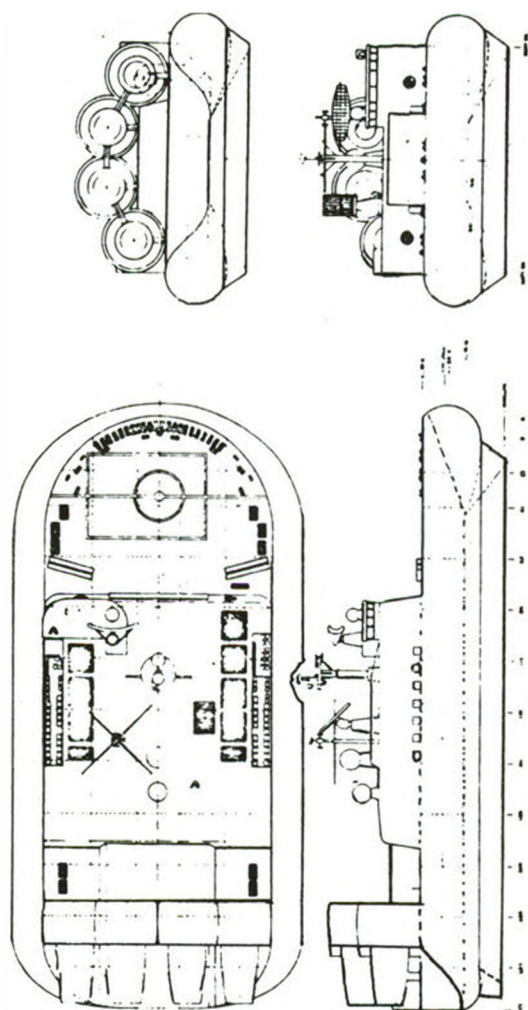


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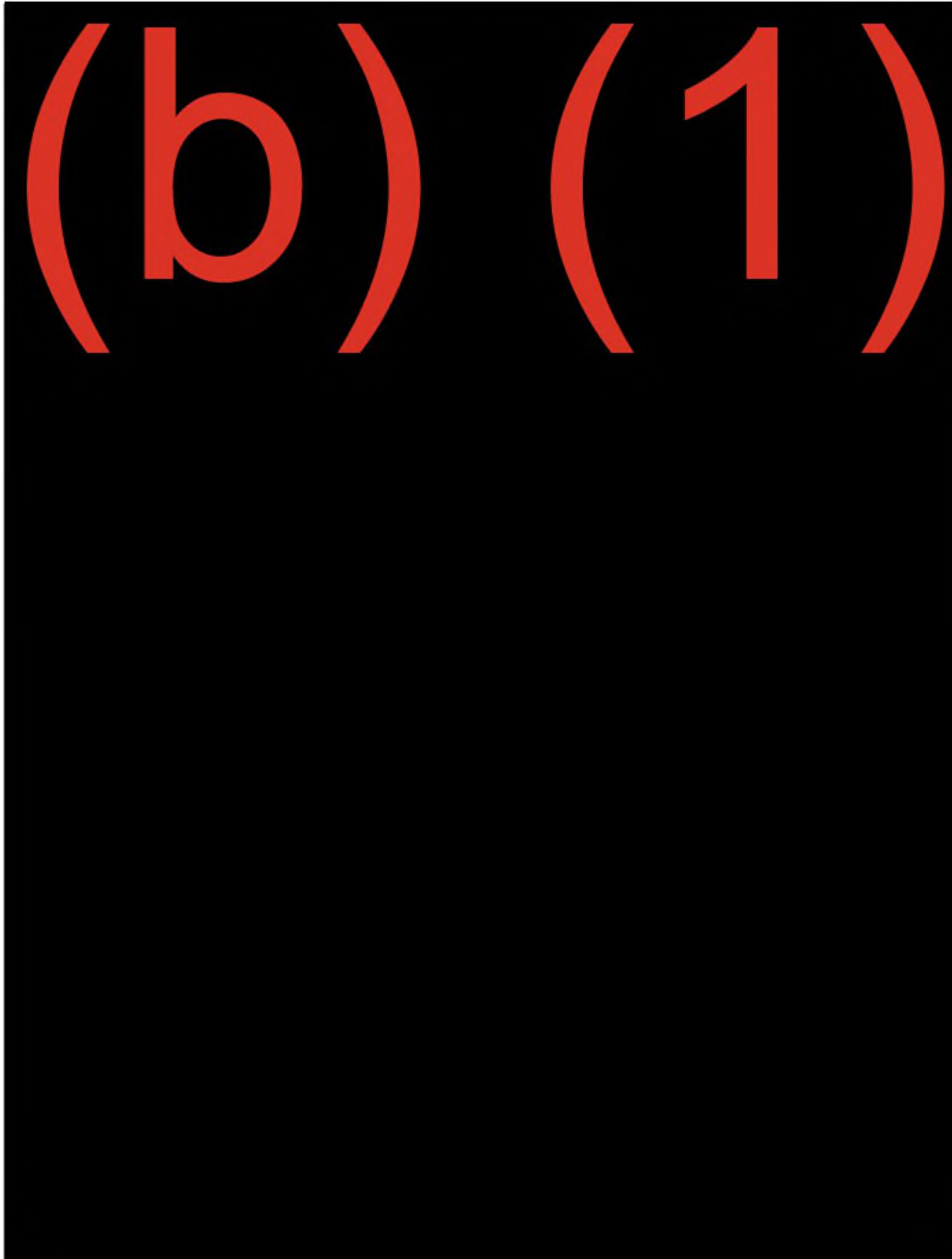
ACV 3



EXTERNAL ARRANGEMENT
(ALTERNATIVE AIR PROPELLED CONFIGURATION)



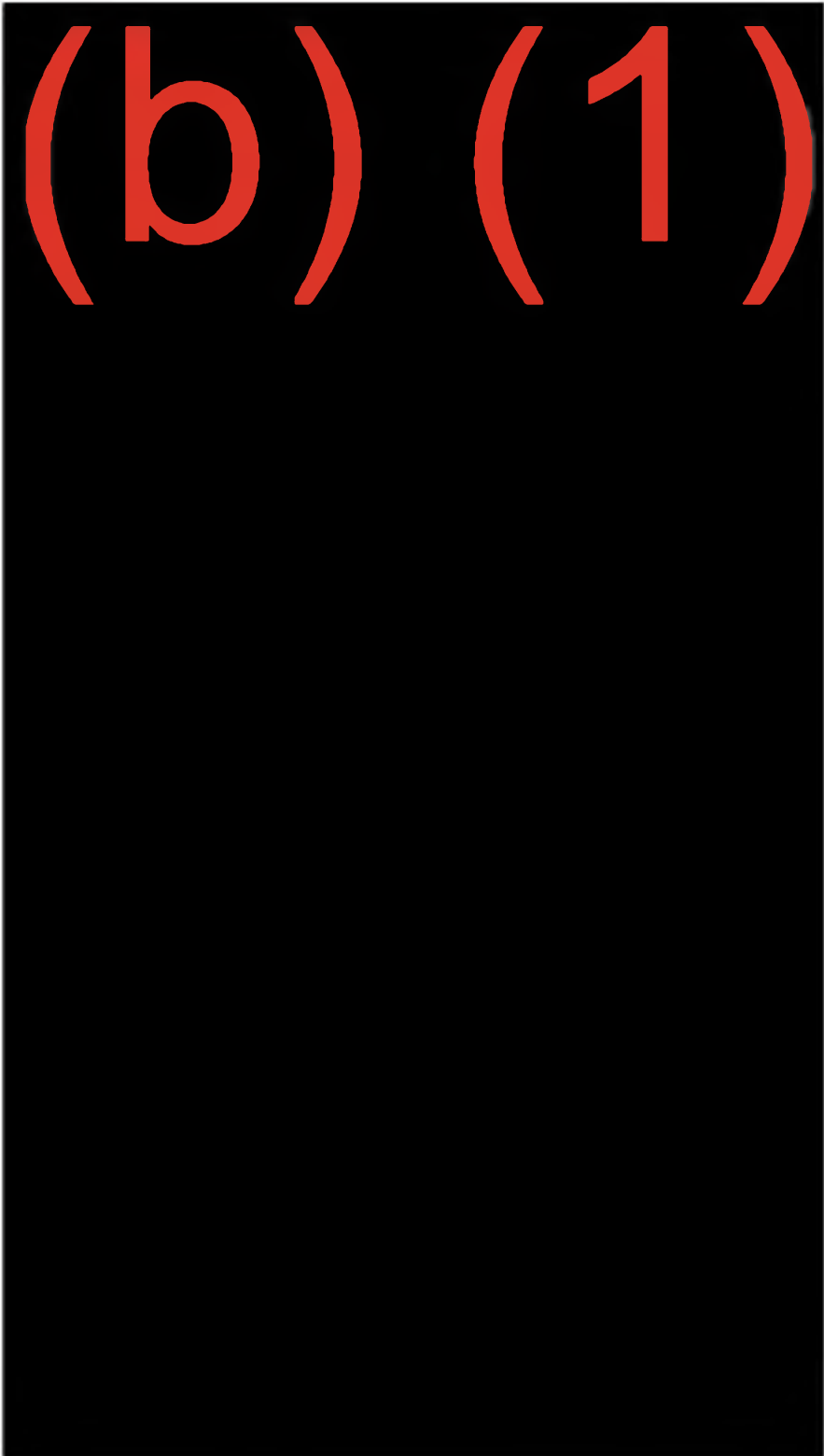
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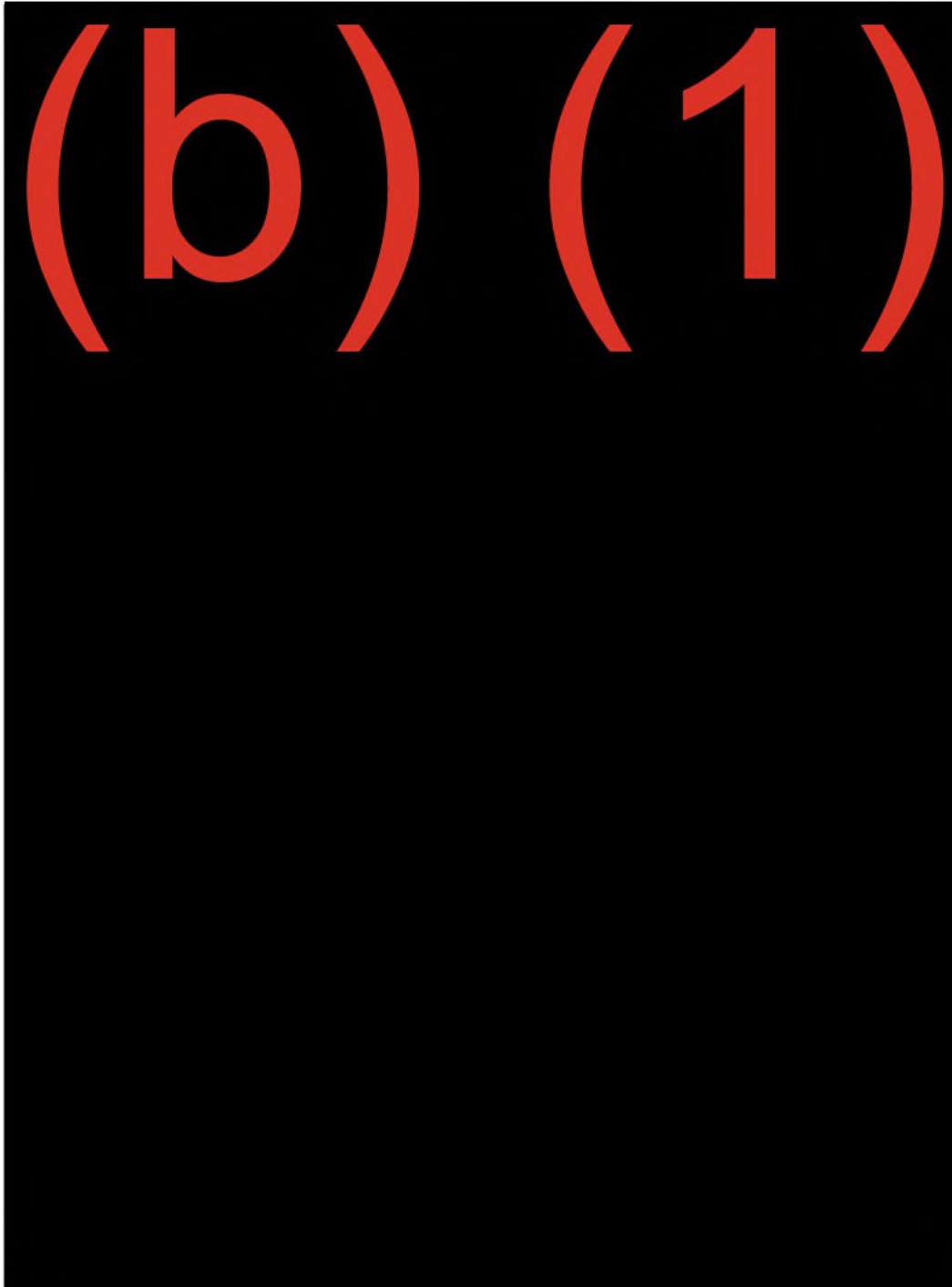
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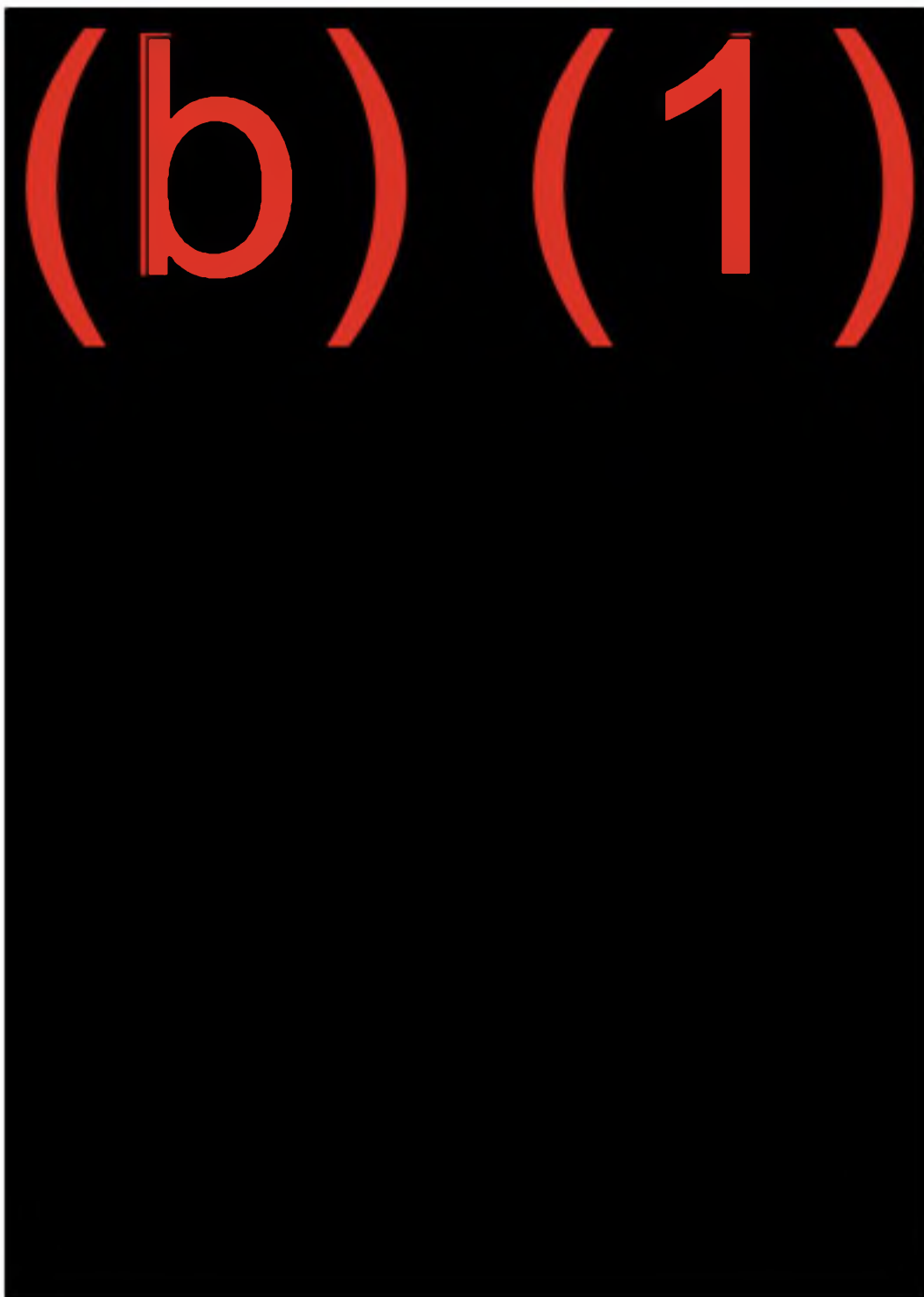
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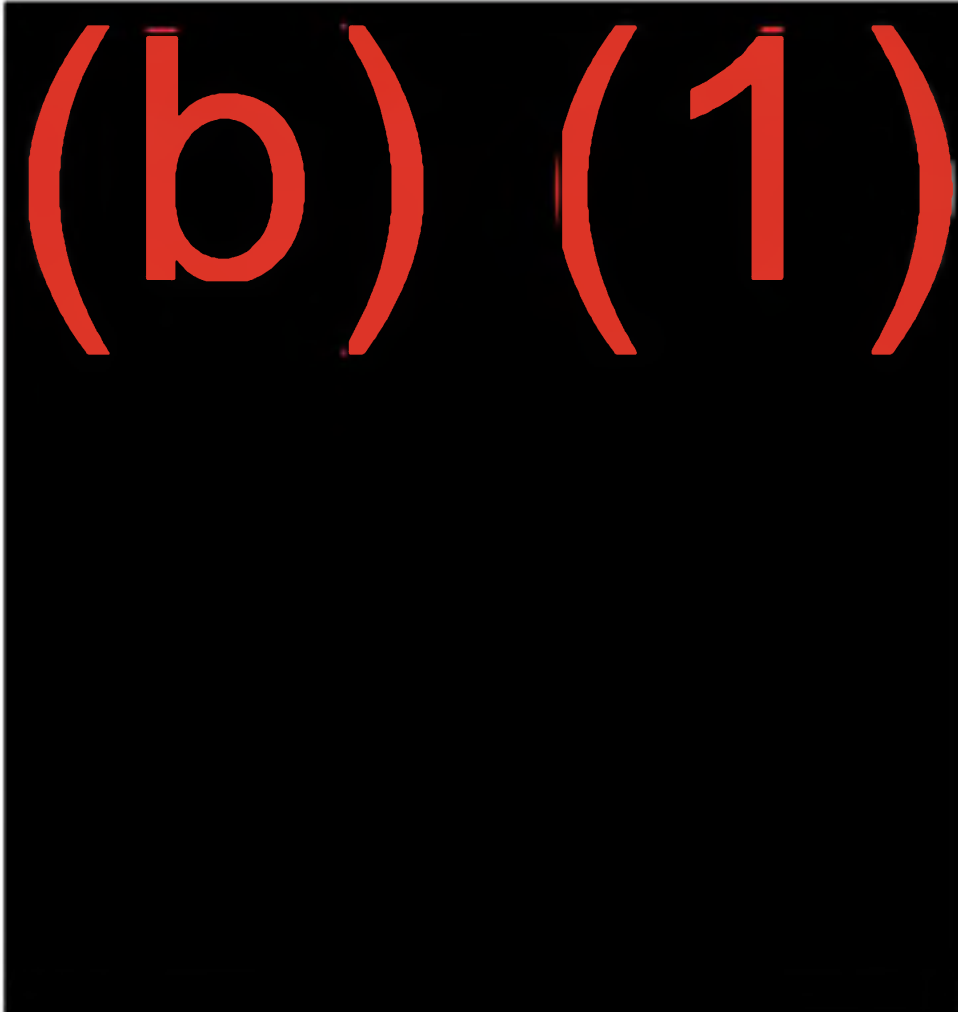
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LCAC

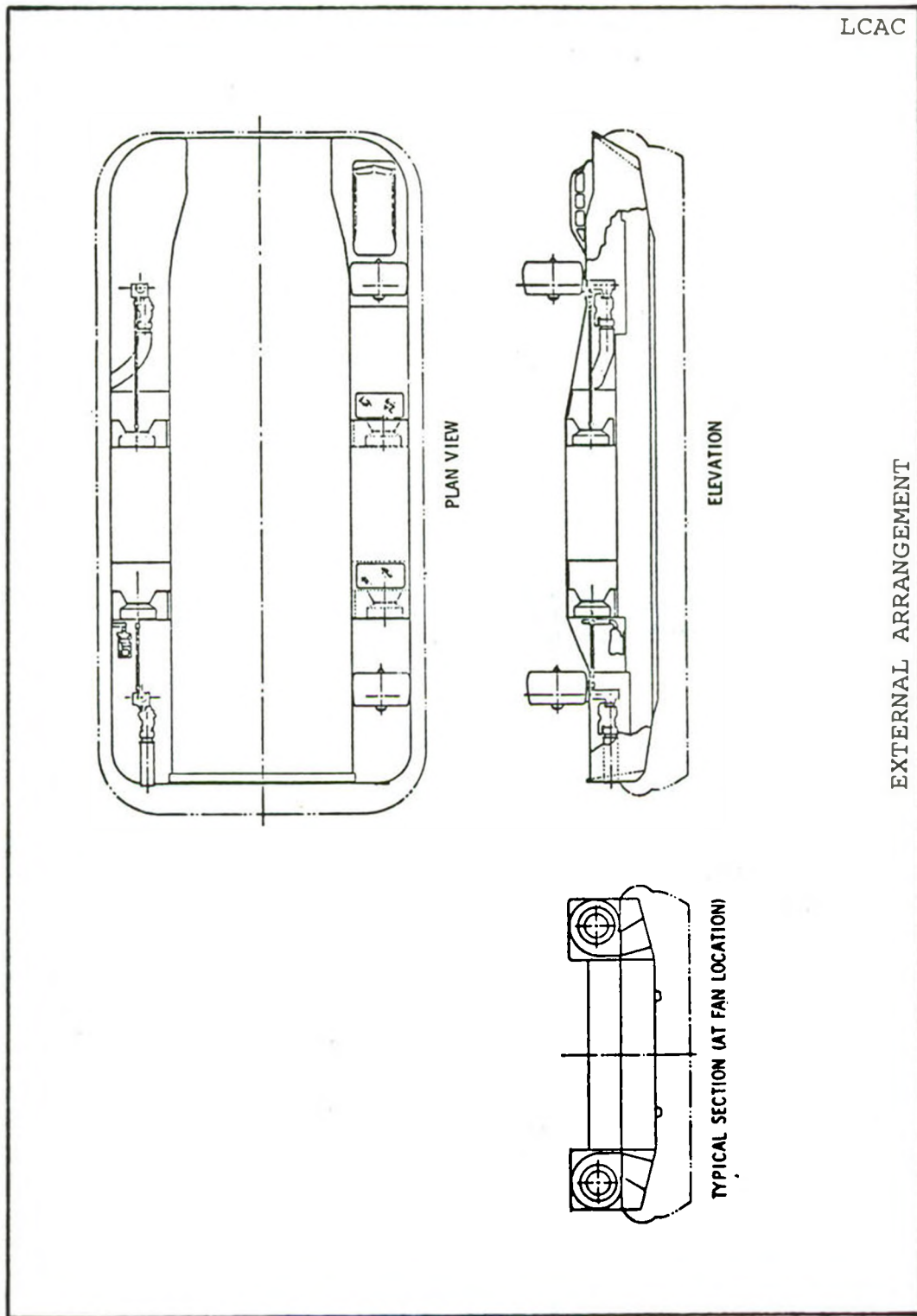


LANDING CRAFT AIR CUSHION

POINT DESIGN SUMMARY

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LCAC

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LCAC

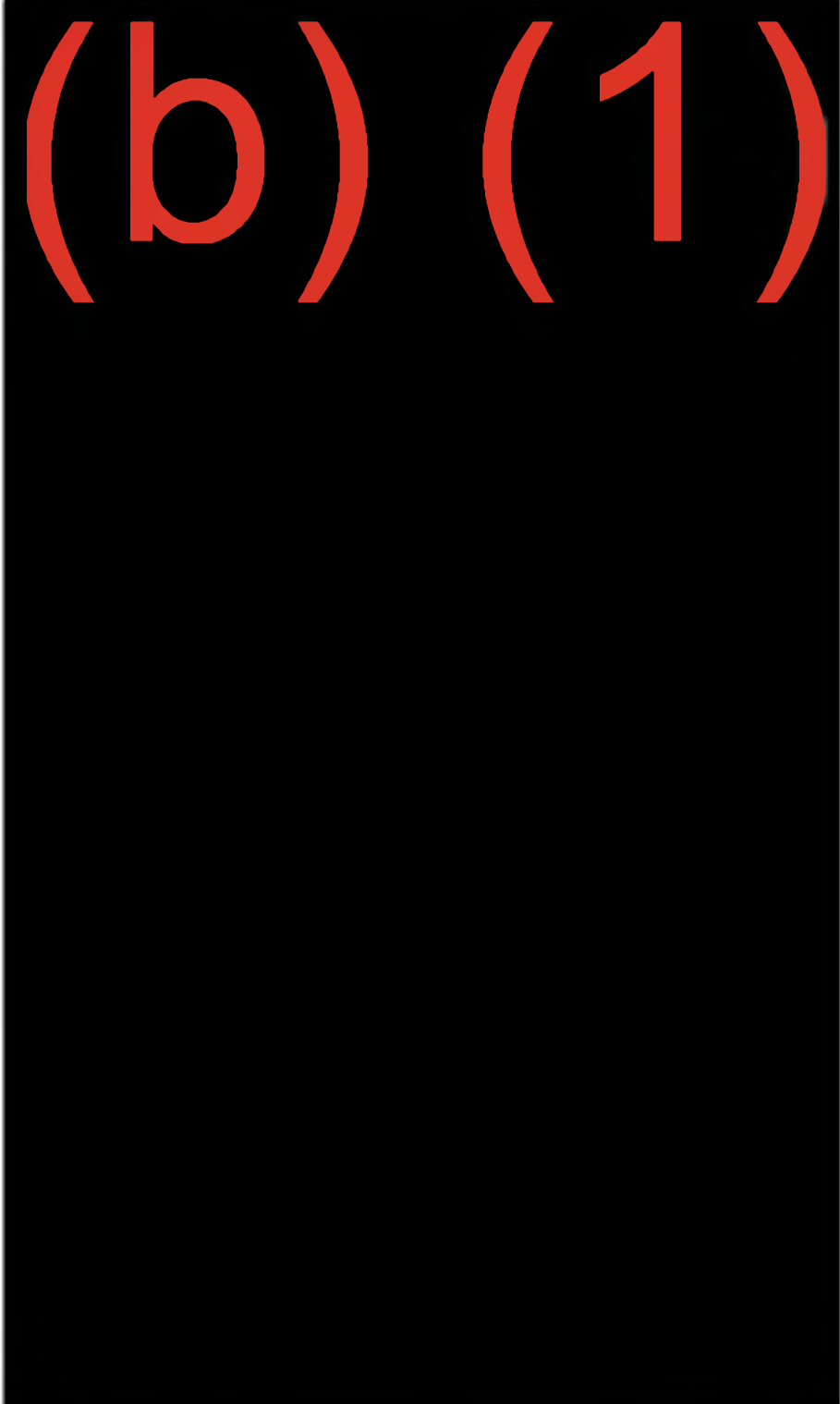
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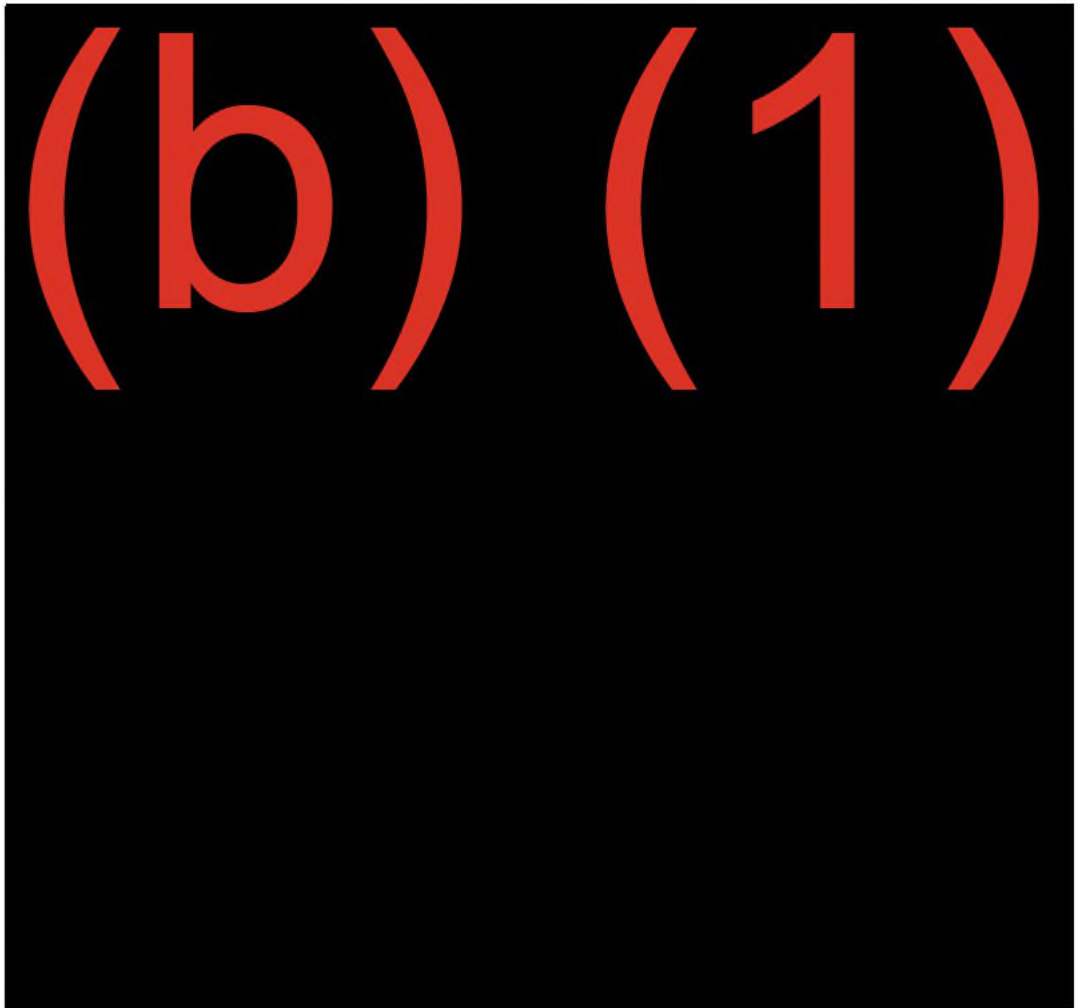
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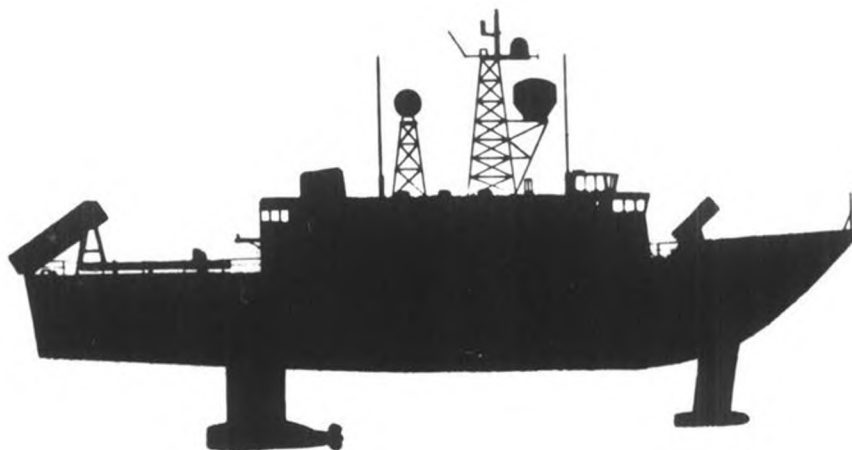


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HYD 7

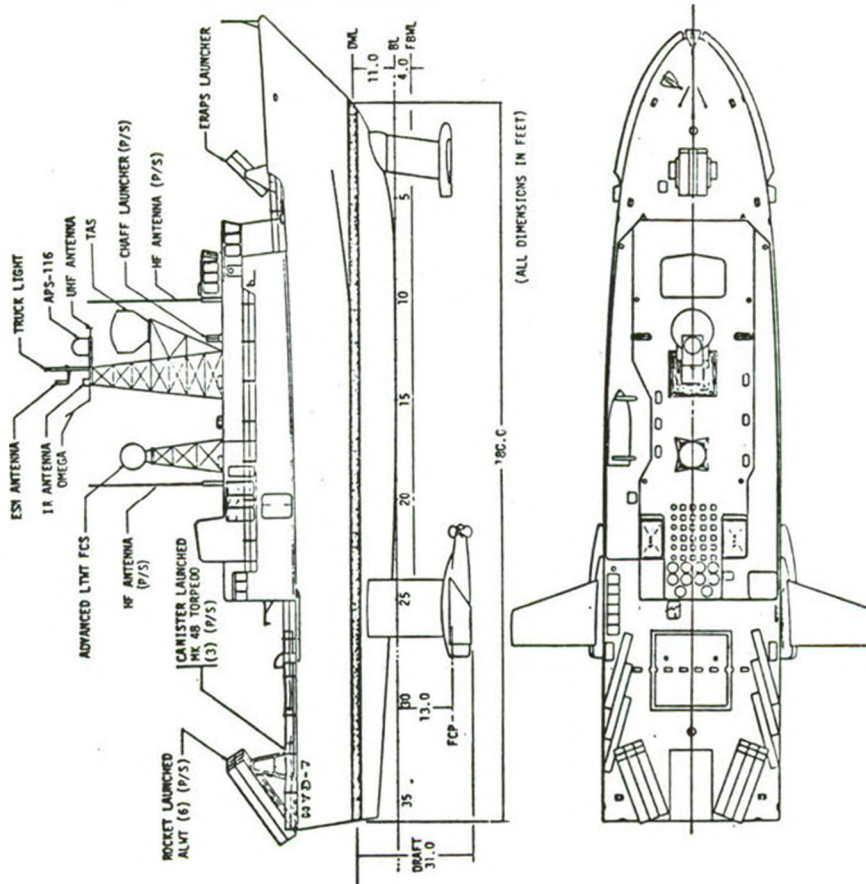


NOMINAL 700 TON HIGH SPEED HYDROFOIL
POINT DESIGN SUMMARY

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UNCLASSIFIED

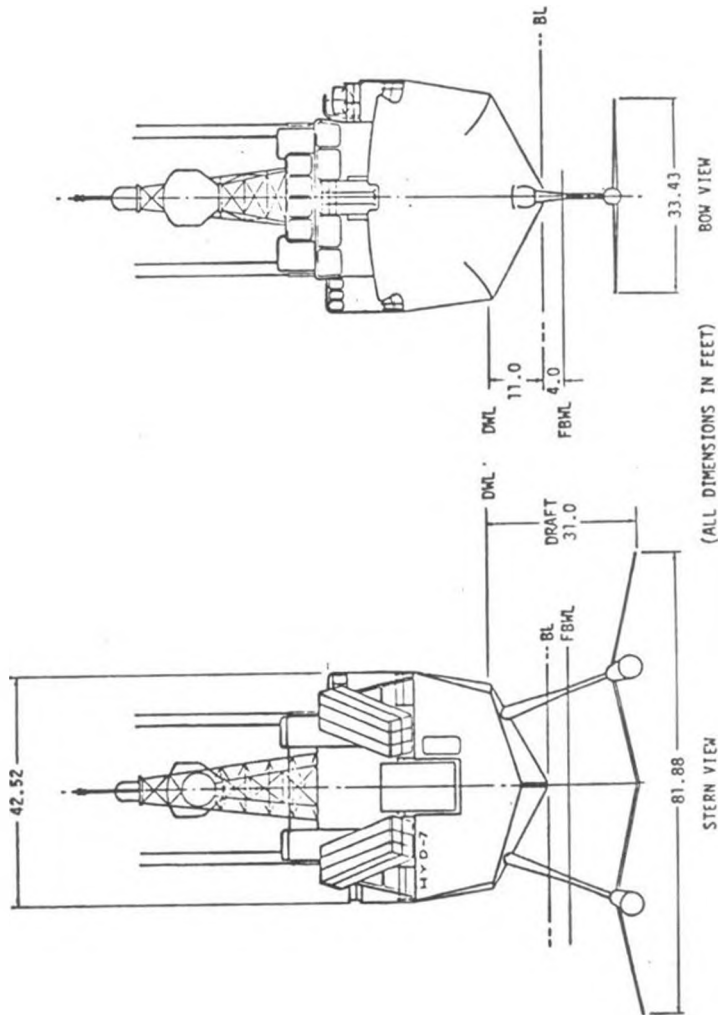
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B-40

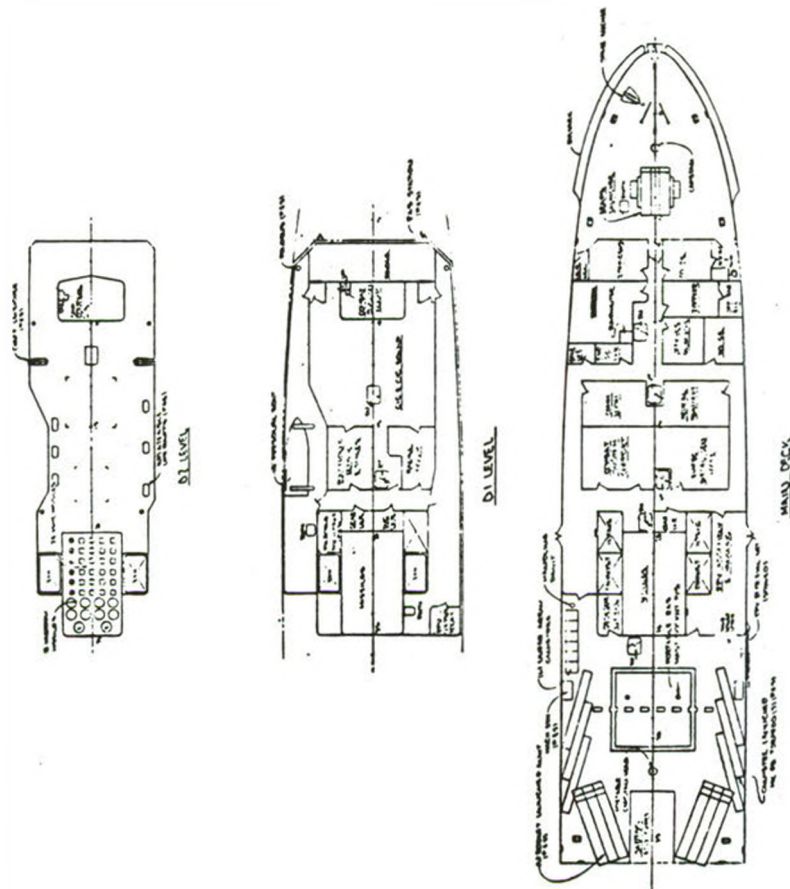
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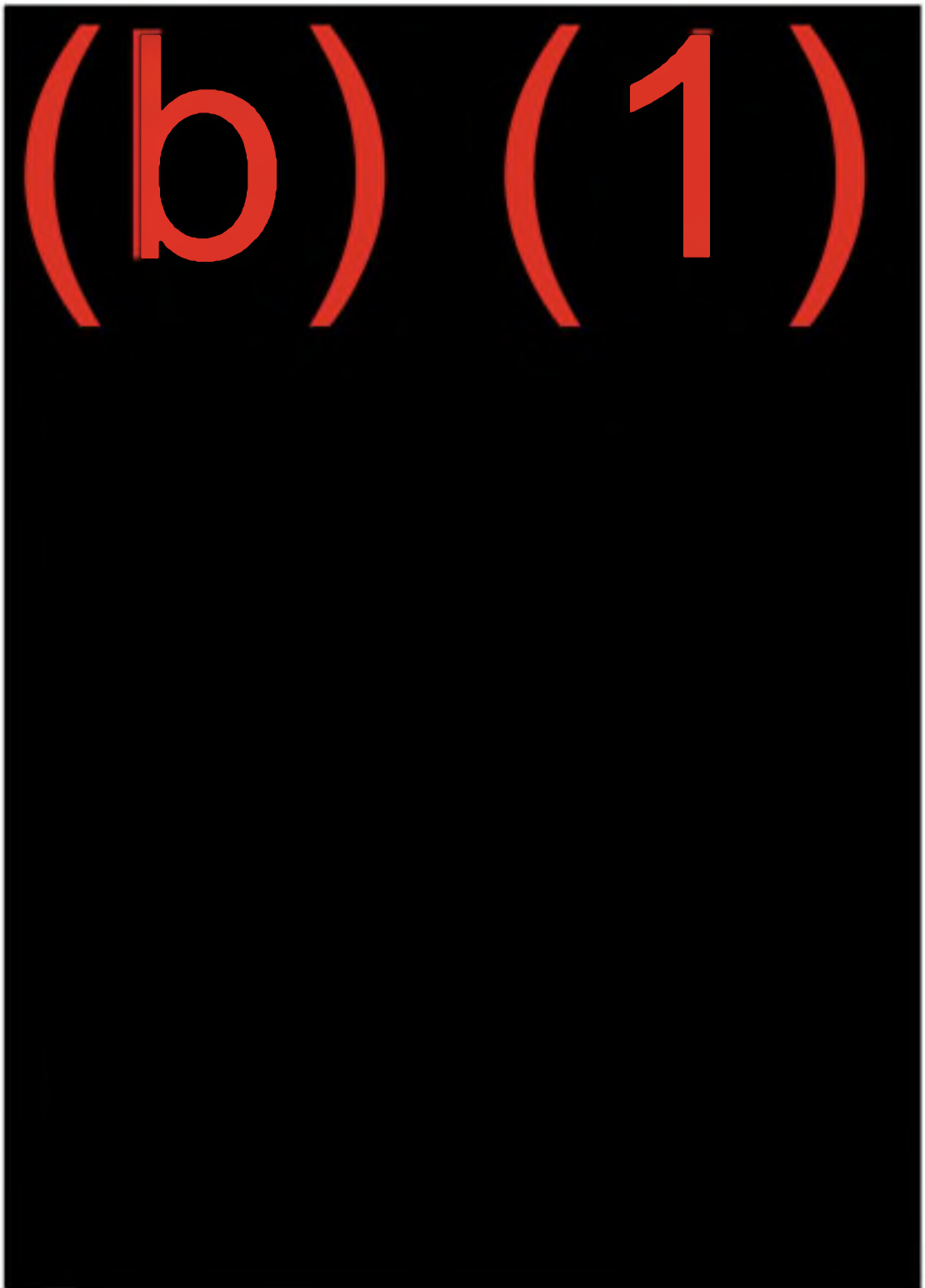


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B-42

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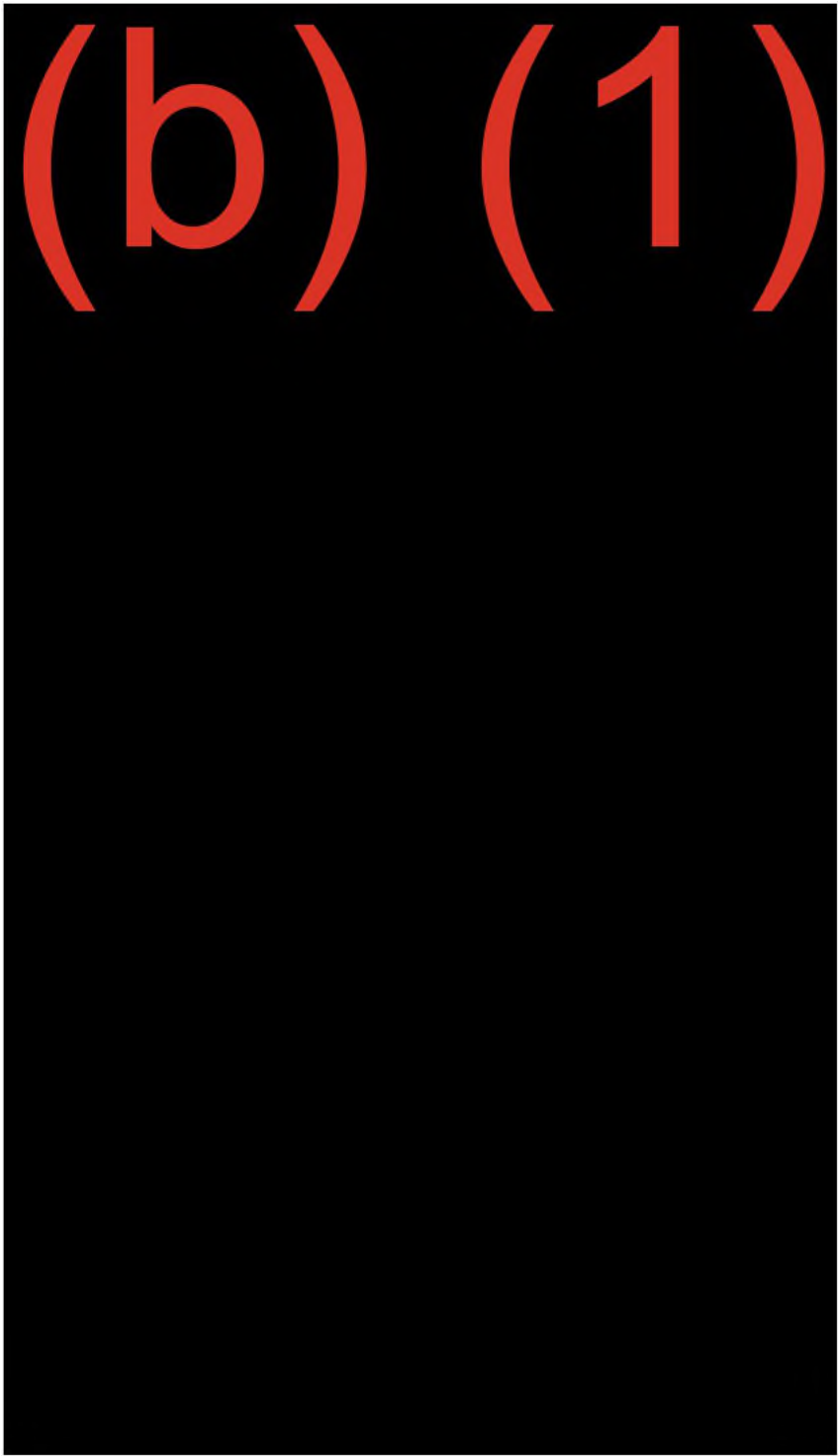


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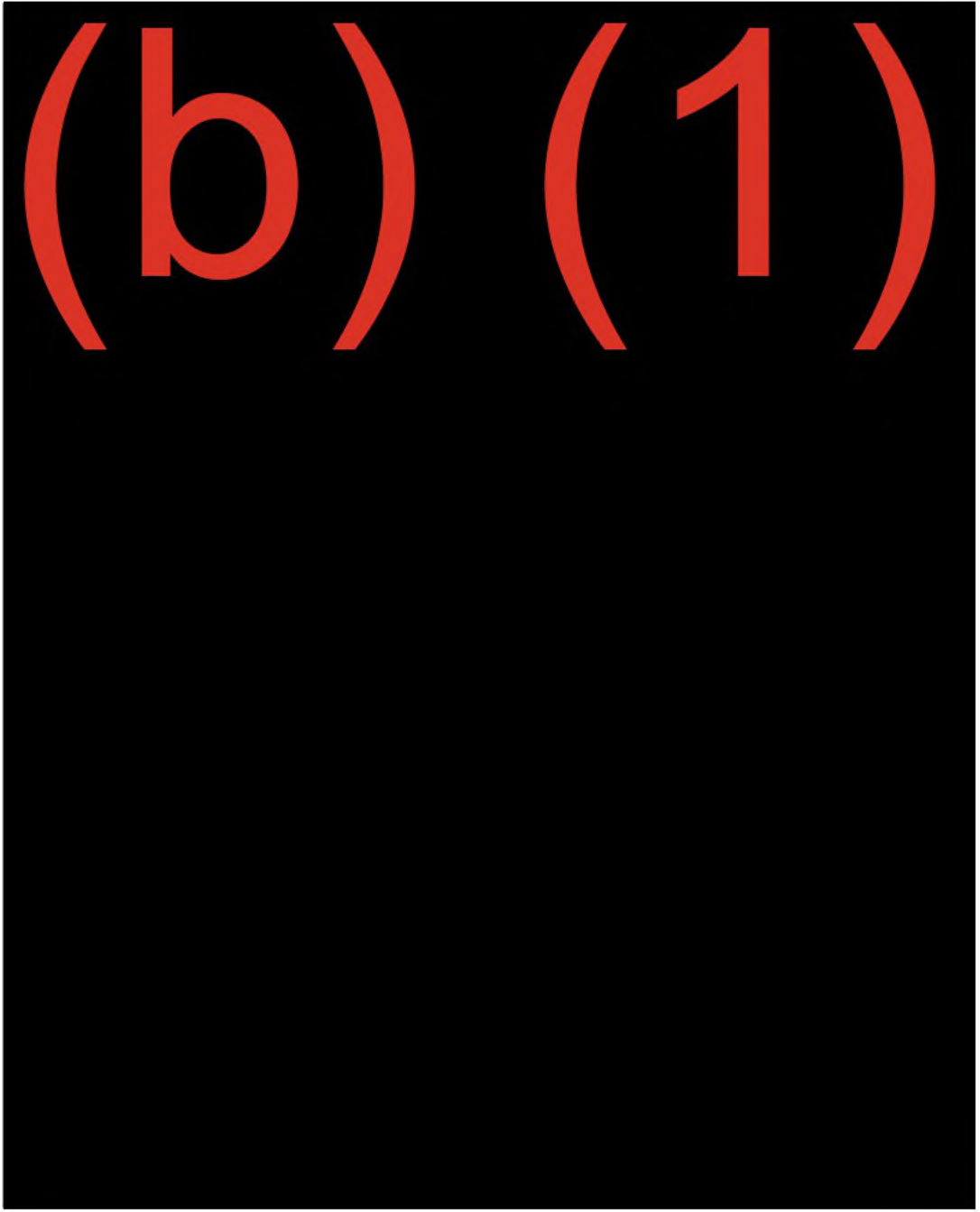


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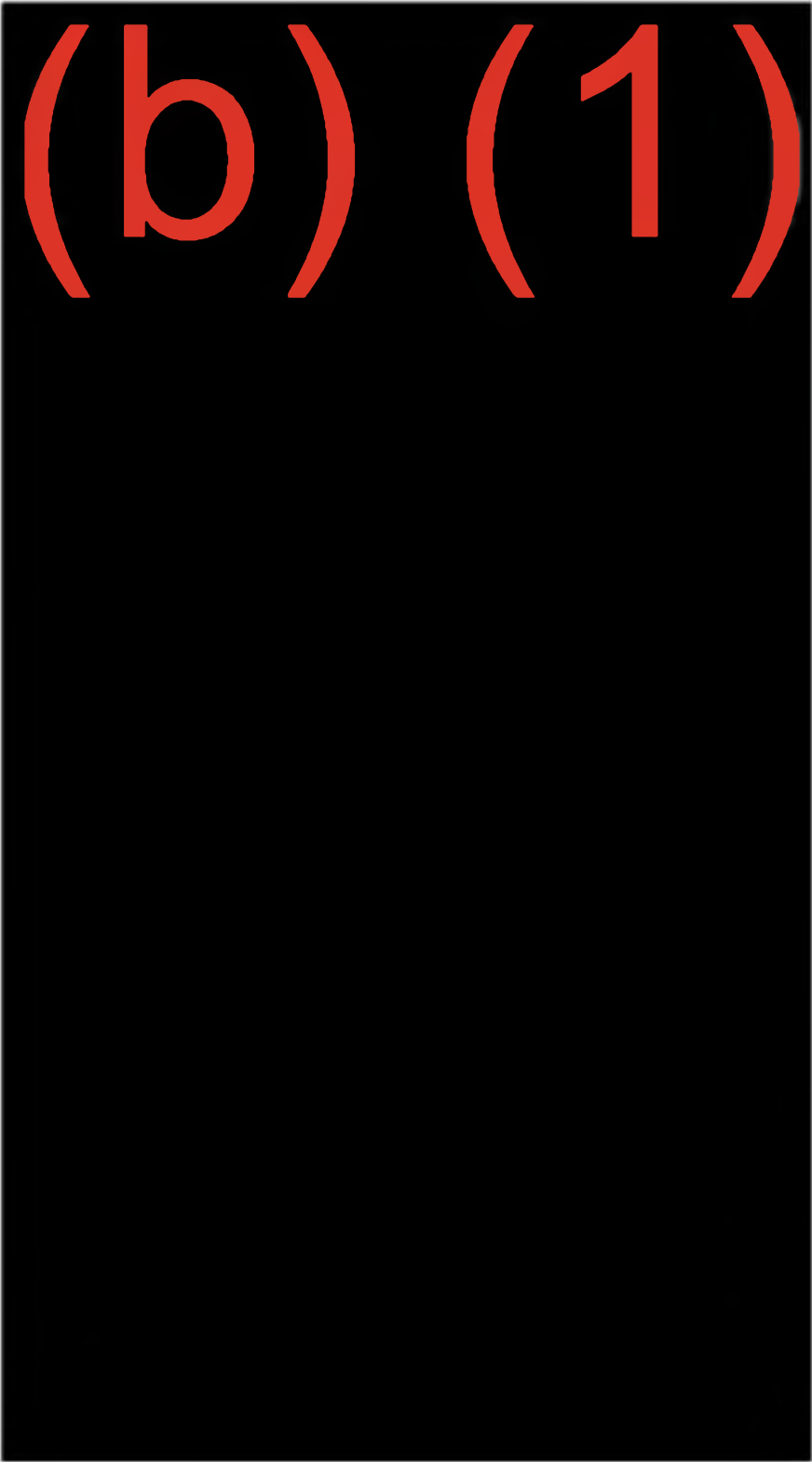


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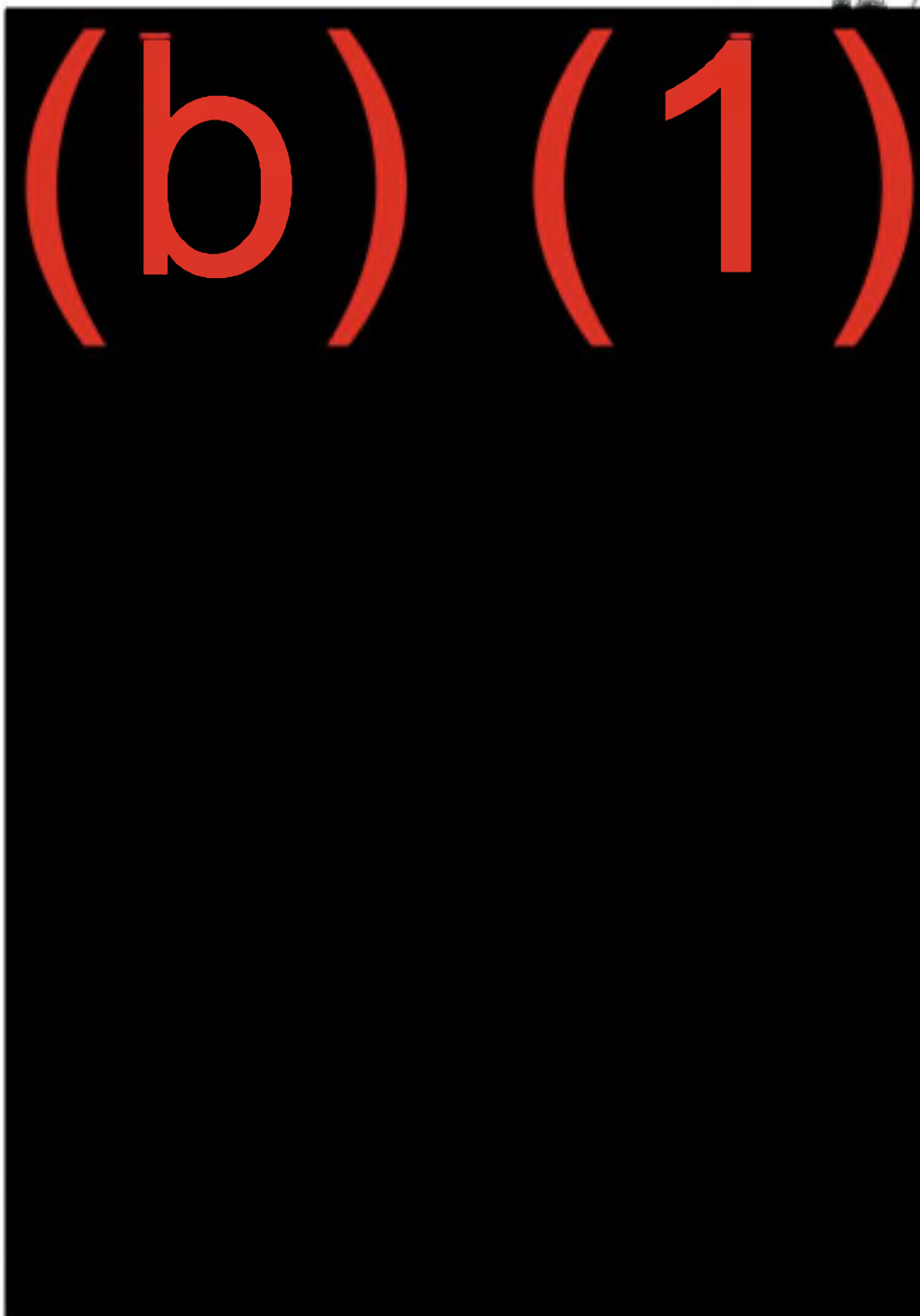
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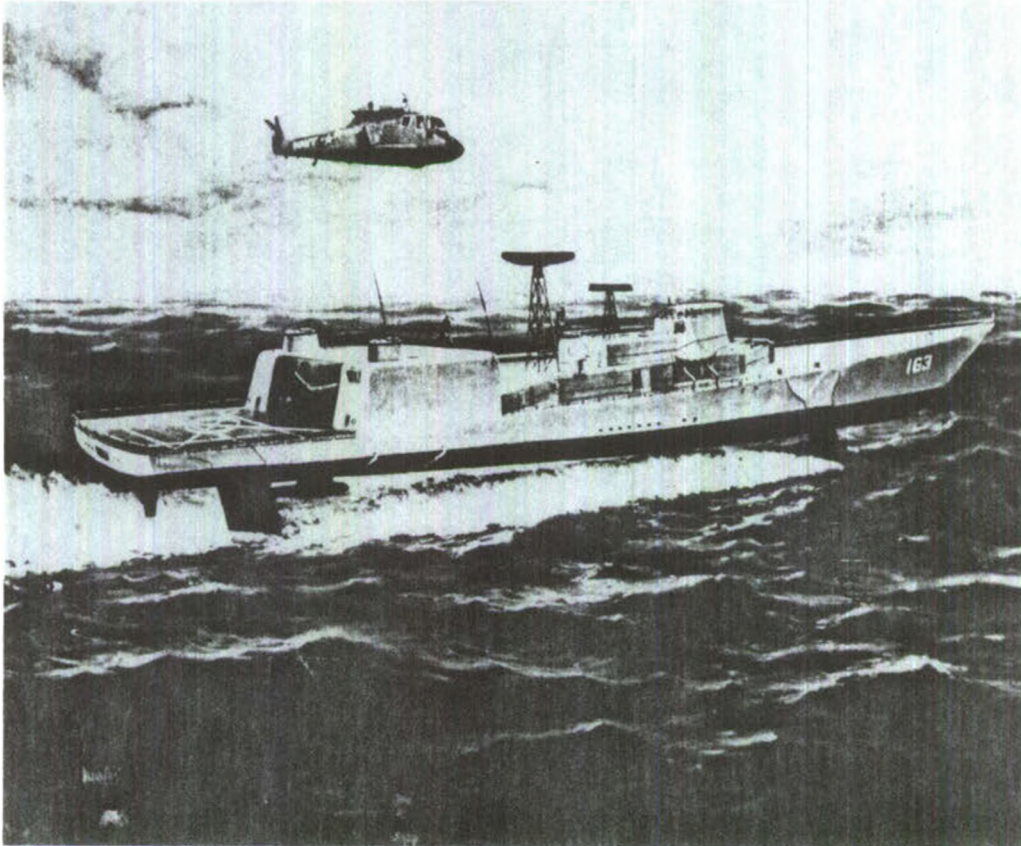


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HYD 2



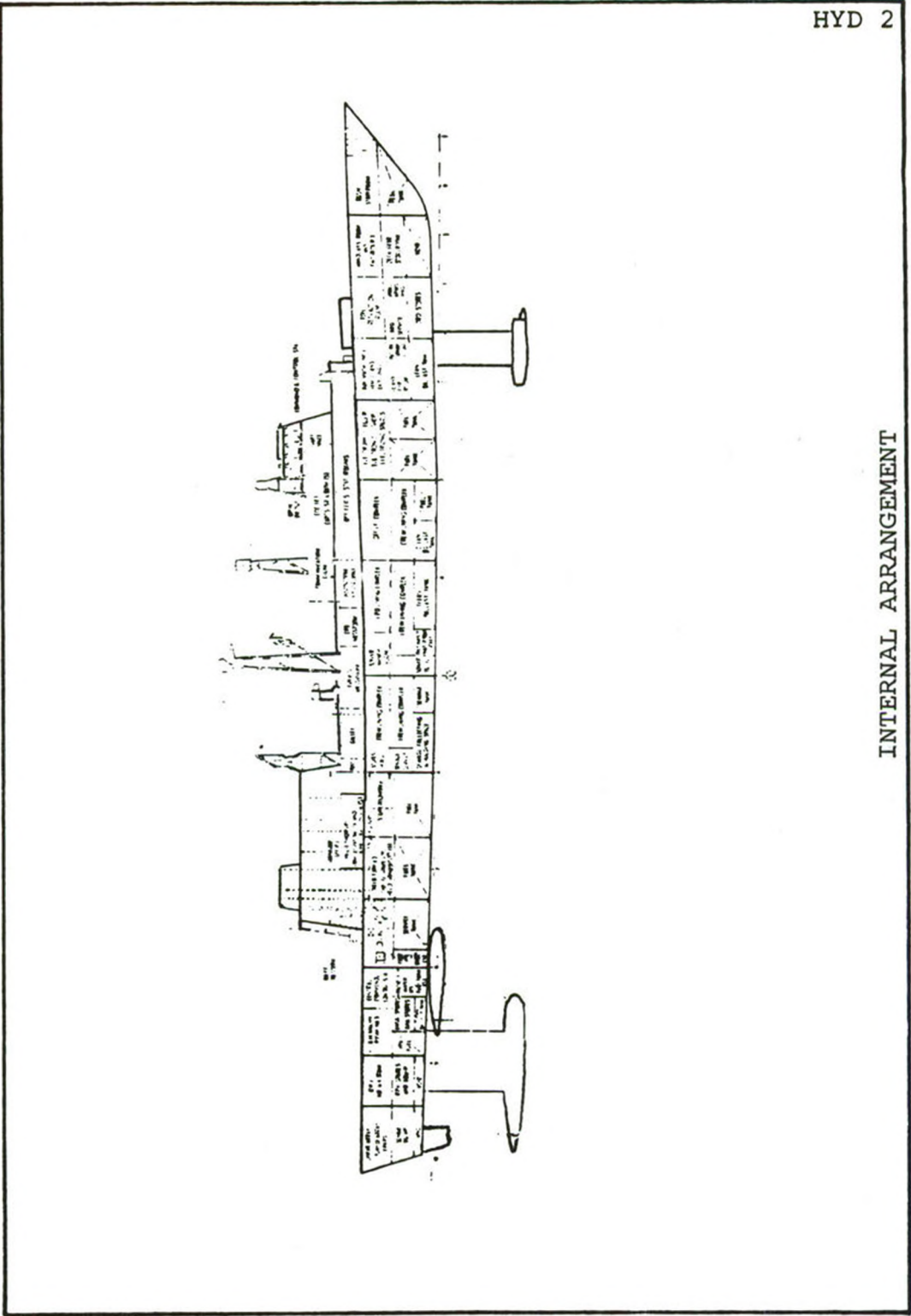
NOMINAL 2000 TON HYDROFOIL

POINT DESIGN SUMMARY

B-51

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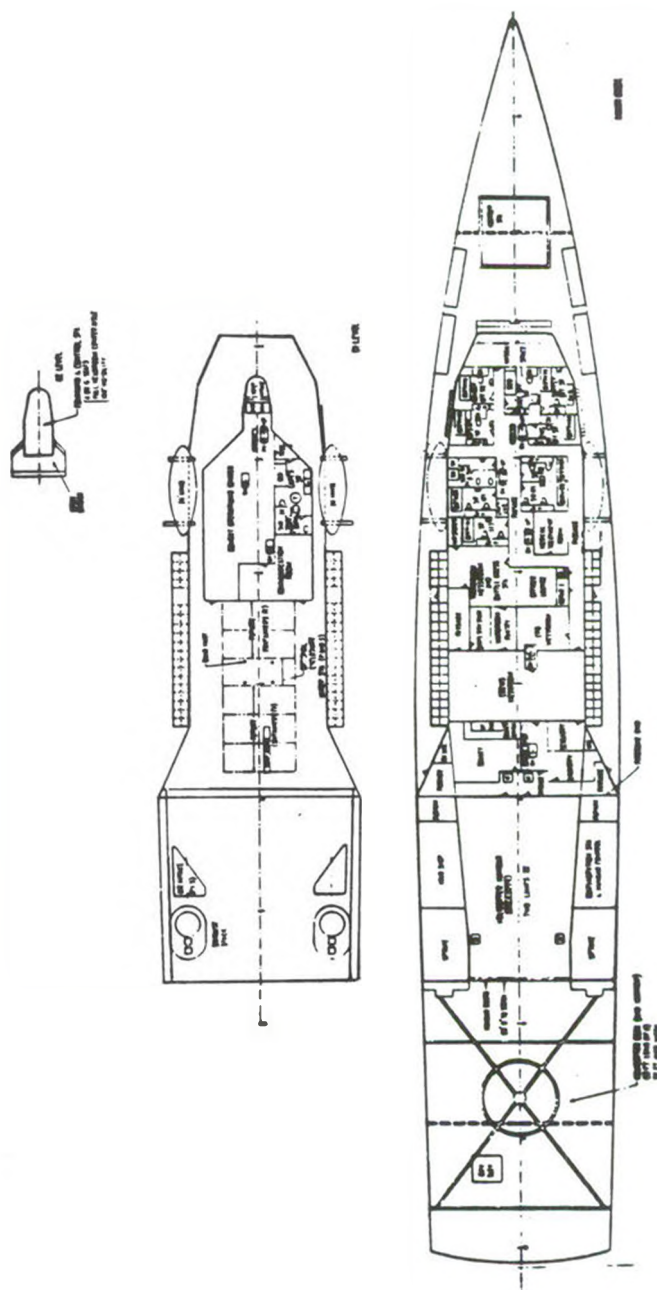
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HYD 2



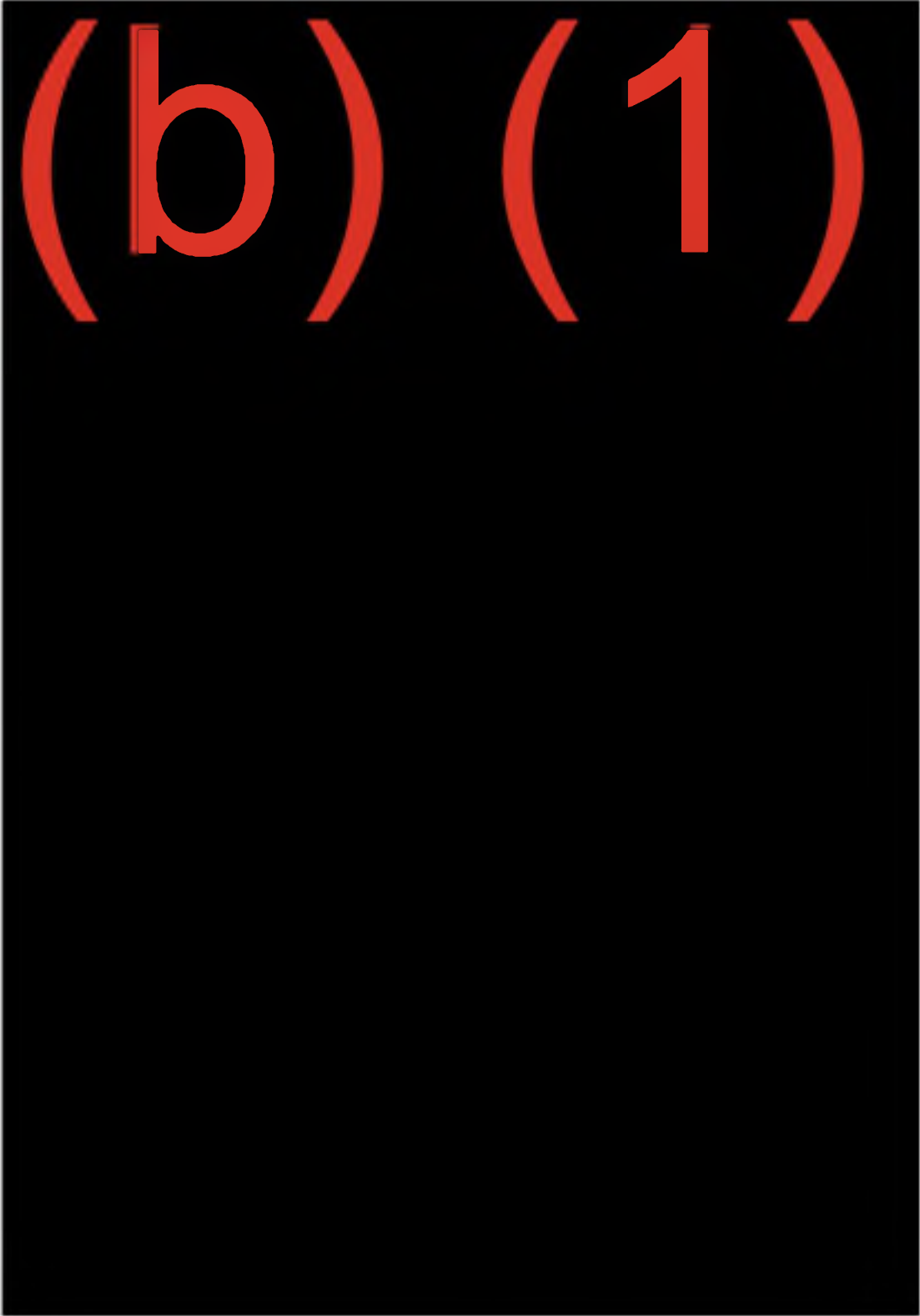
INTERNAL ARRANGEMENT

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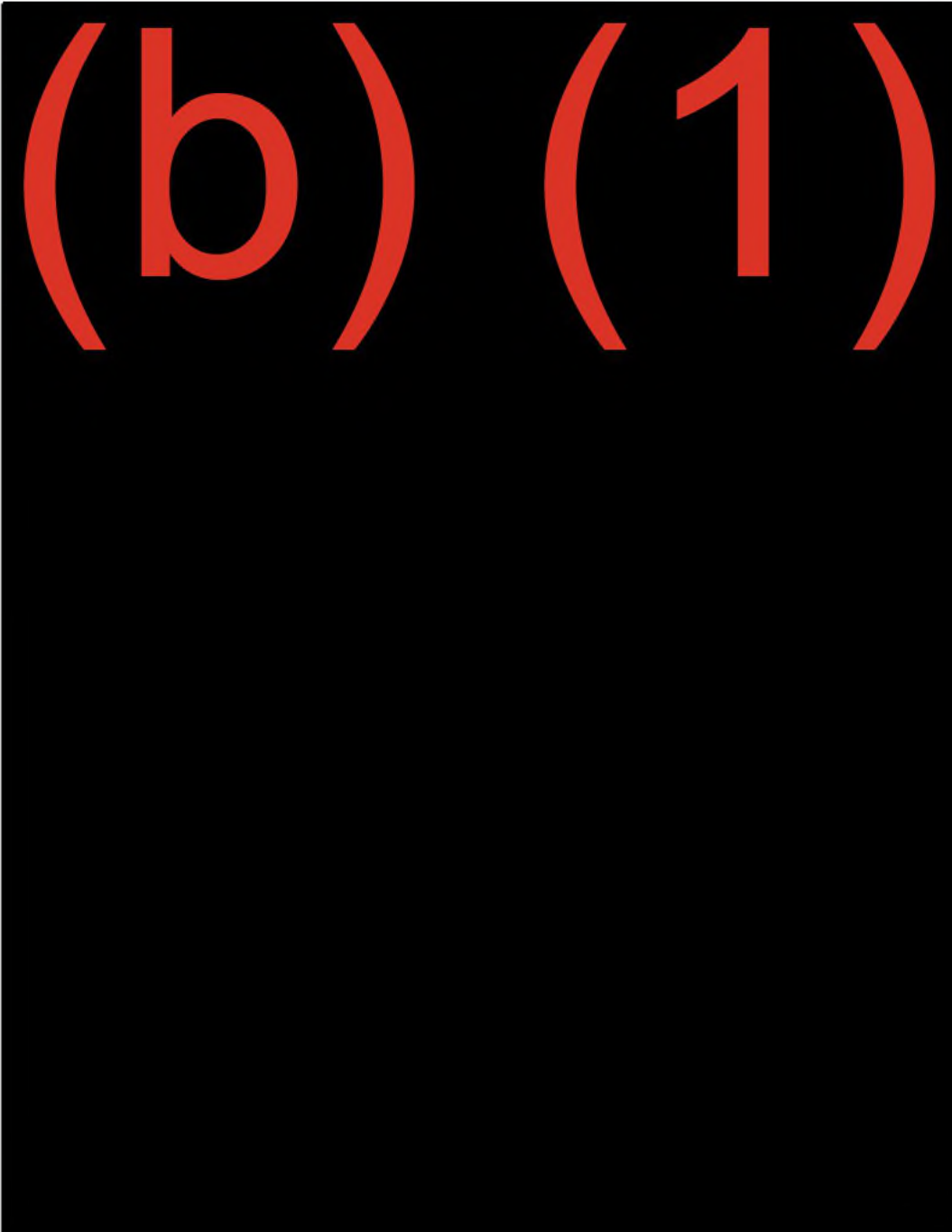


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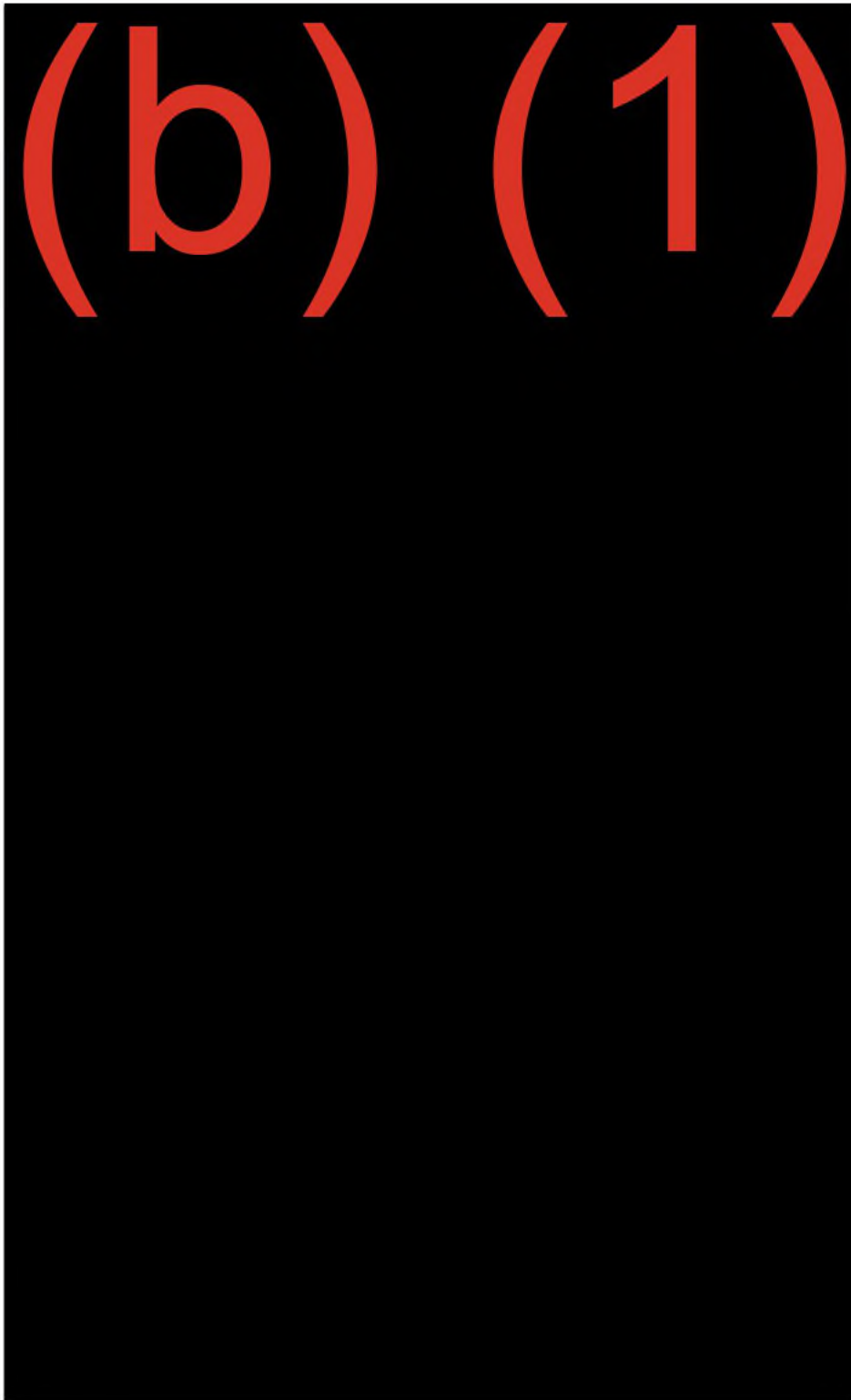
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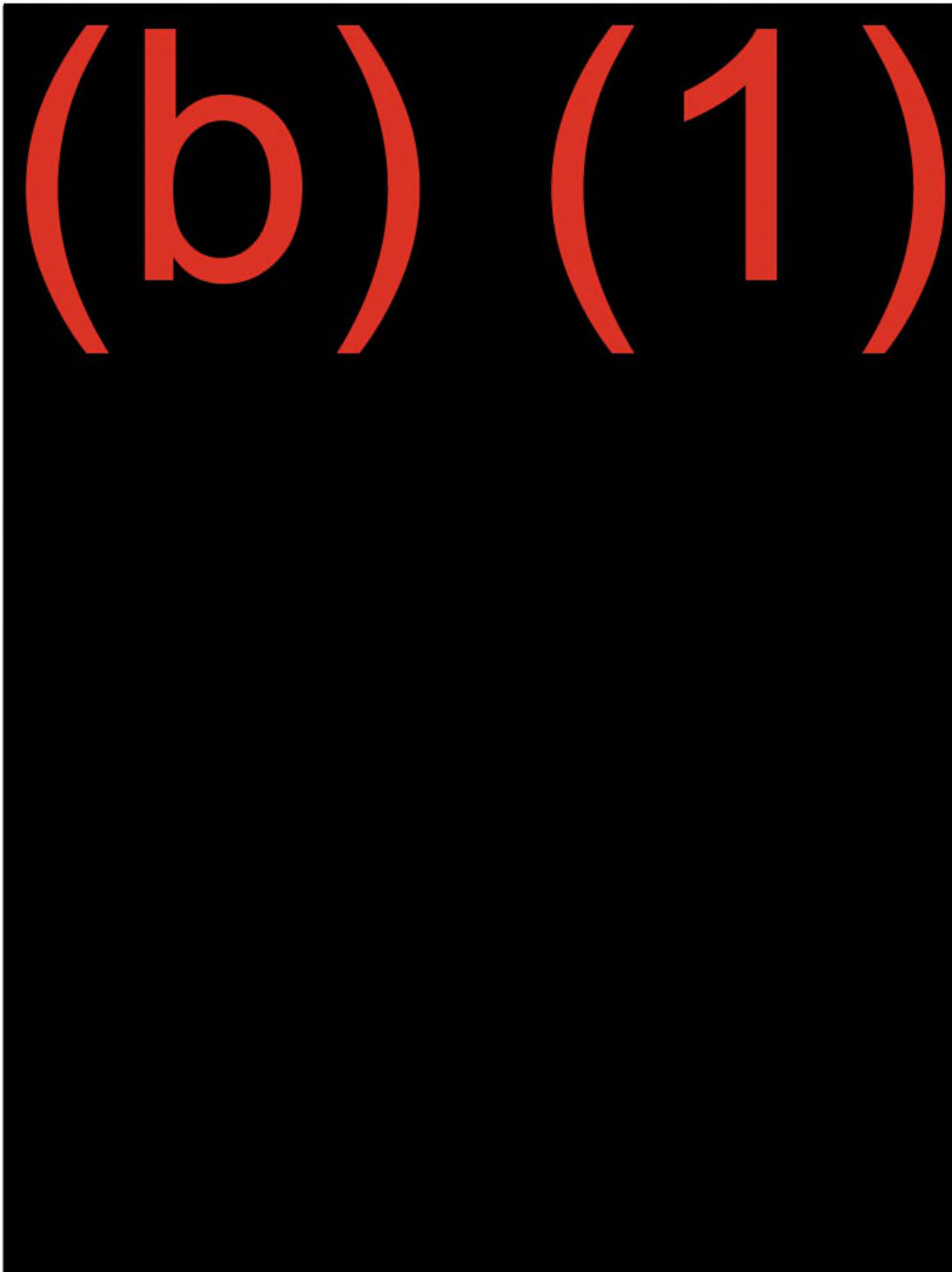


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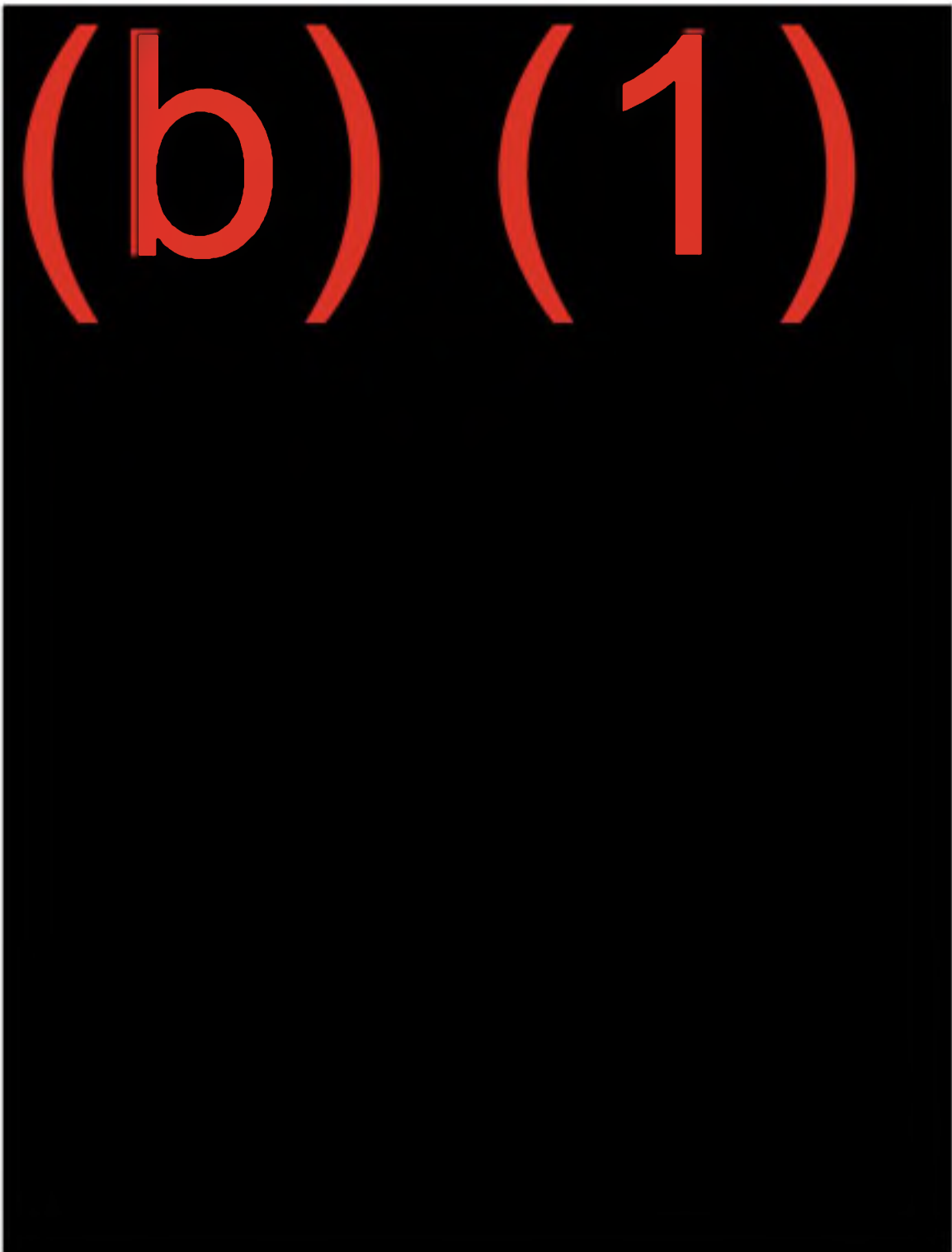
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LCPC



LANDING CRAFT PLANING CRAFT (LCPC)

POINT DESIGN SUMMARY

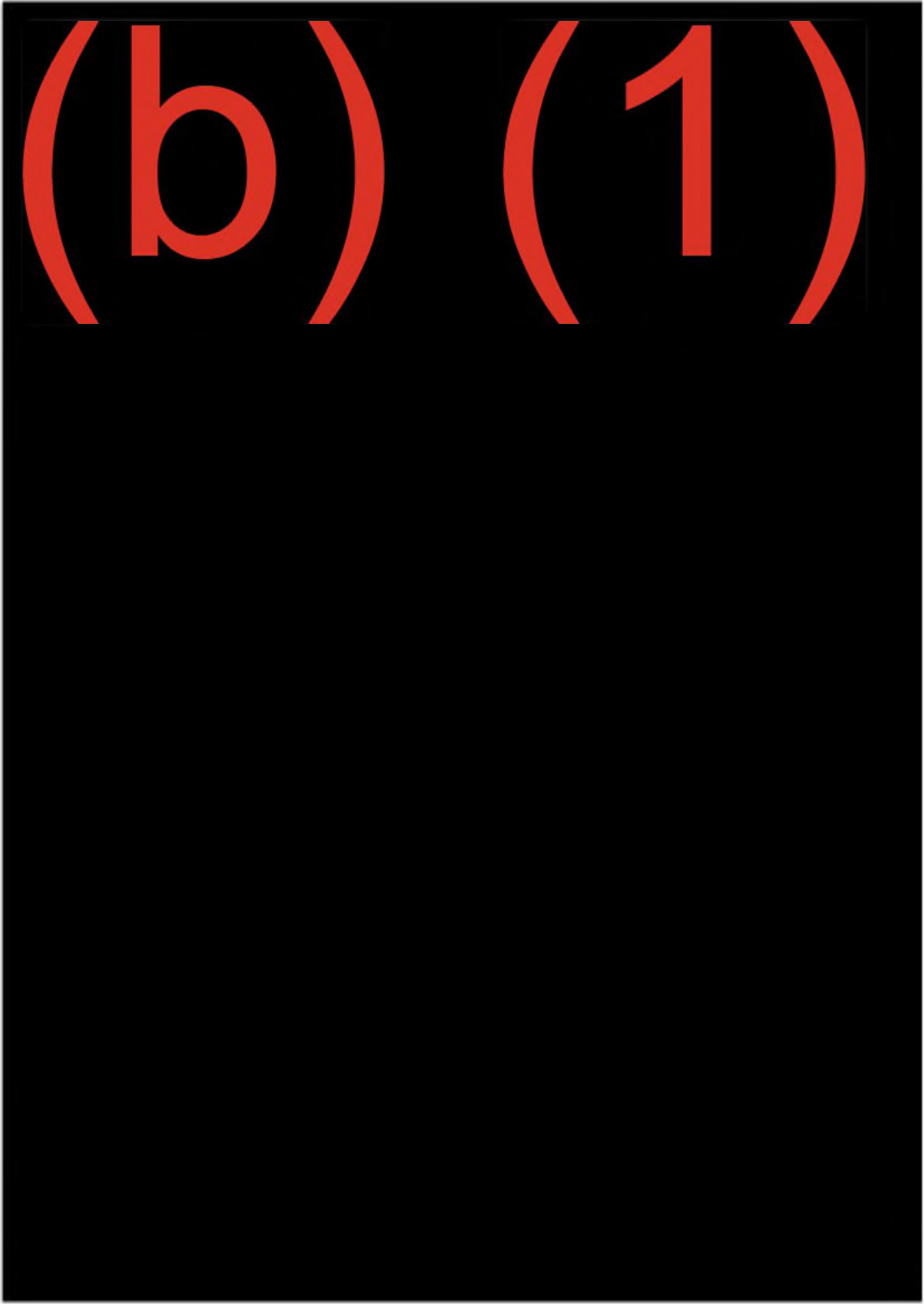
UNCLASSIFIED

The drawing consists of two parts. The upper part is a side elevation of the vessel, showing its long, narrow hull, a central superstructure with a bridge, and a funnel. The hull number '114' is visible on the side. The lower part is a top-down view of the vessel, showing its rectangular shape, internal divisions, and a central longitudinal structure.

EXTERNAL ARRANGEMENT

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LCPC

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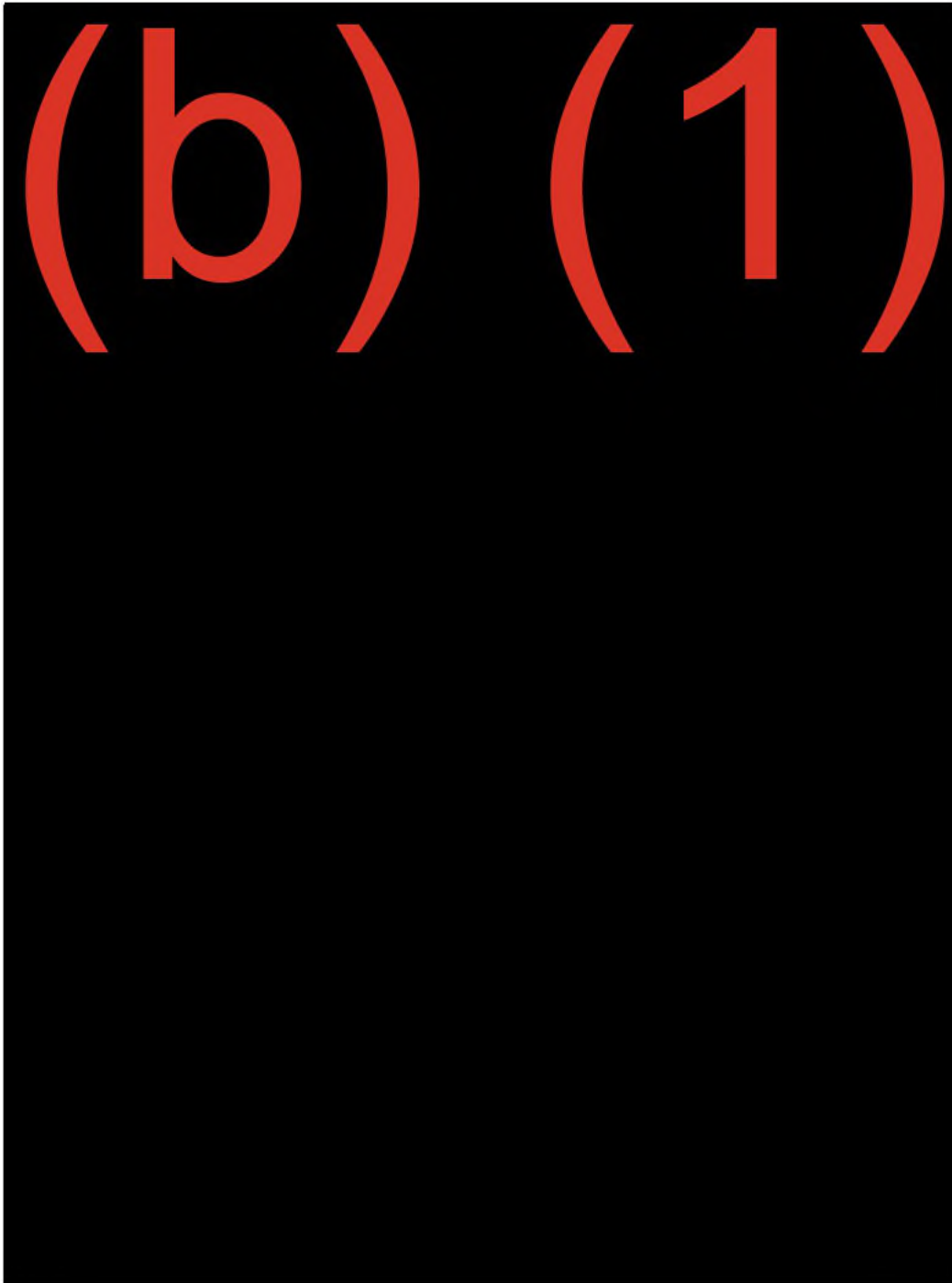


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LCPC

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LCPC



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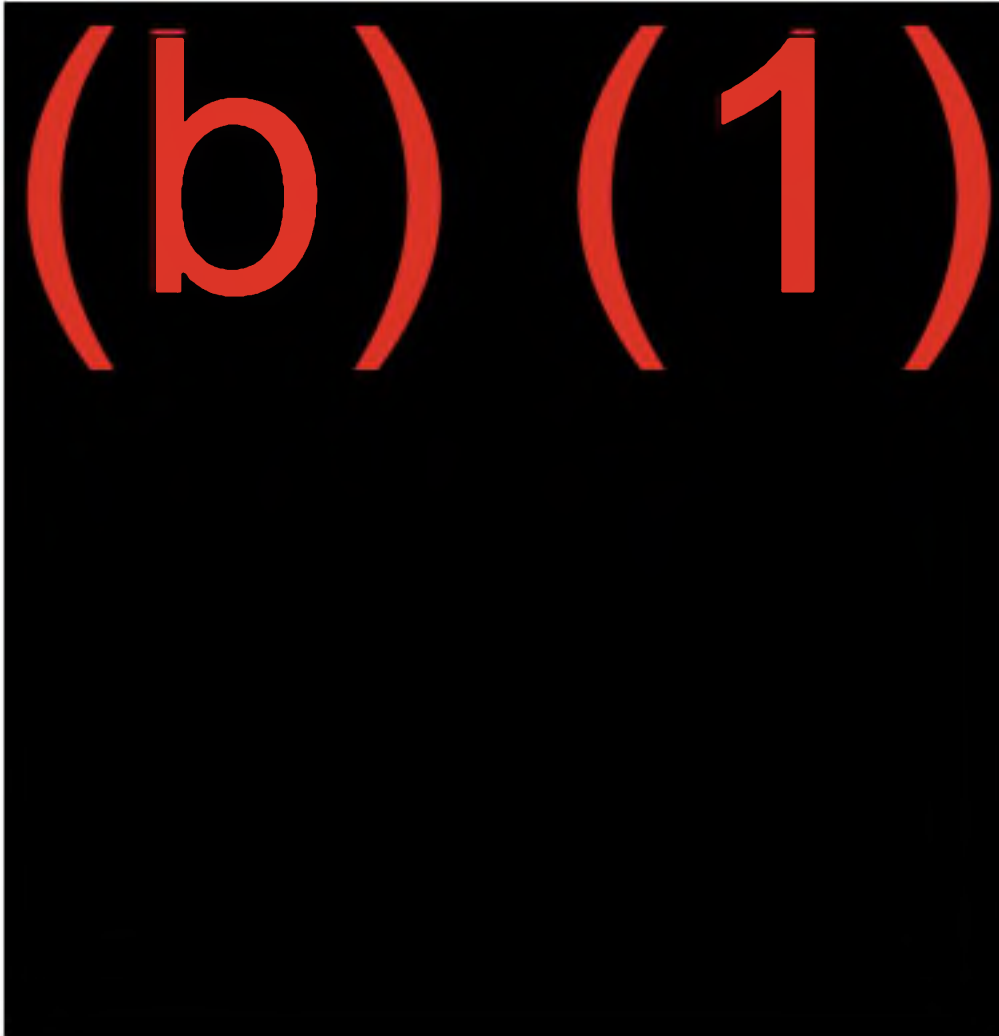
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LCPC



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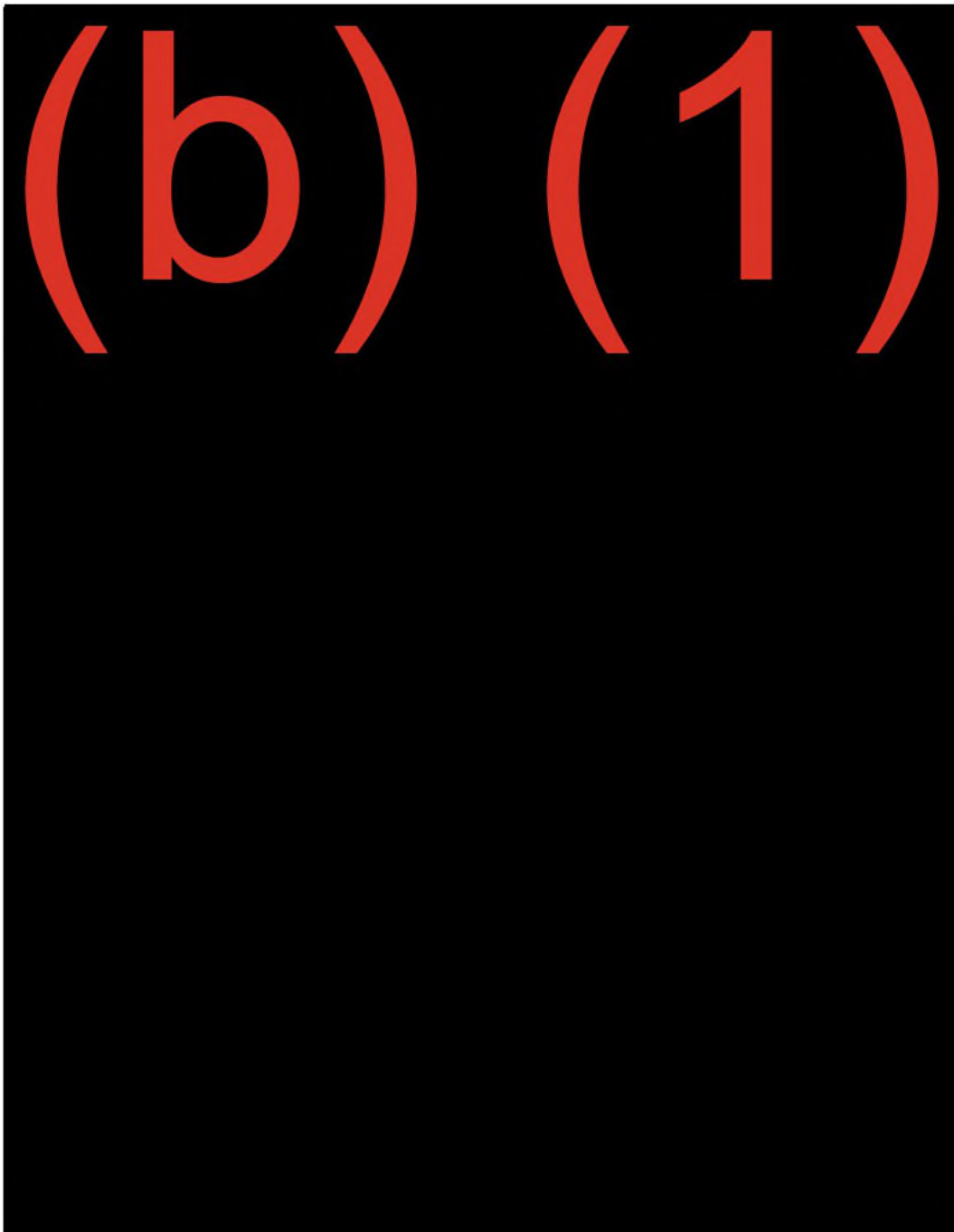
PC 1

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PC 1

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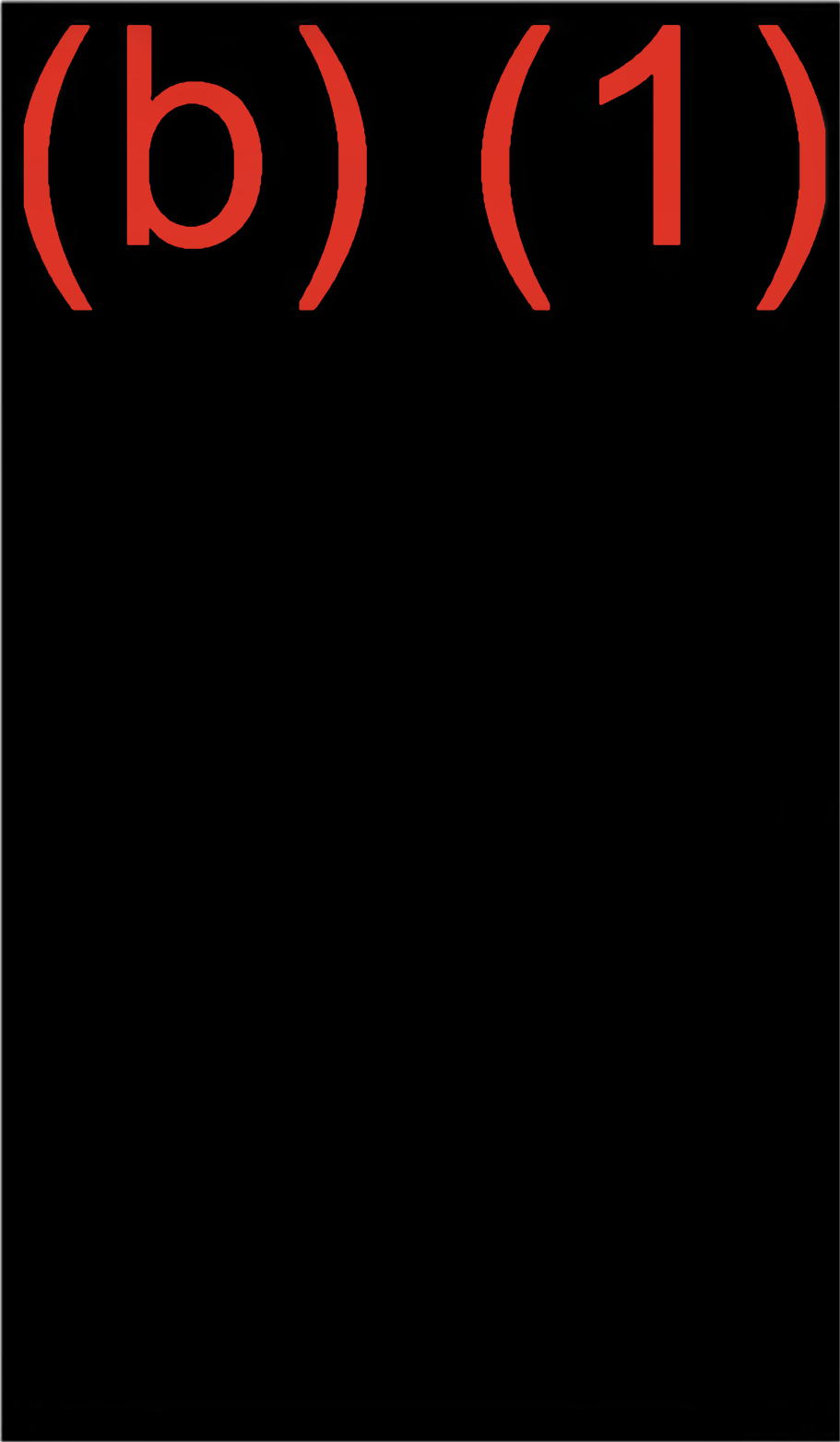
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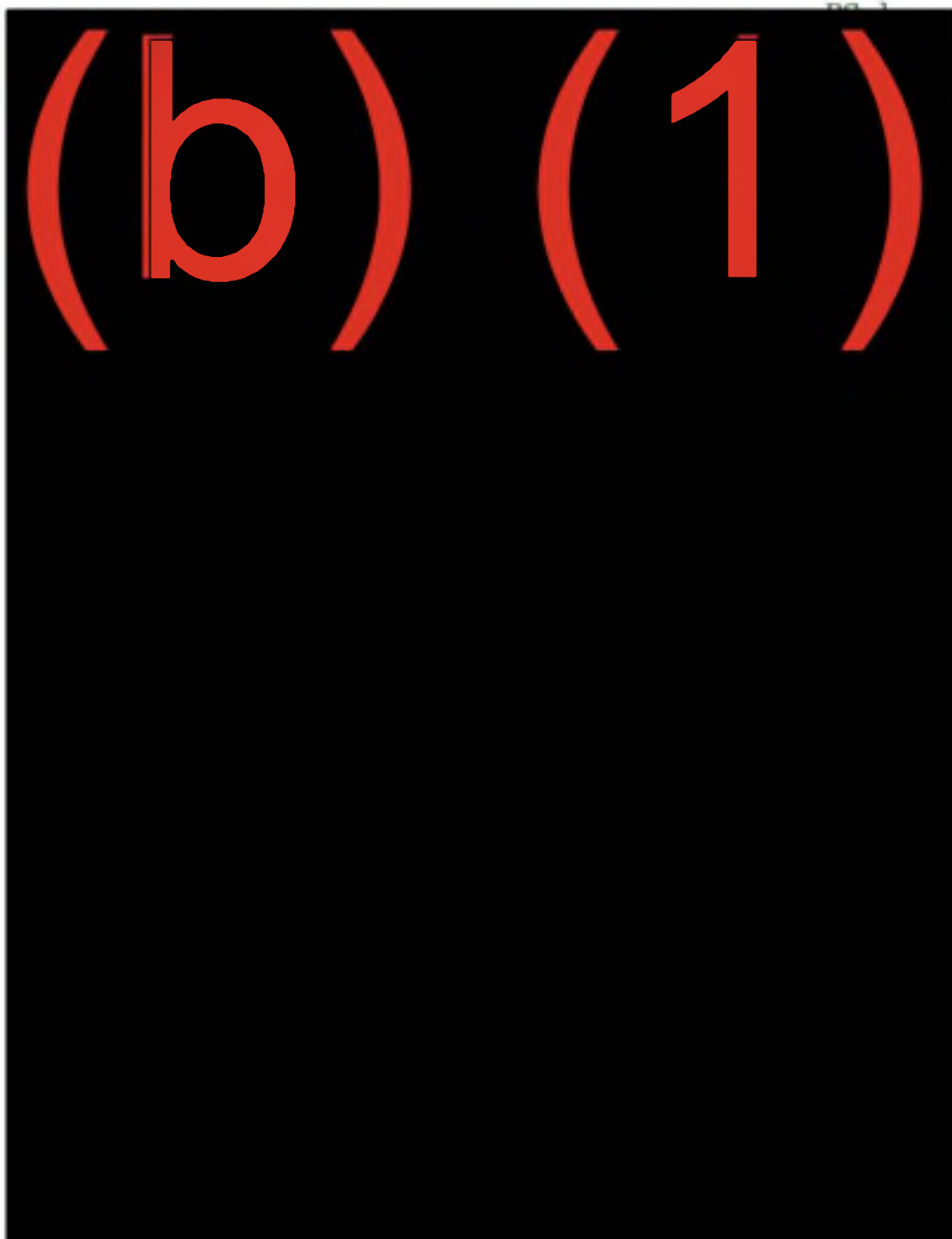
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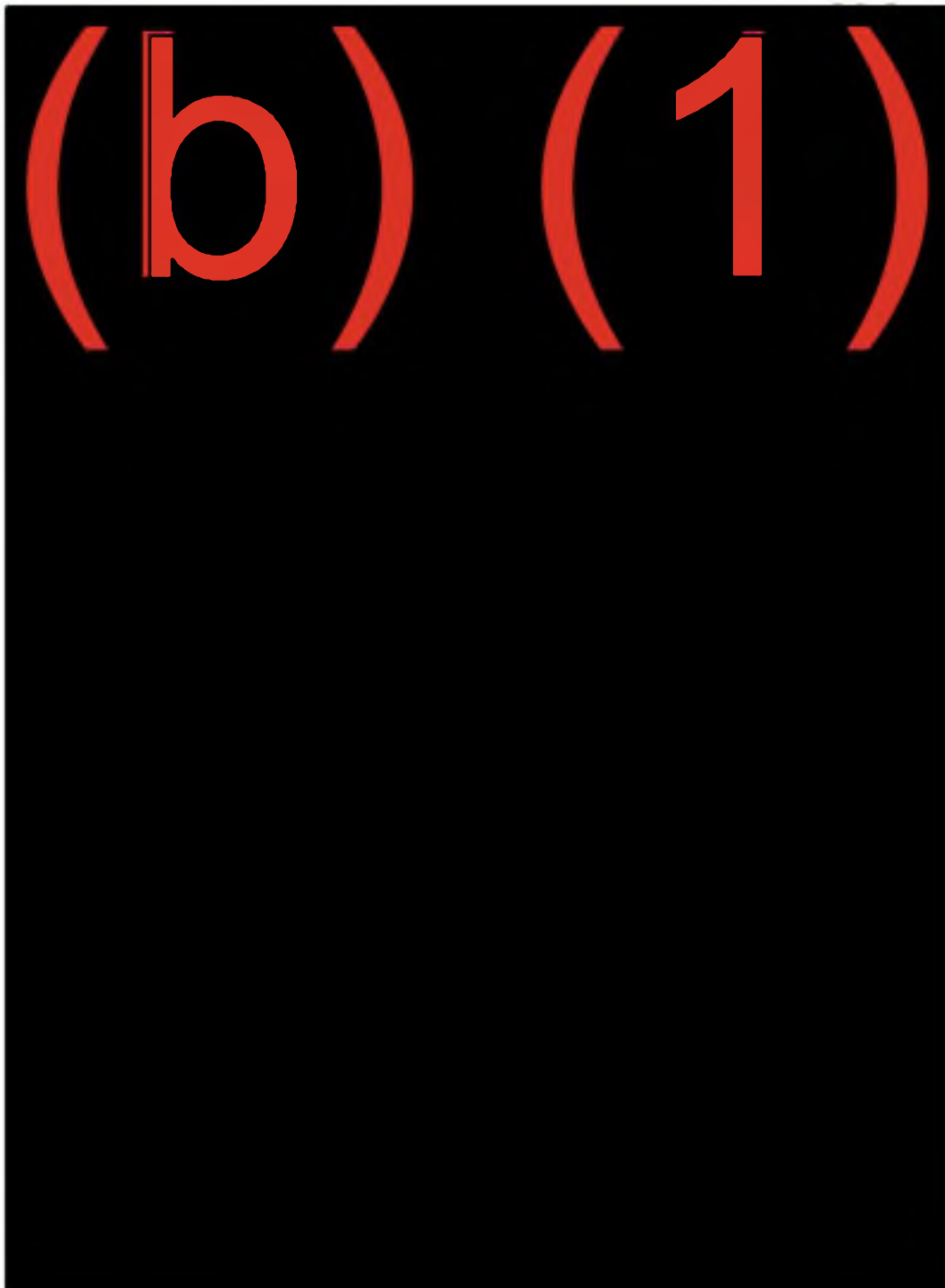
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B-75

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PC 1

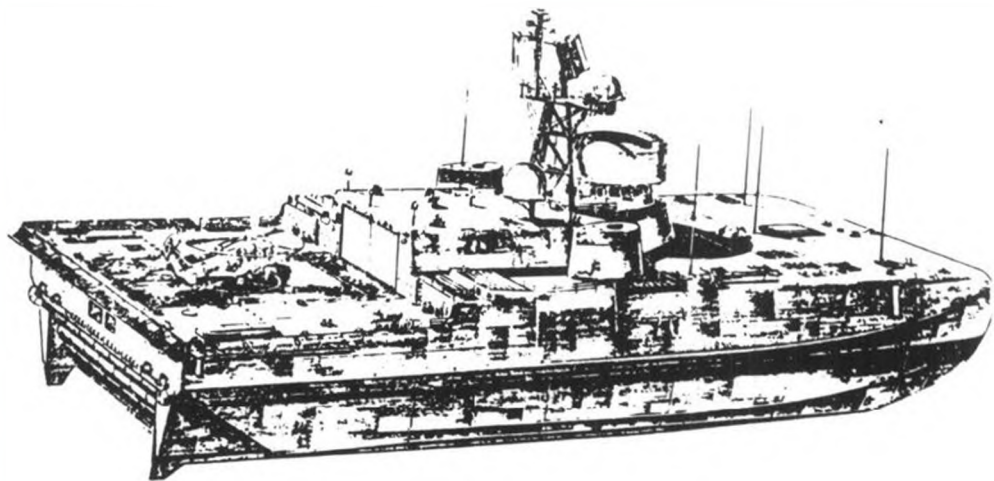
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SES 3



NOMINAL 3000 TON SES

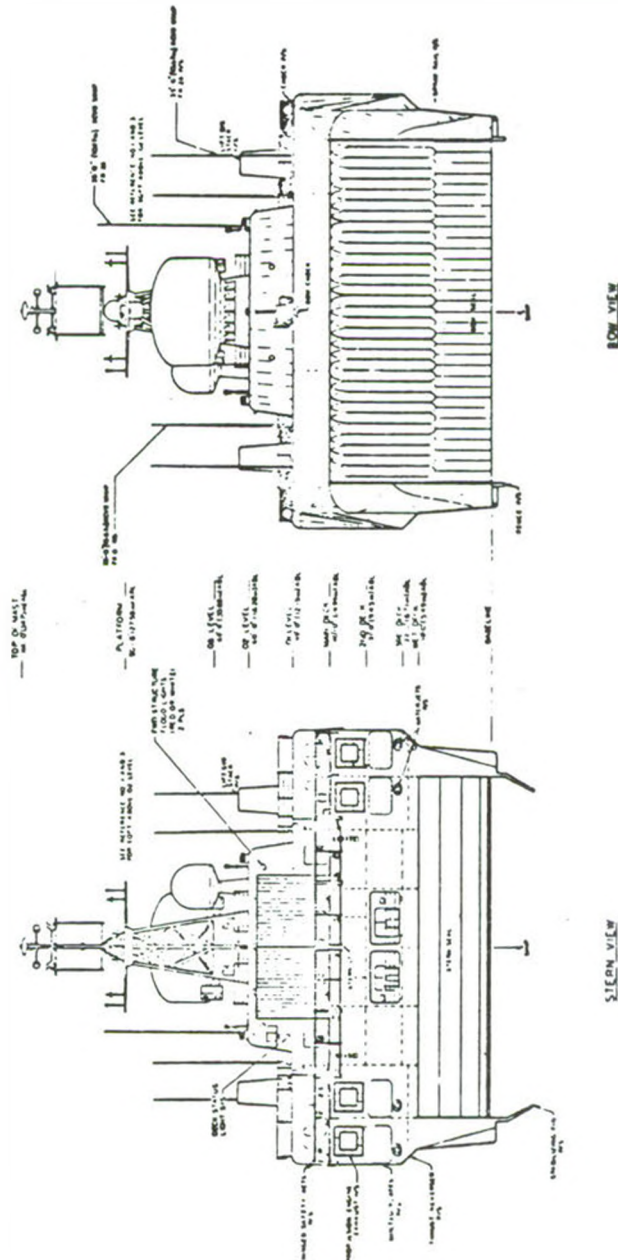
POINT DESIGN SUMMARY

B-79

UNCLASSIFIED

UNCLASSIFIED

SES 3

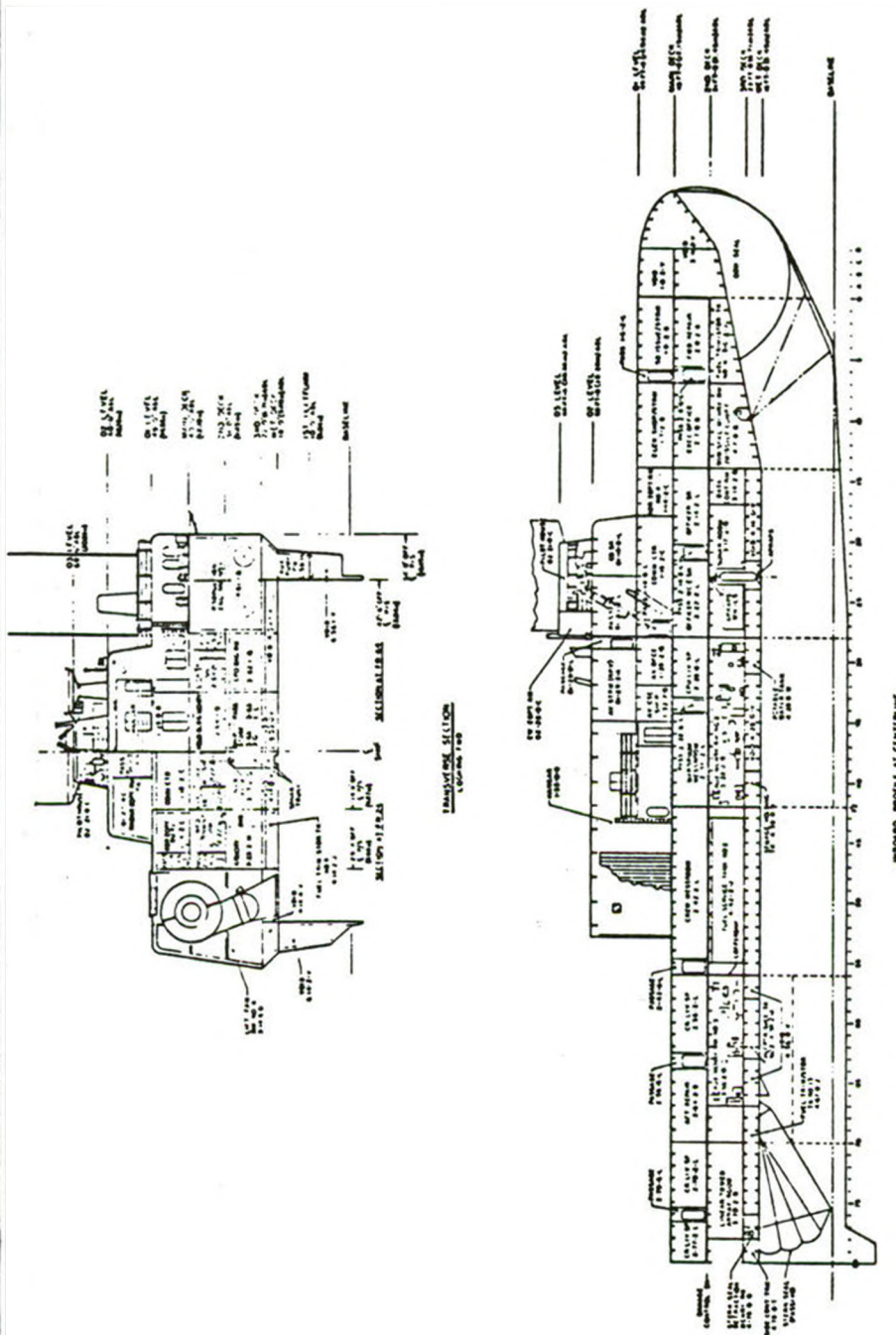


EXTERNAL ARRANGEMENT

UNCLASSIFIED

UNCLASSIFIED

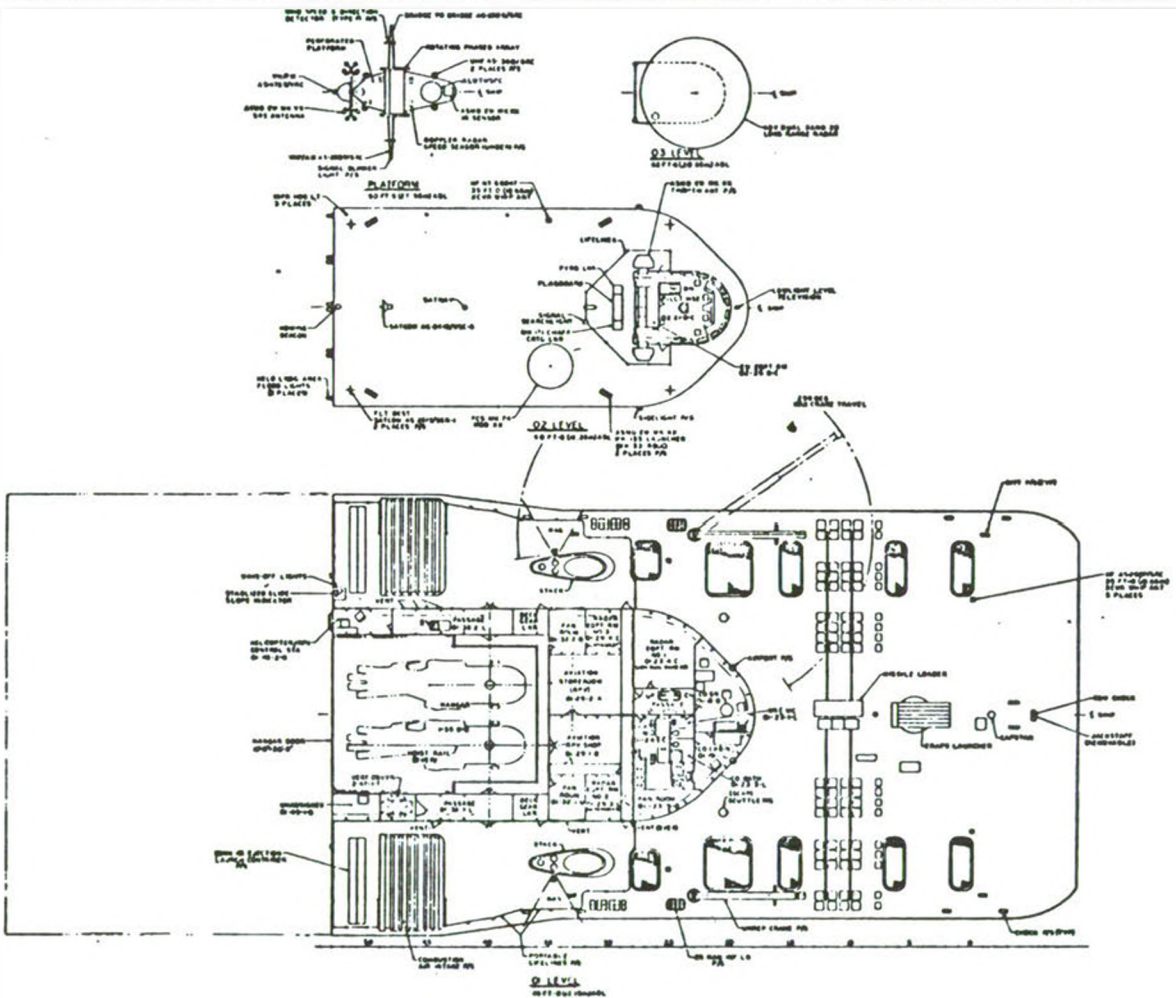
SES 3



INTERNAL ARRANGEMENT

UNCLASSIFIED

UNCLASSIFIED



INTERNAL ARRANGEMENT

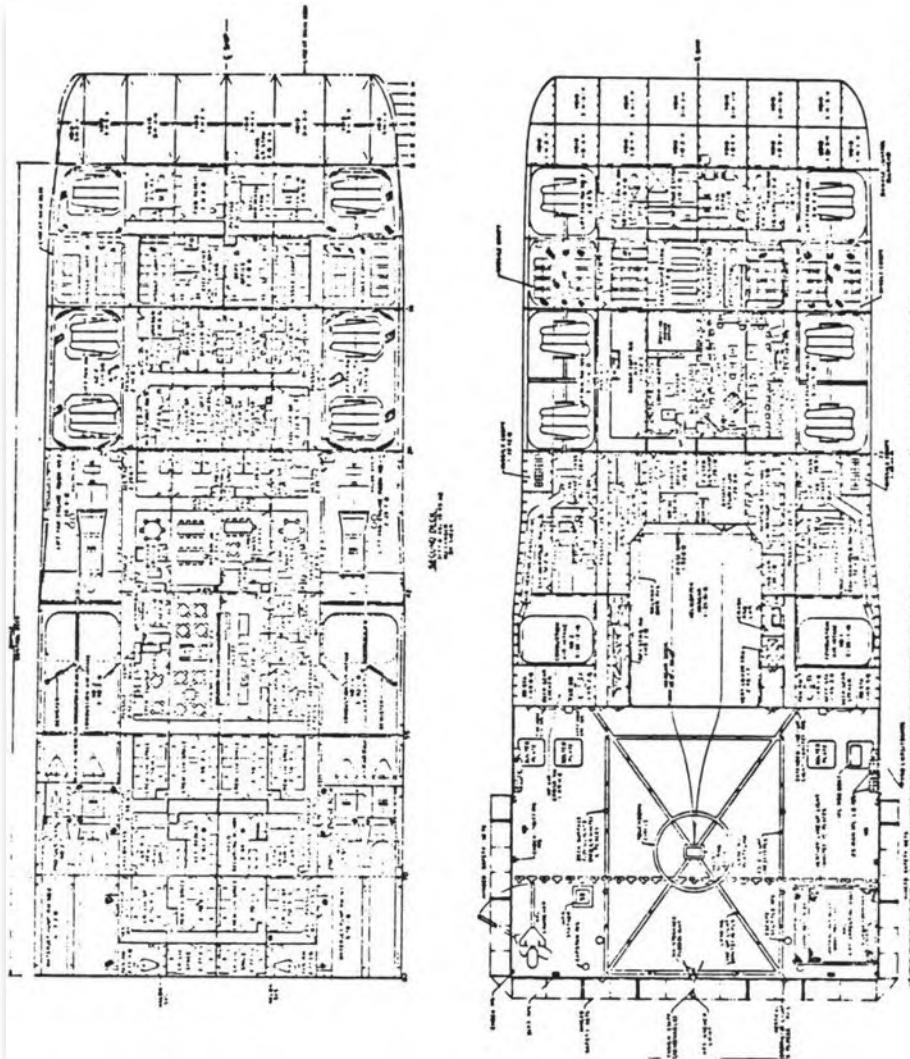
SES 3

B-83

UNCLASSIFIED

UNCLASSIFIED

SES 3



SECTION 3

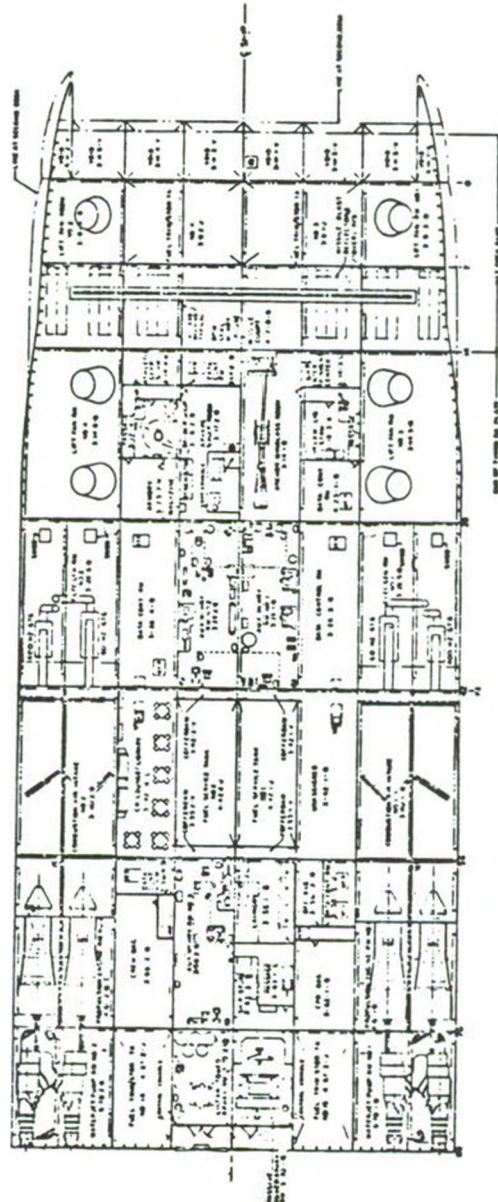
INTERNAL ARRANGEMENT

B-84

UNCLASSIFIED

UNCLASSIFIED

SES 3



INTERNAL ARRANGEMENT

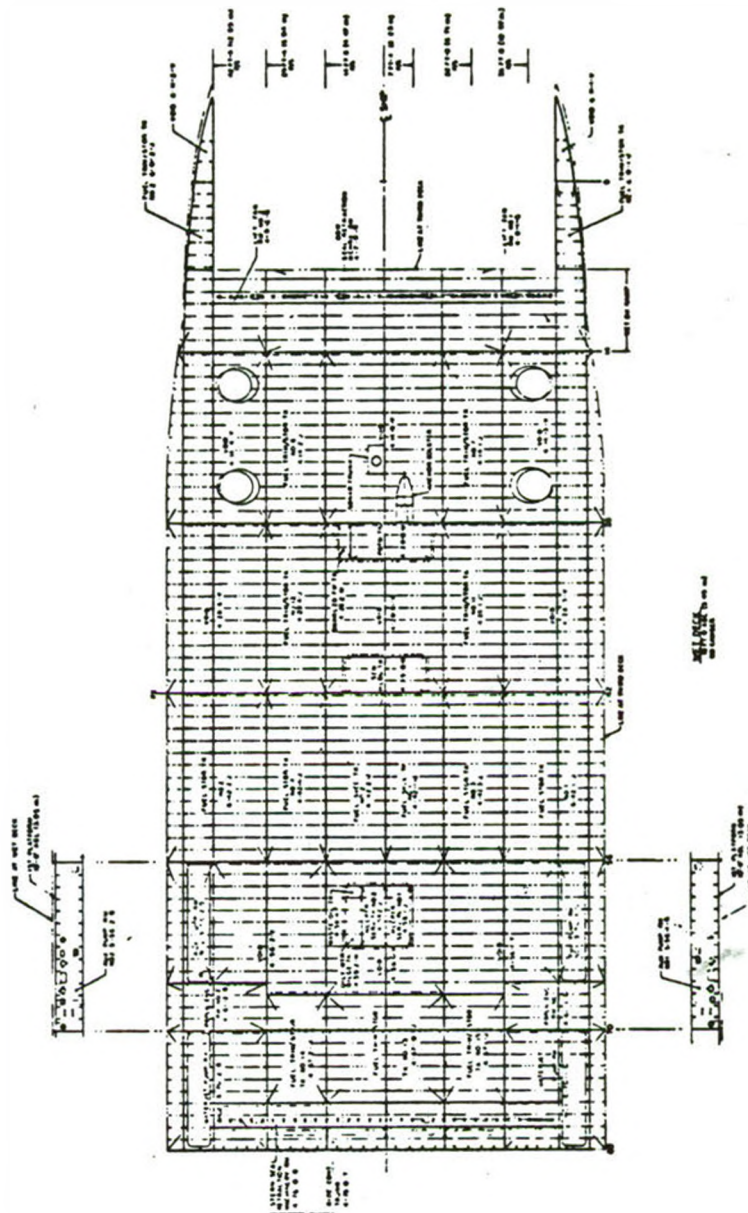
5368 66-57

B-85

UNCLASSIFIED

UNCLASSIFIED

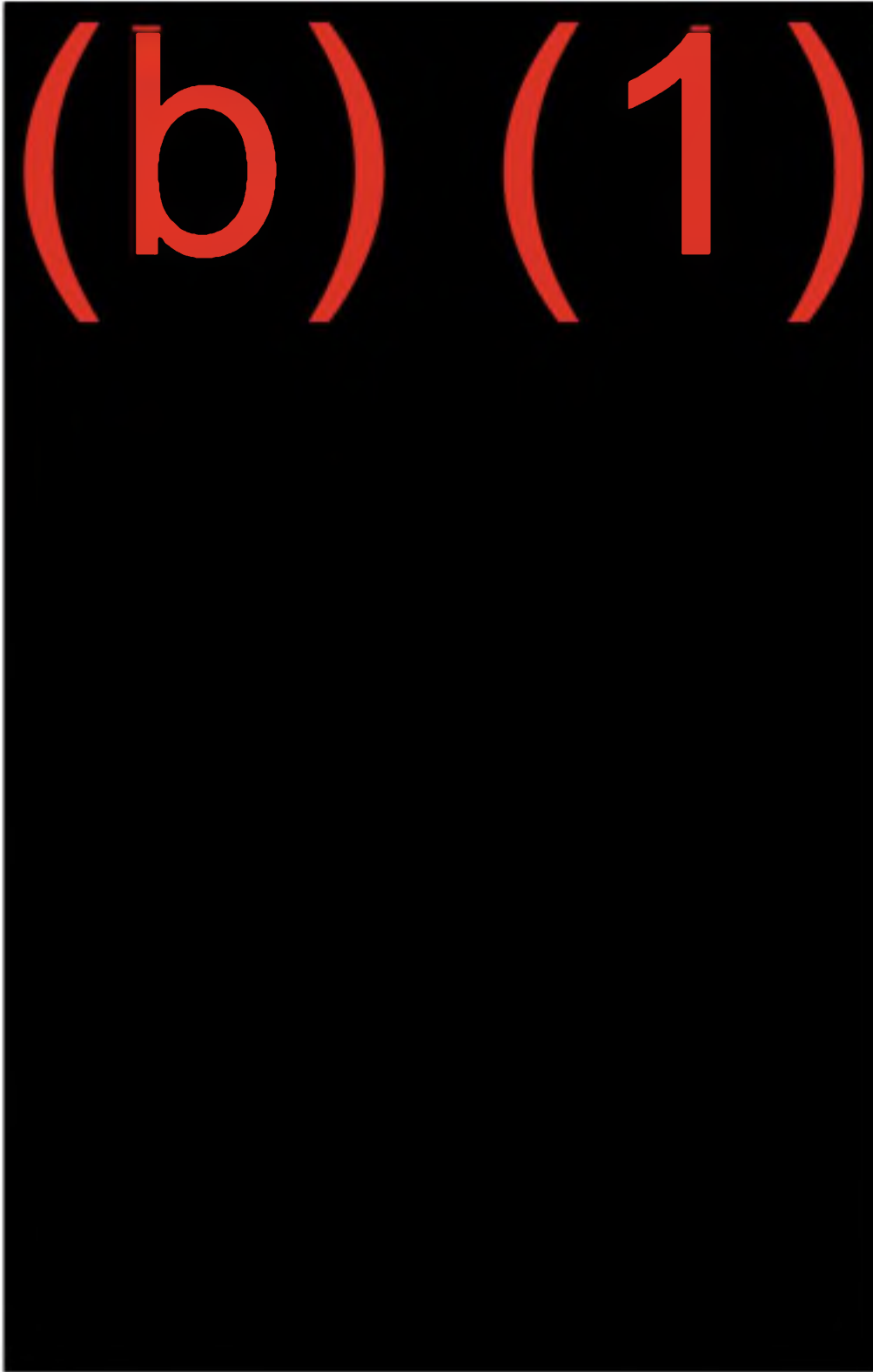
SES 3



INTERNAL ARRANGEMENT

UNCLASSIFIED

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ES 3

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SES 3

(b) (1)

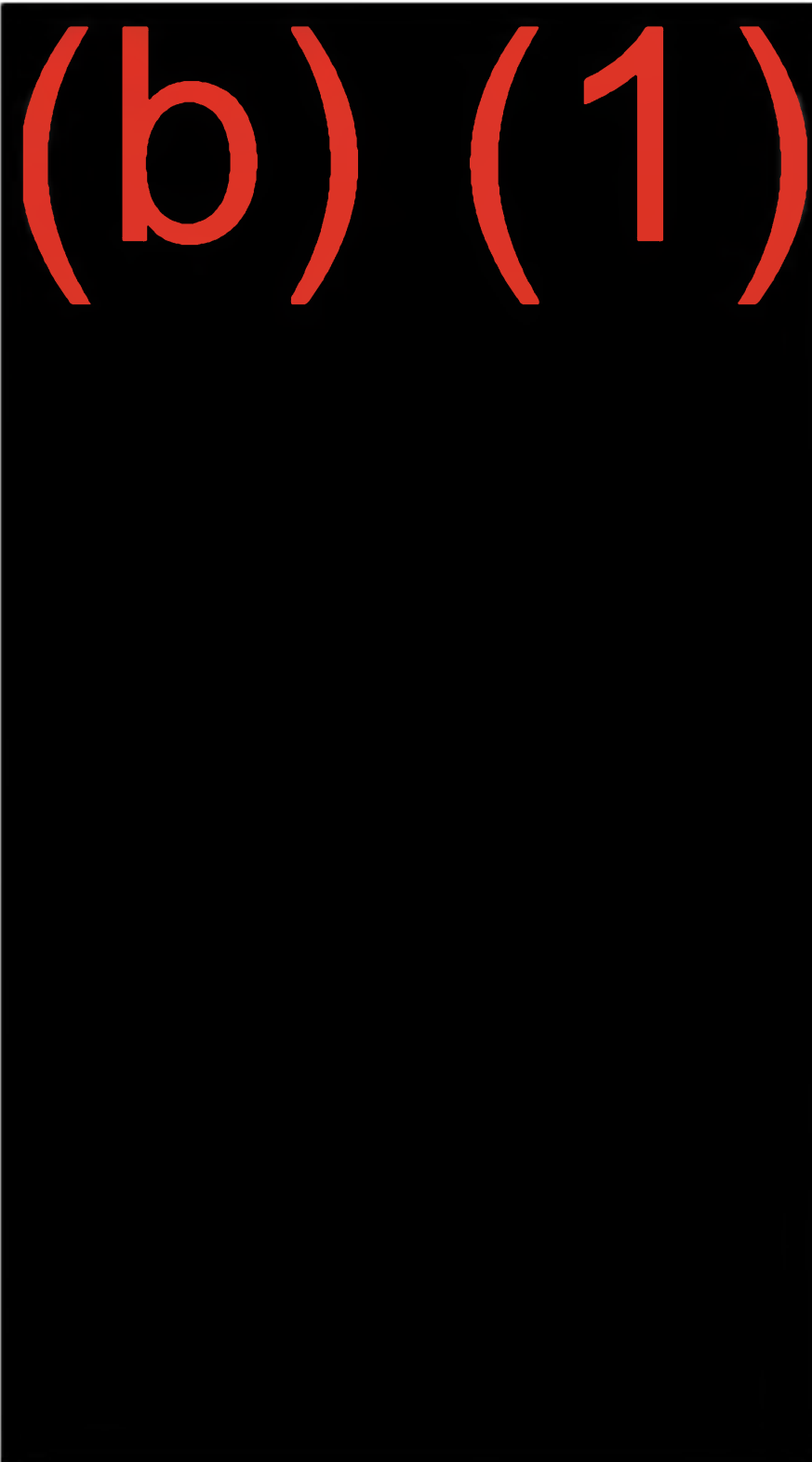


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SES 3

(b) (1)

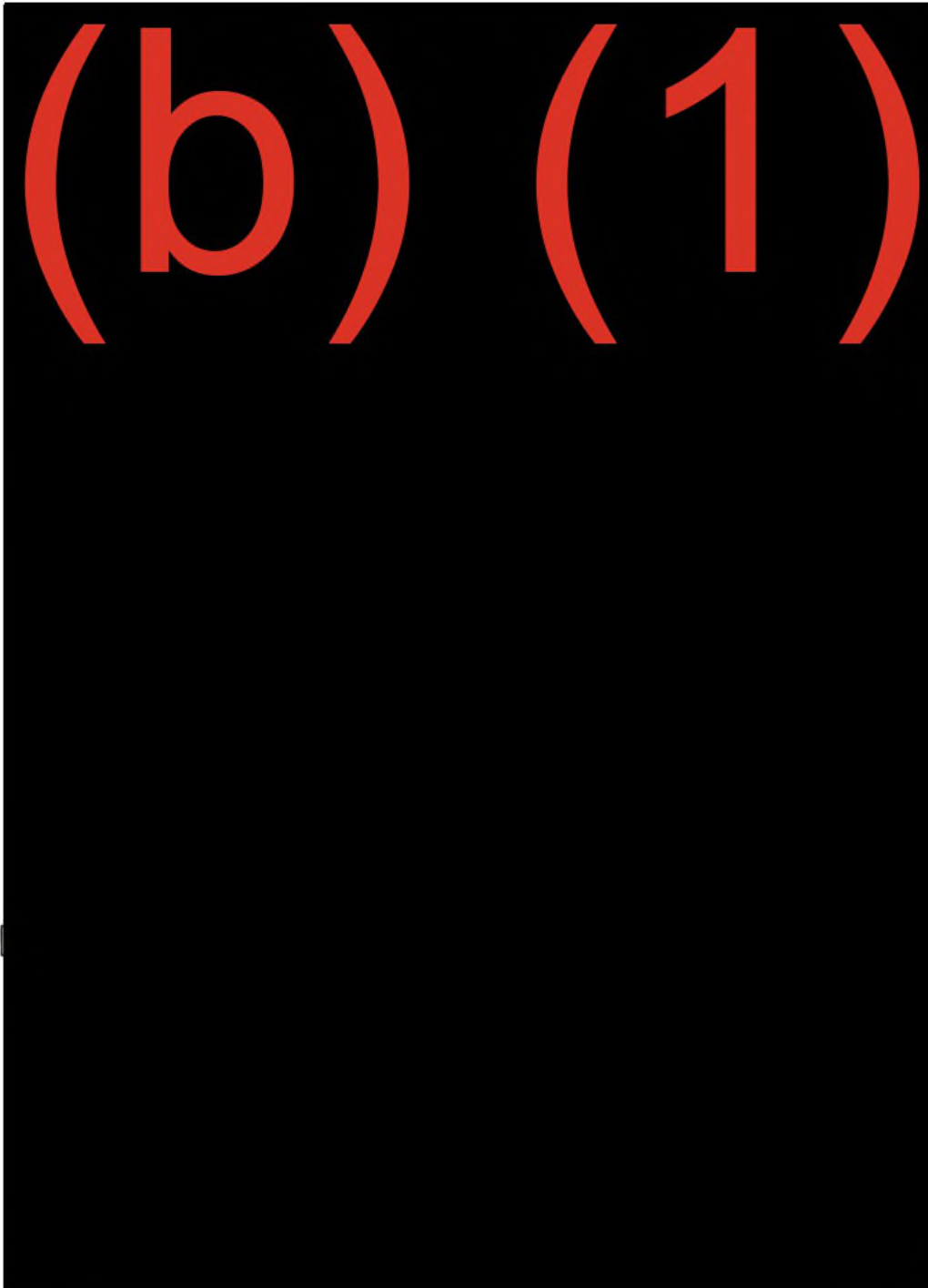


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SES 3

(b) (1)



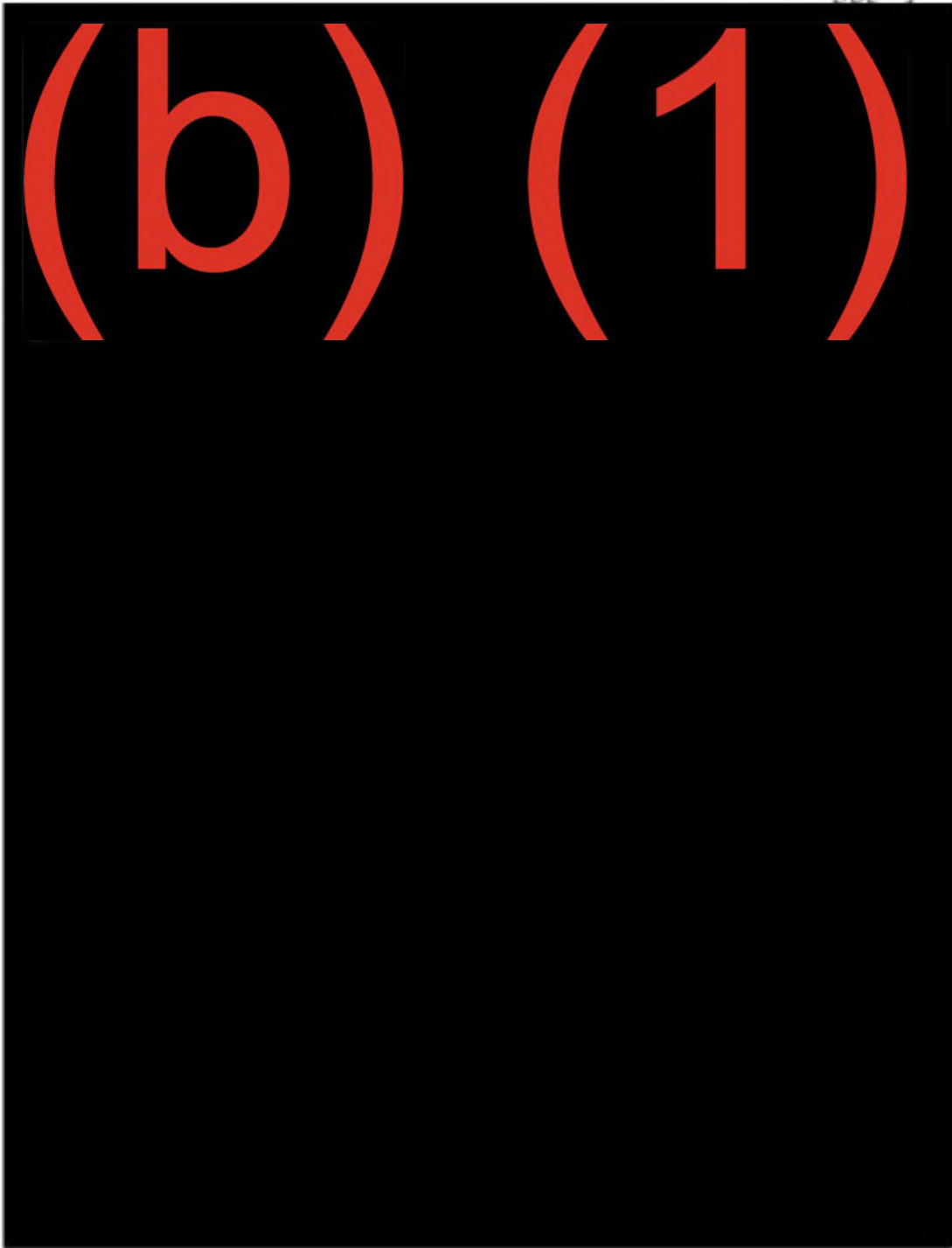
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b7c, 3

(b)

(1)



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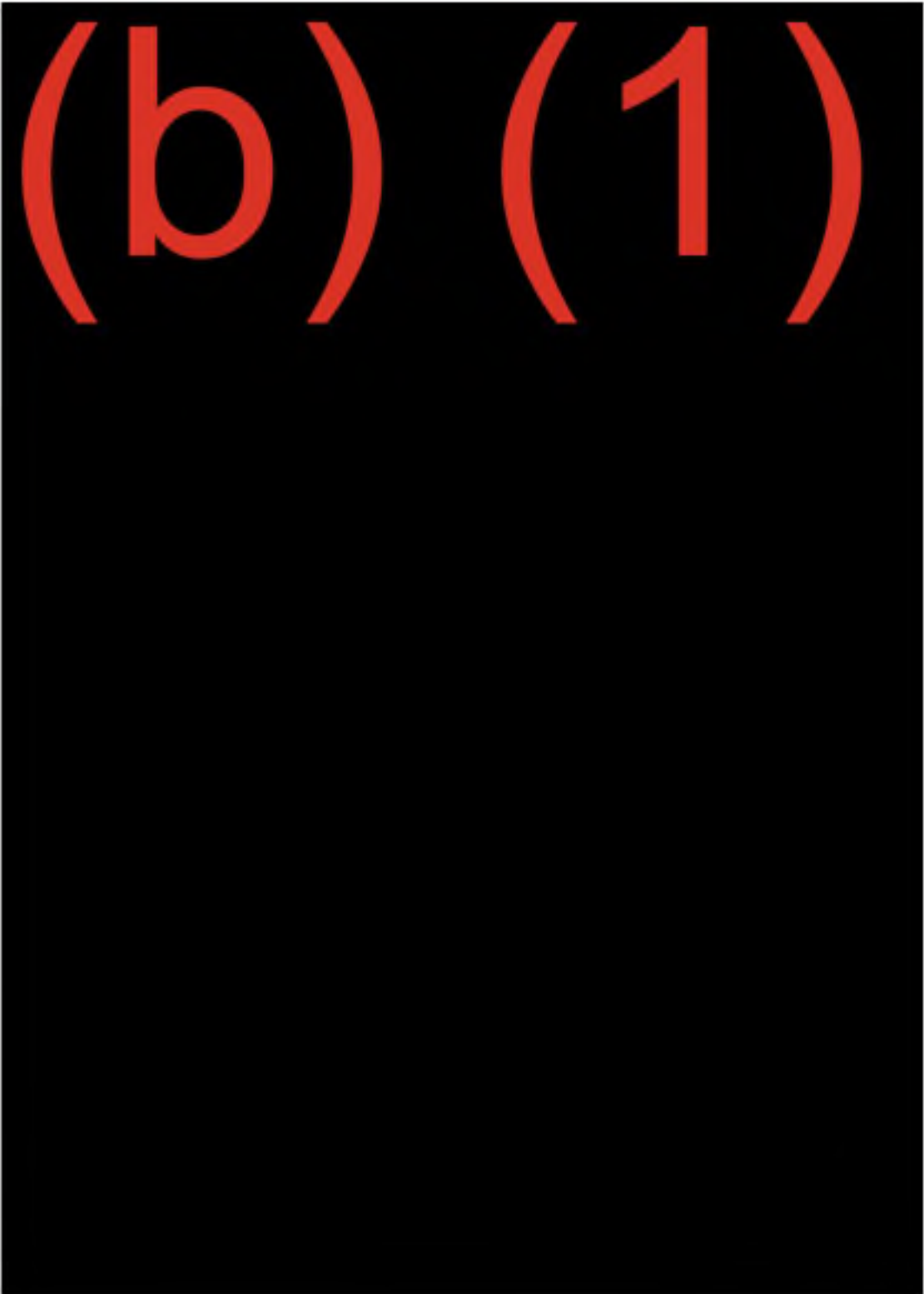
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(b) (1)

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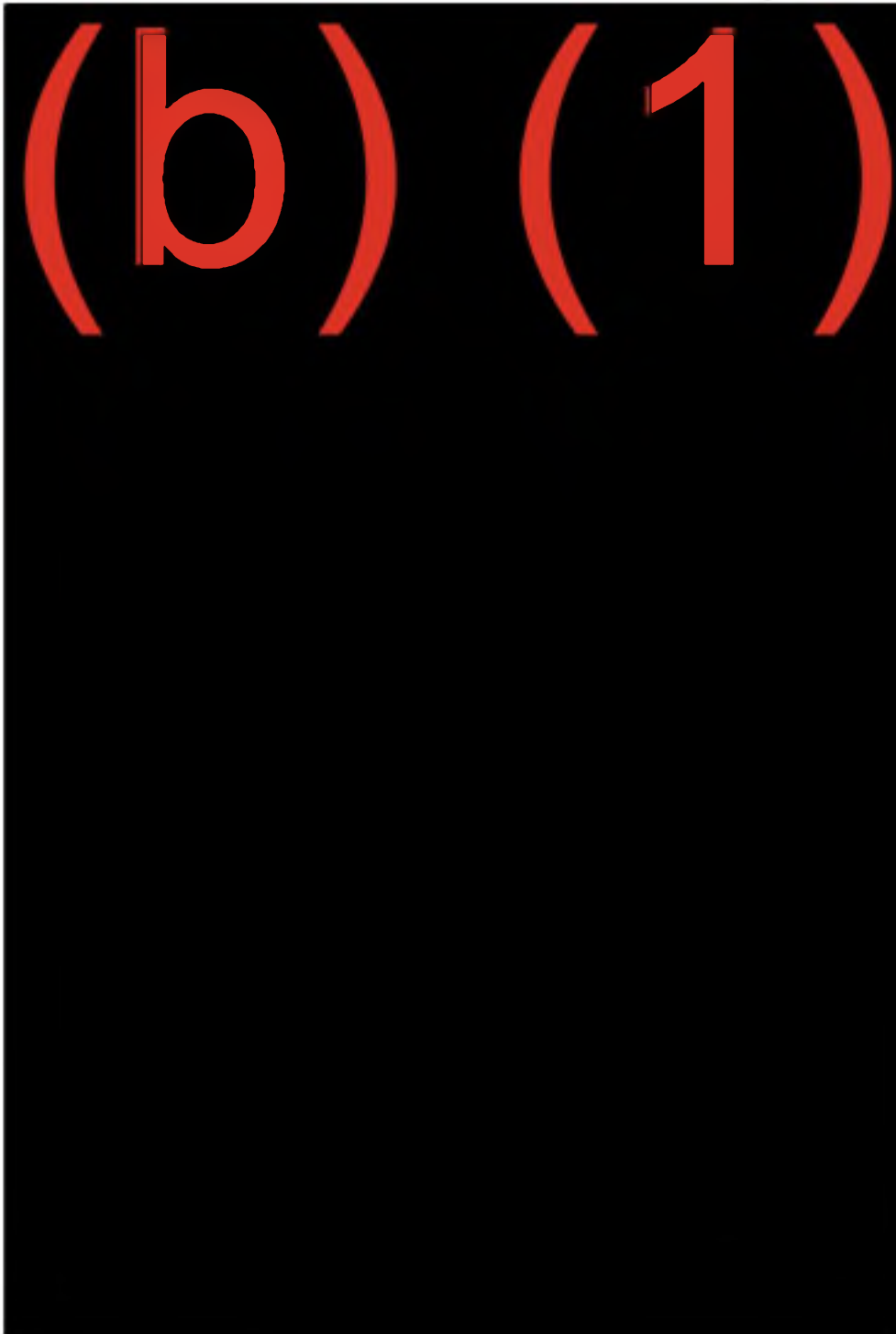
(b) (1)



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SES CV



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SES CV

(b) (1)



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SES CV

(b) (1)



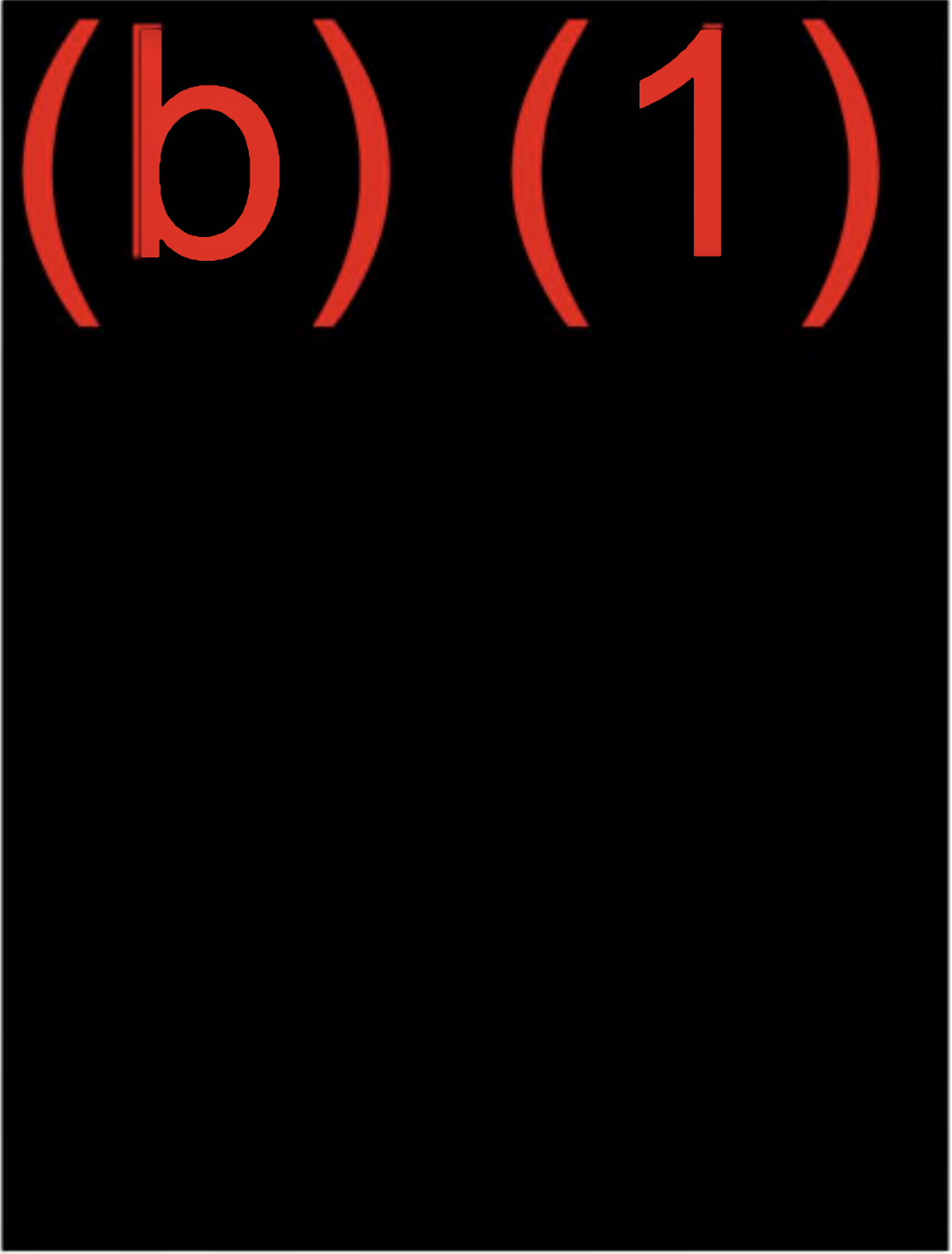
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(b) (1)

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(b) (1)



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SES CV

(b) (1)

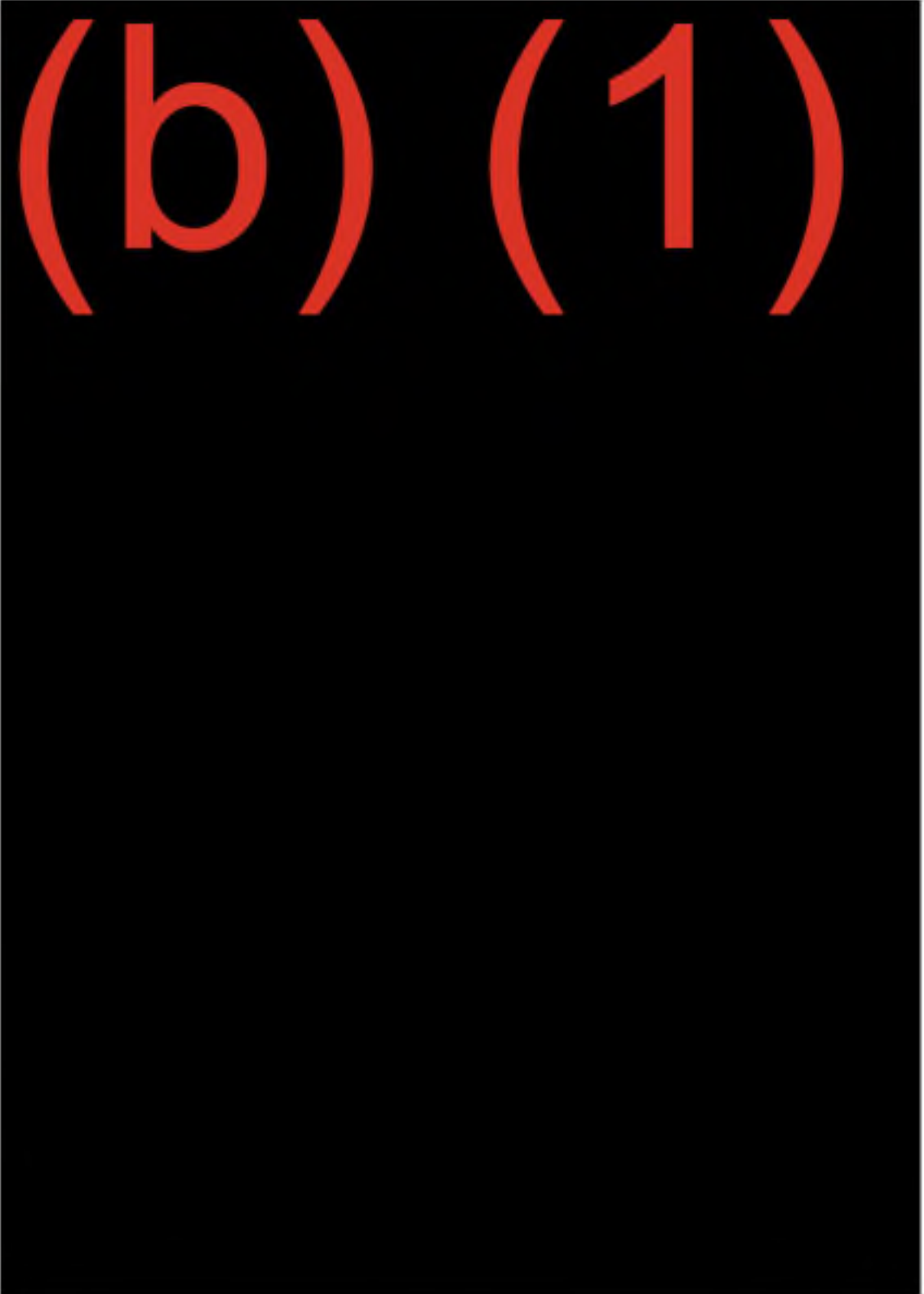
B-99

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(b) (1)

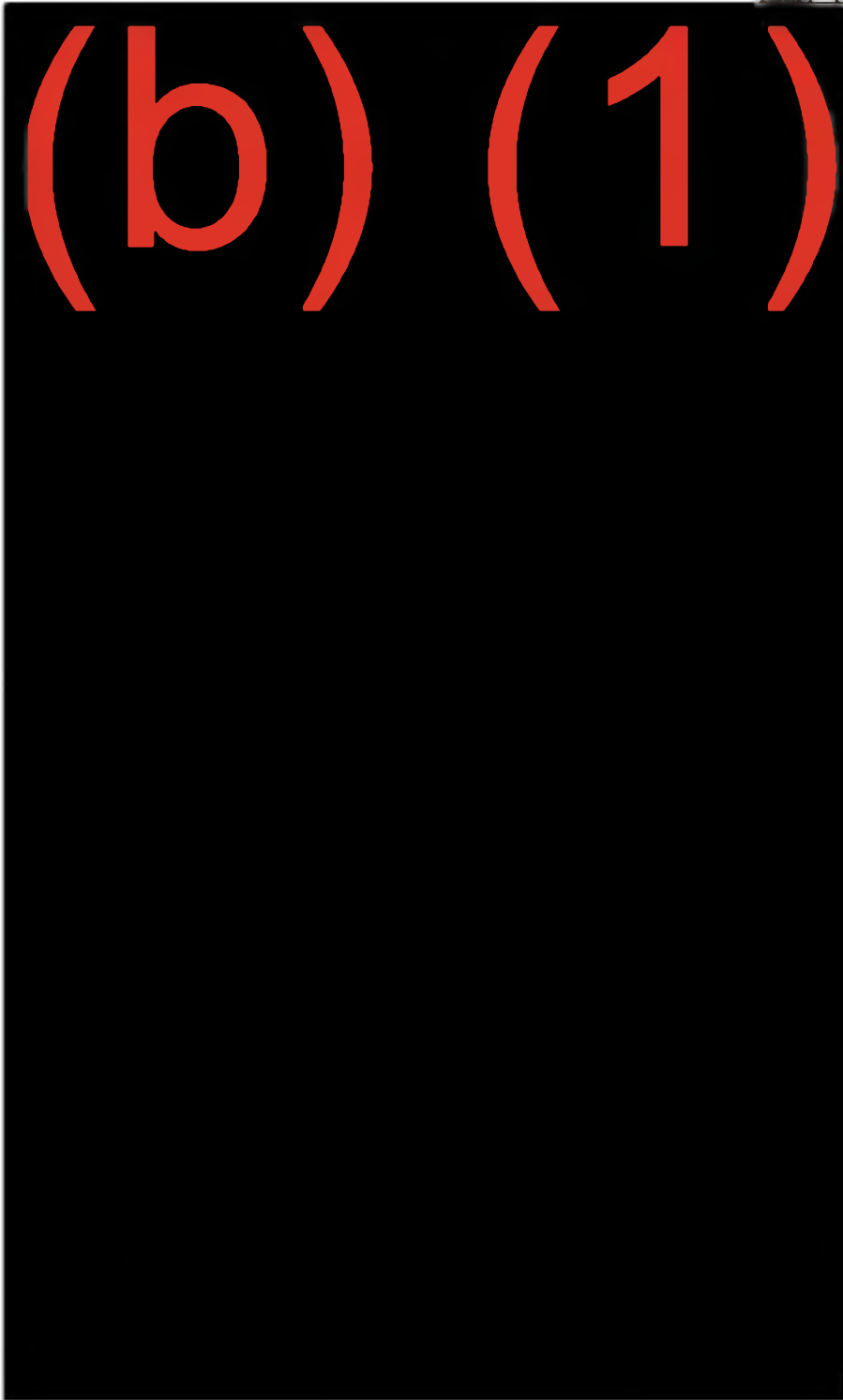


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SBS CVN

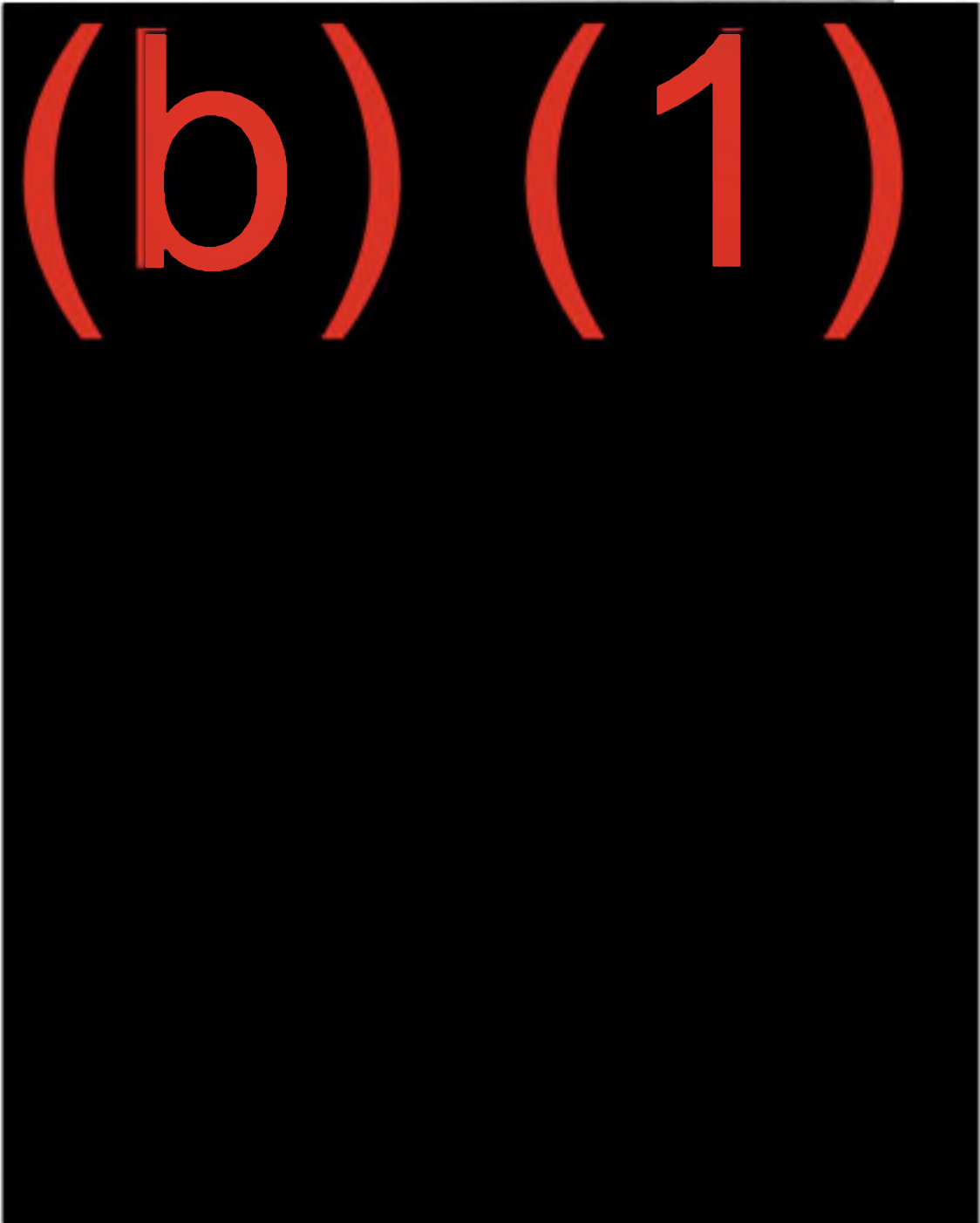
(b) (1)



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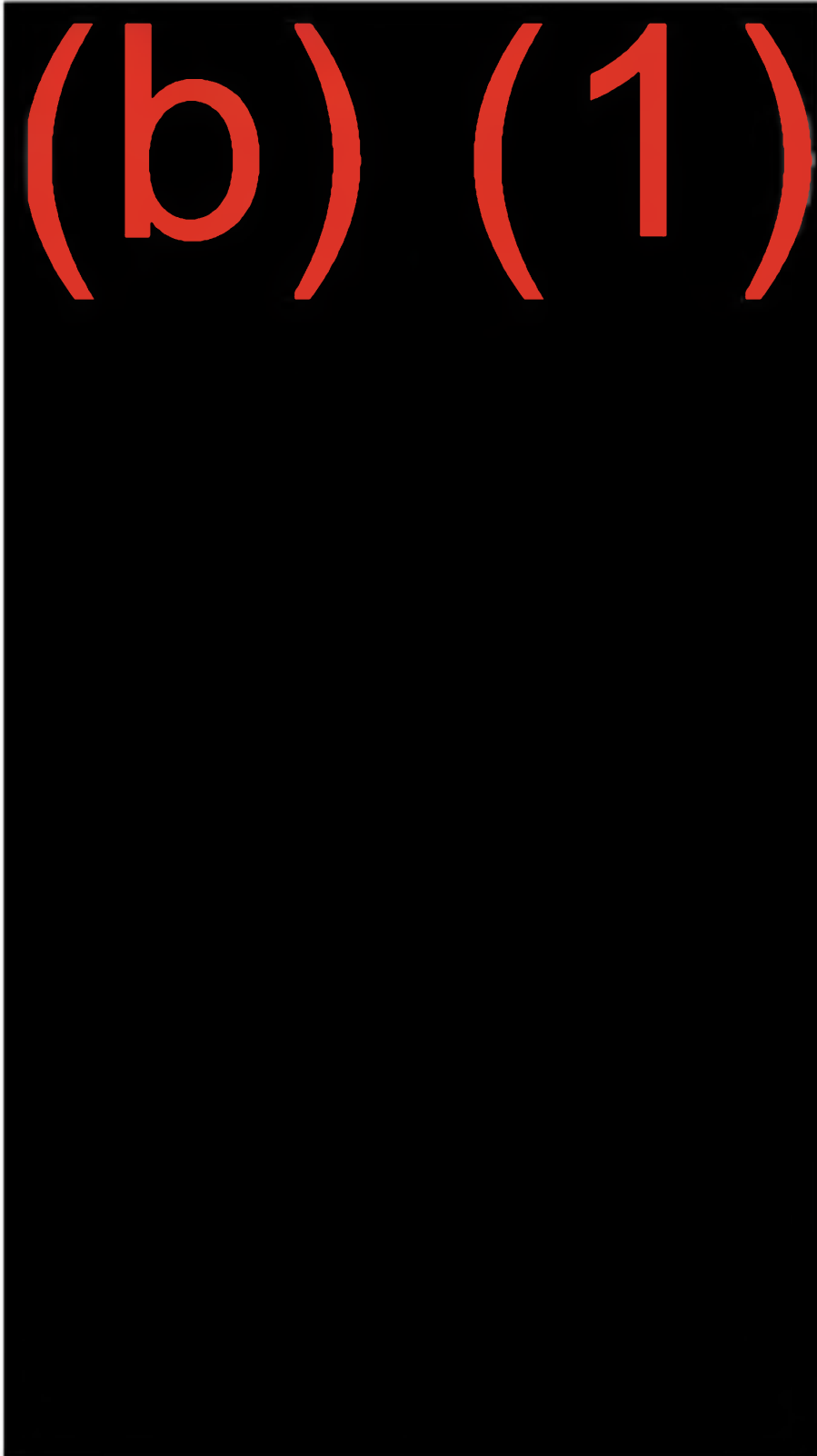
SES CVN



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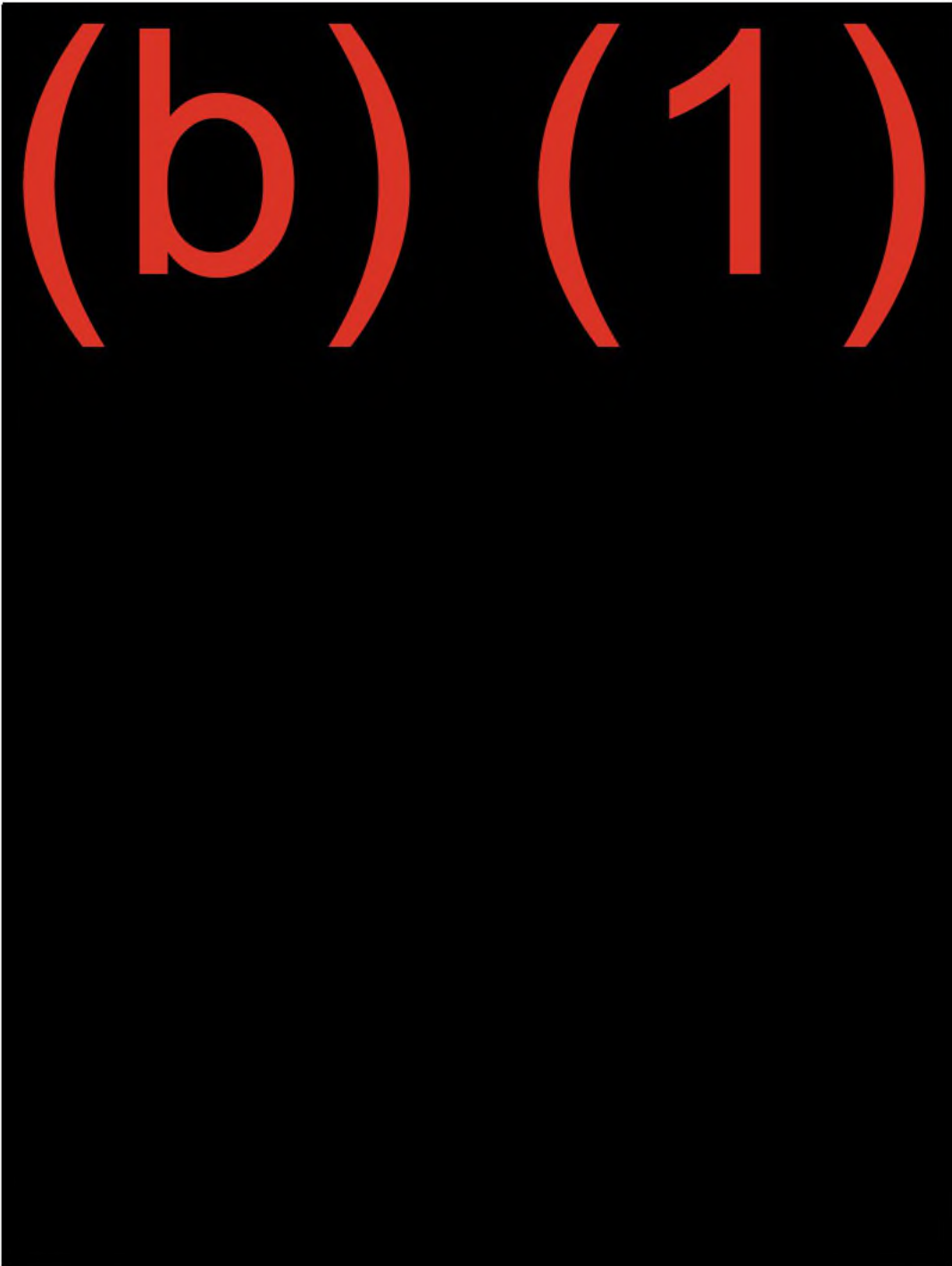
(b) (1)



SES CVN

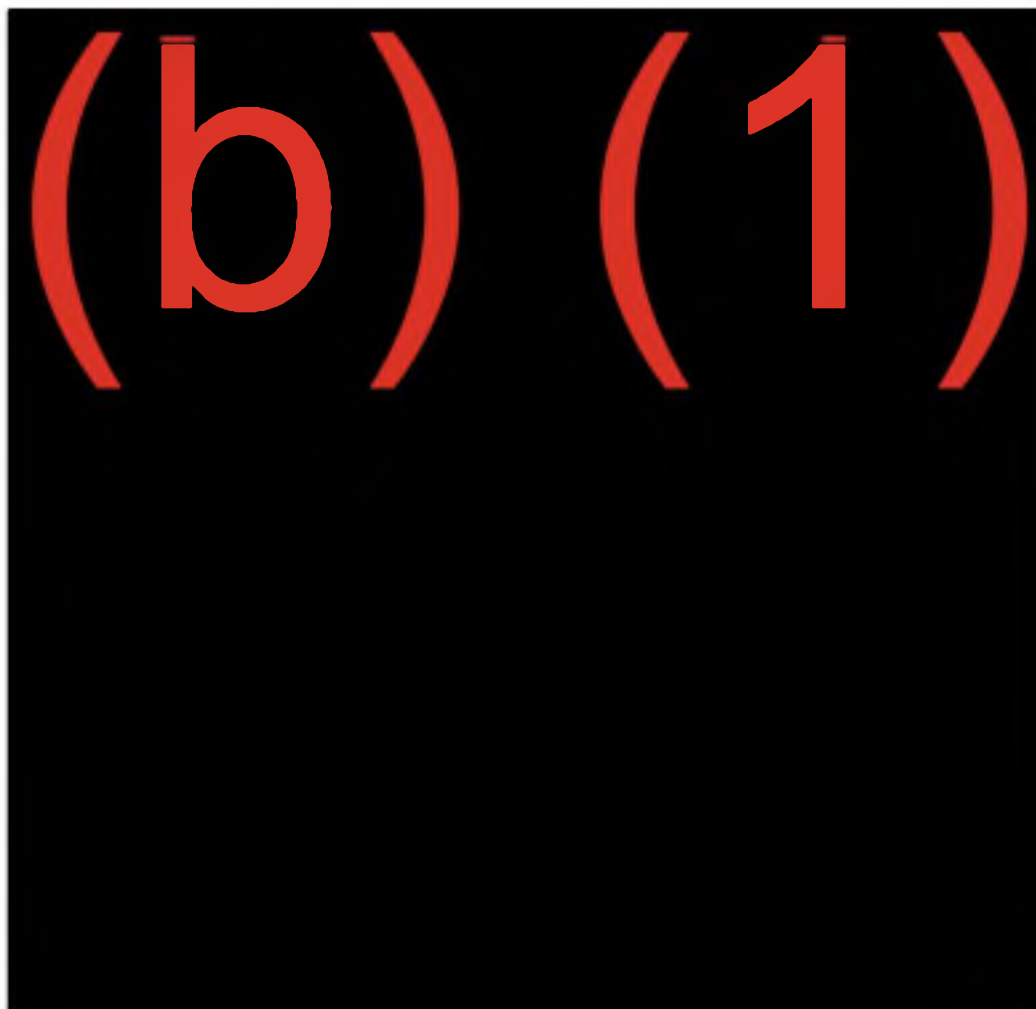
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(b) (1)



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SES CVN

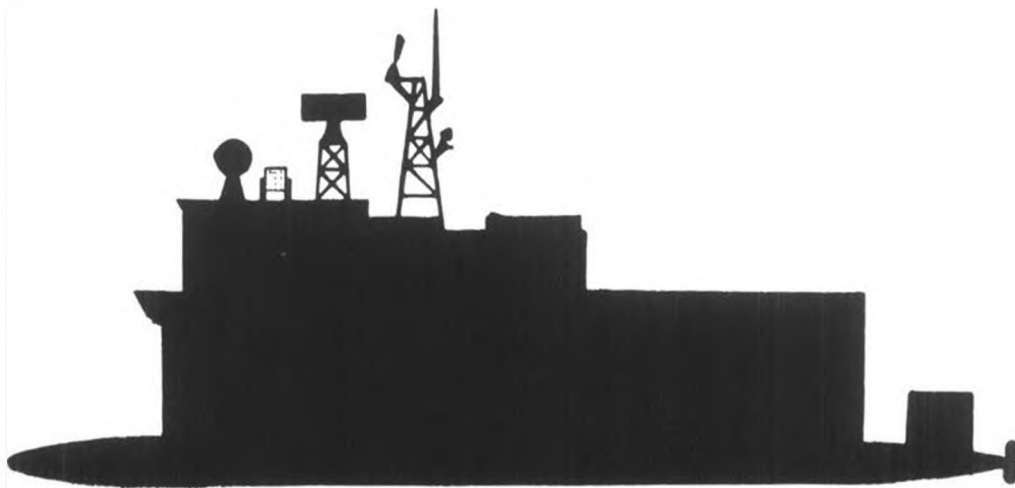


B-106

~~CONFIDENTIAL~~

UNCLASSIFIED

SWA 4



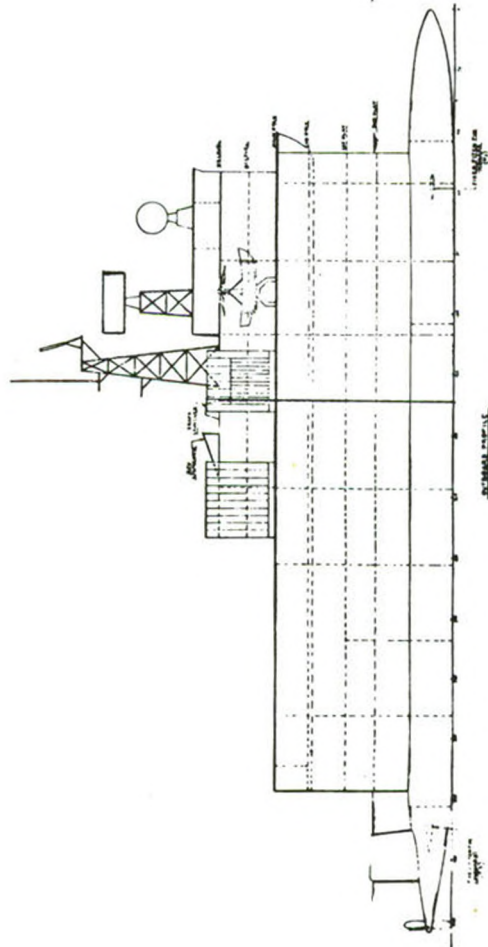
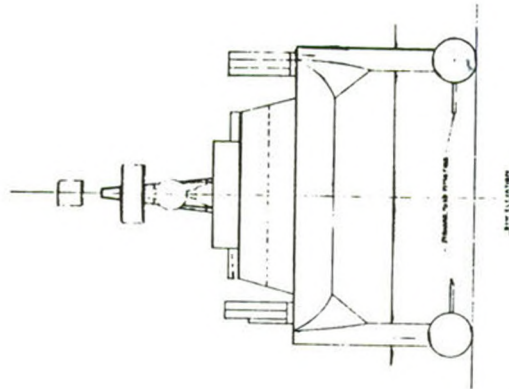
NOMINAL 4000 TON SWATH FRIGATE

POINT DESIGN SUMMARY

UNCLASSIFIED

UNCLASSIFIED

SWA 4

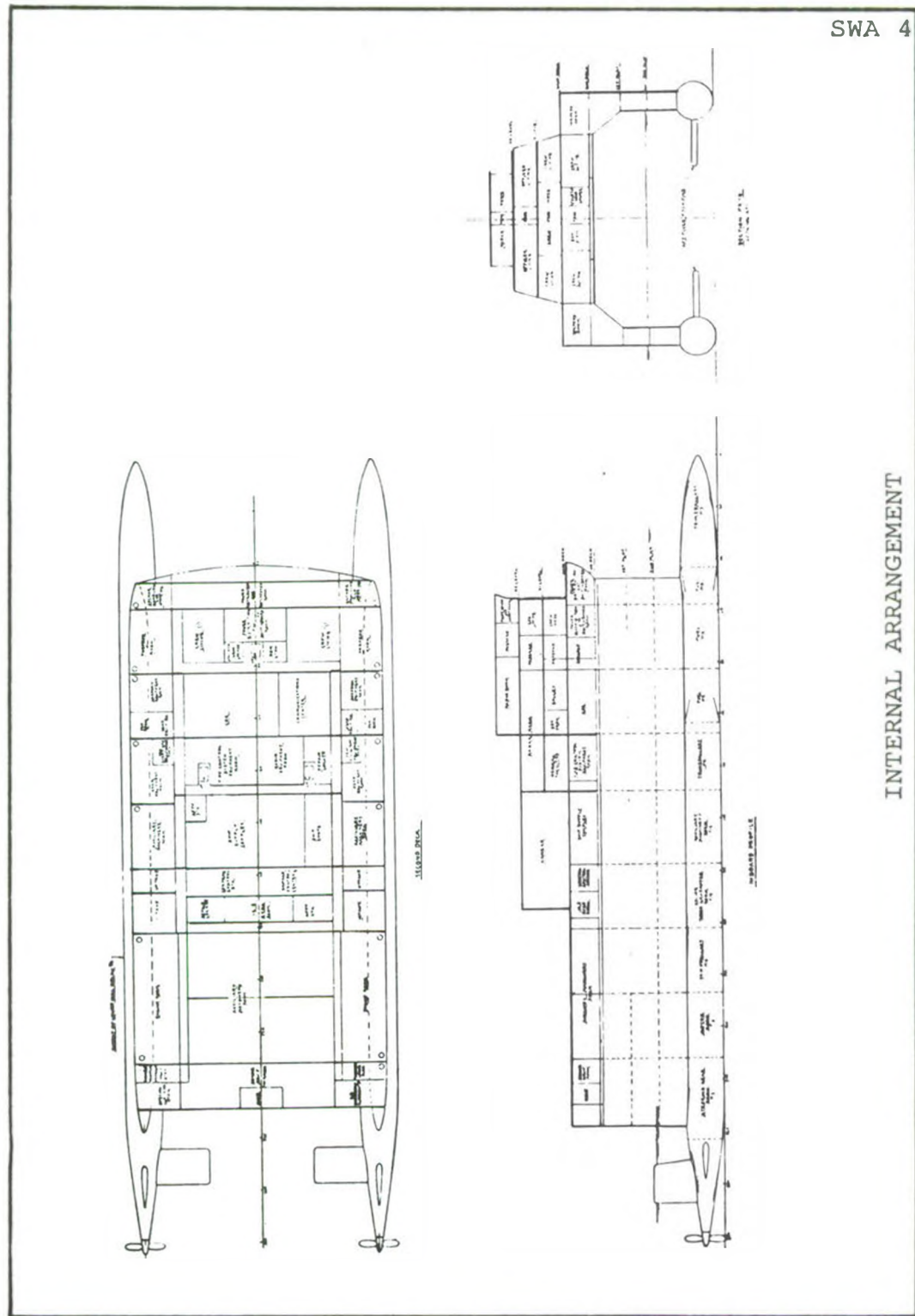


EXTERNAL ARRANGEMENT

EXTERNAL ARRANGEMENT

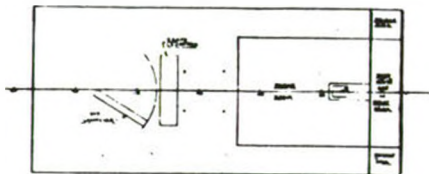
UNCLASSIFIED

UNCLASSIFIED



UNCLASSIFIED

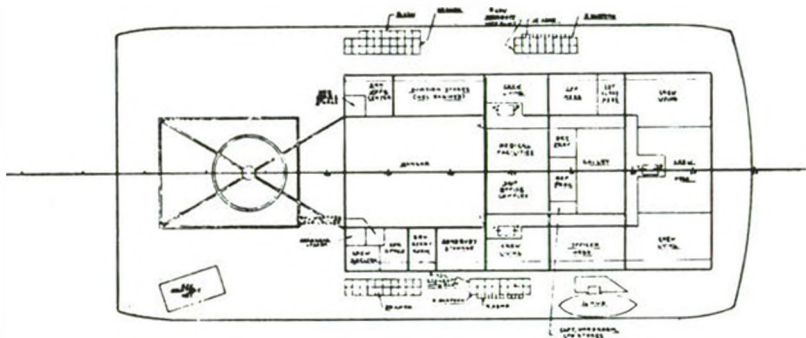
SWA 4



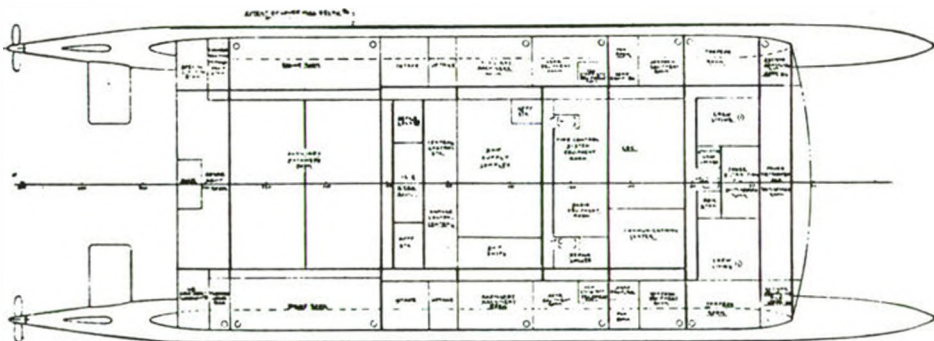
PLAN VIEW



PLAN VIEW



PLAN VIEW



PLAN VIEW

INTERNAL ARRANGEMENT

B-110

UNCLASSIFIED

~~CONFIDENTIAL~~

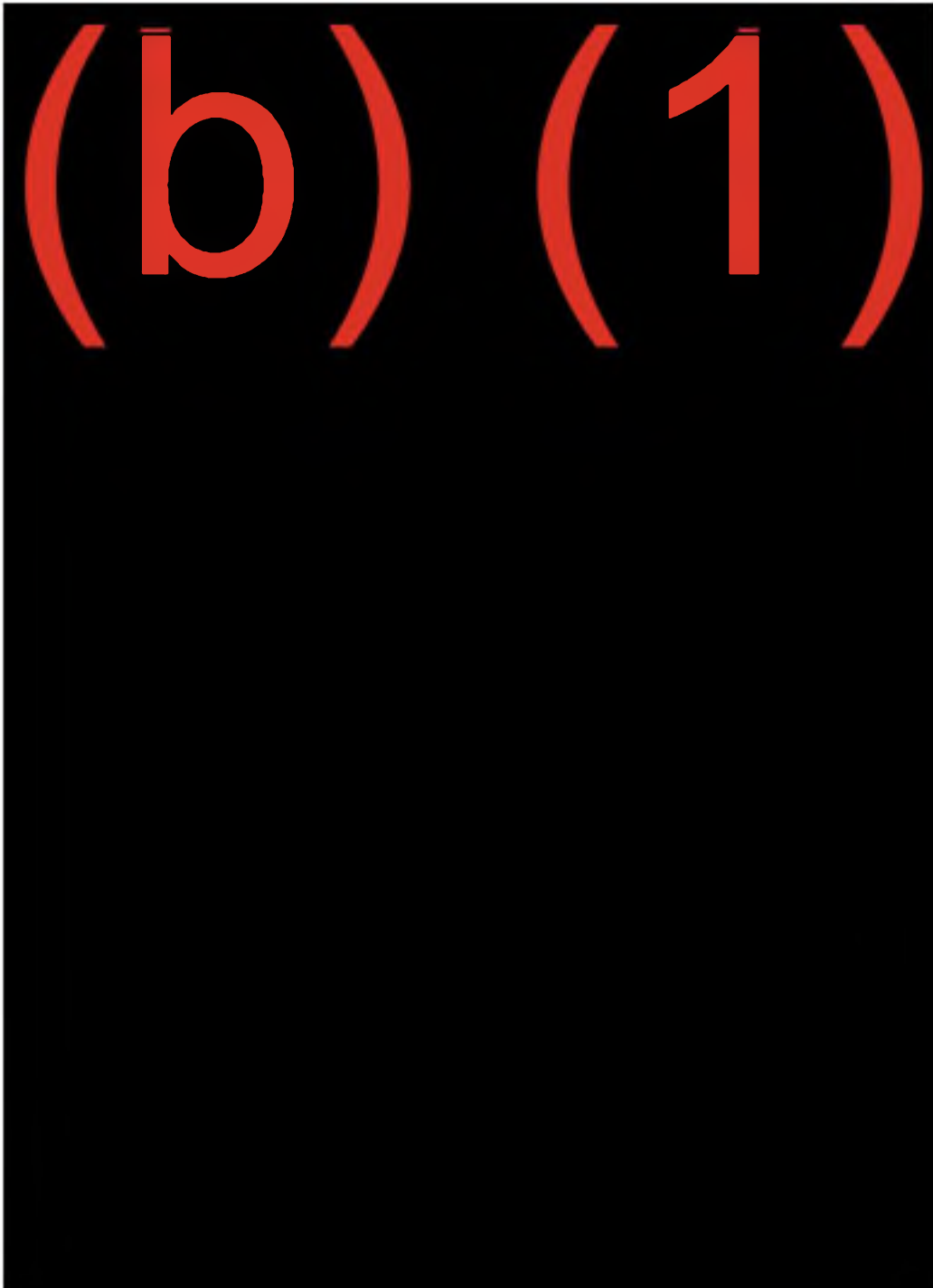
SWA 4

(b) (1)



B-111

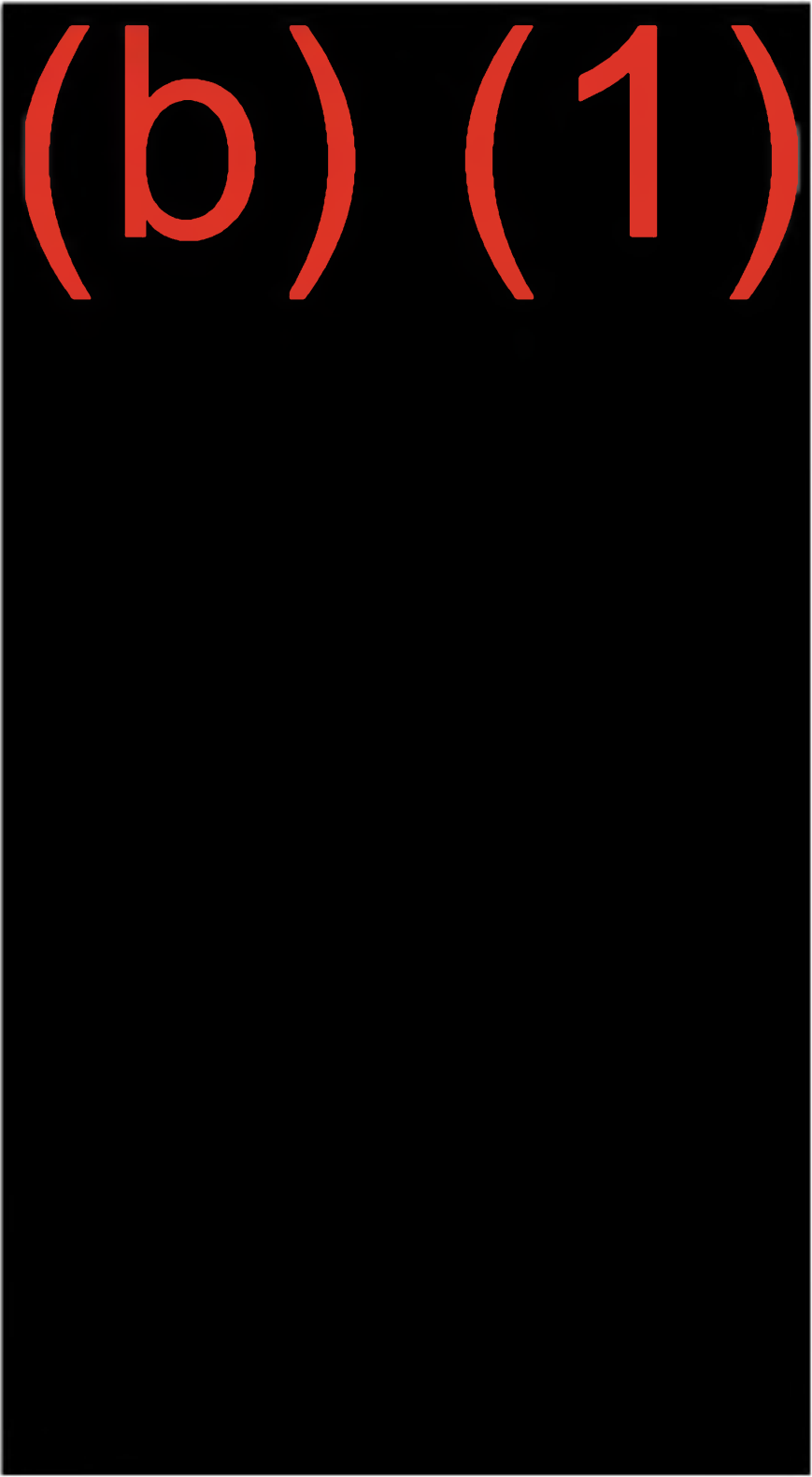
~~CONFIDENTIAL~~



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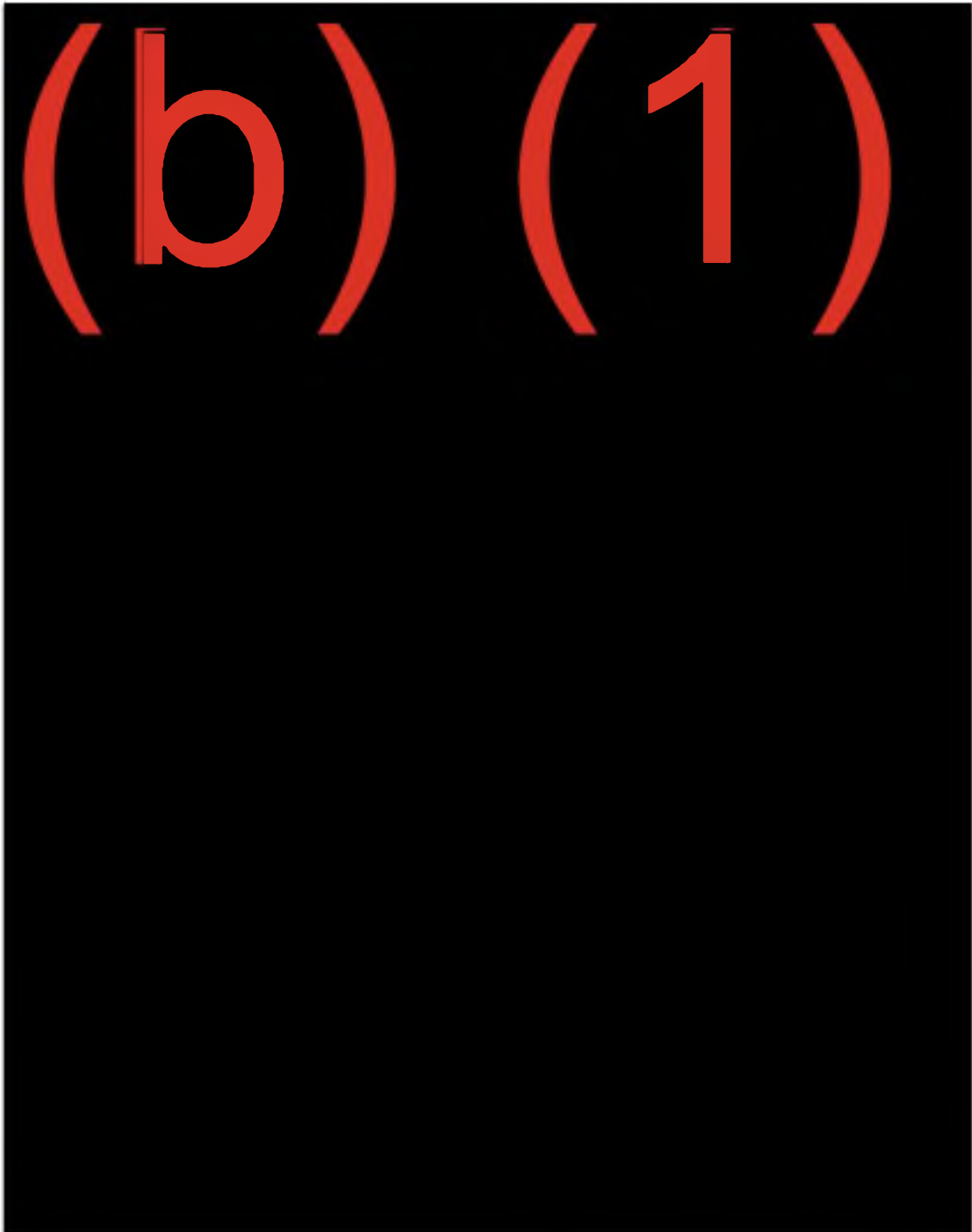
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(b) (1)

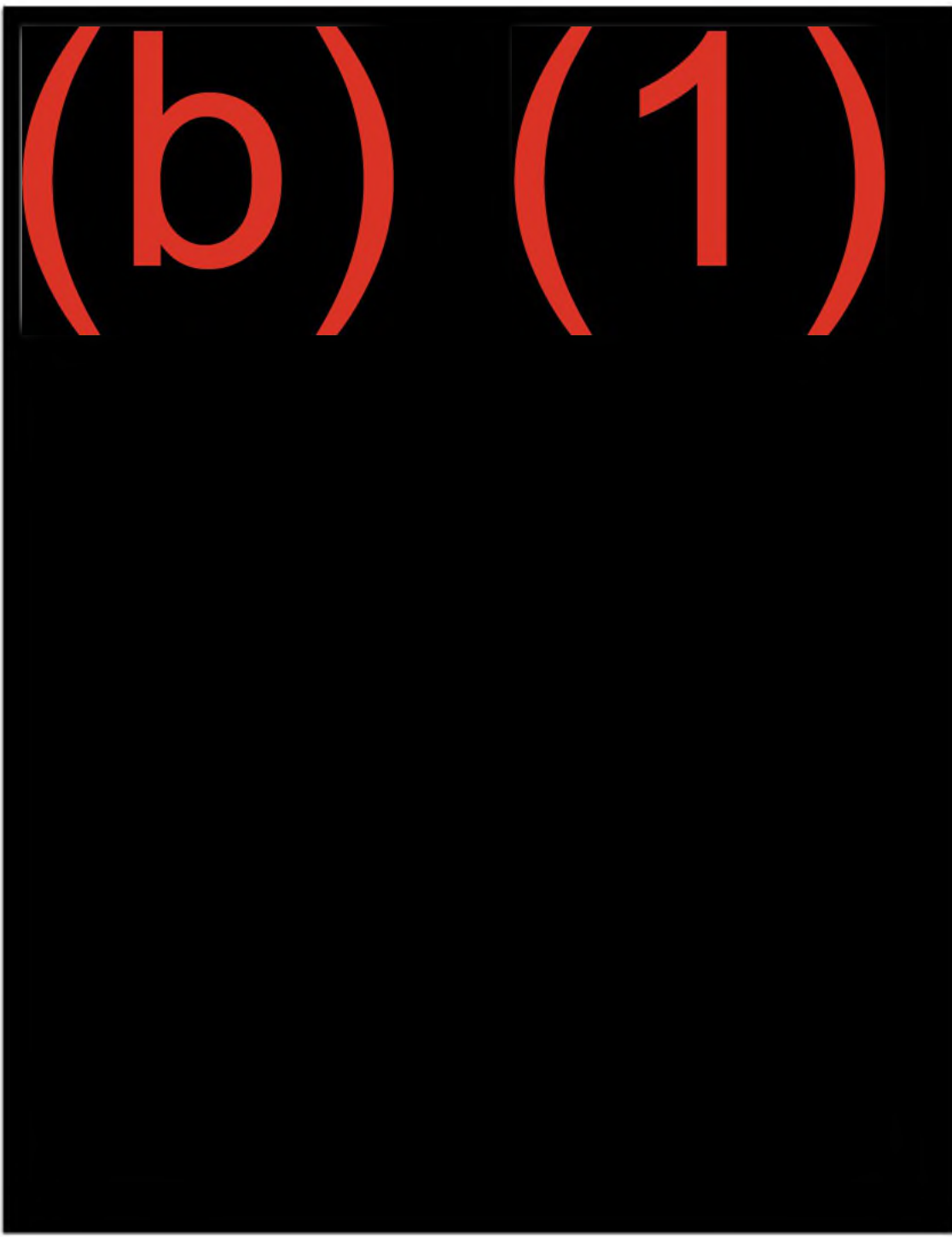


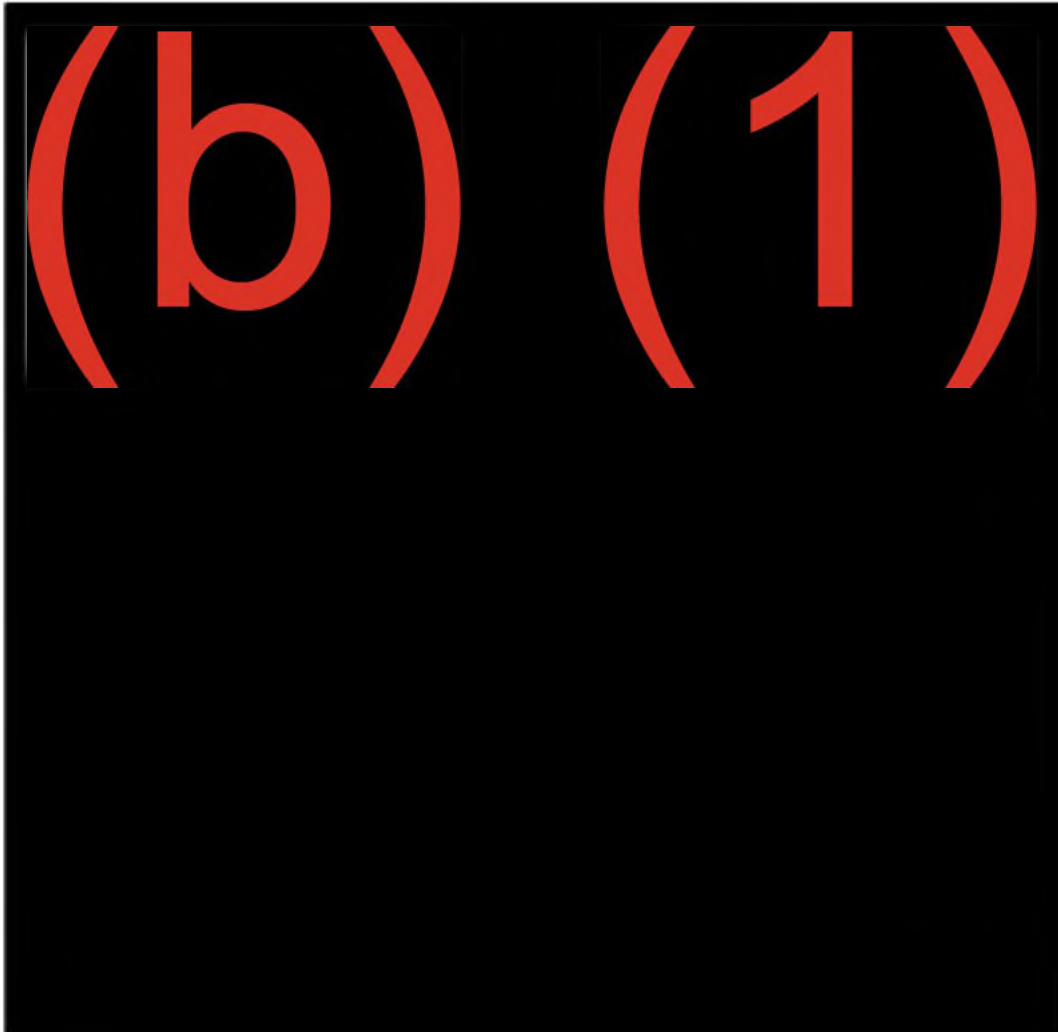
B-113

~~CONFIDENTIAL~~



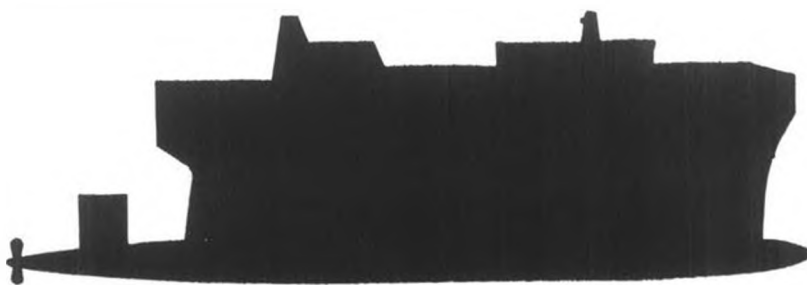
(b) (1)





UNCLASSIFIED

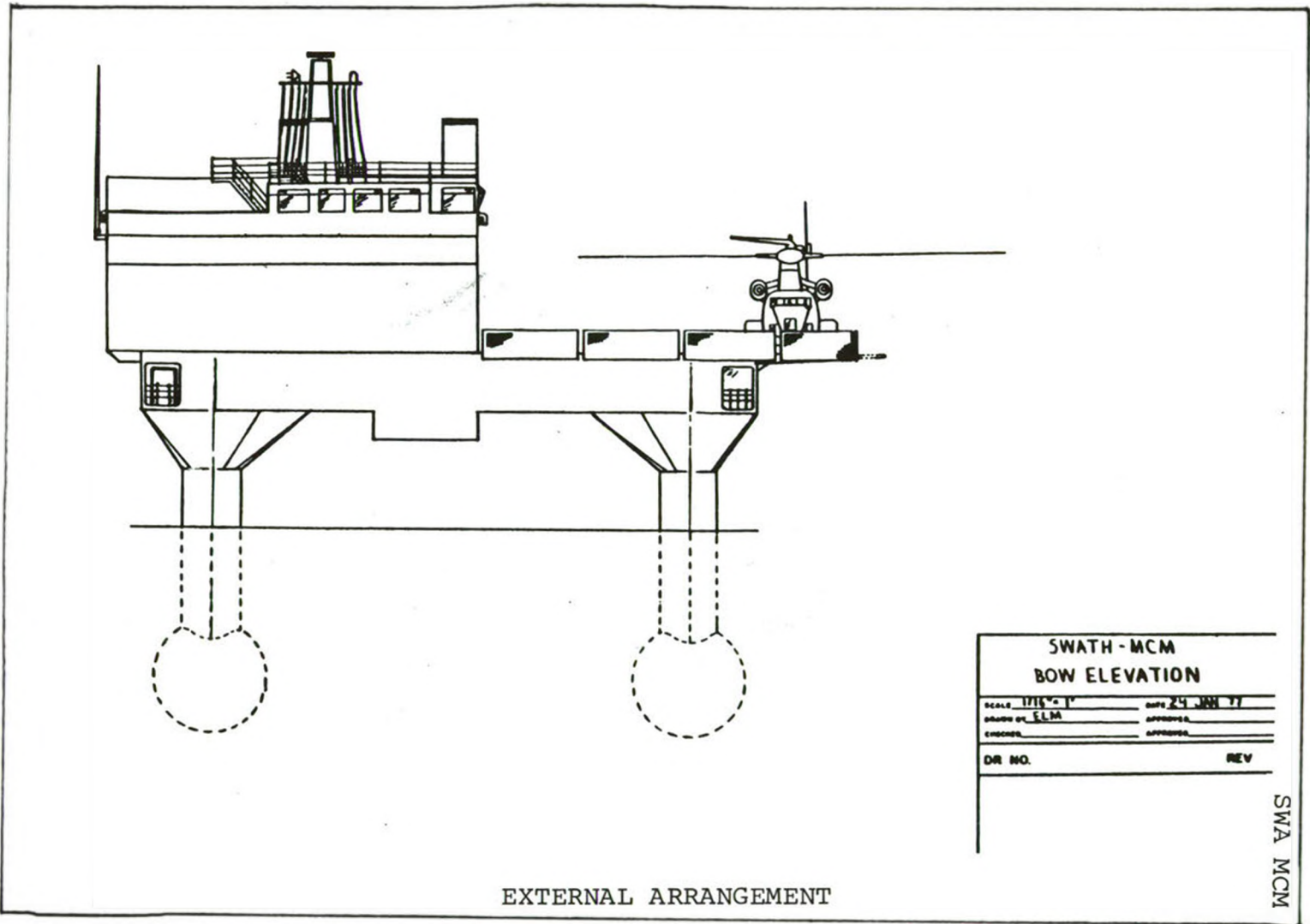
SWA MCM



MINE COUNTERMEASURES SWATH

POINT DESIGN SUMMARY

UNCLASSIFIED

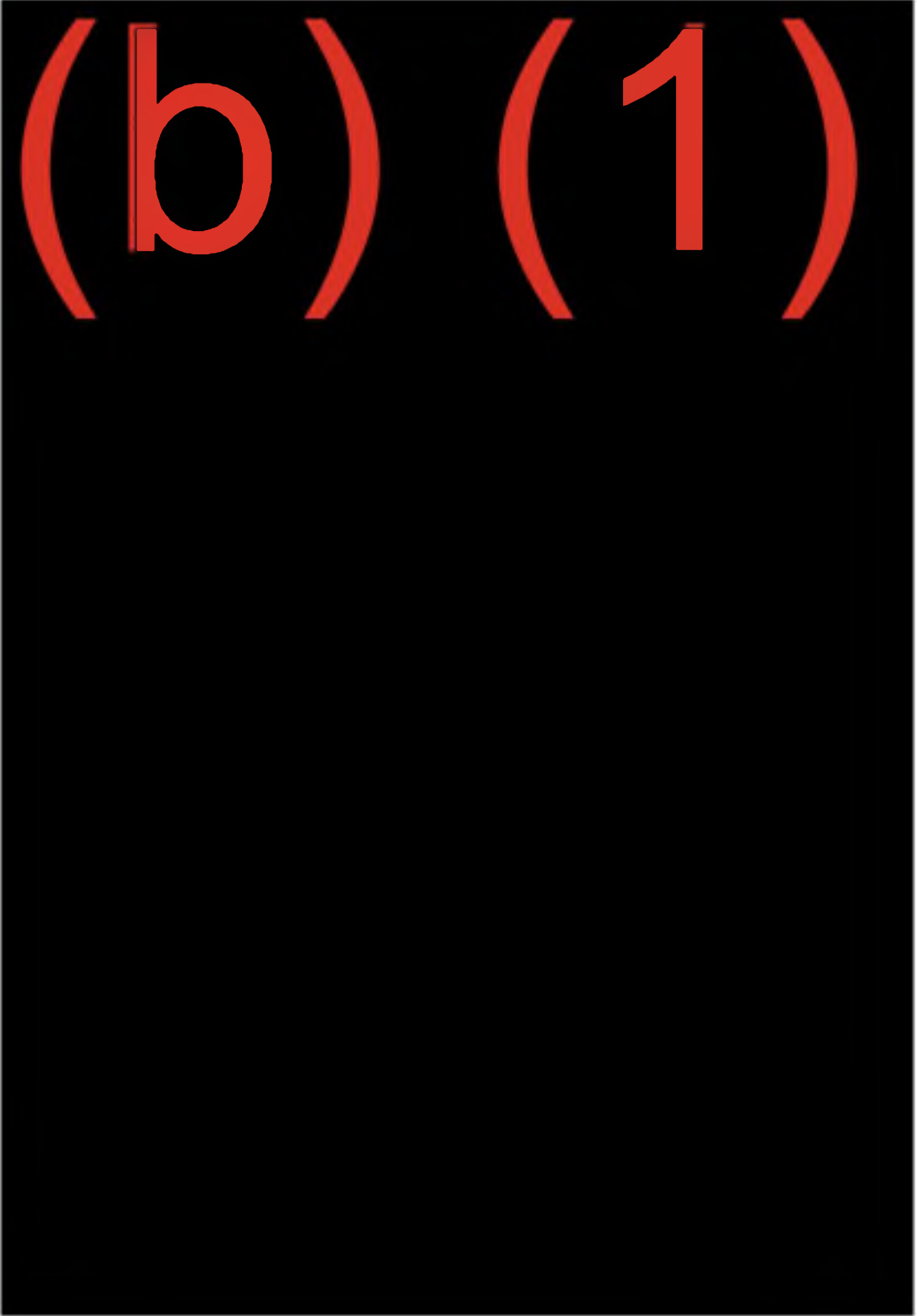


B-118

UNCLASSIFIED

~~CONFIDENTIAL~~

(b) (1)



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SWA MCM

(b) (1)

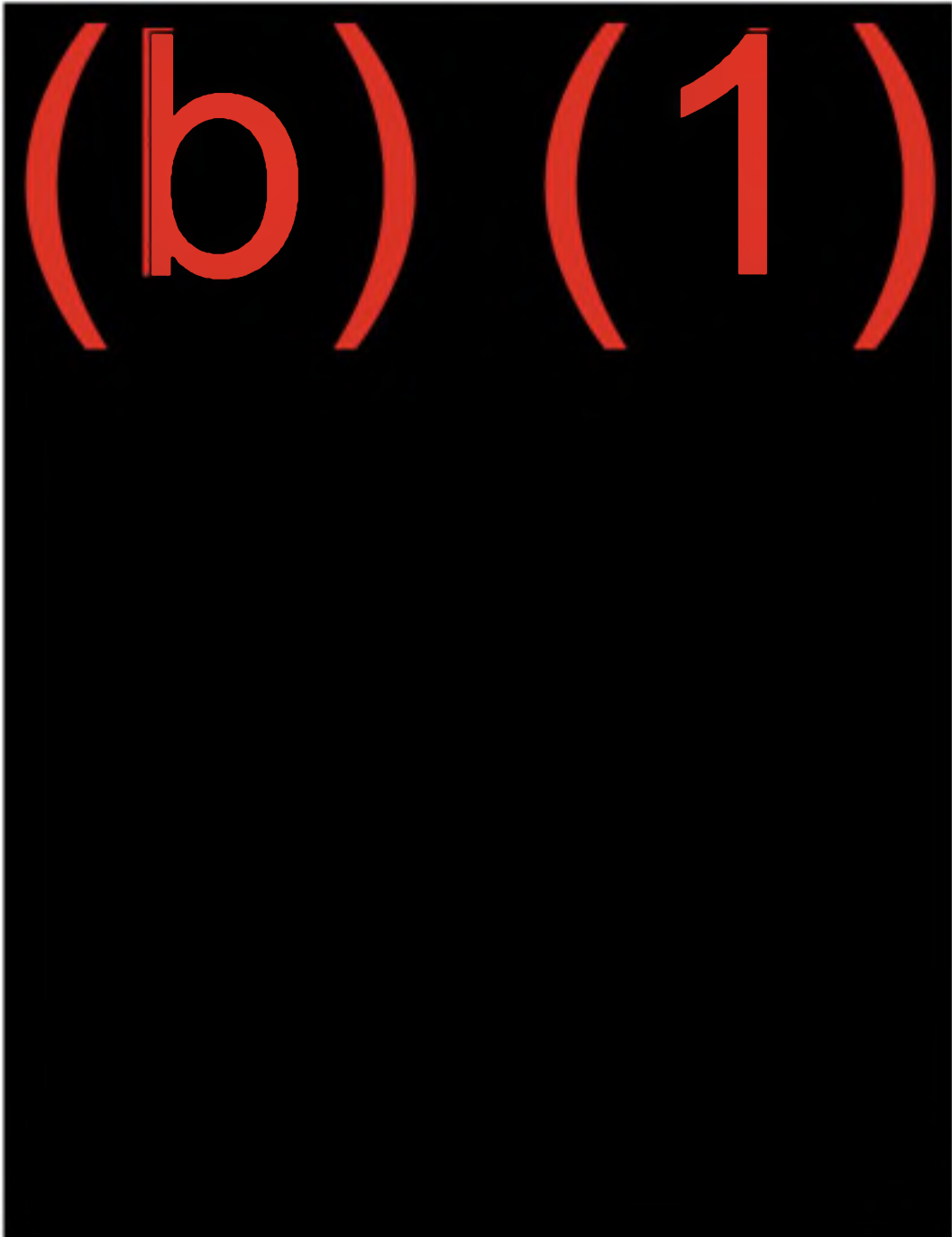


B-120

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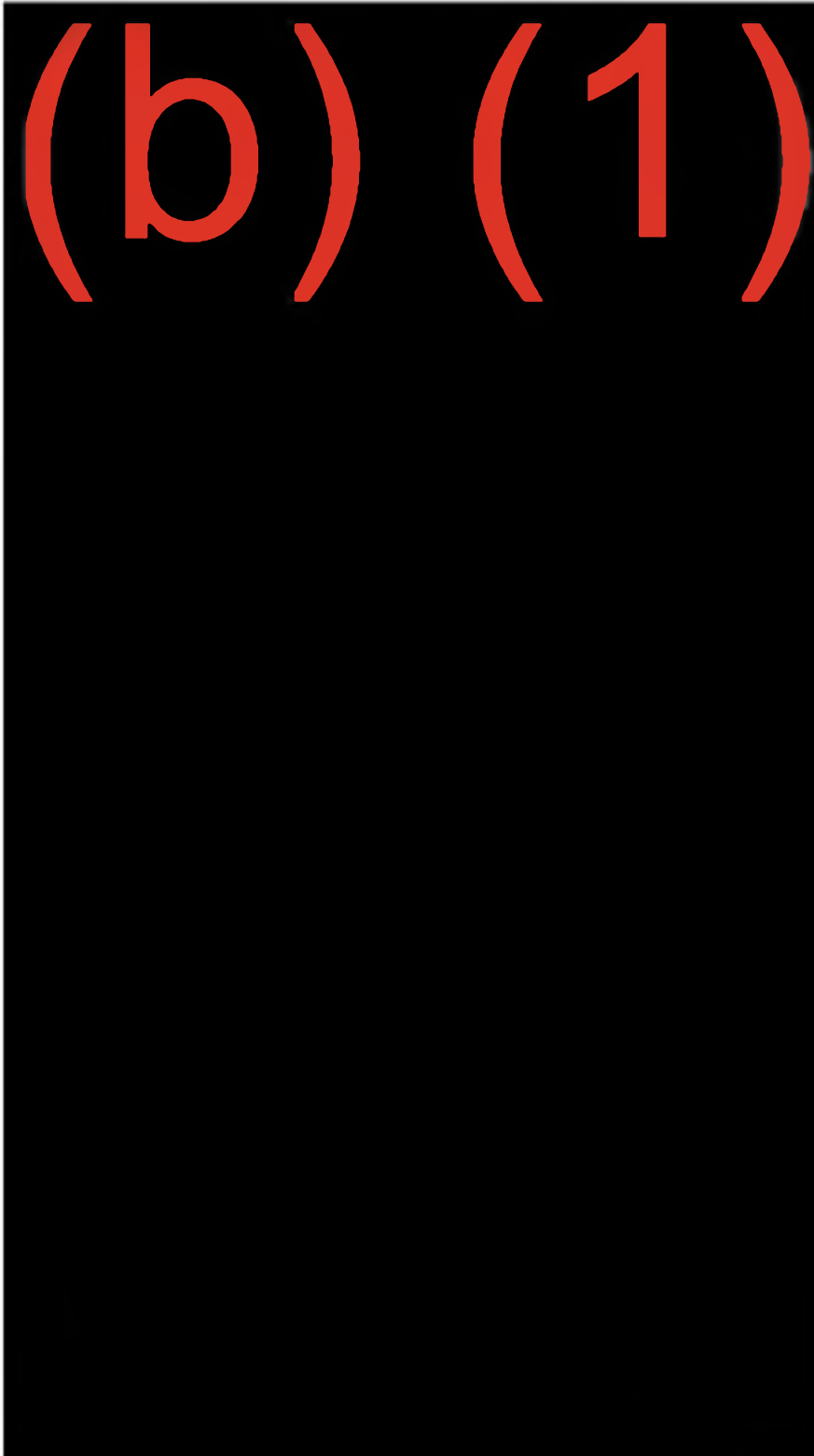
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SWA MCM



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A MCM

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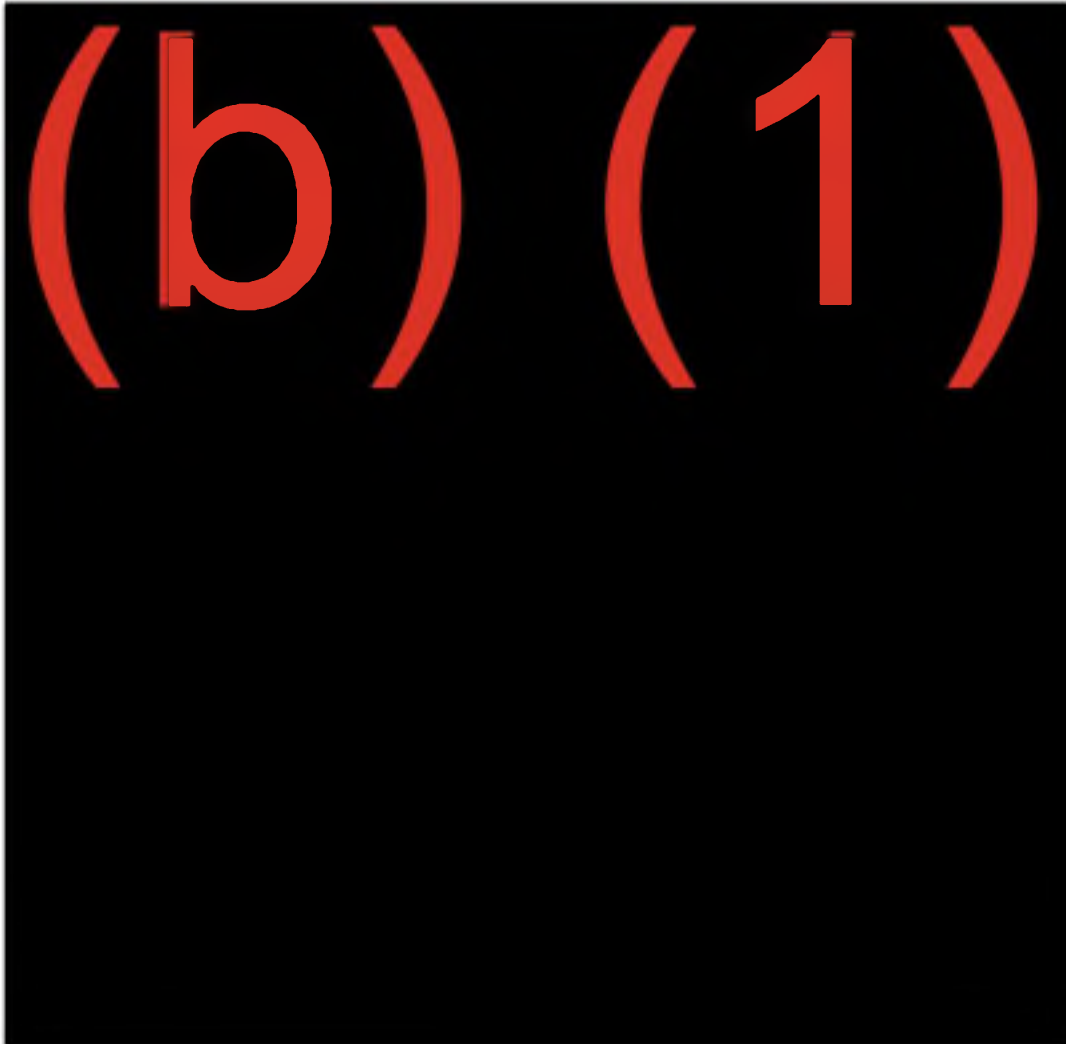
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(b) (1)

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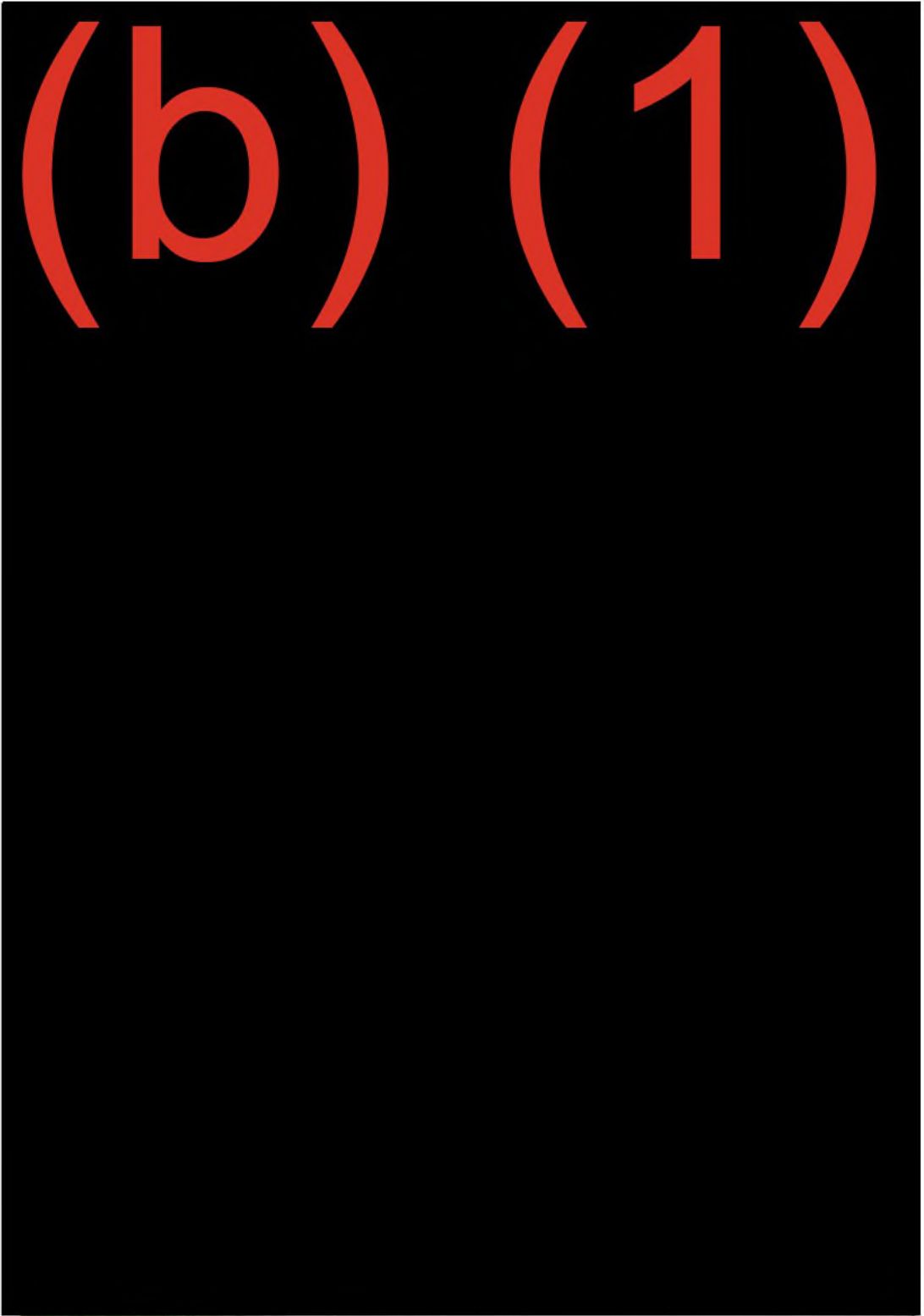
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(b) (1)



B-125

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(b) (1)



B-126

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B-127

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B-128

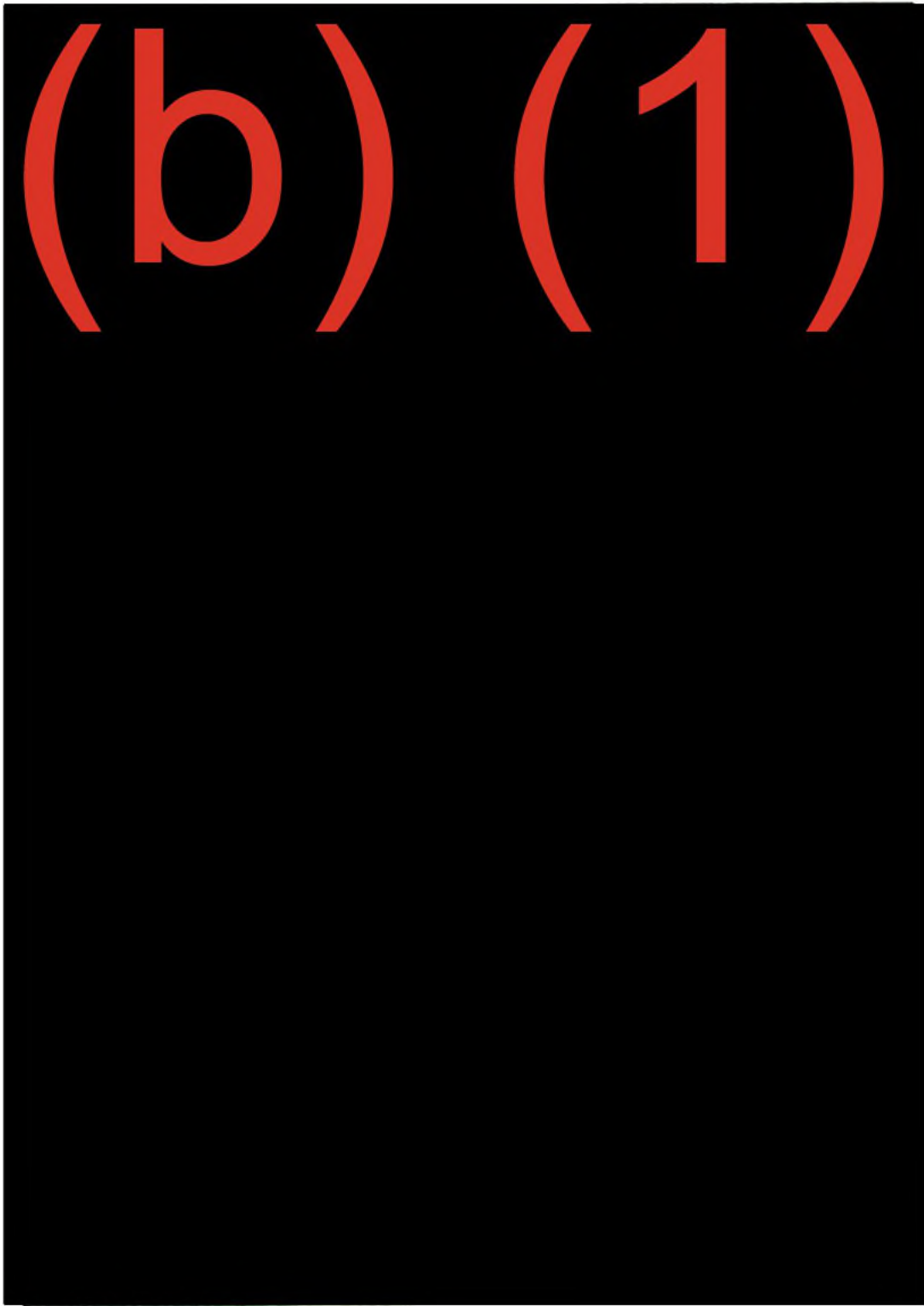
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(b) (1)



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(b) (1)

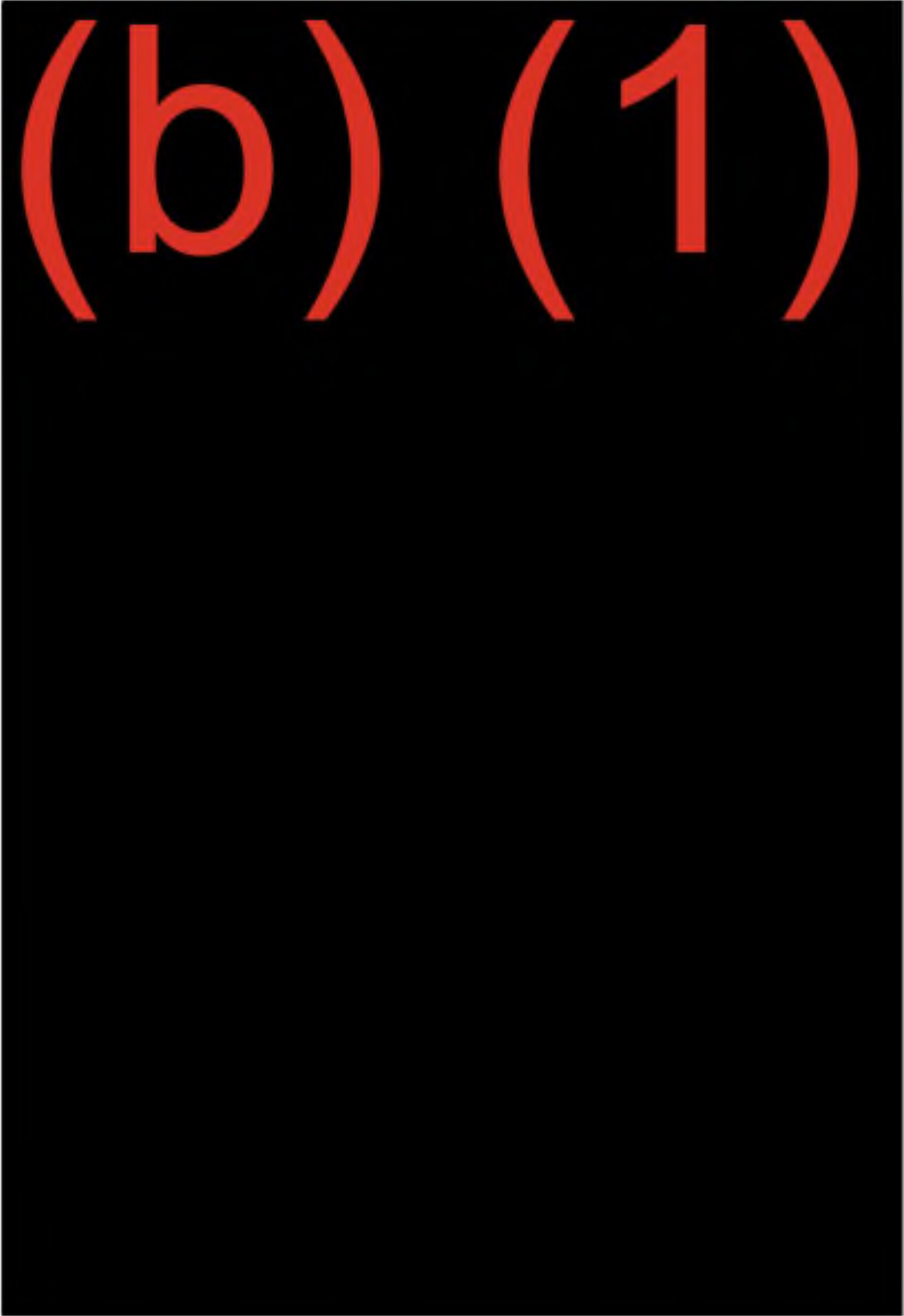


B-130

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(b) (1)



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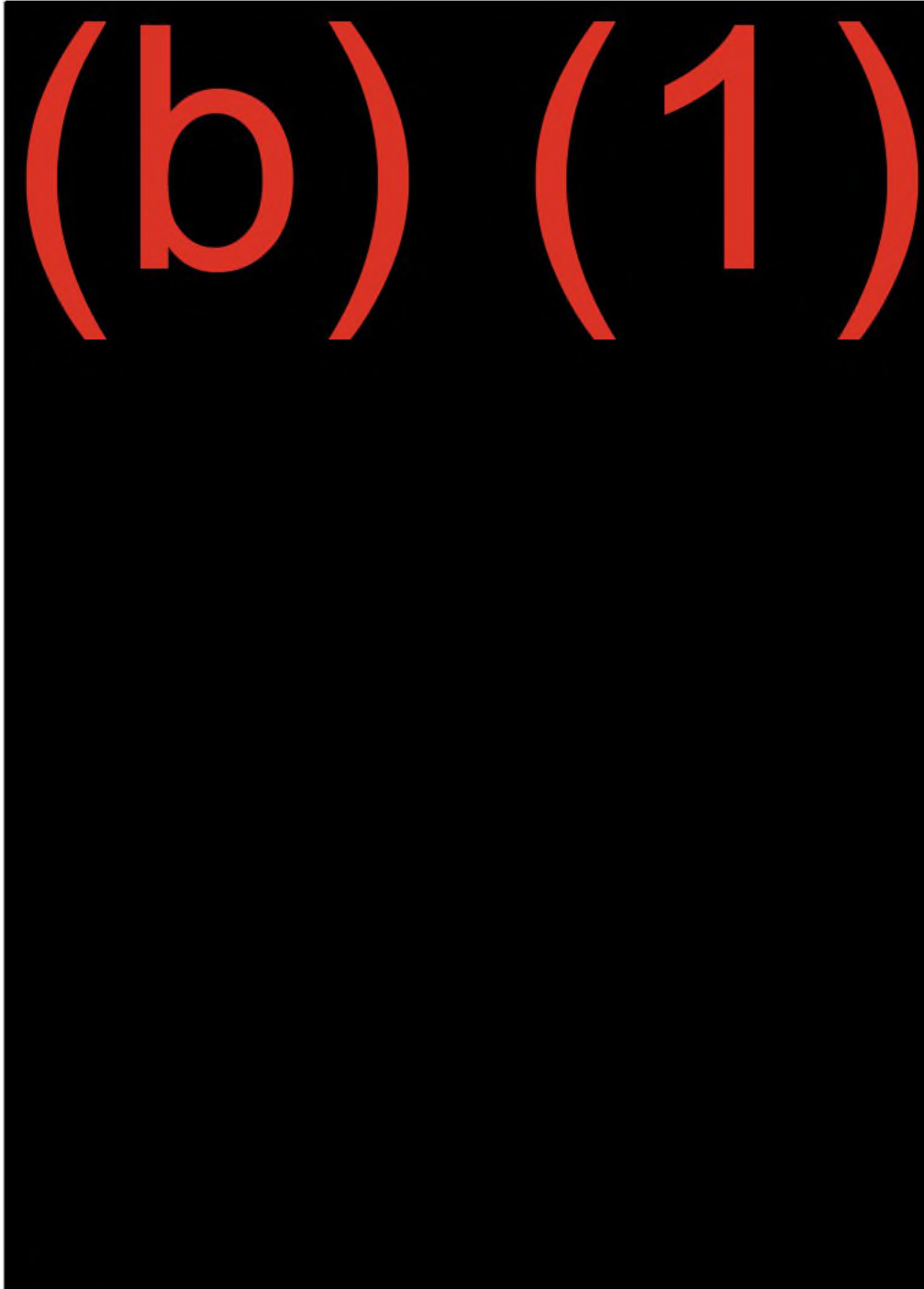
CVN

B-133

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SWA CVN

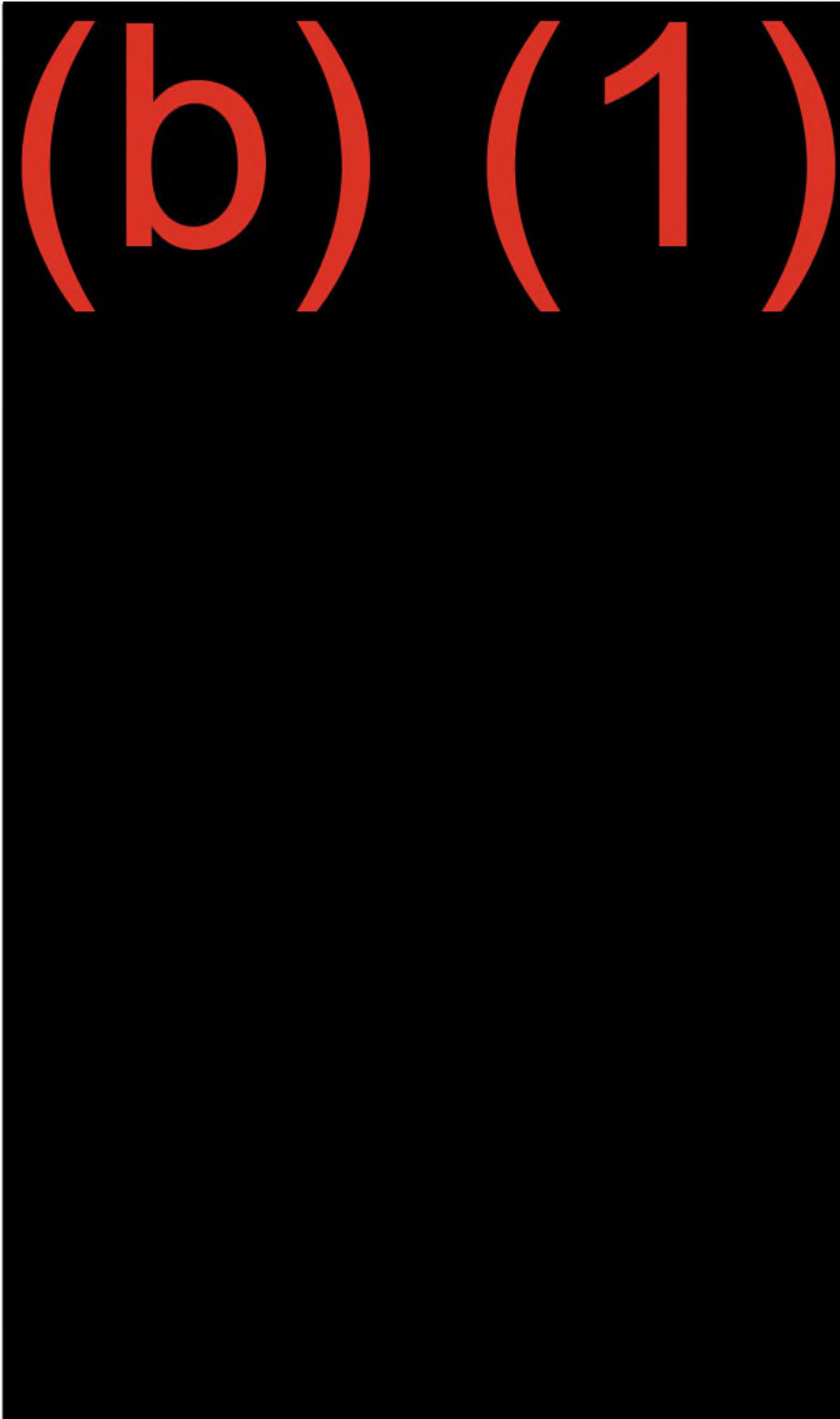


B-134

~~CONFIDENTIAL NOFORN~~

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SWA CVN



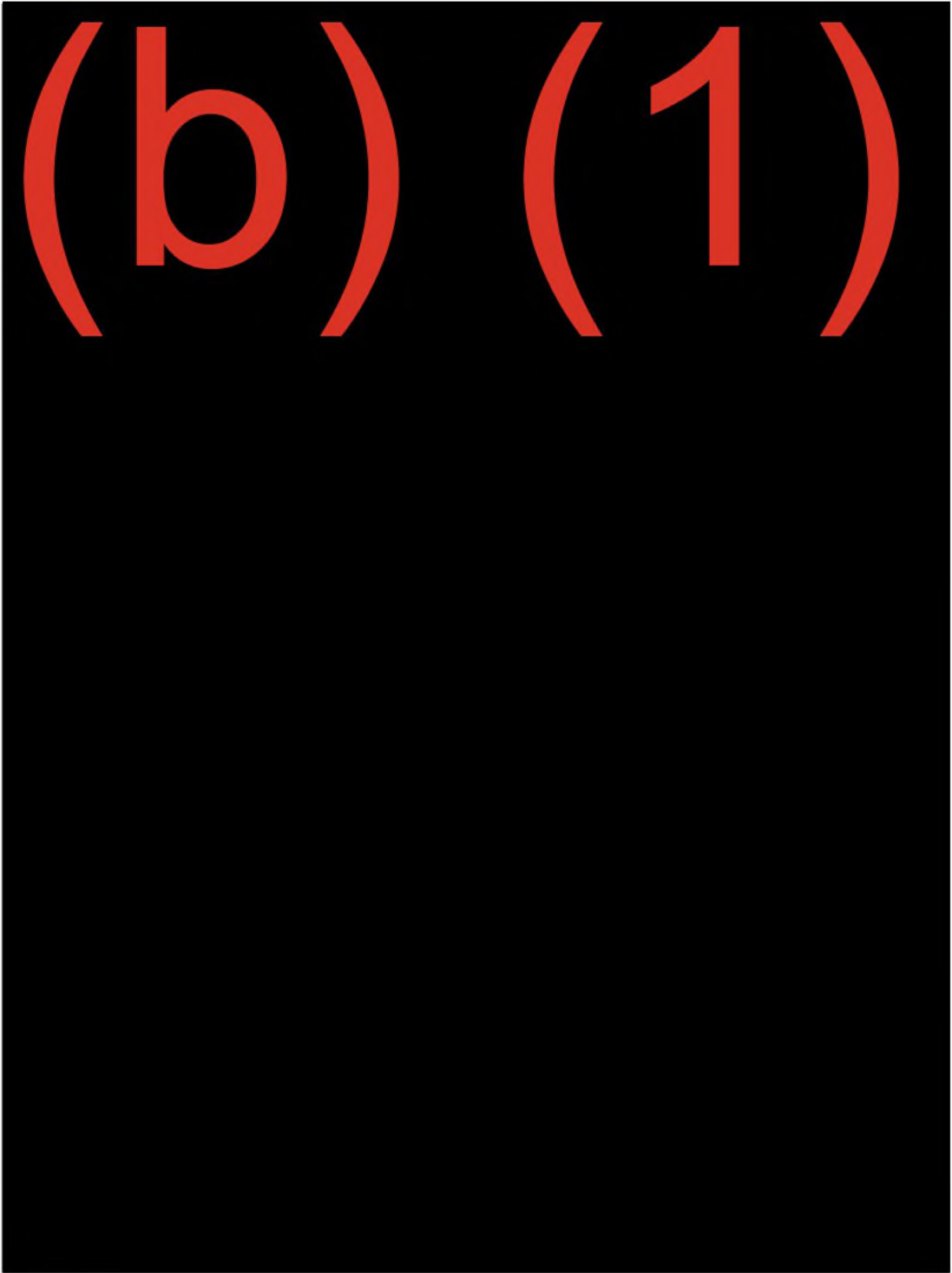
B-135

~~CONFIDENTIAL NOFORN~~

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SWA CVN

(b) (1)



B-136

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SWA CVN

(b) (1)

B-137
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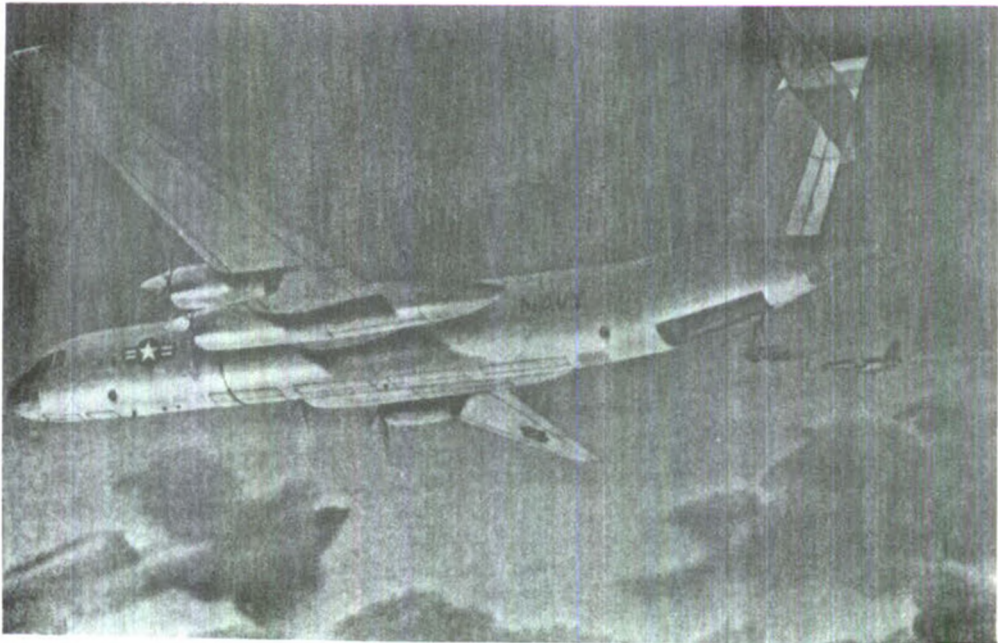
~~CONFIDENTIAL NOFORN~~

UNCLASSIFIED

III. AIR VEHICLE POINT DESIGNS

UNCLASSIFIED

A/L

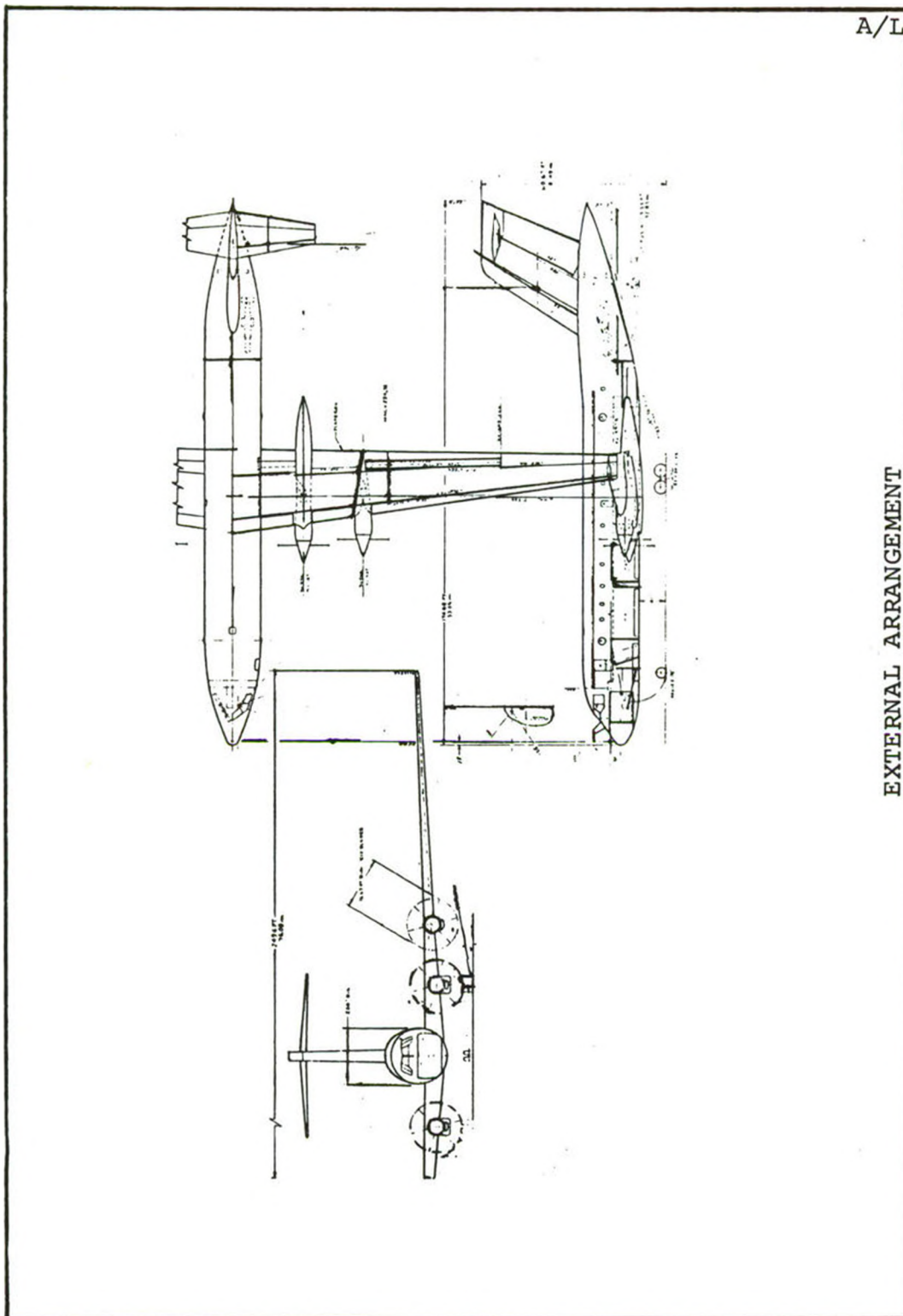


AIR LOITER AIRCRAFT
POINT DESIGN SUMMARY

B-141

UNCLASSIFIED

UNCLASSIFIED



B-142

UNCLASSIFIED

~~CONFIDENTIAL~~



B-143

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A/L

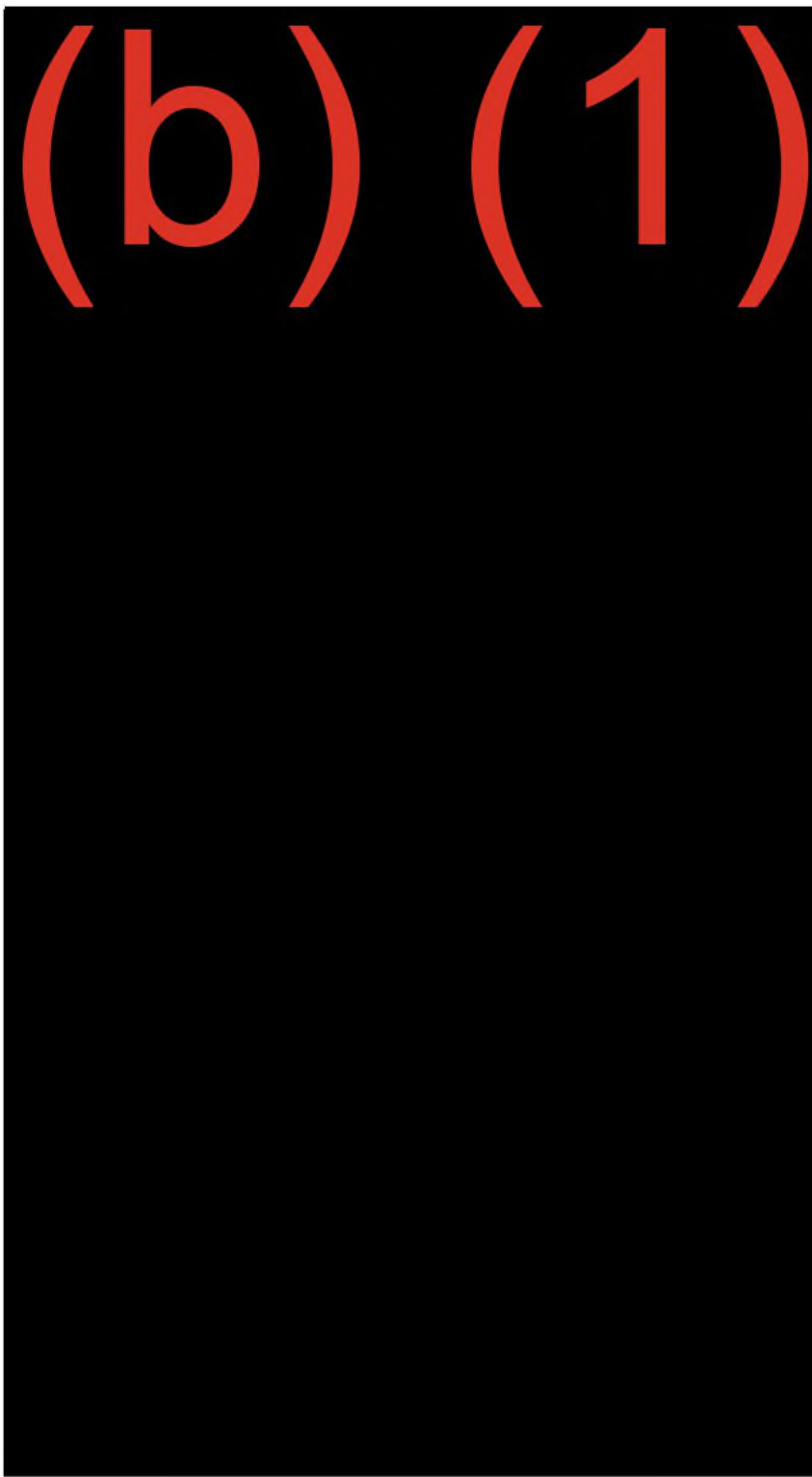


B-144

~~CONFIDENTIAL~~

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A/L

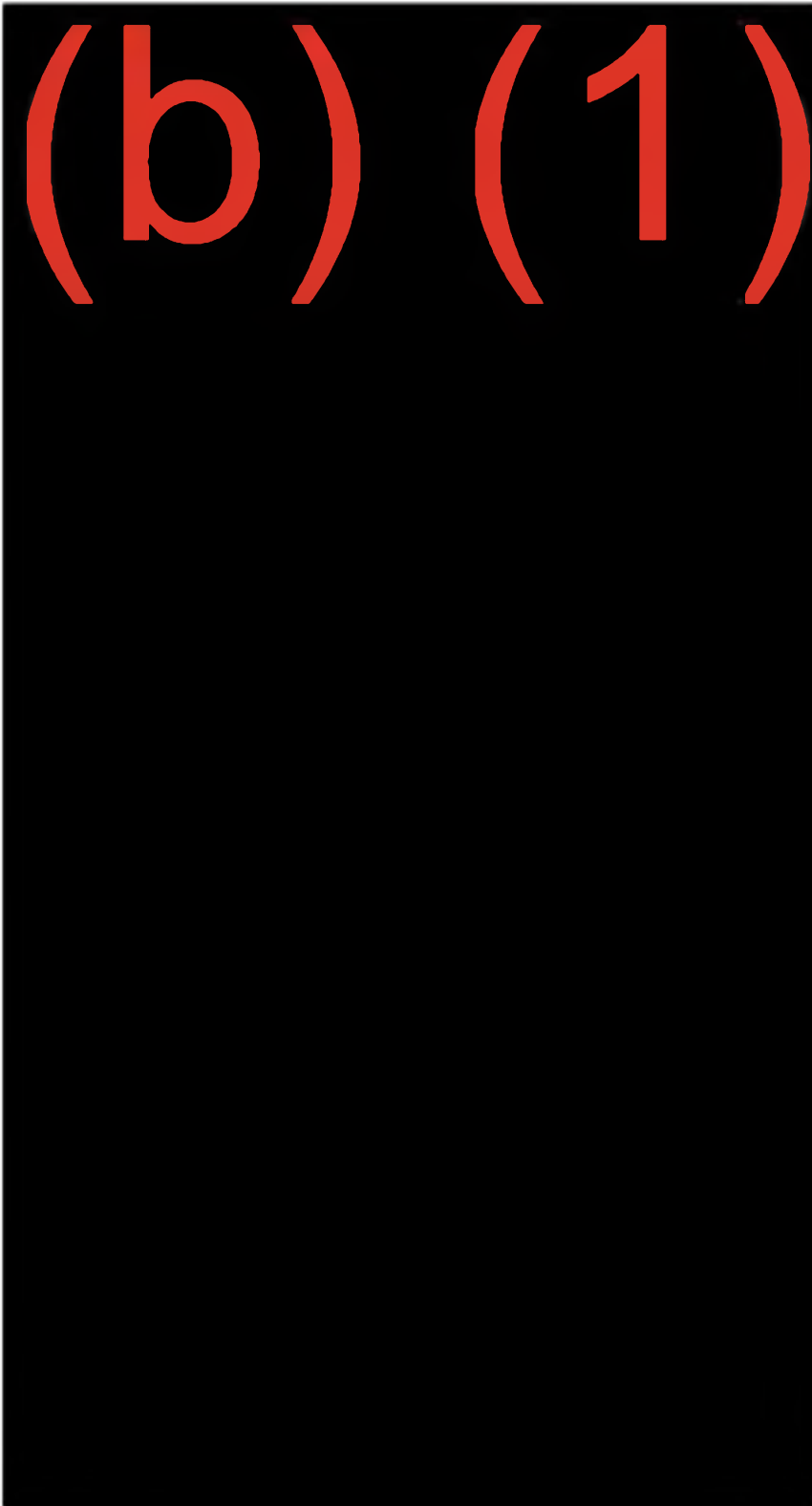


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A/L

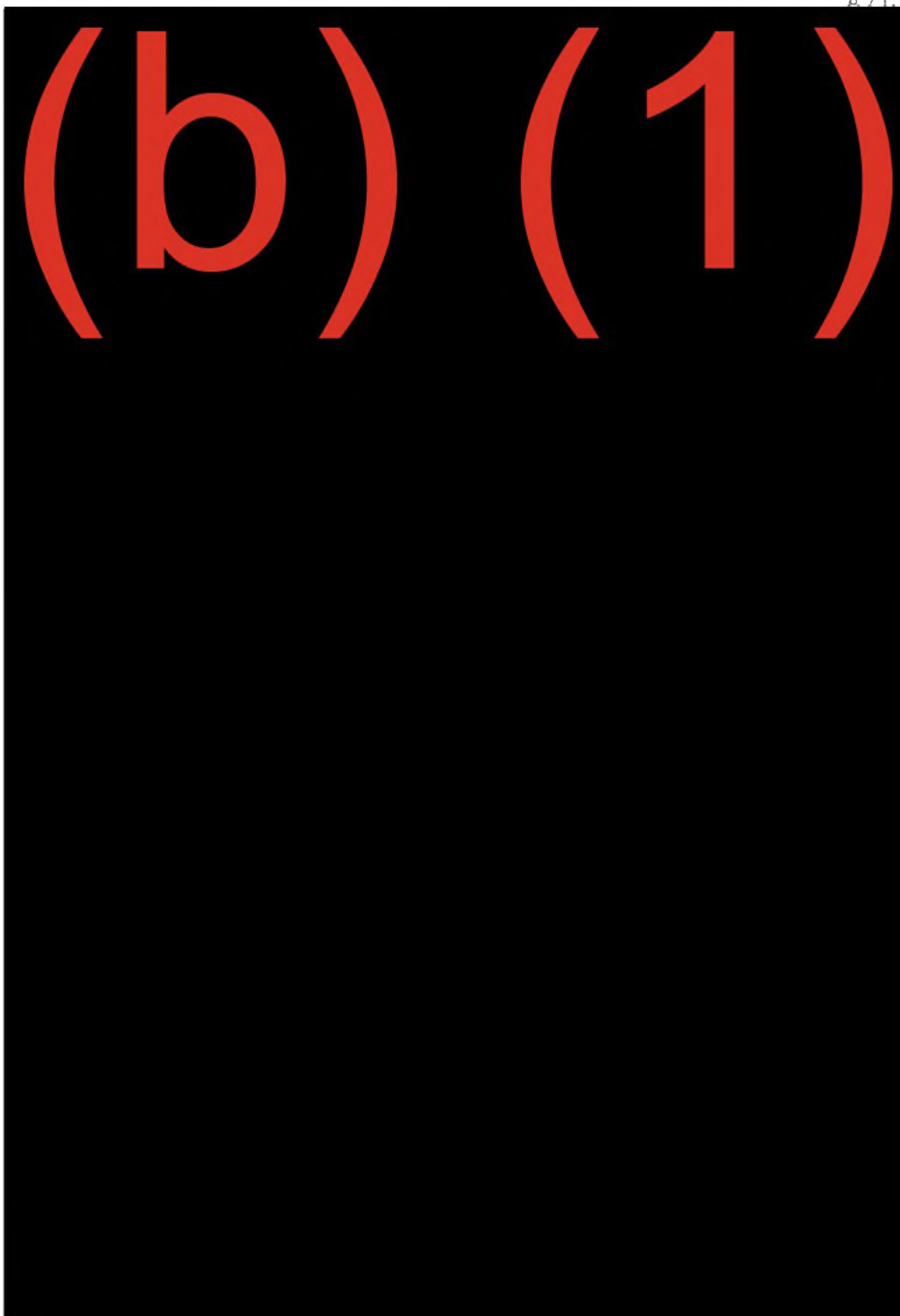
(b) (1)



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B-1.

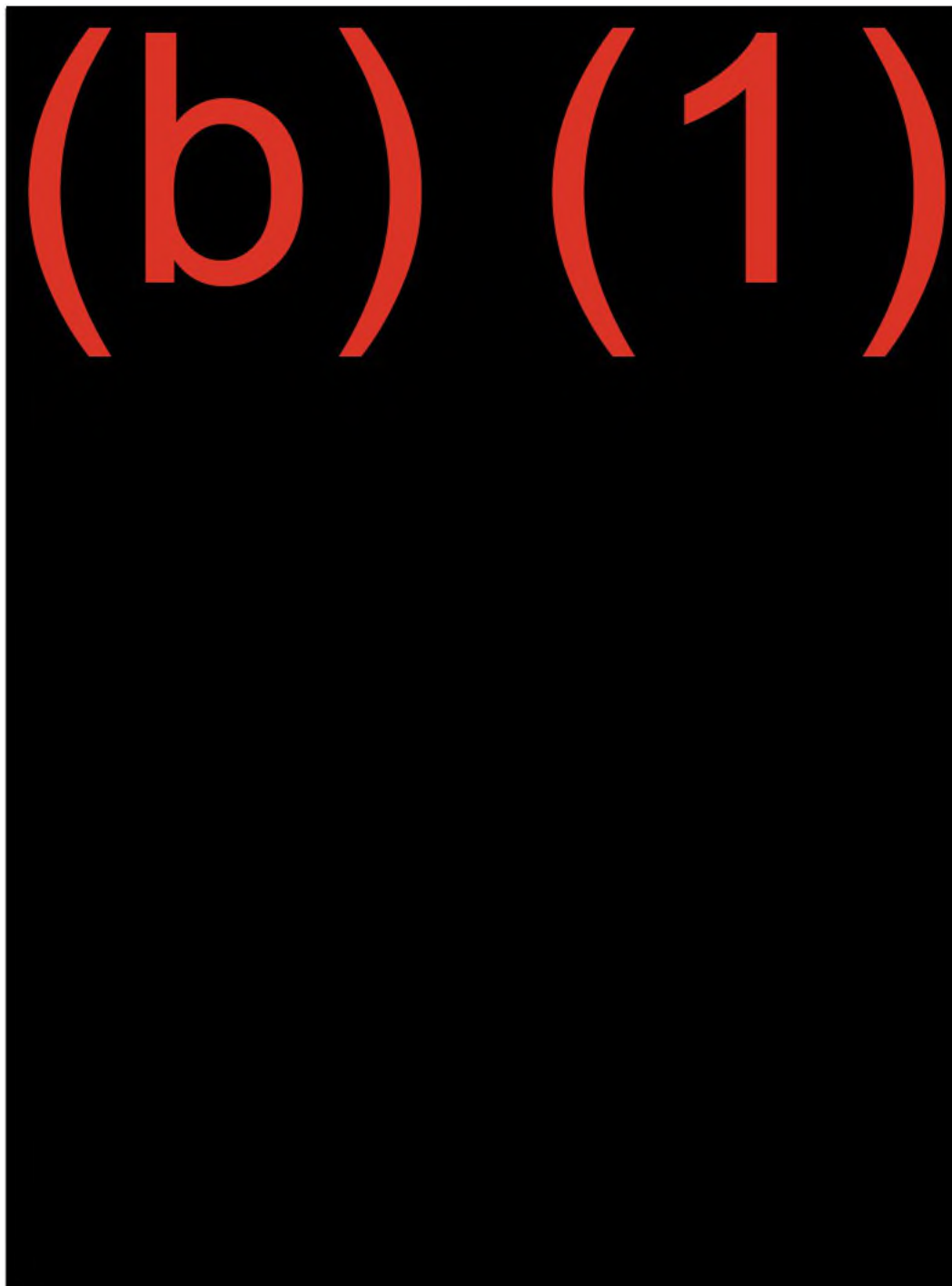


B-147

~~CONFIDENTIAL~~

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A/L

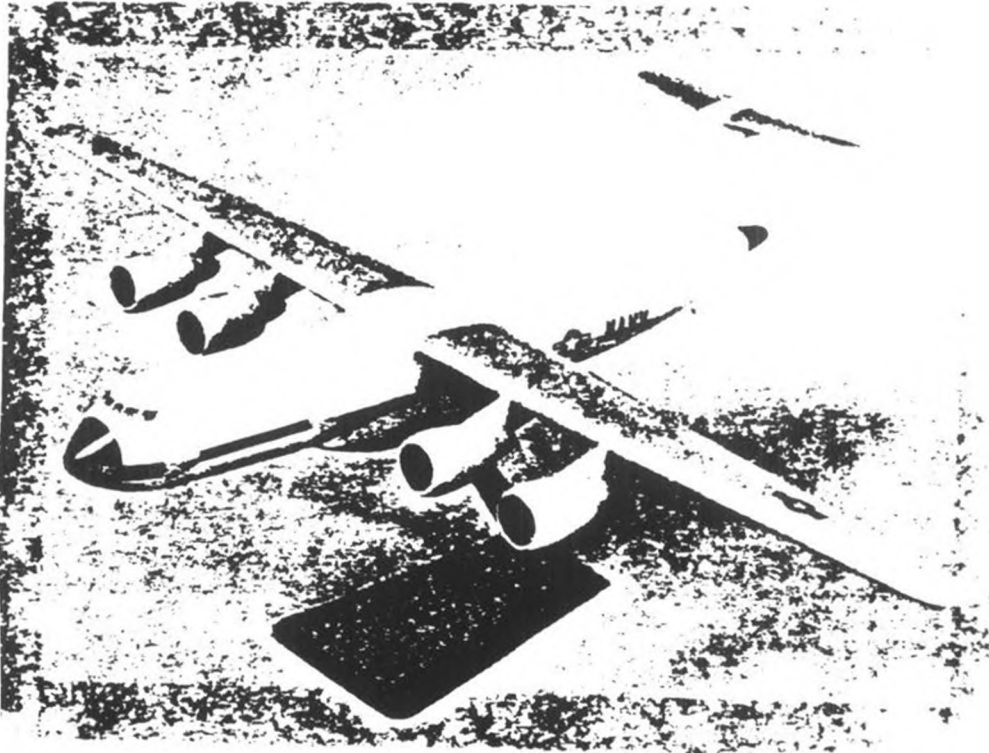


B-148

~~CONFIDENTIAL~~

UNCLASSIFIED

A/L(N)



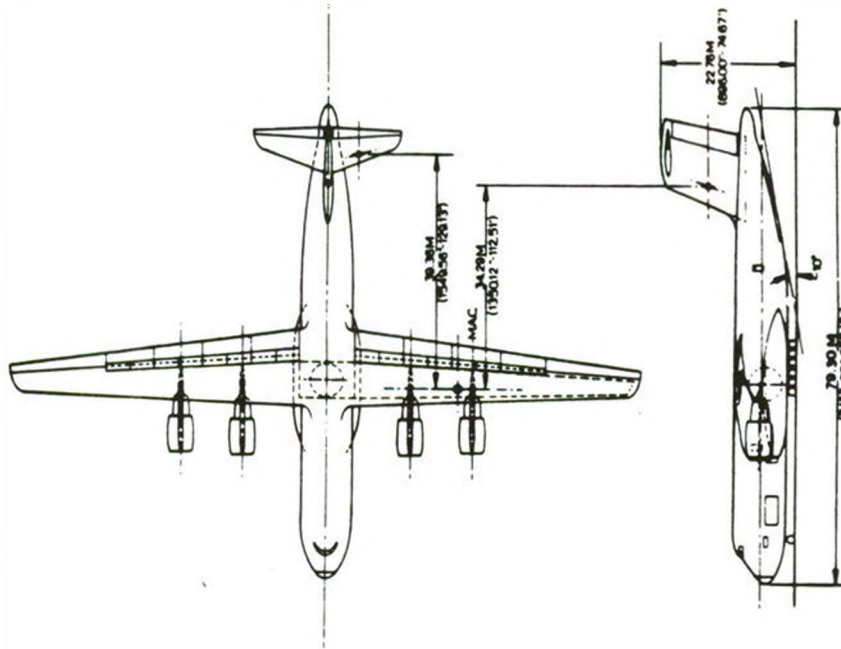
NUCLEAR POWERED AIR LOITER AIRCRAFT

POINT DESIGN SUMMARY

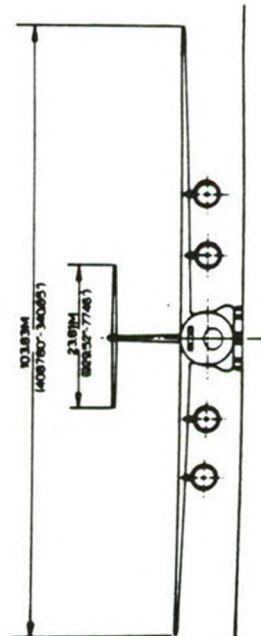
UNCLASSIFIED

UNCLASSIFIED

A/L (N)



DIMENSIONAL DATA			
AREA - SQ M	WING	HORIZ	VERT
878.45	121.88	106.85	
(8434.08)	(333.46)	(1703.89)	
SPAN - M	103.83	23.61	12.91
(340.85)	(77.46)	(42.35)	
ASPECT RATIO	12.30	4.50	10.0
TAPER RATIO	0.35	0.35	0.80
T/C	19.1%	9.50%	9.50%
ROOT CH - M	12.50	7.77	14.34
(41.03)	(25.50)	(47.08)	
TIP CH - M	4.38	2.72	11.48
(14.38)	(8.93)	(37.65)	
M.A.C. - M	8.09	5.85	12.88
(26.53)	(19.54)	(42.53)	
SWEEP @ 1/4 CH - M	0	20.16	34.91
(0.00)	(17)	(17)	

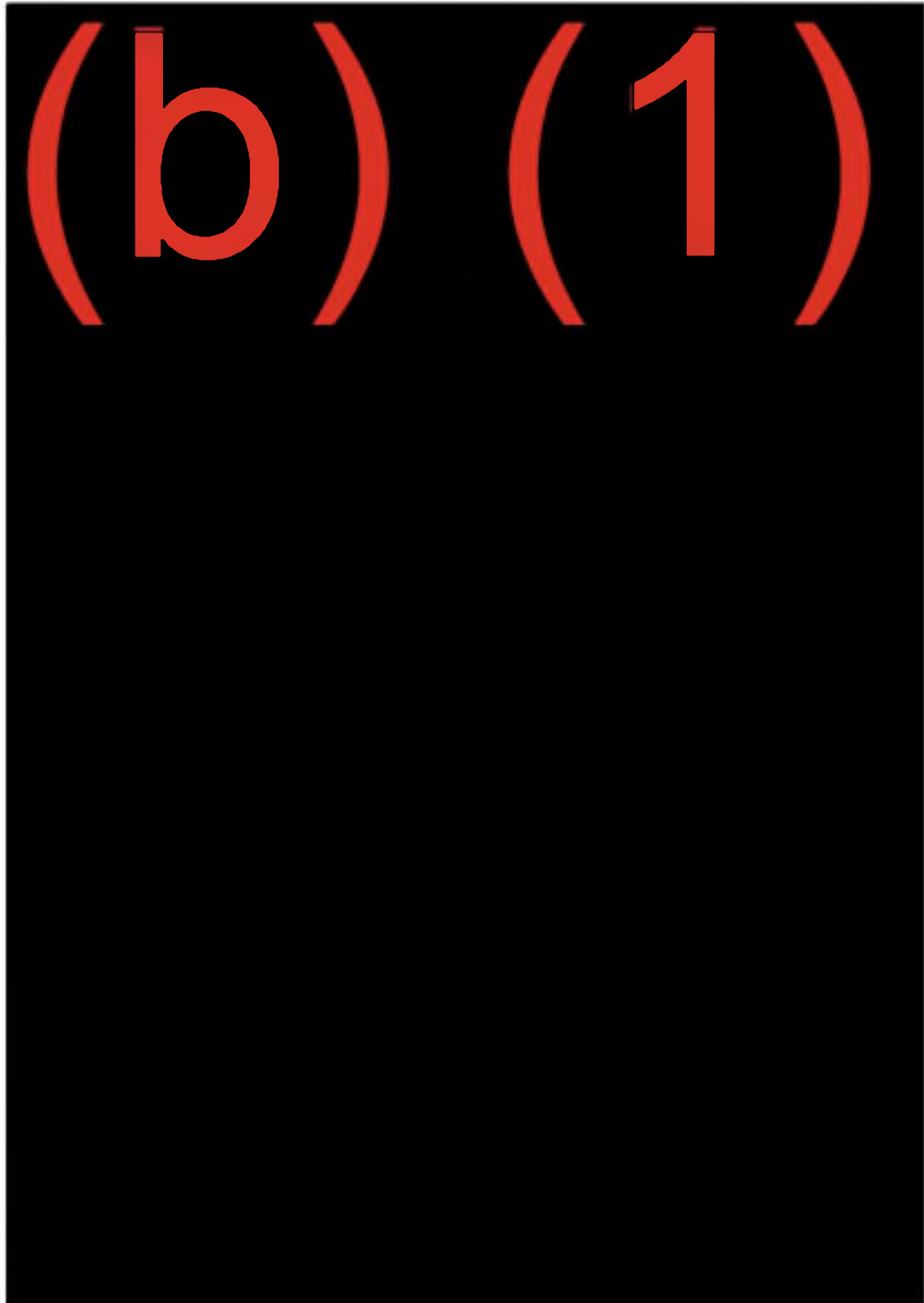


EXTERNAL ARRANGEMENT

B-150

UNCLASSIFIED

~~CONFIDENTIAL~~



B-151

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A/L(N)

(b) (1)



~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

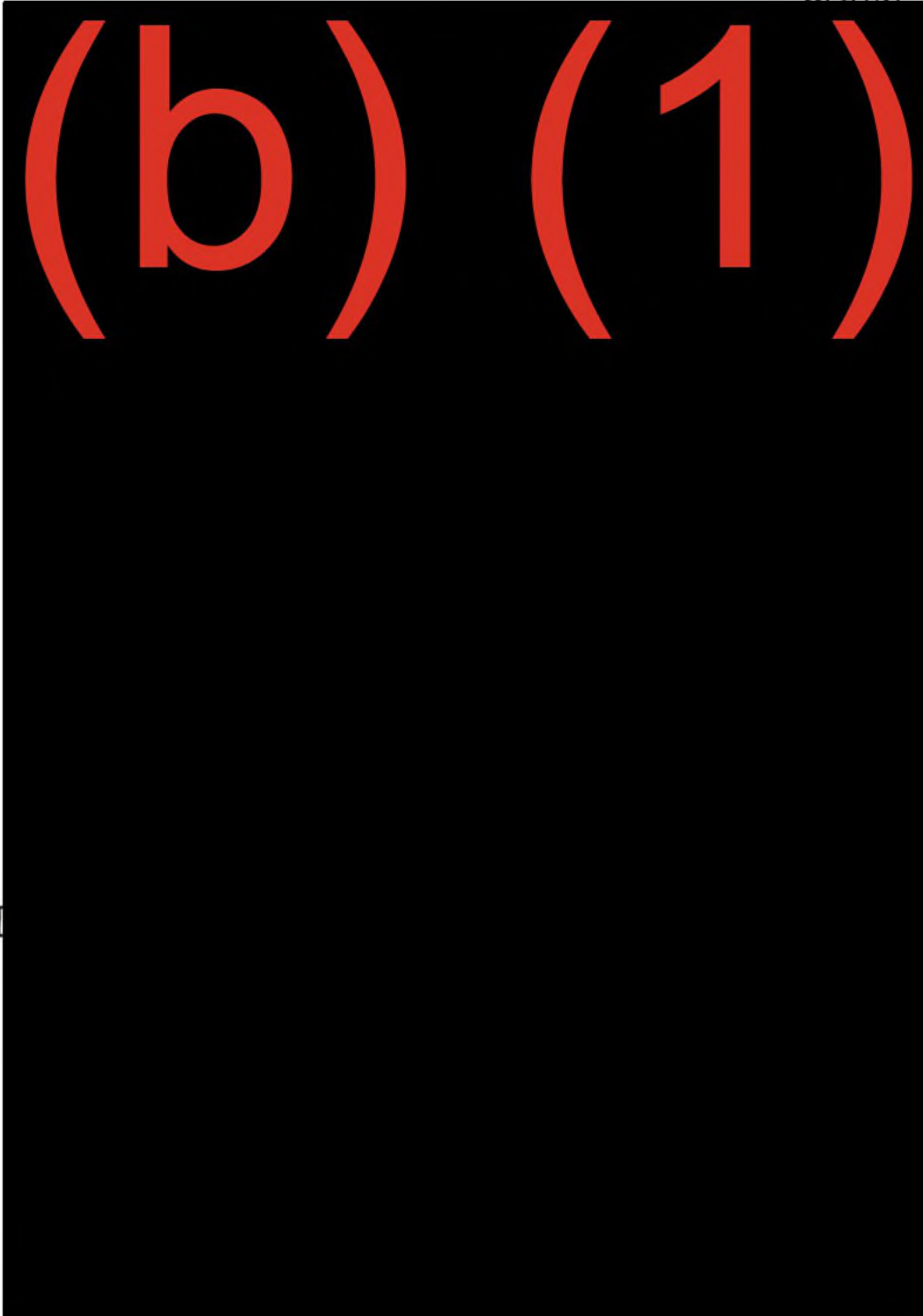


R/L (N)

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

A/L(N)



~~CONFIDENTIAL~~

UNCLASSIFIED

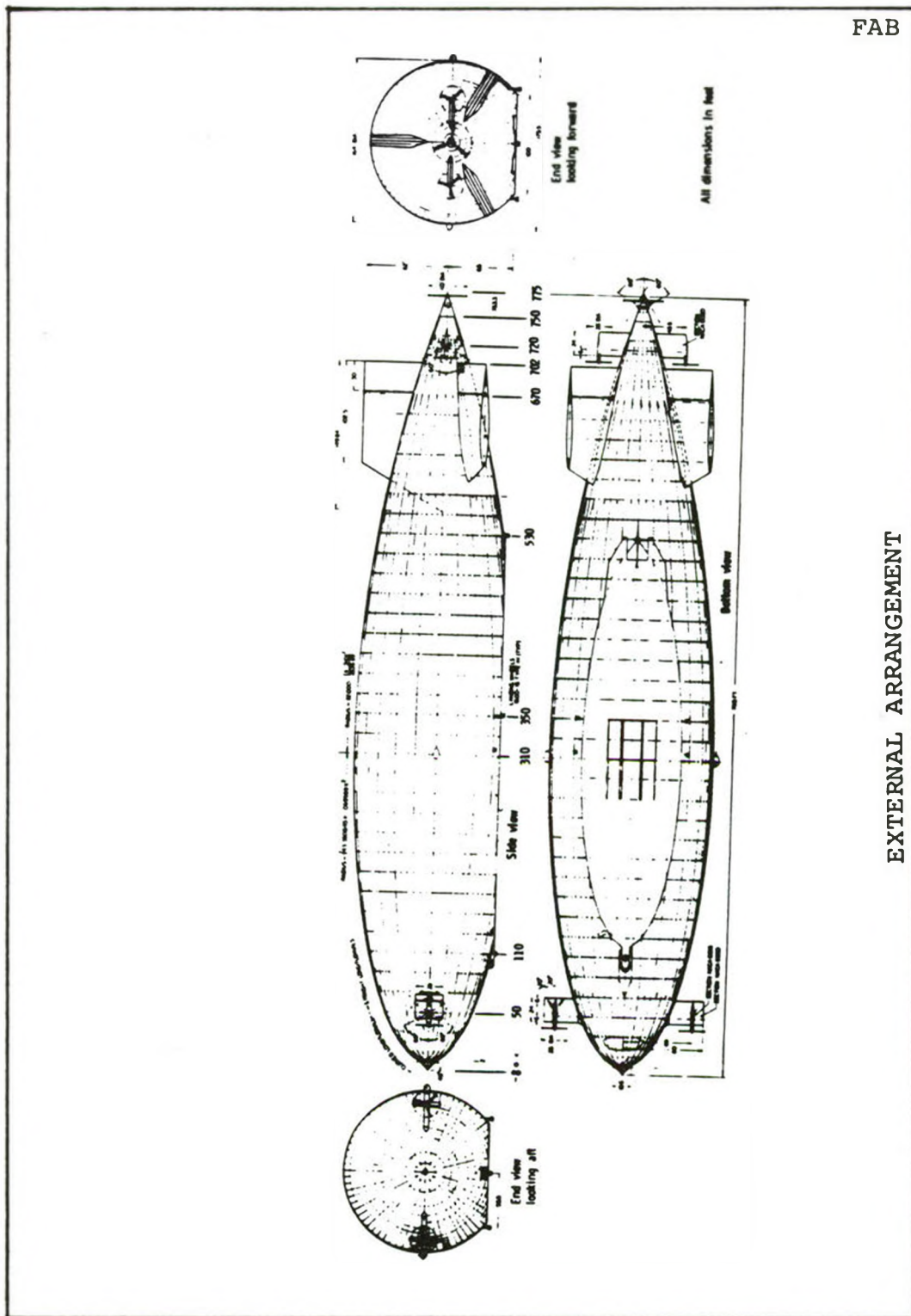
FAB



FULLY AIR BUOYANT LTA VEHICLE

POINT DESIGN SUMMARY

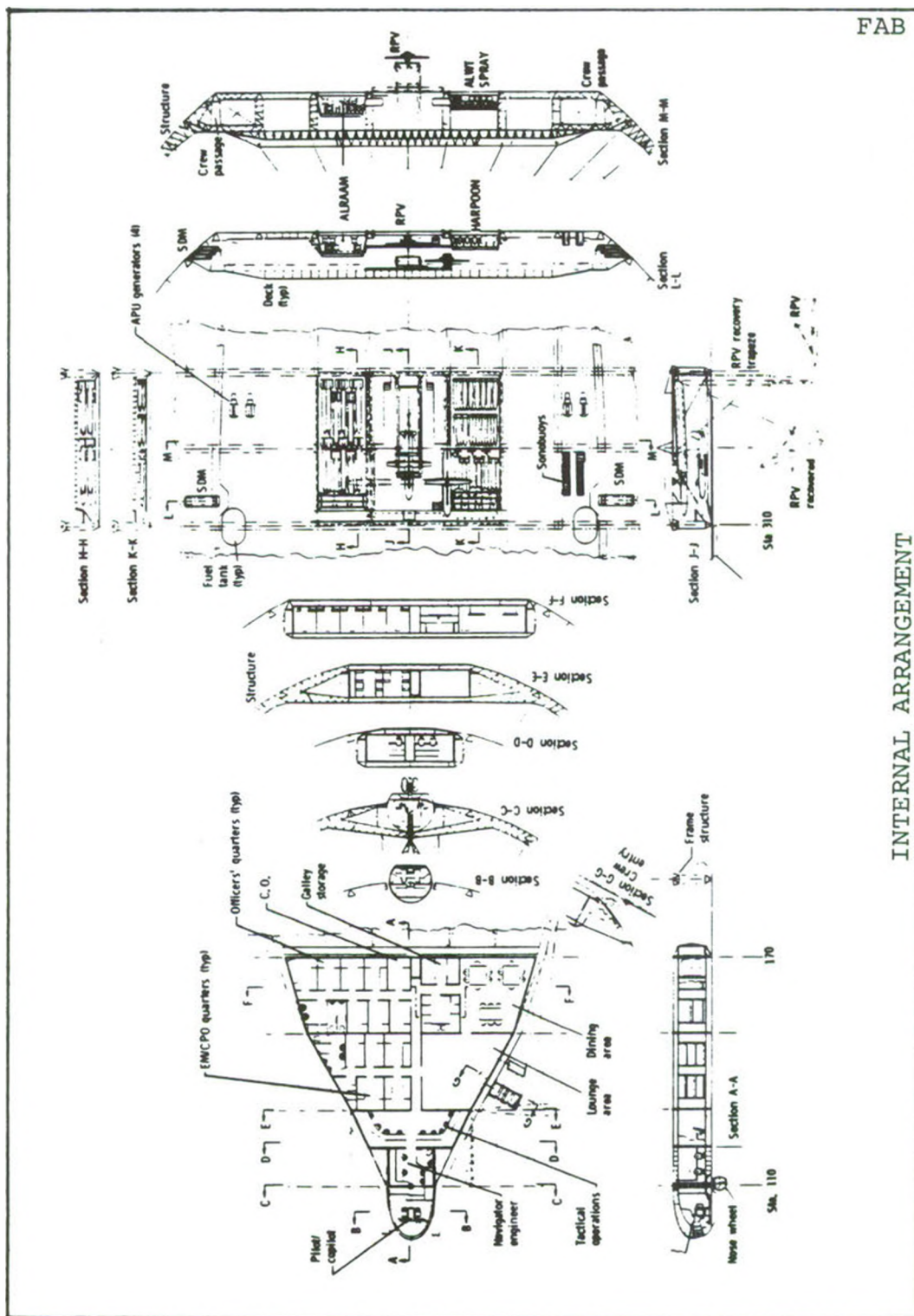
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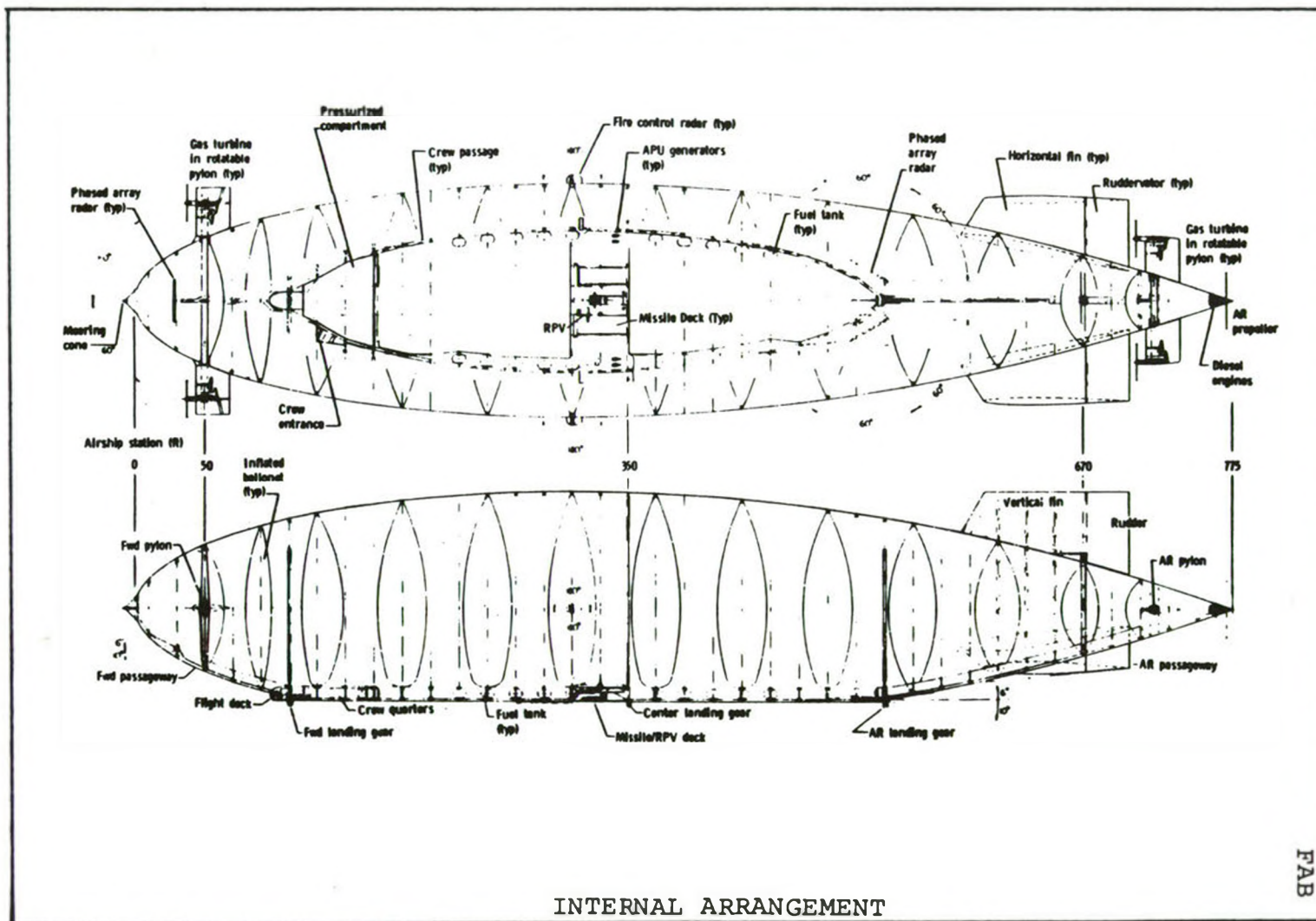
B-156

UNCLASSIFIED

UNCLASSIFIED



UNCLASSIFIED



FAB

B-158

UNCLASSIFIED

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FAB

(b) (1)



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~~CONFIDENTIAL~~



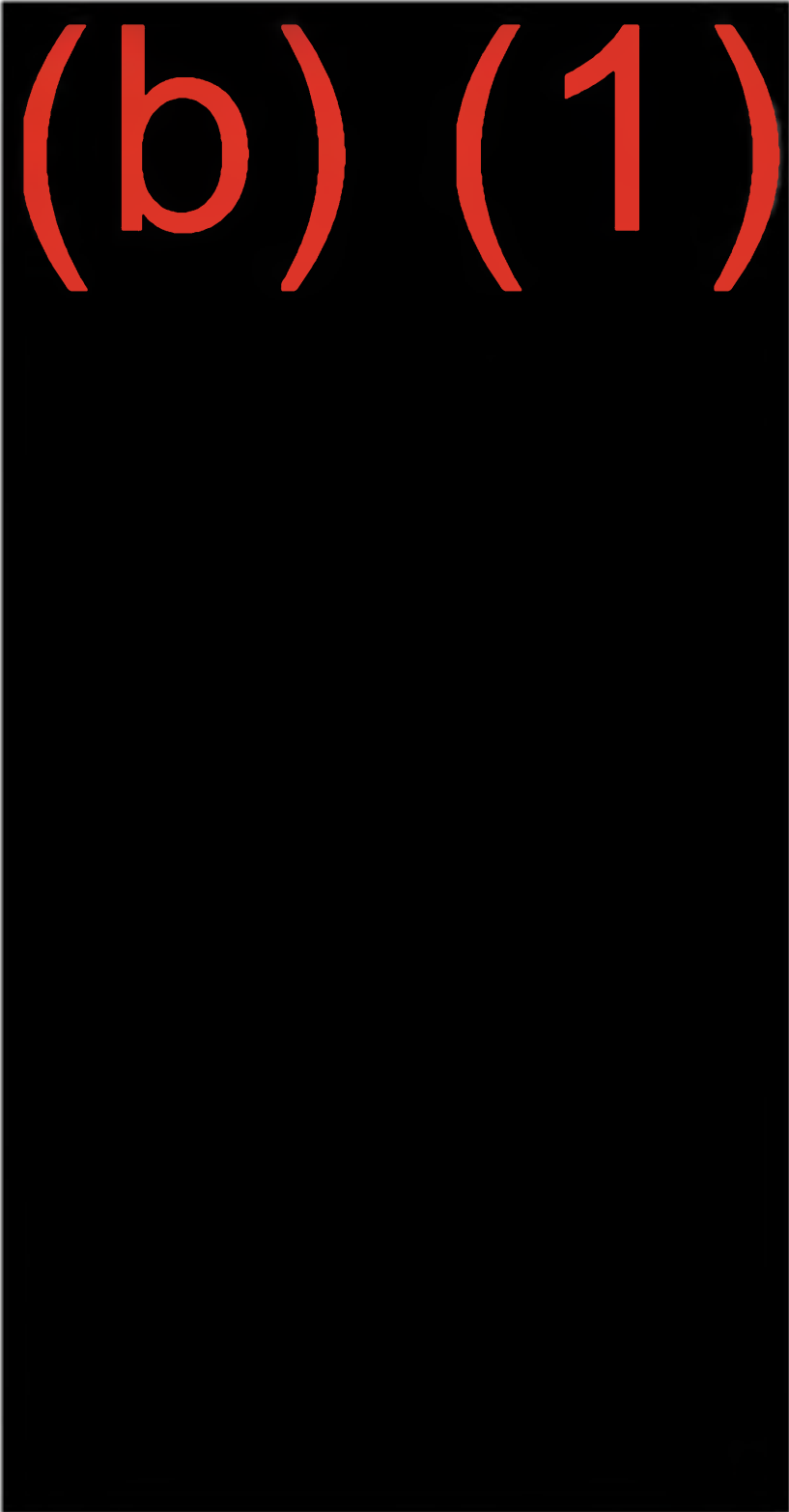
FAB

~~CONFIDENTIAL~~

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FAB

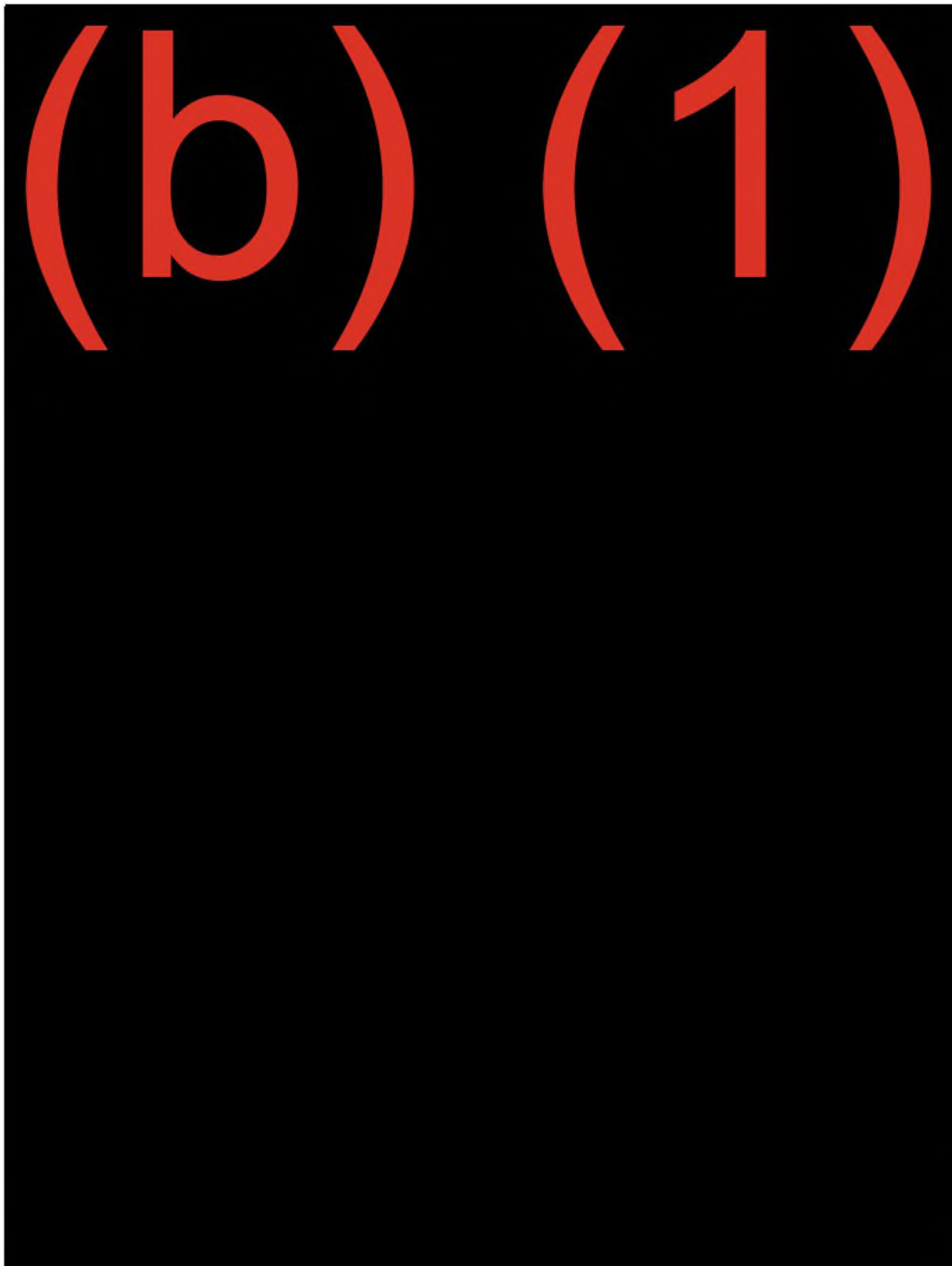
(b) (1)



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FAB



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(b) (1)



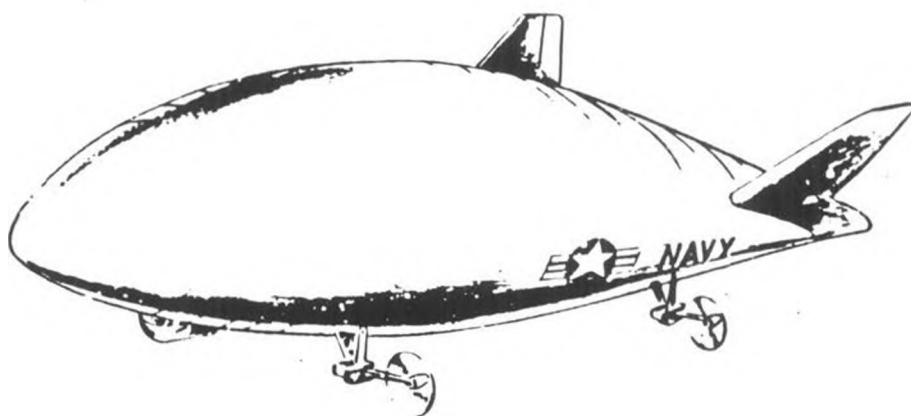
B-163

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UNCLASSIFIED

SAB



SEMAIR BUOYANT LTA VEHICLE

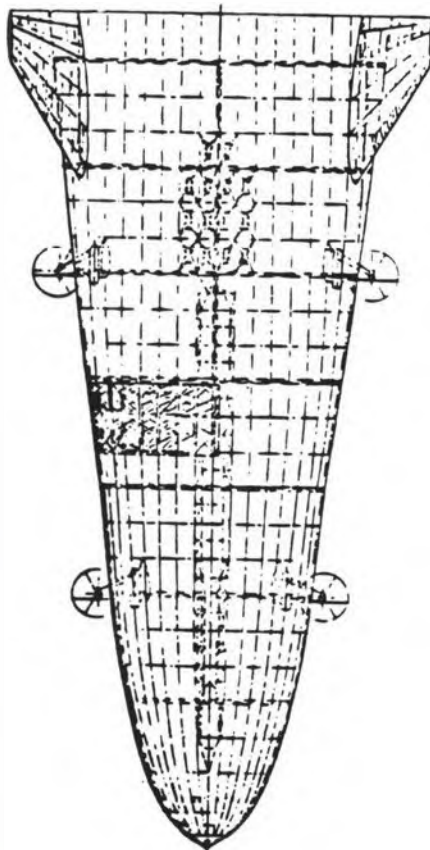
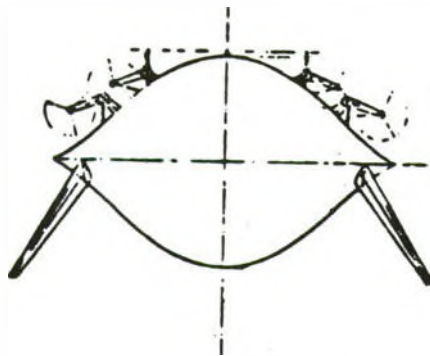
POINT DESIGN SUMMARY

B-165

UNCLASSIFIED

UNCLASSIFIED

SAB



EXTERNAL ARRANGEMENT

B-166

UNCLASSIFIED

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SAB

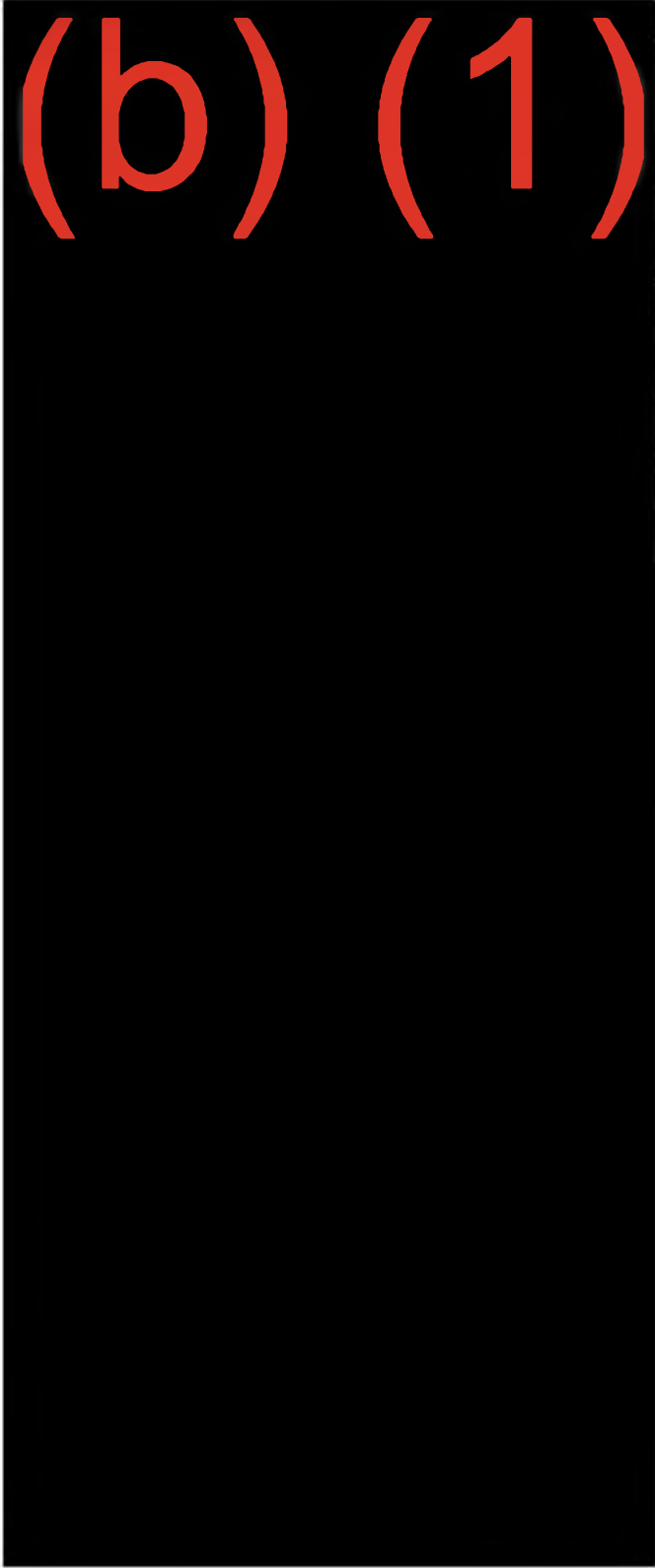
(b) (1)



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(b) (1)



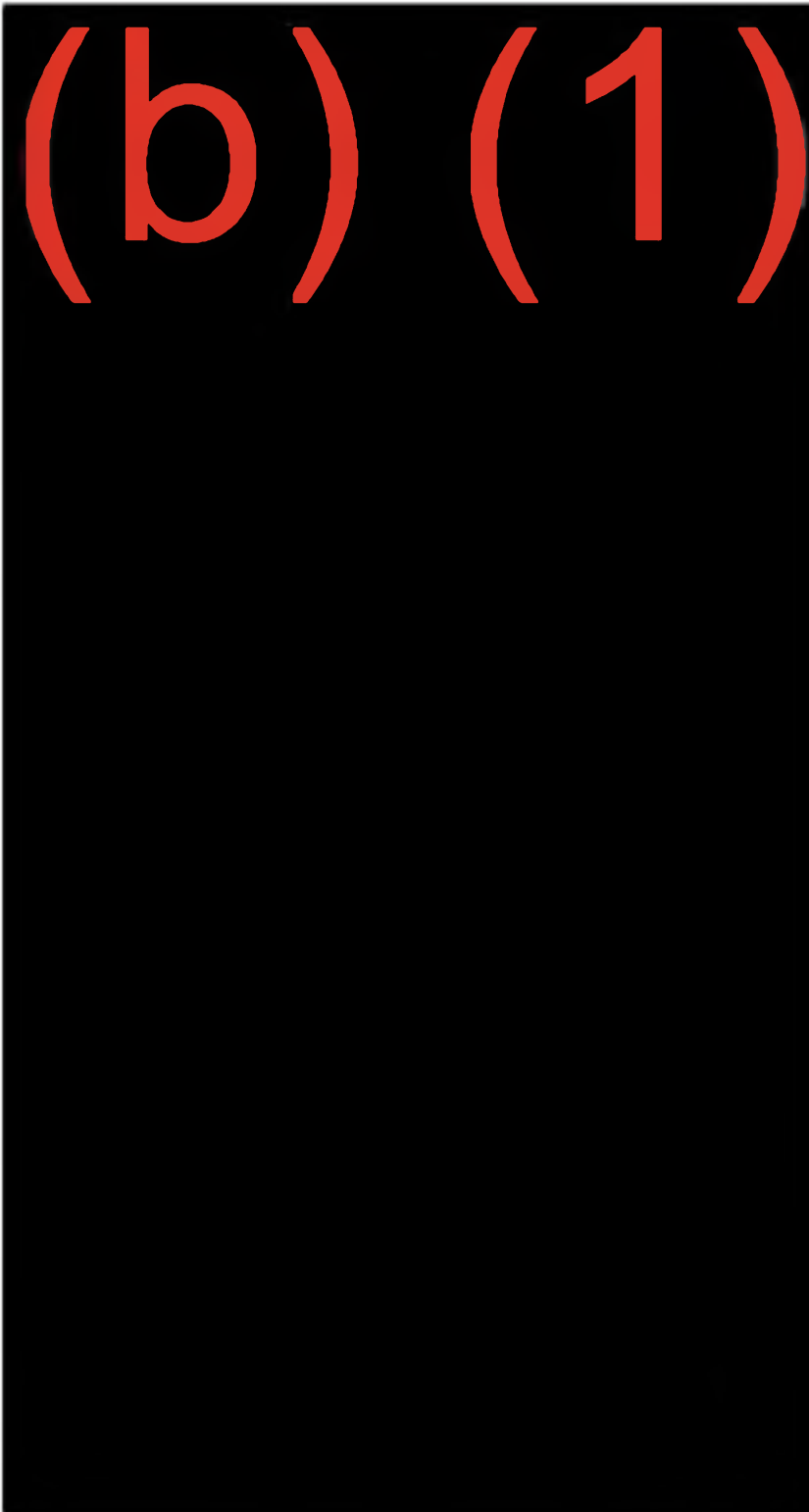
SAB

~~CONFIDENTIAL~~

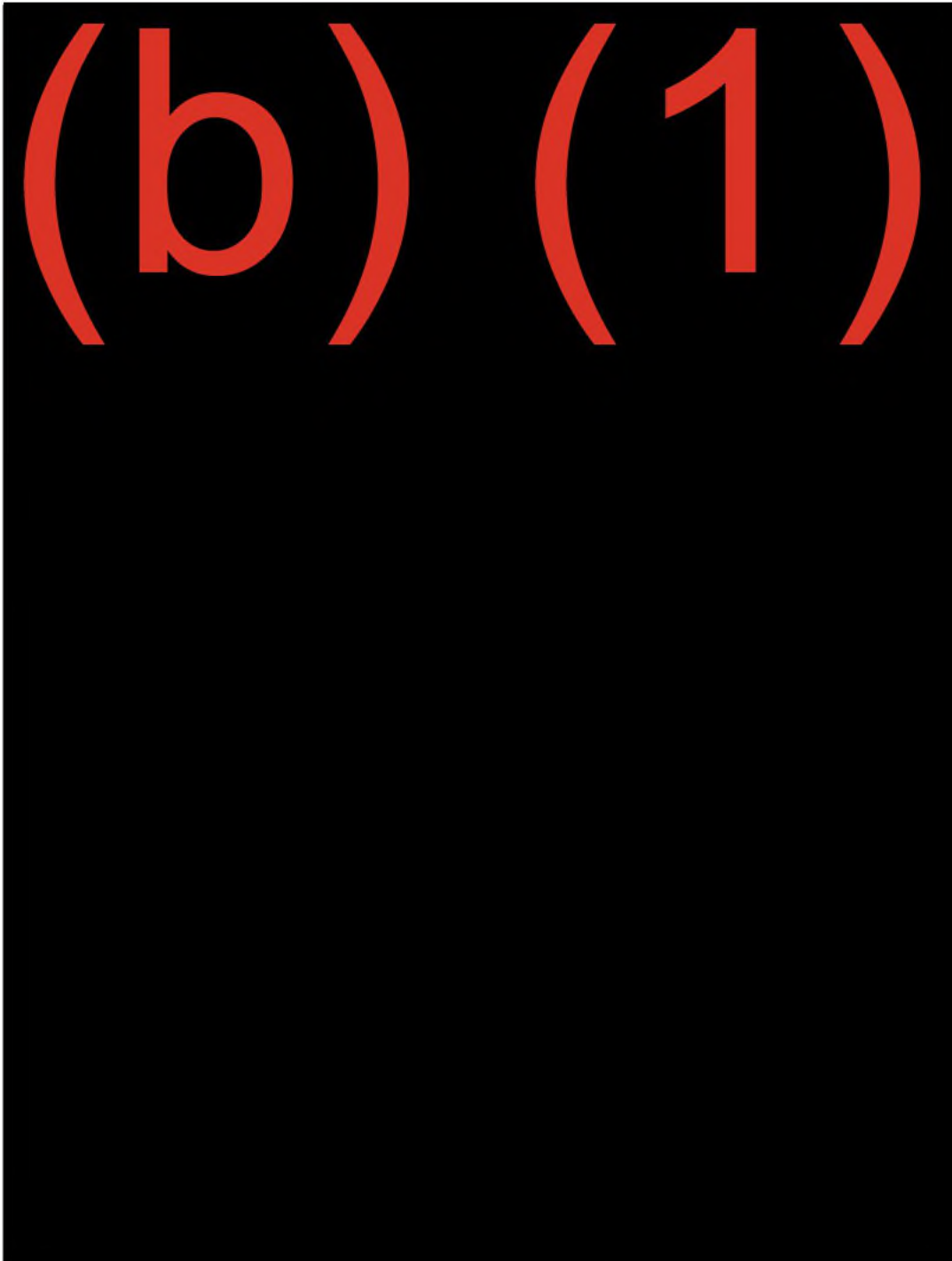
~~CONFIDENTIAL~~

SAB

(b) (1)



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(b) (1)

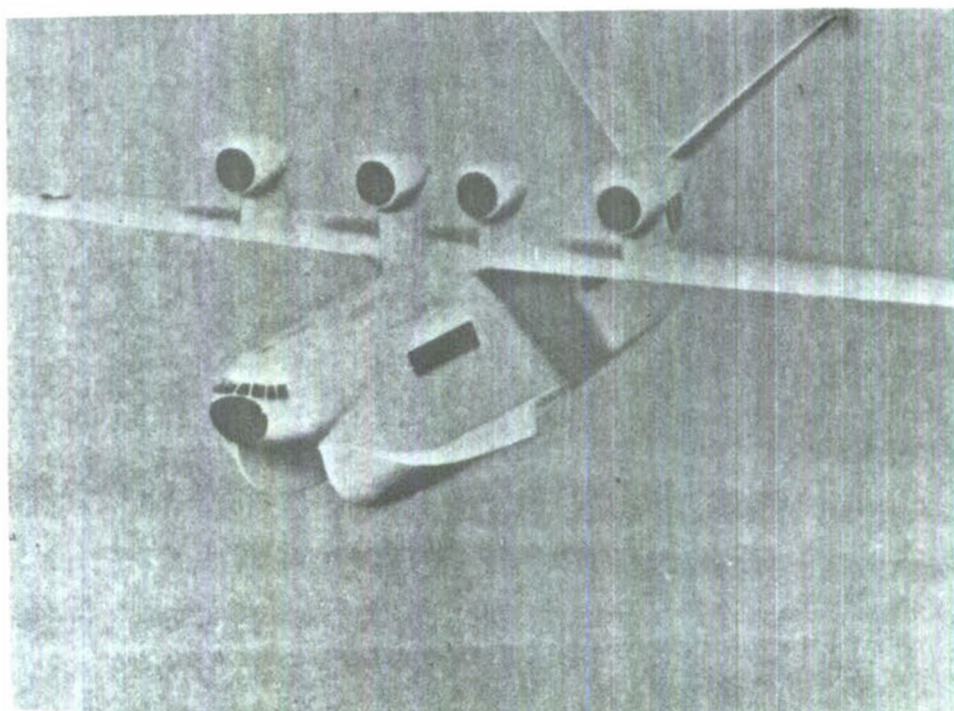
B-171

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~~CONFIDENTIAL~~

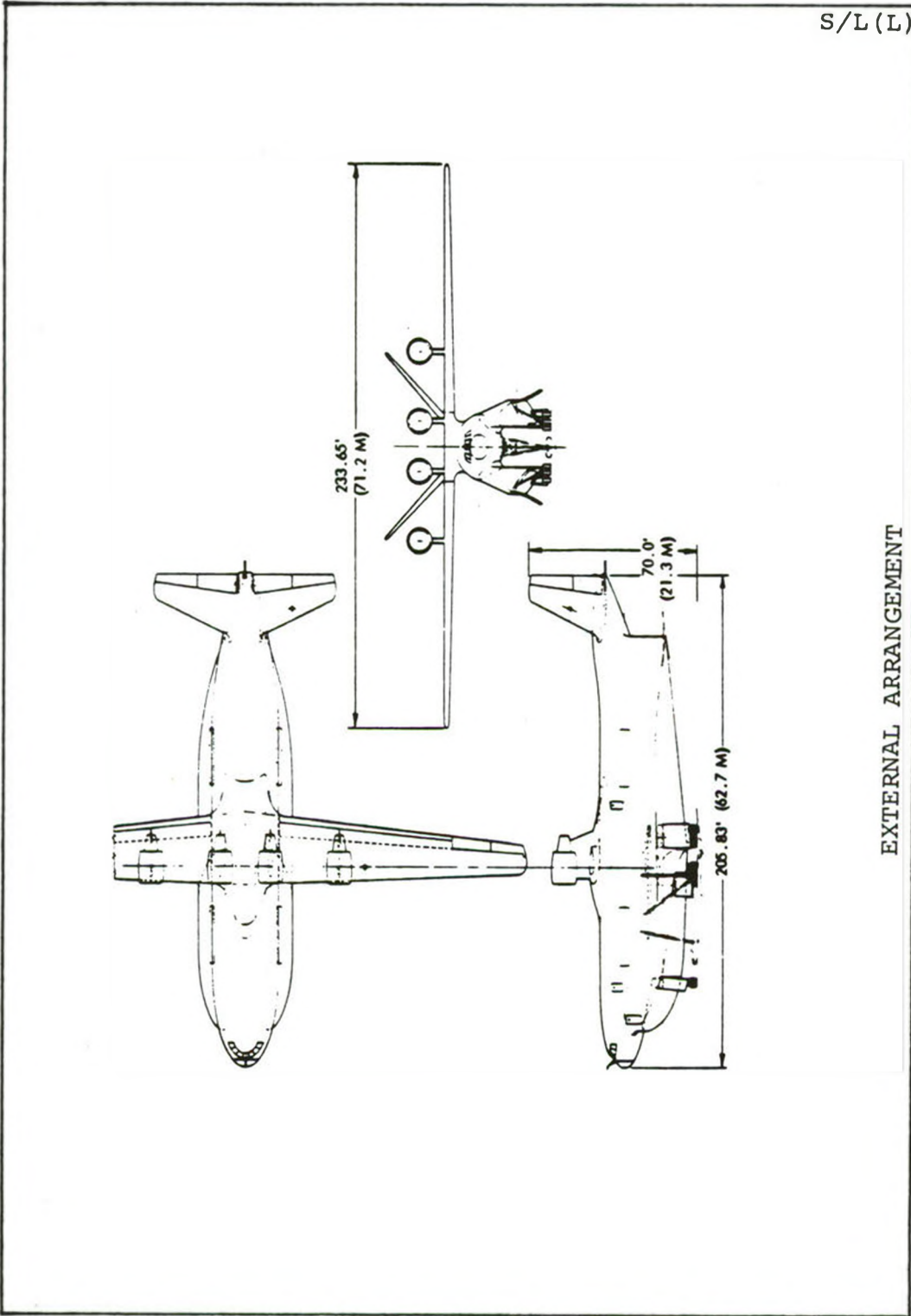
UNCLASSIFIED

S/L (L)



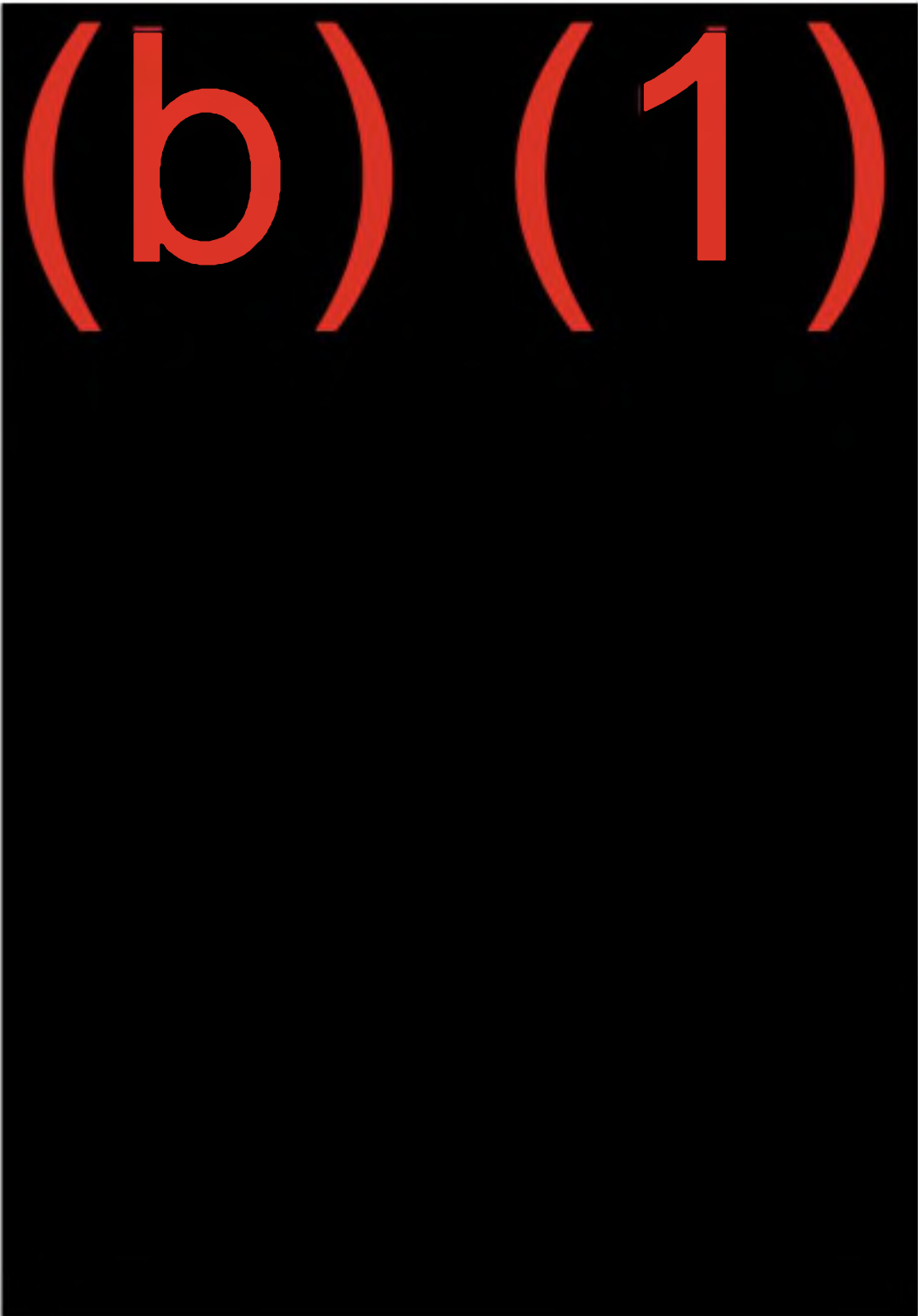
LARGE SEA AIR LOITER AIRCRAFT

POINT DESIGN SUMMARY



~~CONFIDENTIAL~~

(b) (1)

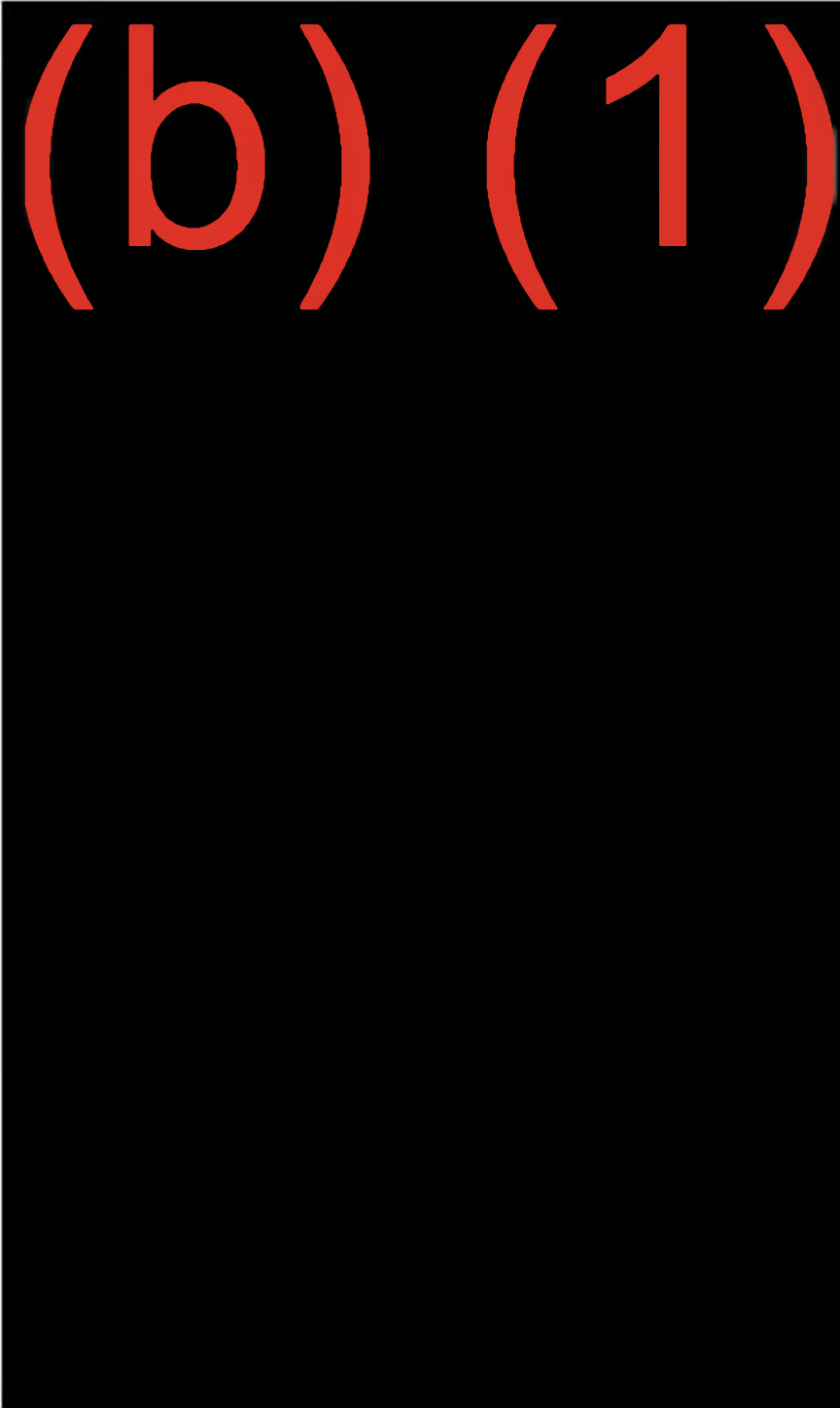


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S/L(L)

(b) (1)



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S/L (L)

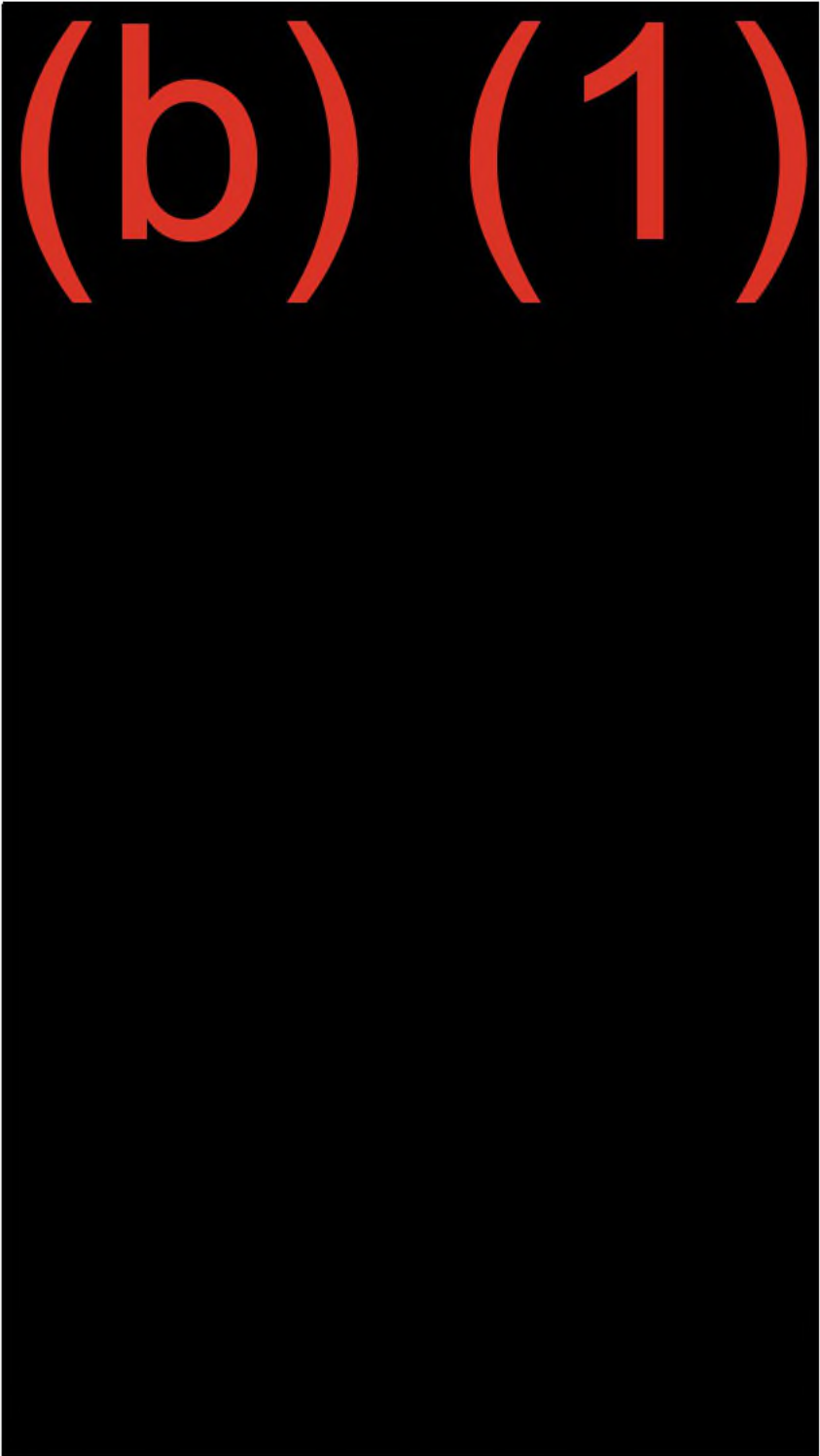


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S/(L)

(b) (1)



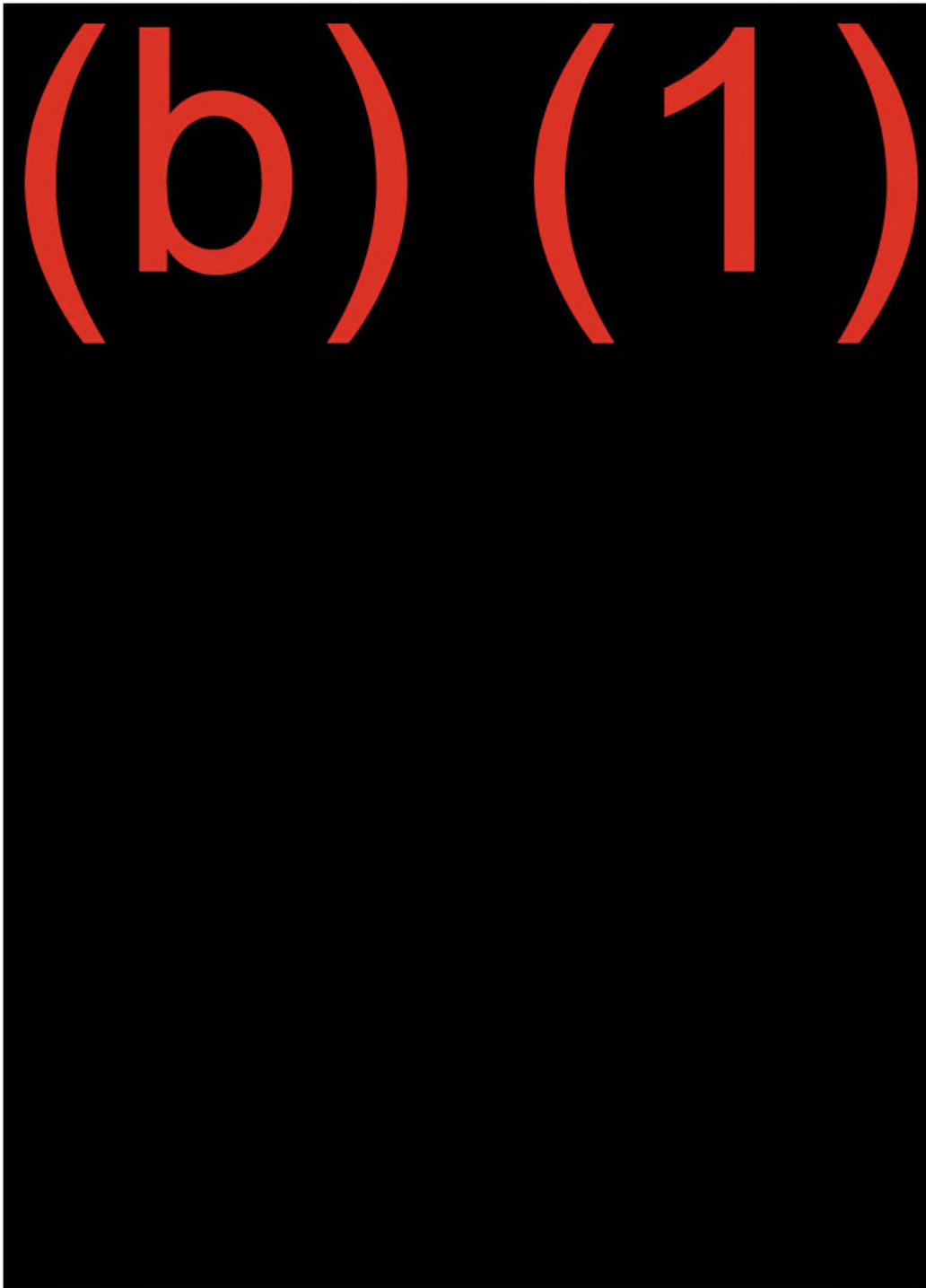
B-178

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S/L(L)

(b) (1)



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S/L(L)

(b) (1)

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UNCLASSIFIED

S/L(S)



SMALL SEA LOITER AIRCRAFT

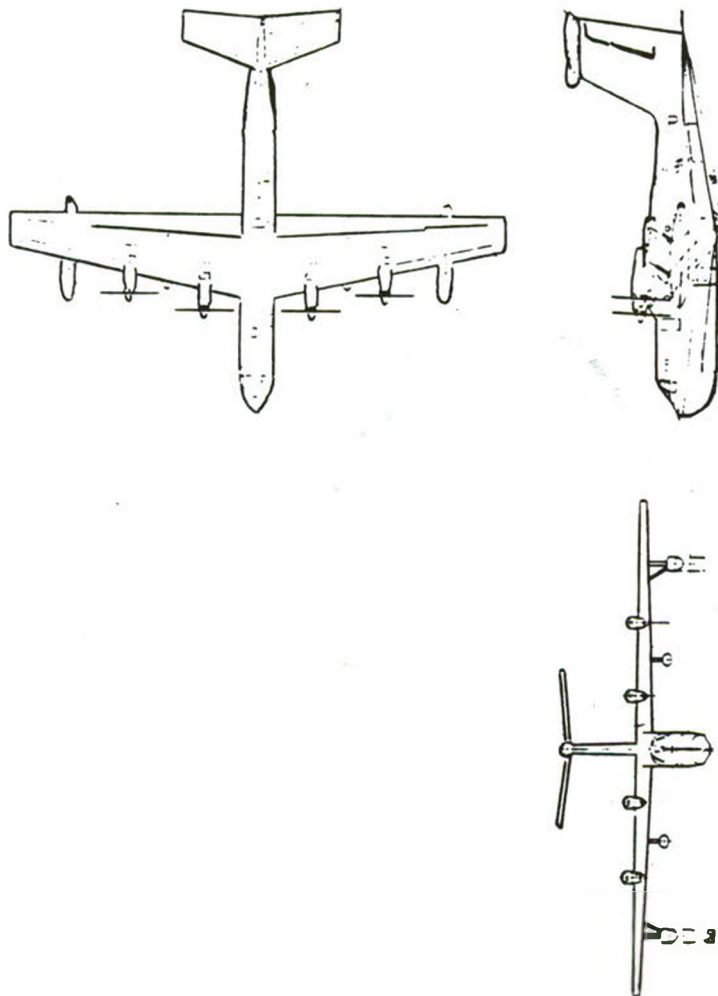
POINT DESIGN SUMMARY

UNCLASSIFIED

B-181

UNCLASSIFIED

S/L(S)

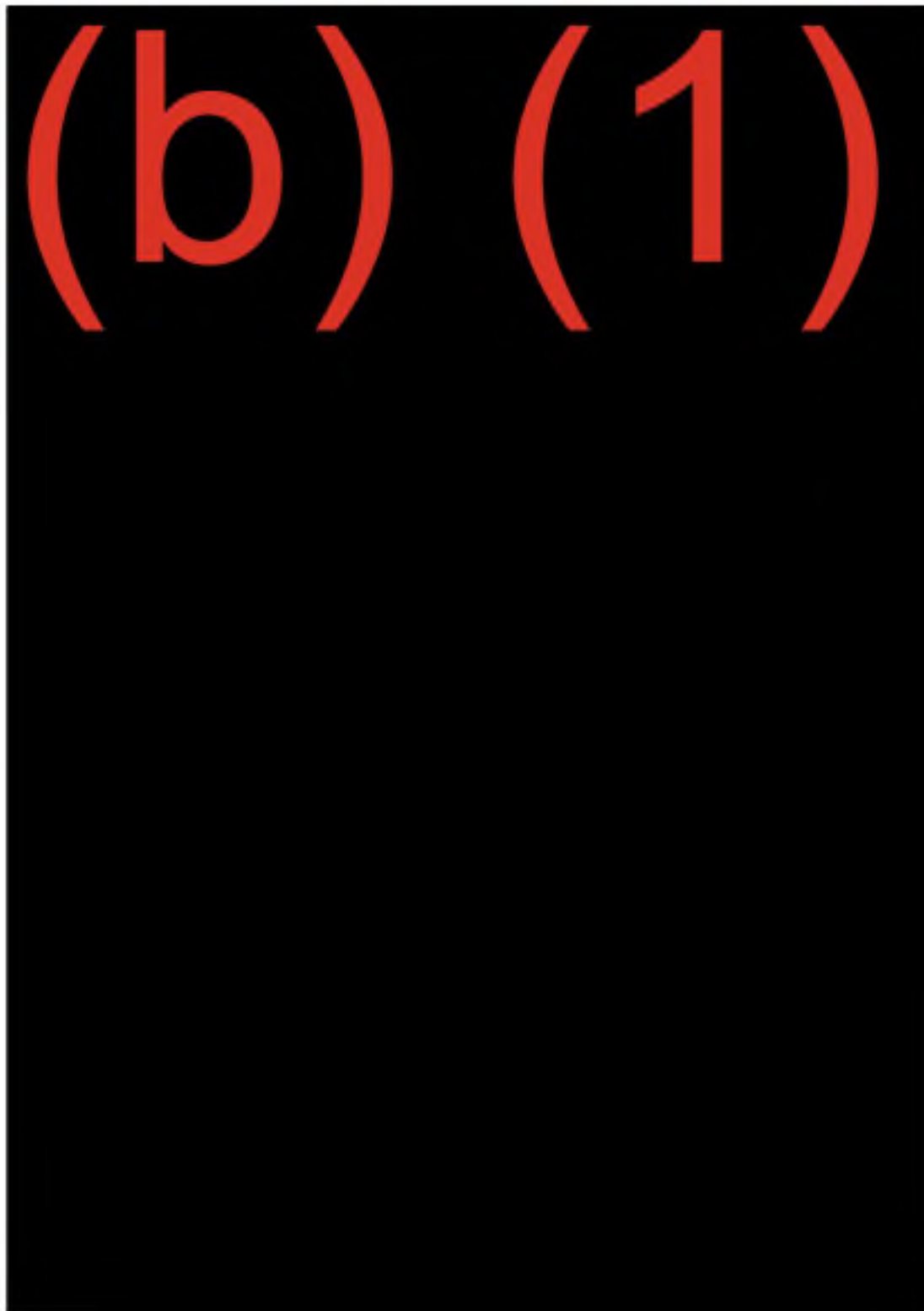


EXTERNAL ARRANGEMENT

UNCLASSIFIED

B-182

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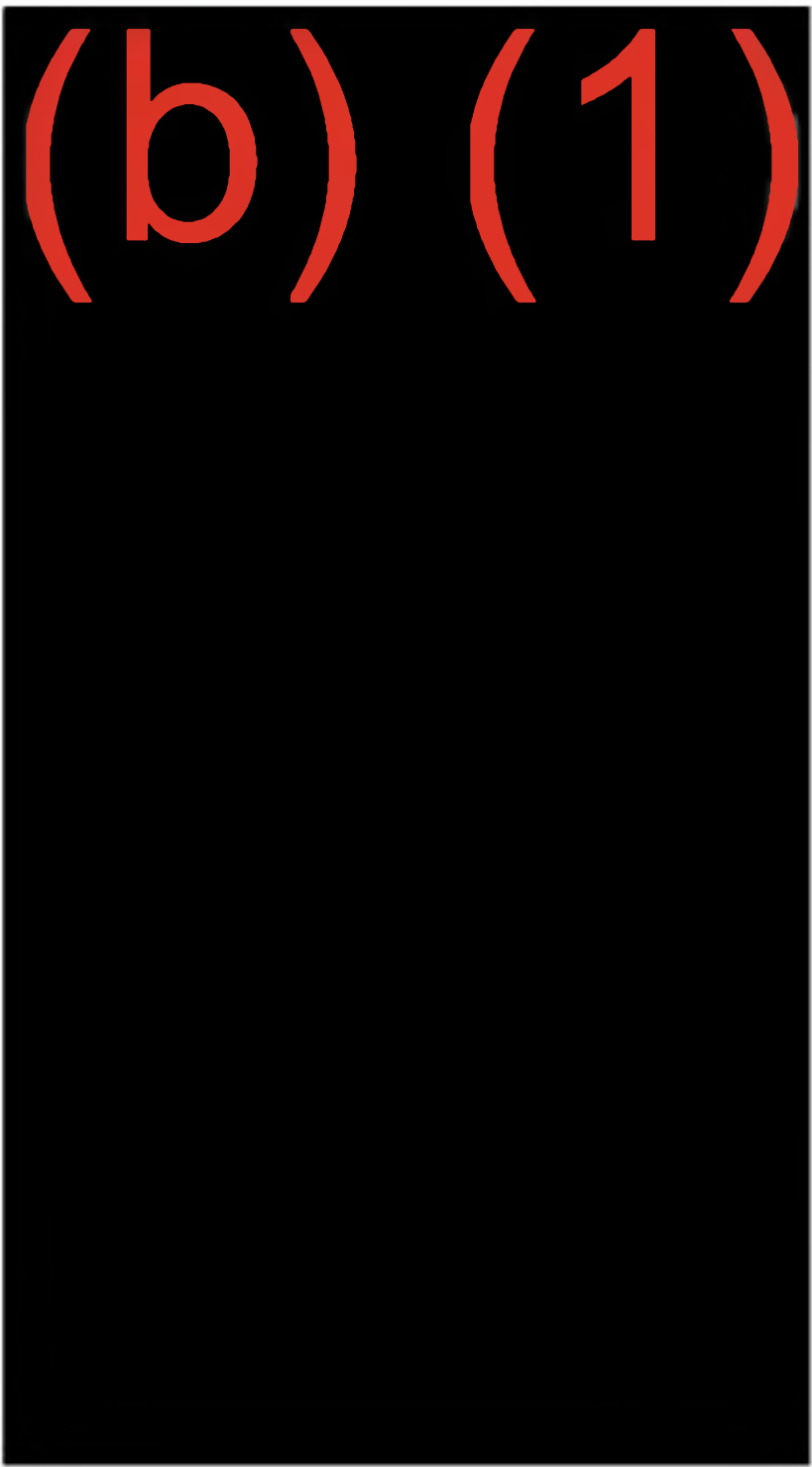


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S/L(S)

(b) (1)



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~~CONFIDENTIAL~~



S/L (S)

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S/L(S)

(b) (1)

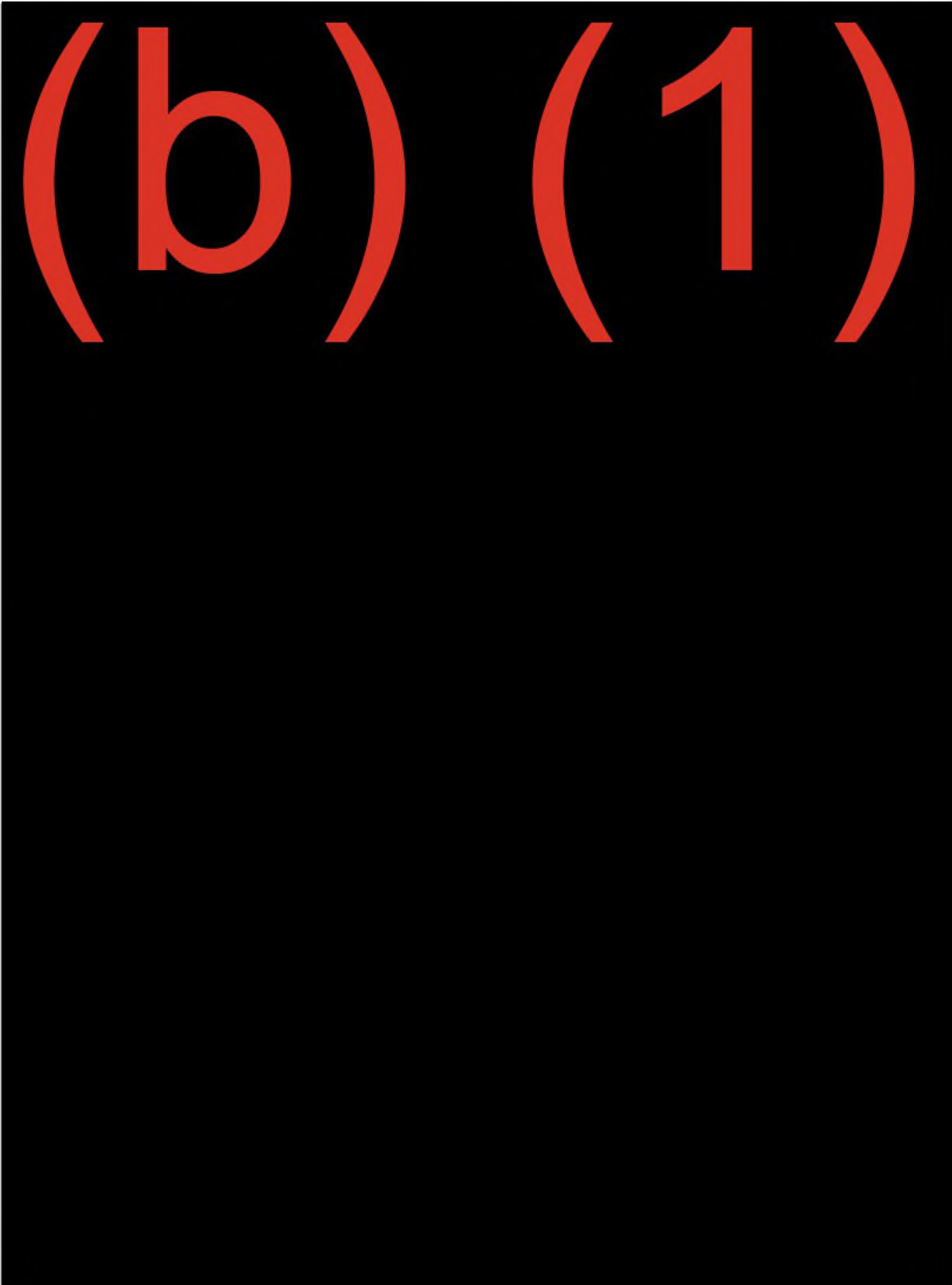


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S/L(S)

(b) (1)



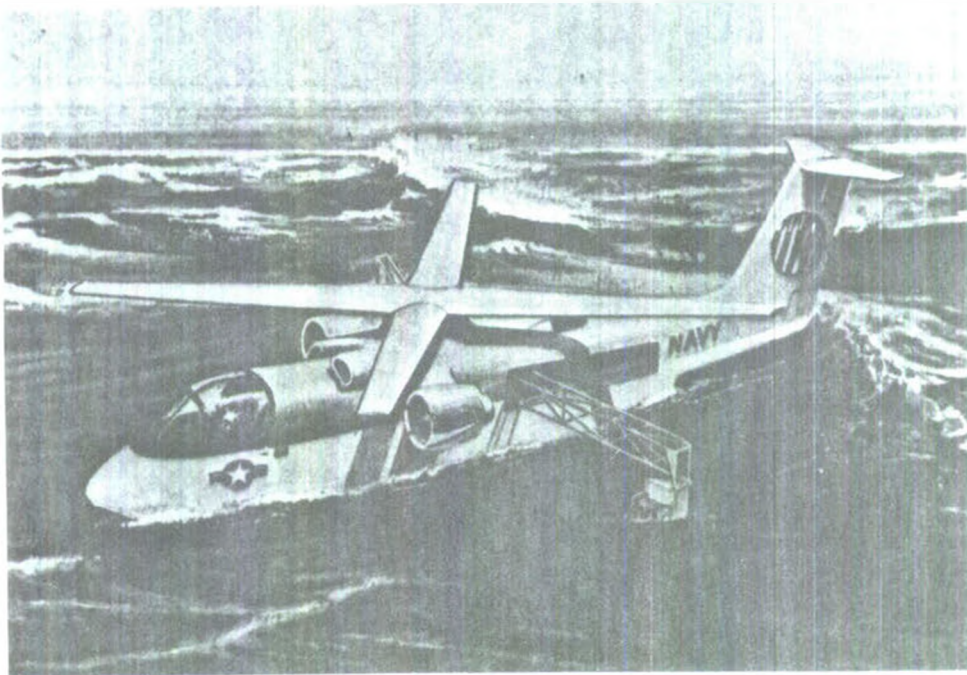
B-187

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UNCLASSIFIED

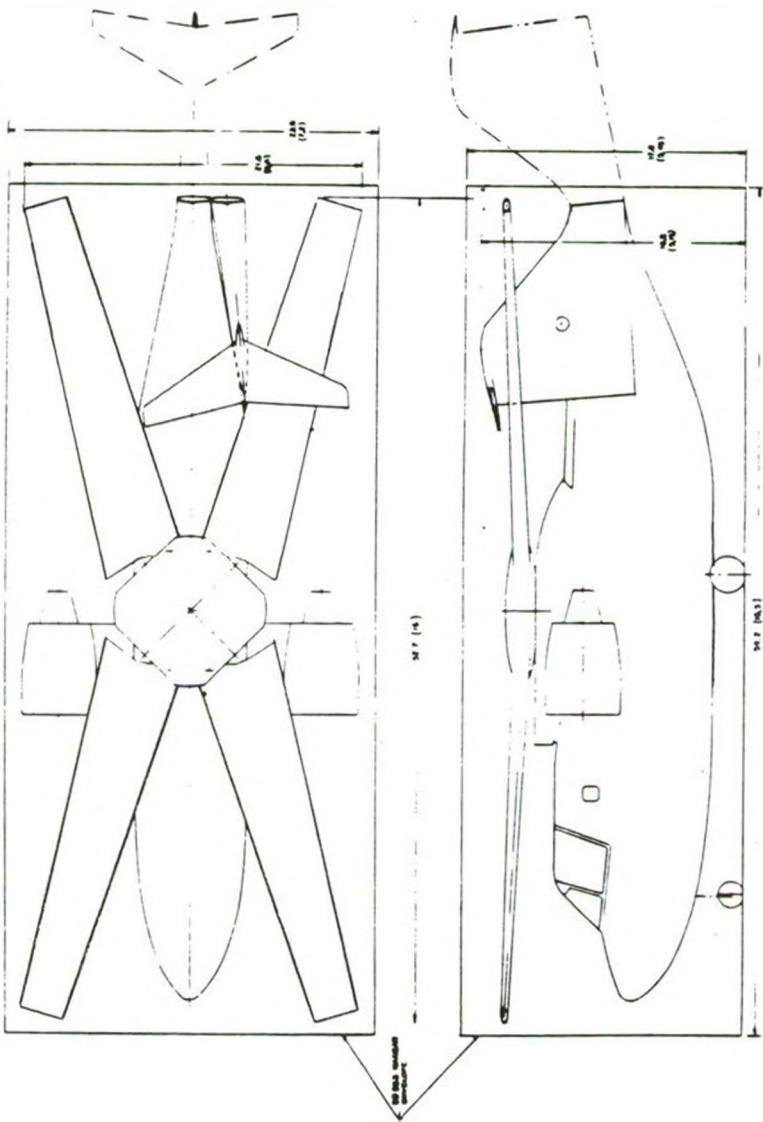
S/L(V)



SHIP BASED V/STOL SEA LOITER AIRCRAFT

POINT DESIGN SUMMARY

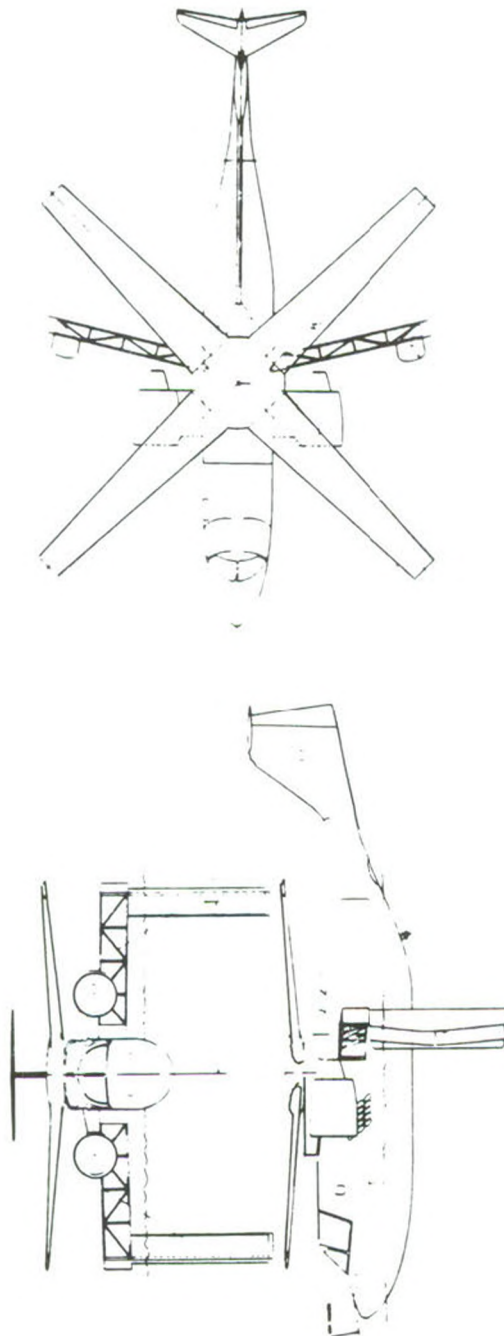
UNCLASSIFIED



EXTERNAL ARRANGEMENT - STOWAGE CONFIGURATION

UNCLASSIFIED

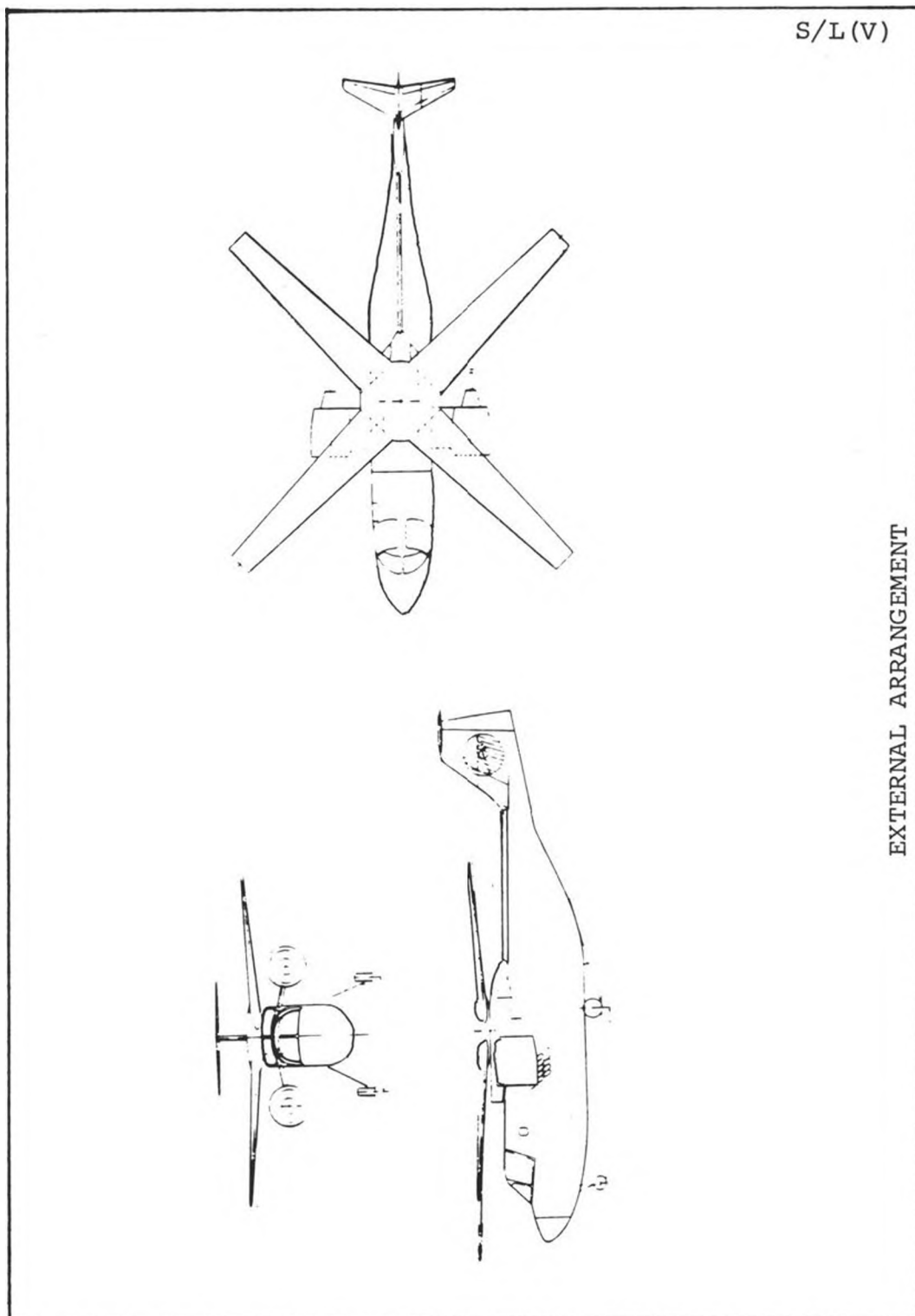
S/L(V)



EXTERNAL ARRANGEMENT WHILE SEA SITTING

UNCLASSIFIED

UNCLASSIFIED

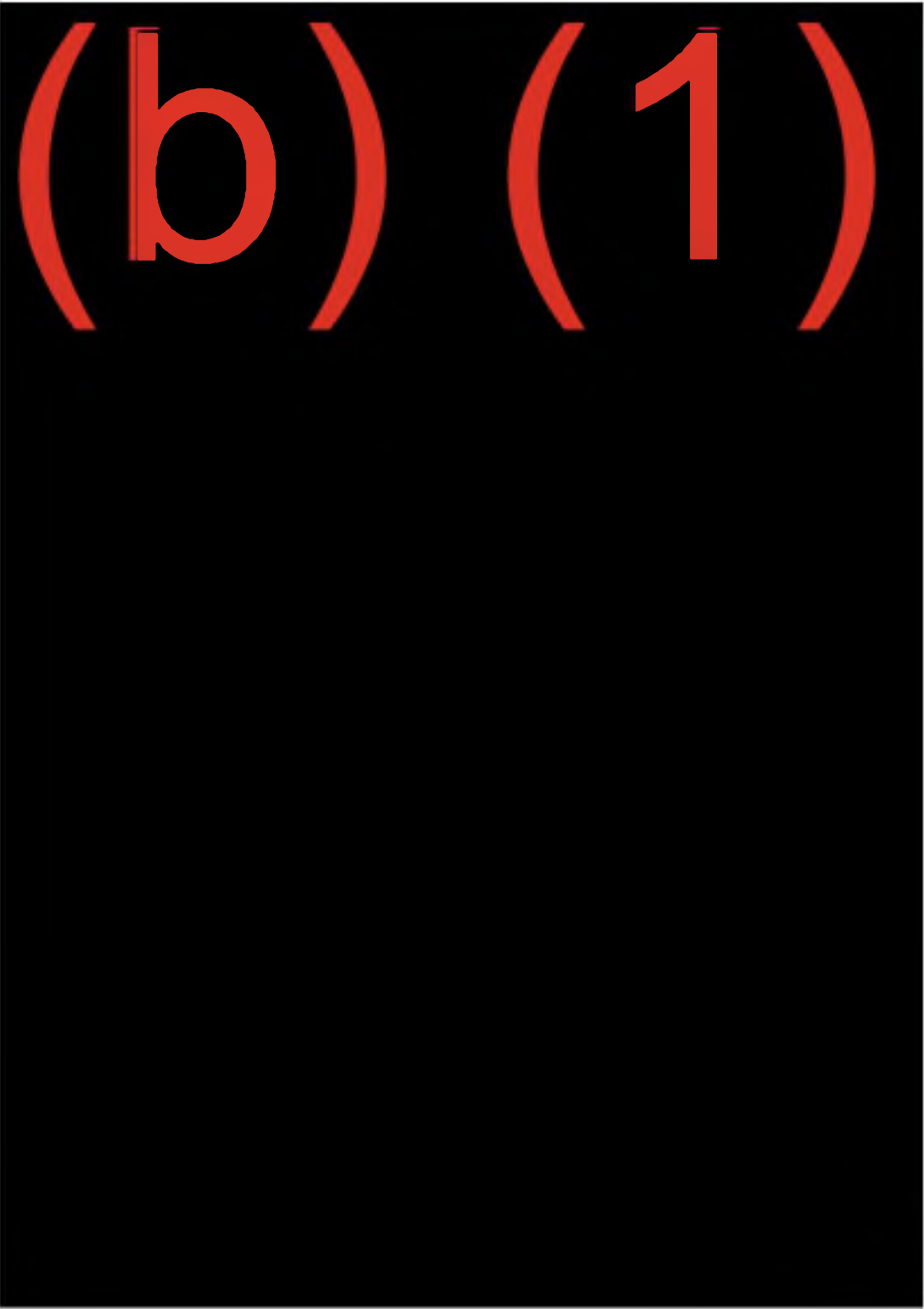


B-192

UNCLASSIFIED

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(b) (1)



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S/L(V)

(b) (1)



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S/L(V)

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

S/L(V)

(b) (1)



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S/L(V)

(b) (1)

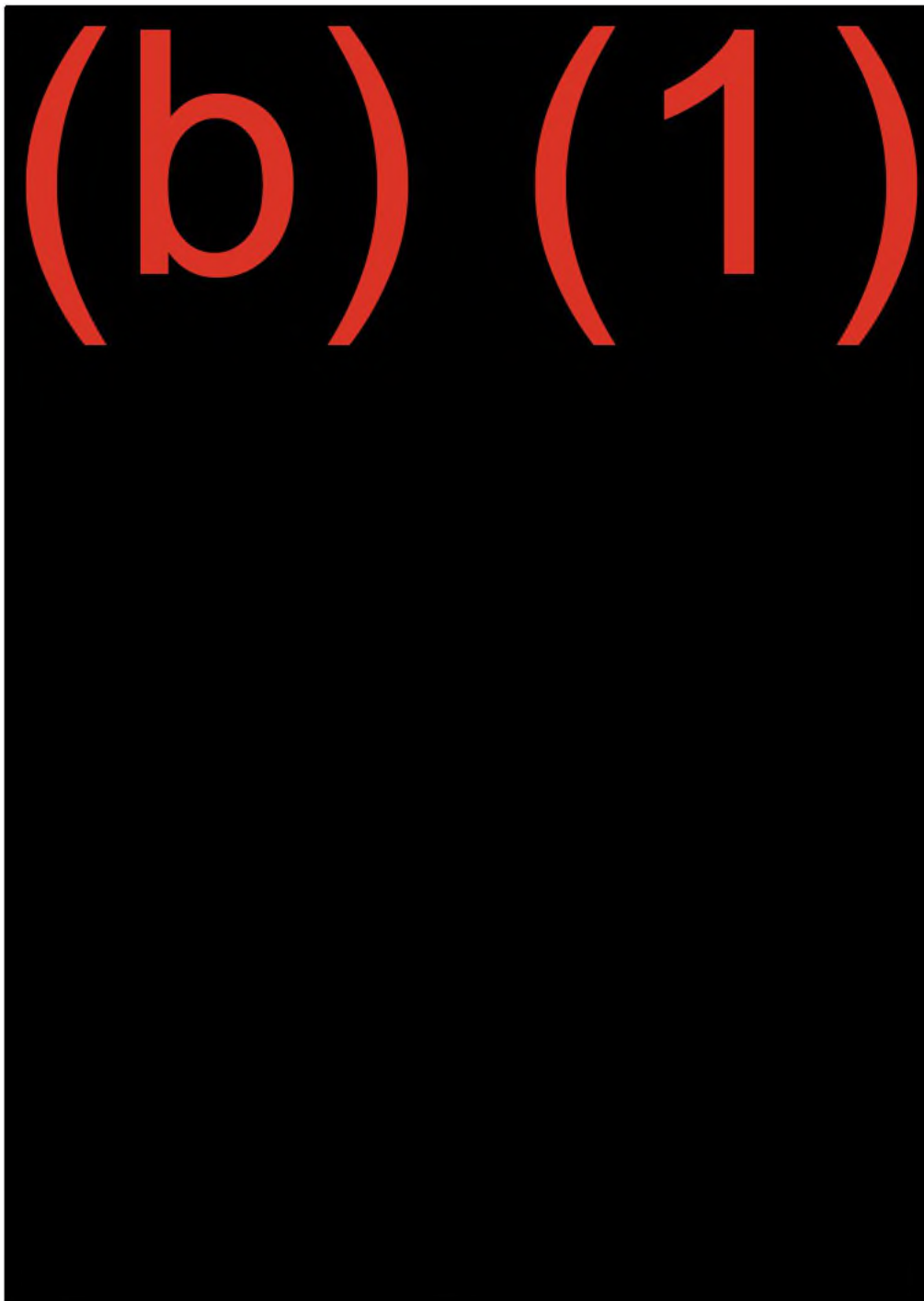


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S/L (V)

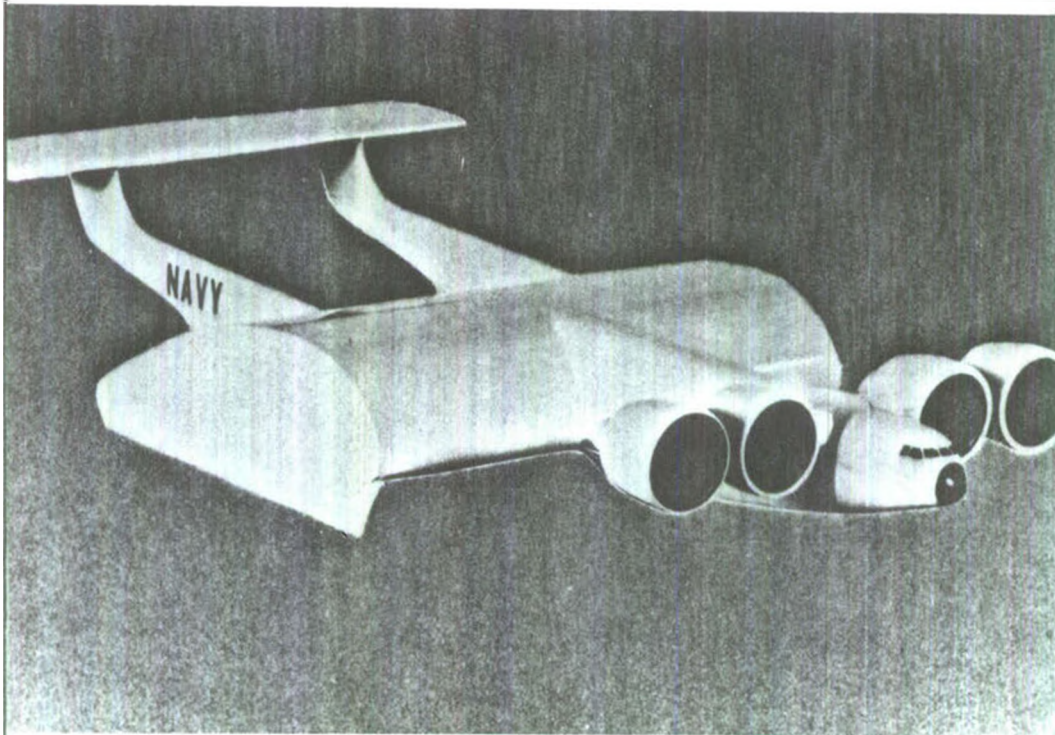
(b) (1)



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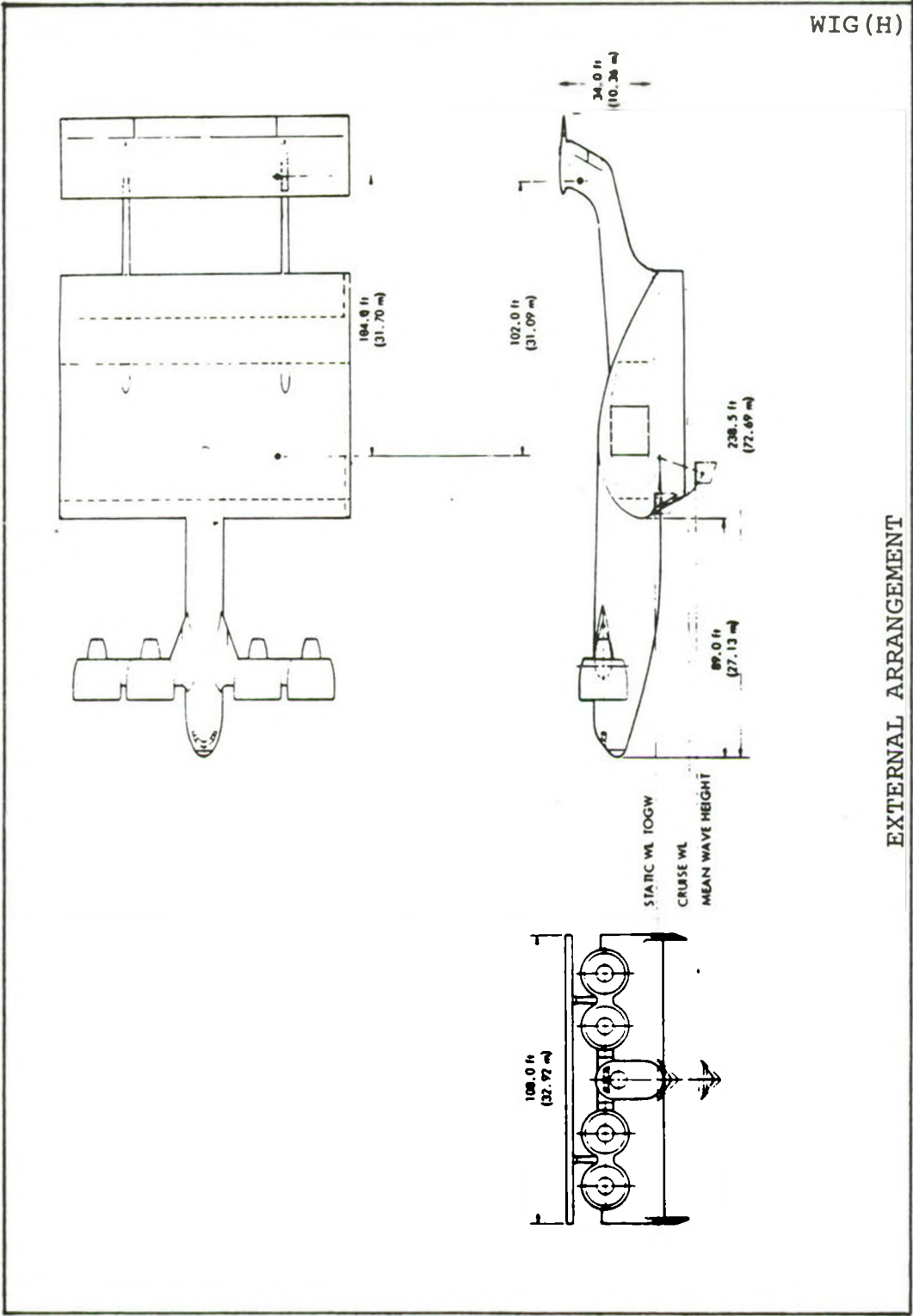
UNCLASSIFIED

WIG (H)



HARD END PLATE WING-IN-GROUND EFFECT VEHICLE
POINT DESIGN SUMMARY

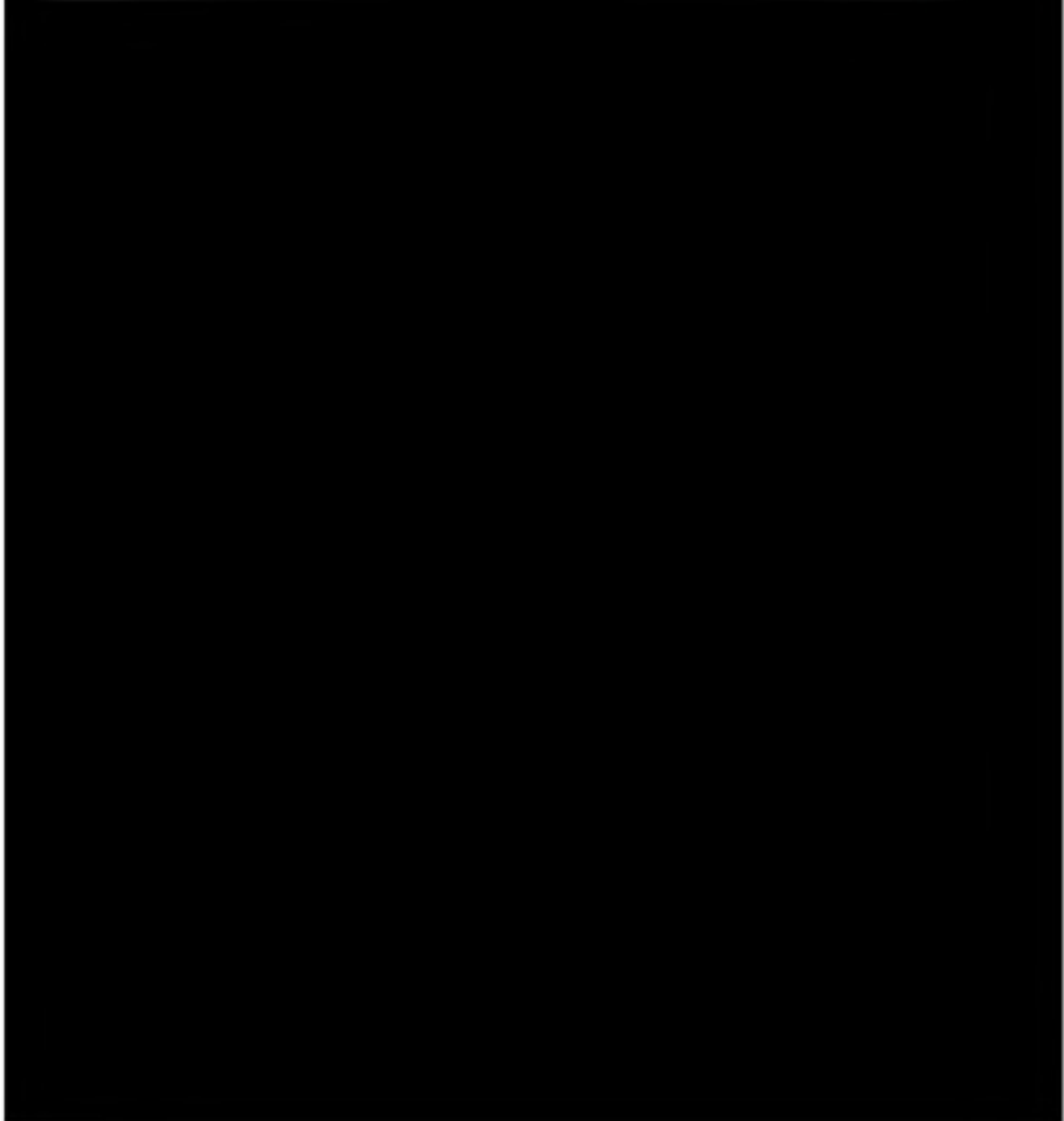
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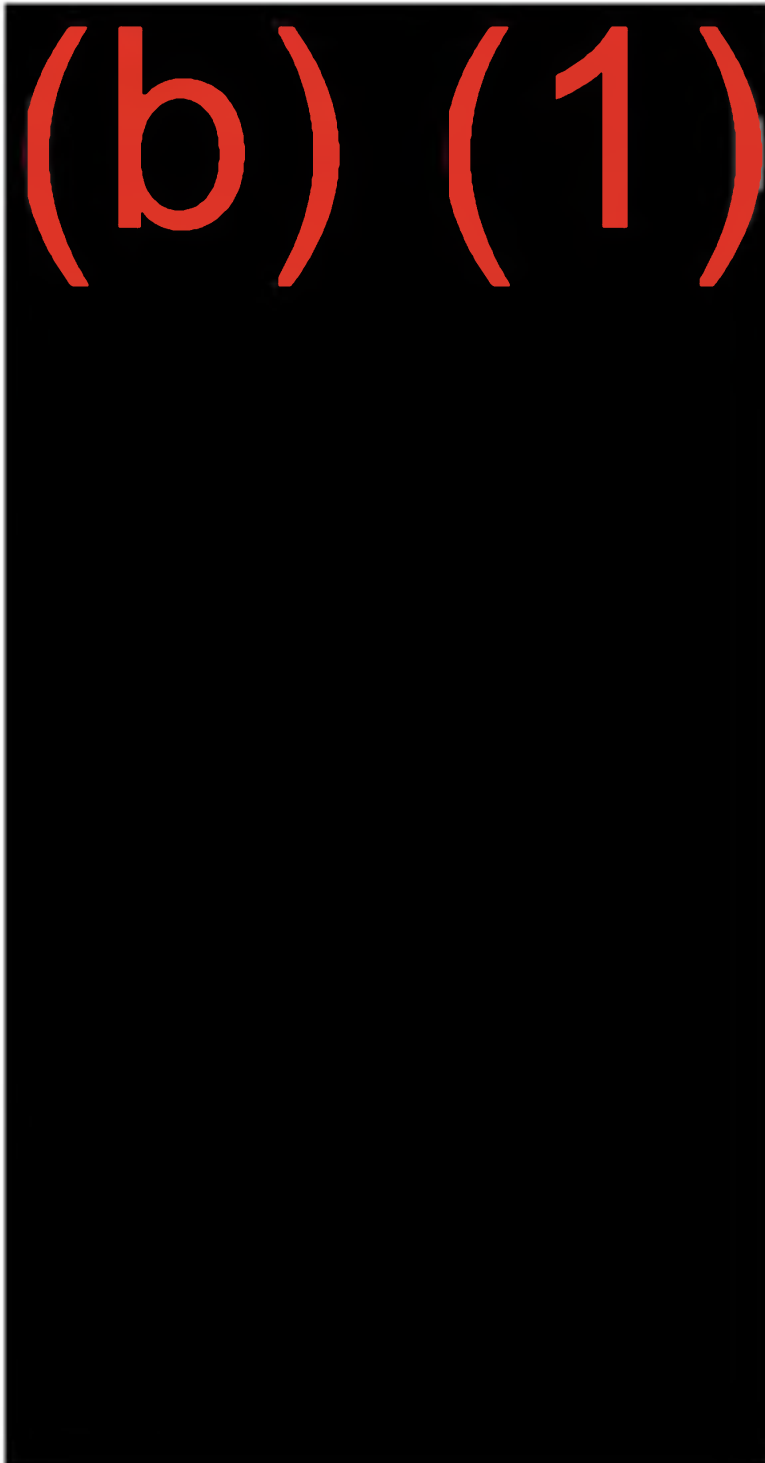
~~CONFIDENTIAL~~

(b)

(1)



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WIG (H)

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~~CONFIDENTIAL~~

WIG (H)

(b) (1)



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WIG(H)

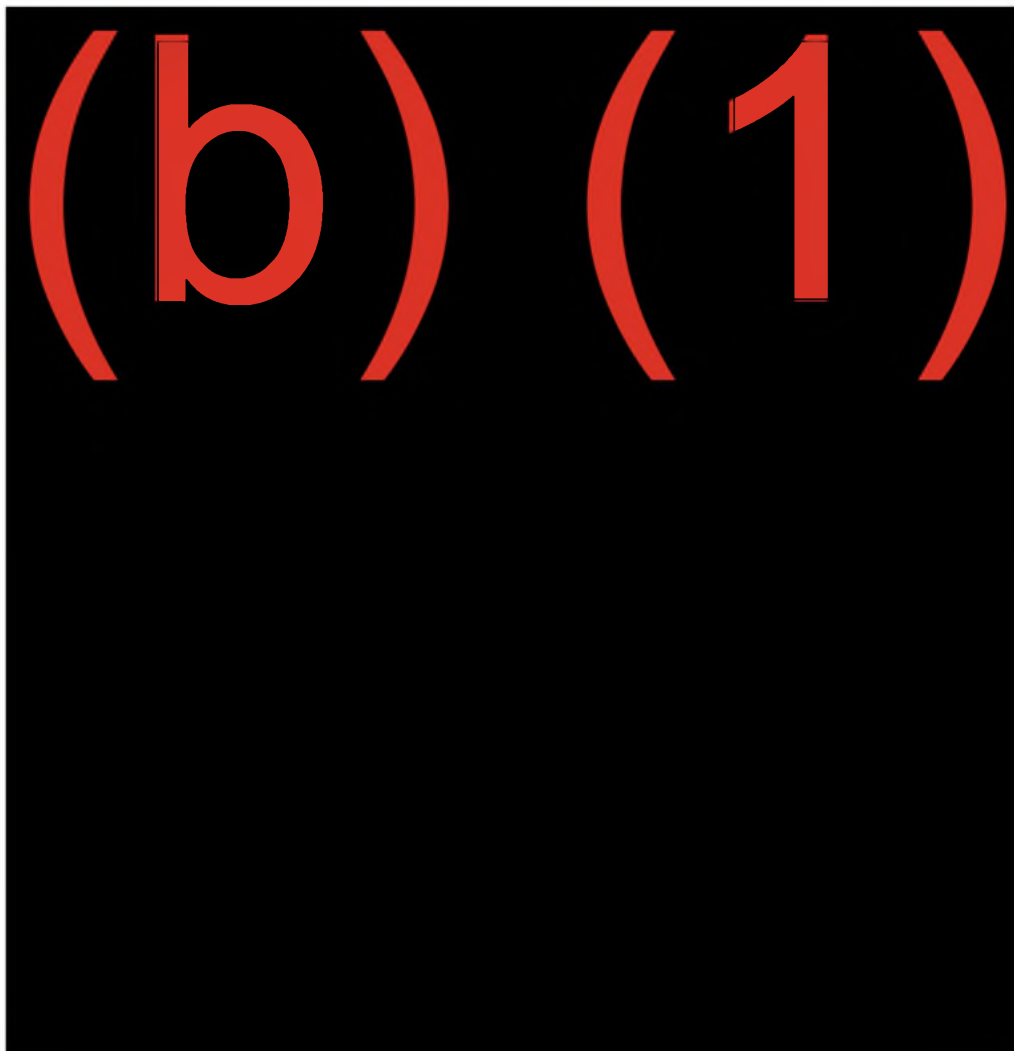
(b) (1)



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WIG (H)

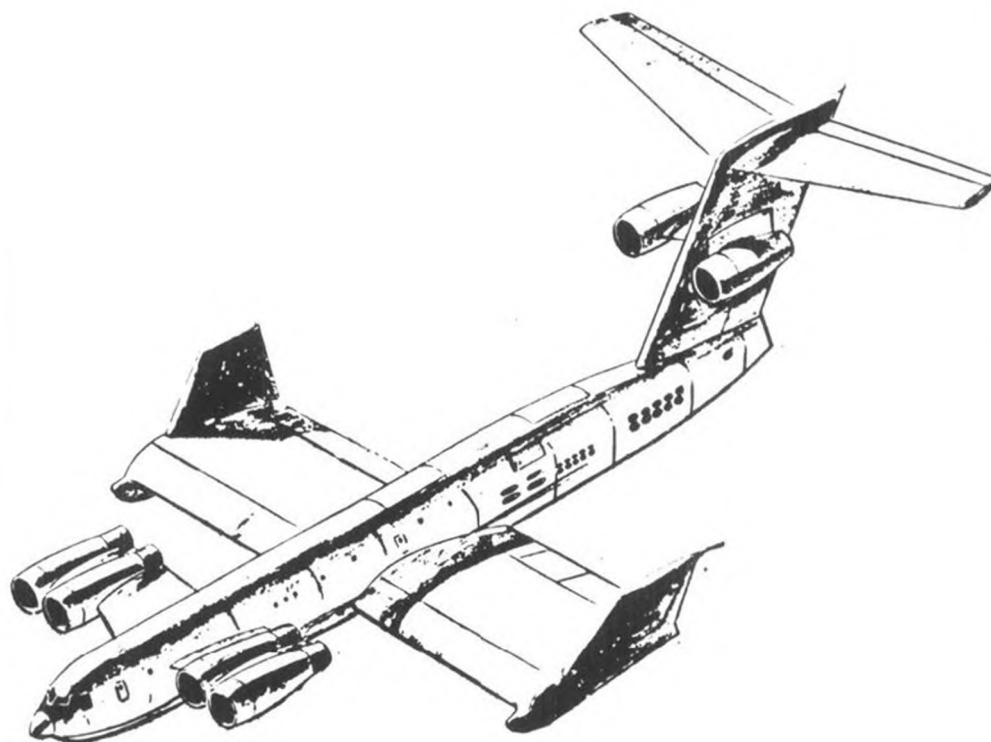


B-205
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UNCLASSIFIED

WIG (O)

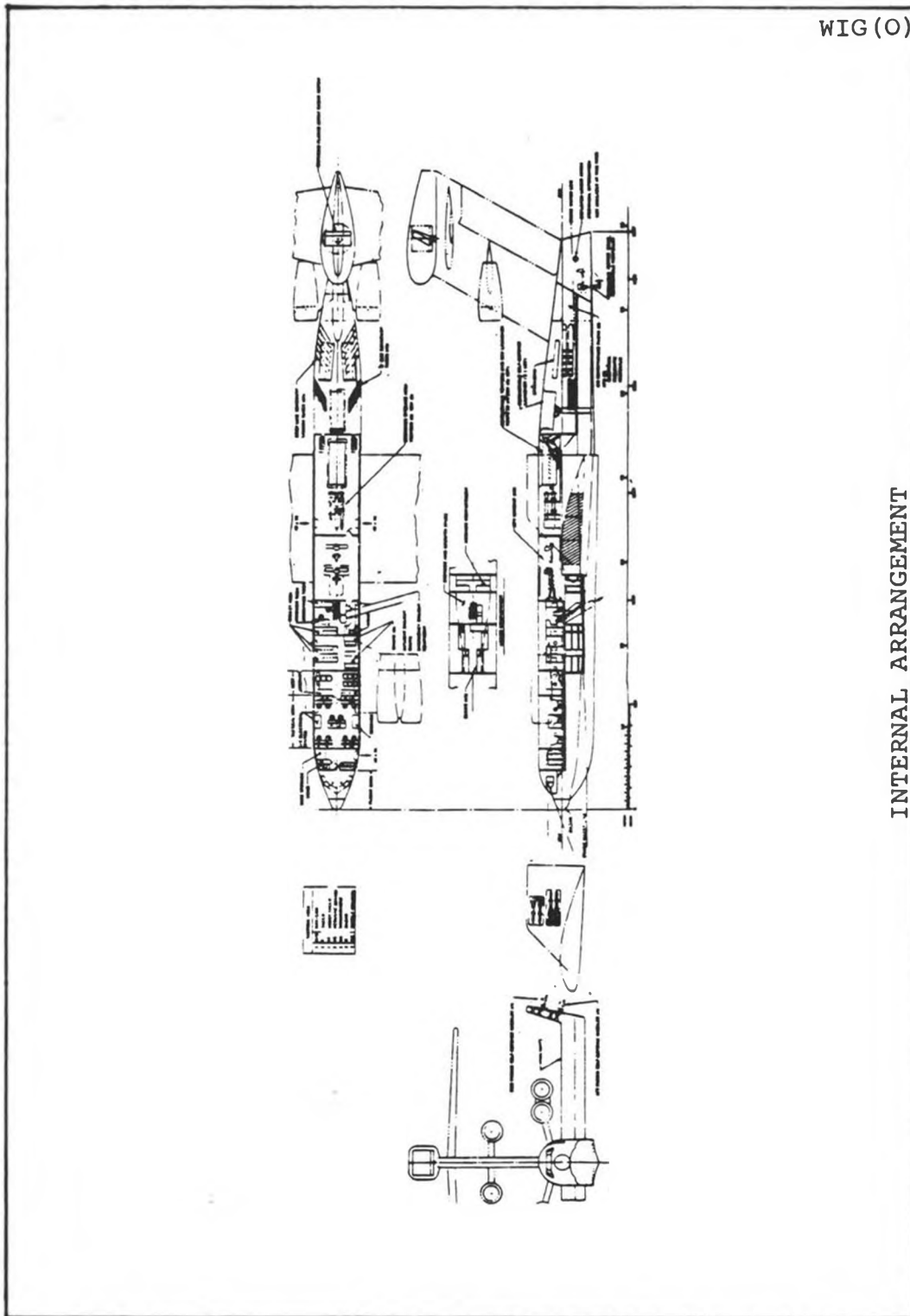


OUT OF GROUND EFFECT WING-IN-GROUND EFFECT VEHICLE
POINT DESIGN SUMMARY

B-207

UNCLASSIFIED

UNCLASSIFIED

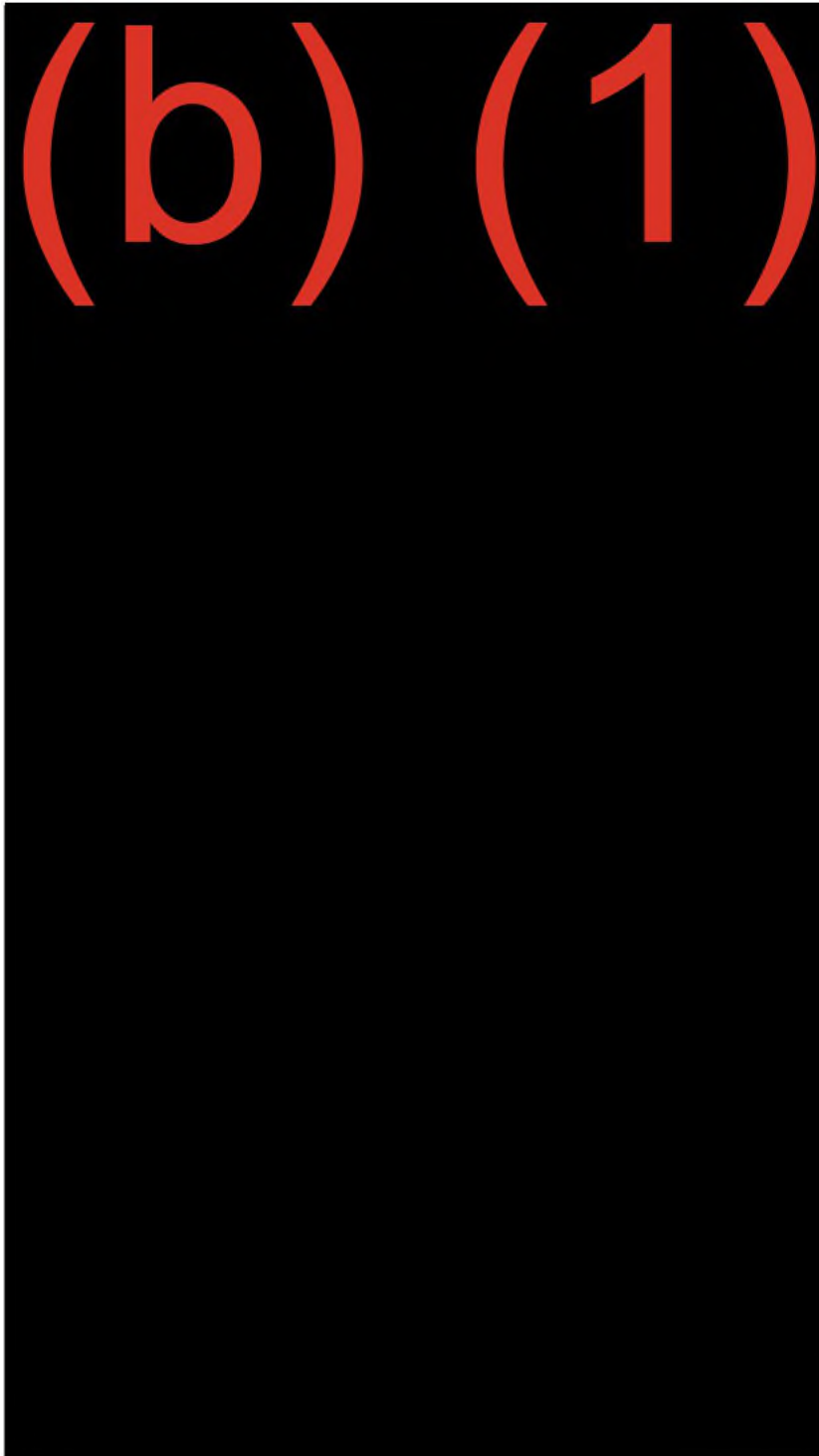


UNCLASSIFIED

~~CONFIDENTIAL~~

WIG(O)

(b) (1)

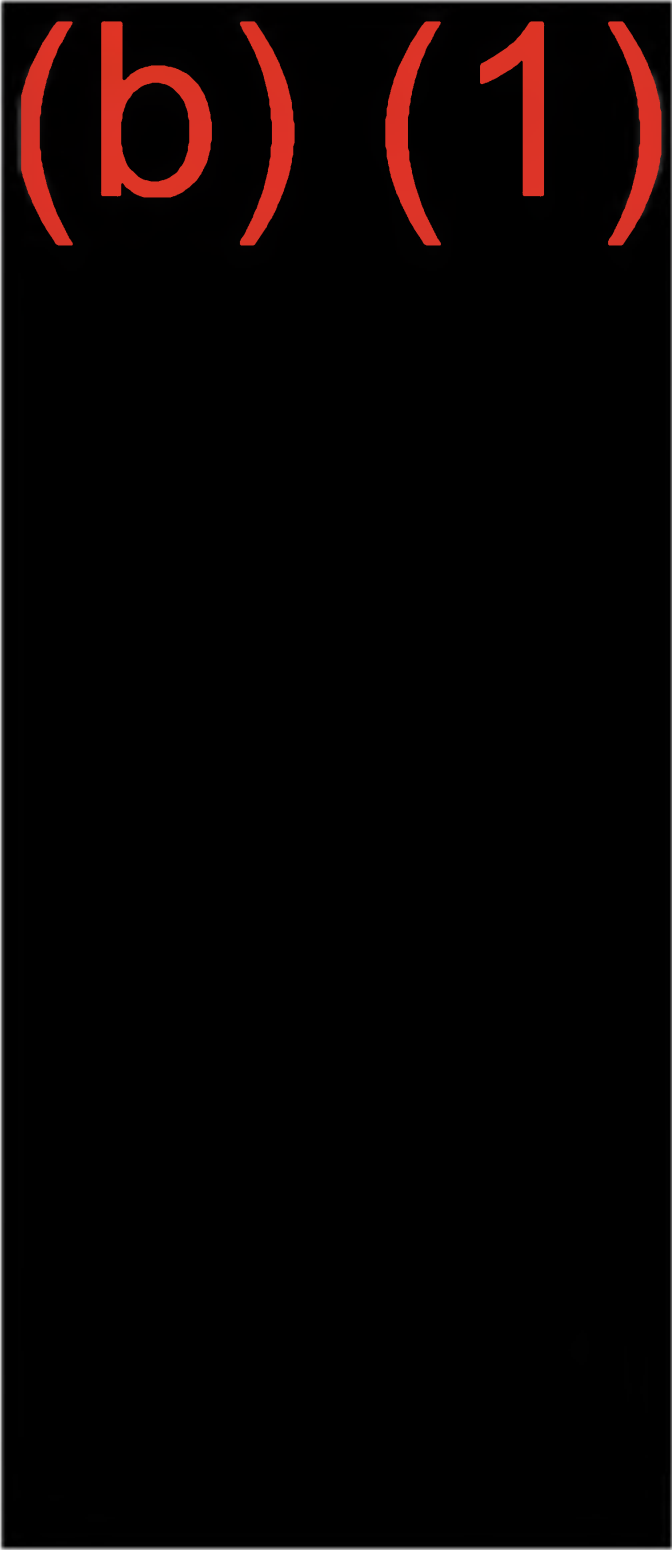


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~~CONFIDENTIAL~~

WIG (O)

(b) (1)



B-210

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~~CONFIDENTIAL~~

WIG (O)

(b) (1)



B-211

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WIG(O)

(b) (1)

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~~CONFIDENTIAL~~

WIG (O)

(b) (1)

B-213

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UNCLASSIFIED

WIG (S)

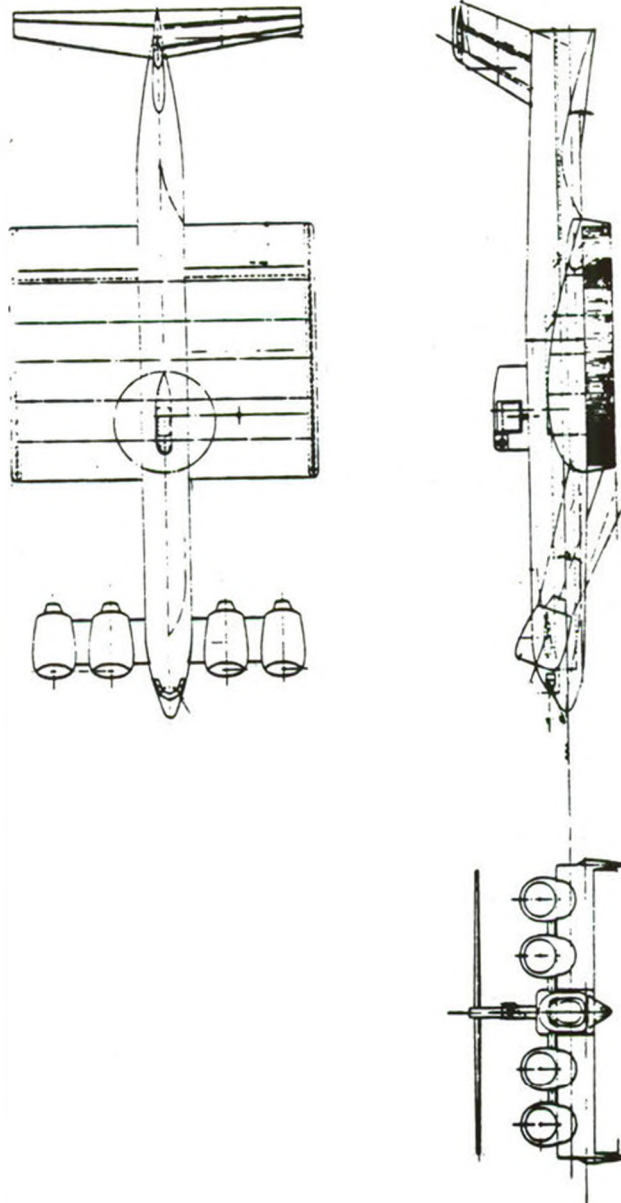


SOFT END PLATE WING-IN-GROUND EFFECT VEHICLE

POINT DESIGN SUMMARY

UNCLASSIFIED

WIG(S)



EXTERNAL ARRANGEMENT

B-216

UNCLASSIFIED

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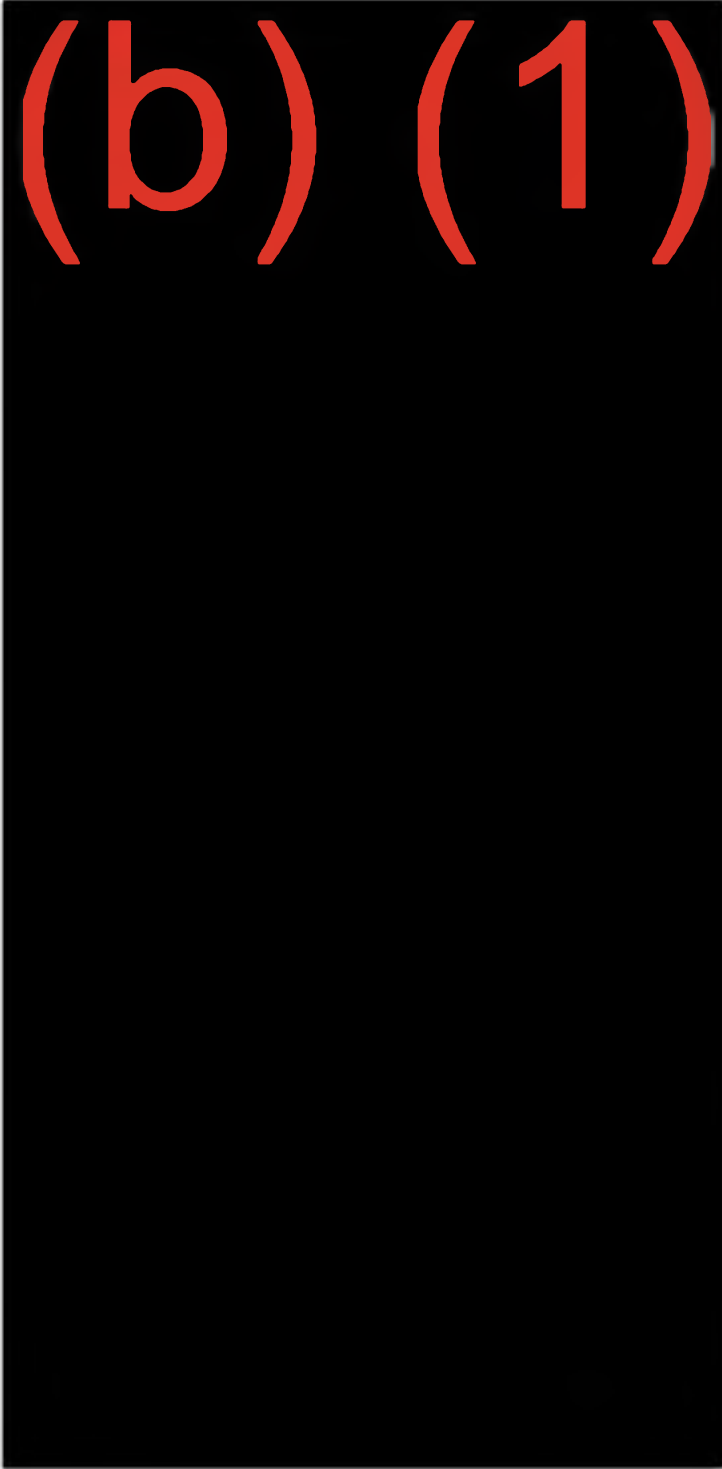


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WIG(S)

(b) (1)



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WIG (S)

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WIG(S)

(b) (1)



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(b) (1)

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WIG(S)

(b) (1)

B-222

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IV. BASELINE POINT DESIGNS

UNCLASSIFIED

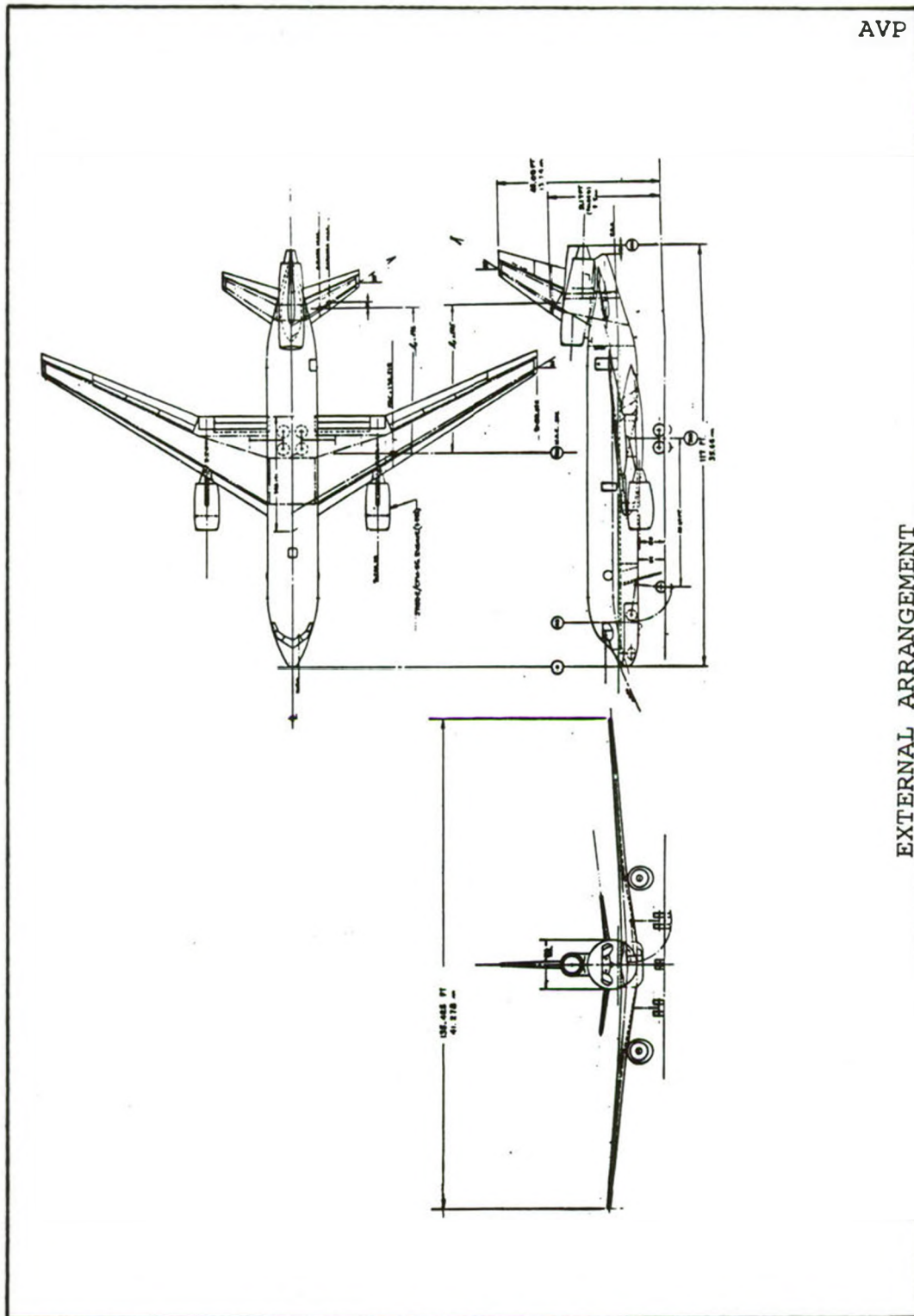
AVP



TYPICAL ADVANCED PATROL AIRCRAFT

POINT DESIGN SUMMARY

UNCLASSIFIED



B-226

UNCLASSIFIED

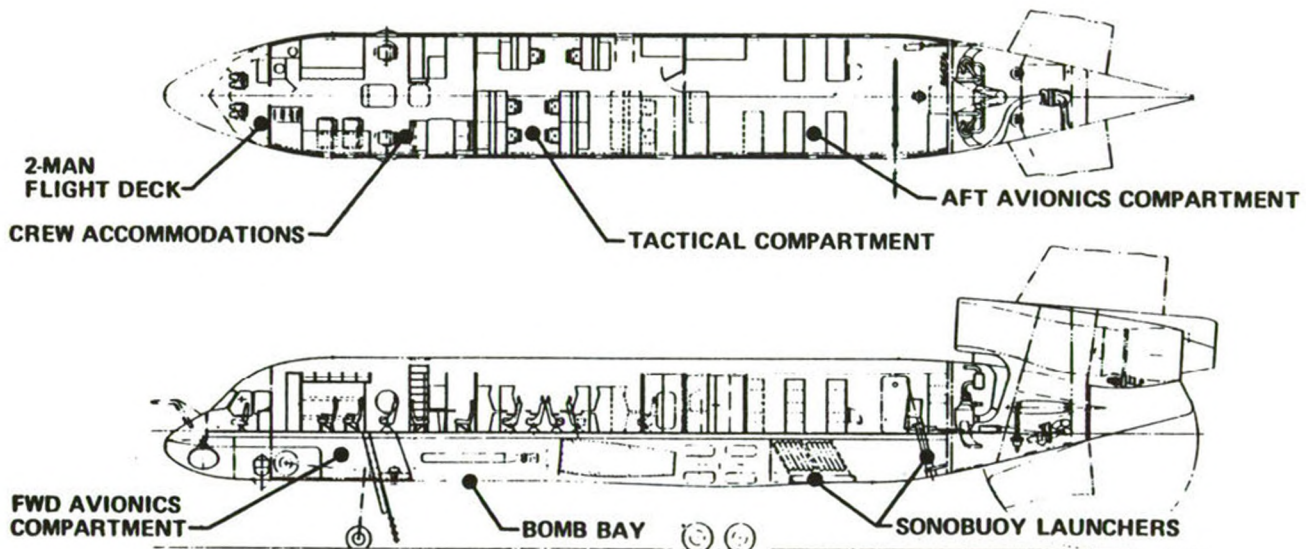
AVP



B-227

UNCLASSIFIED

UNCLASSIFIED



INTERNAL ARRANGEMENT

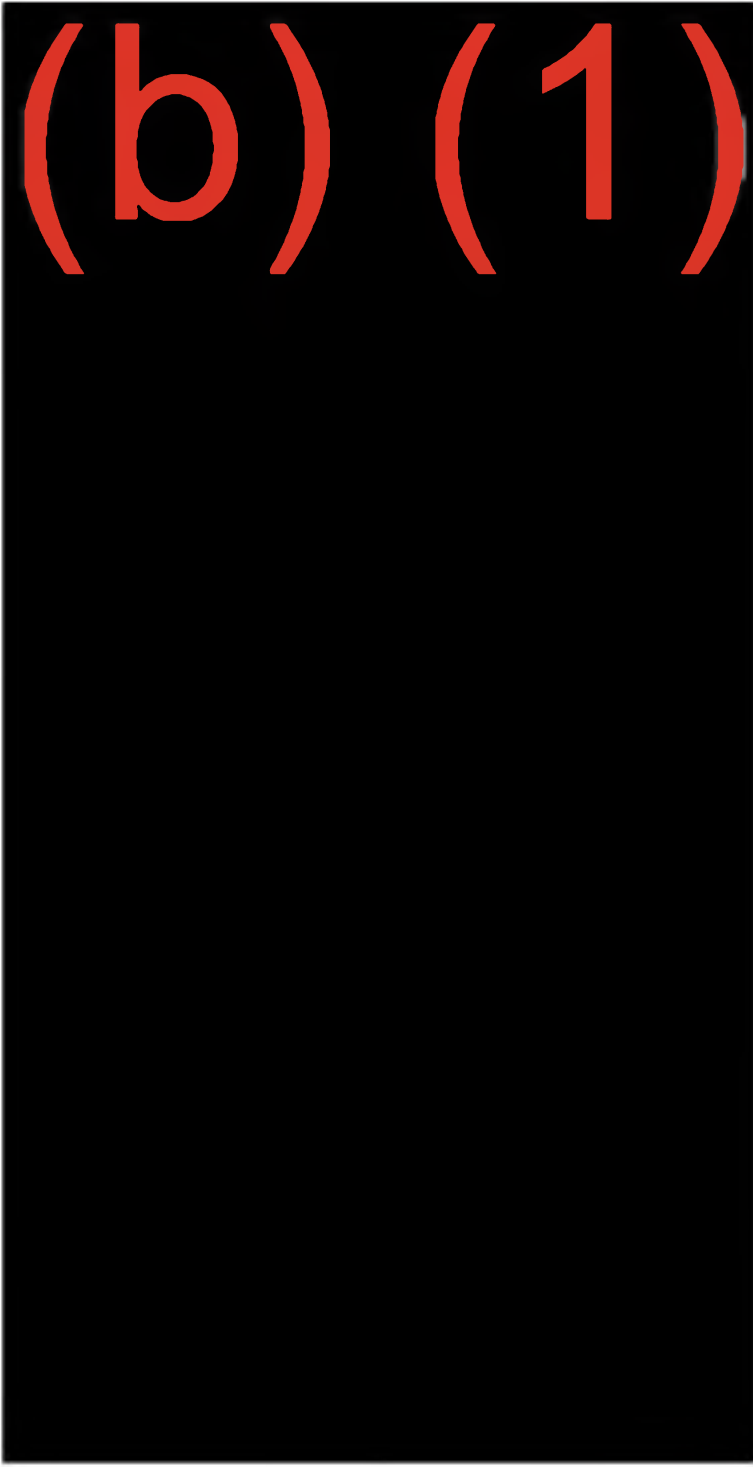
AVP

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AVP

(b) (1)

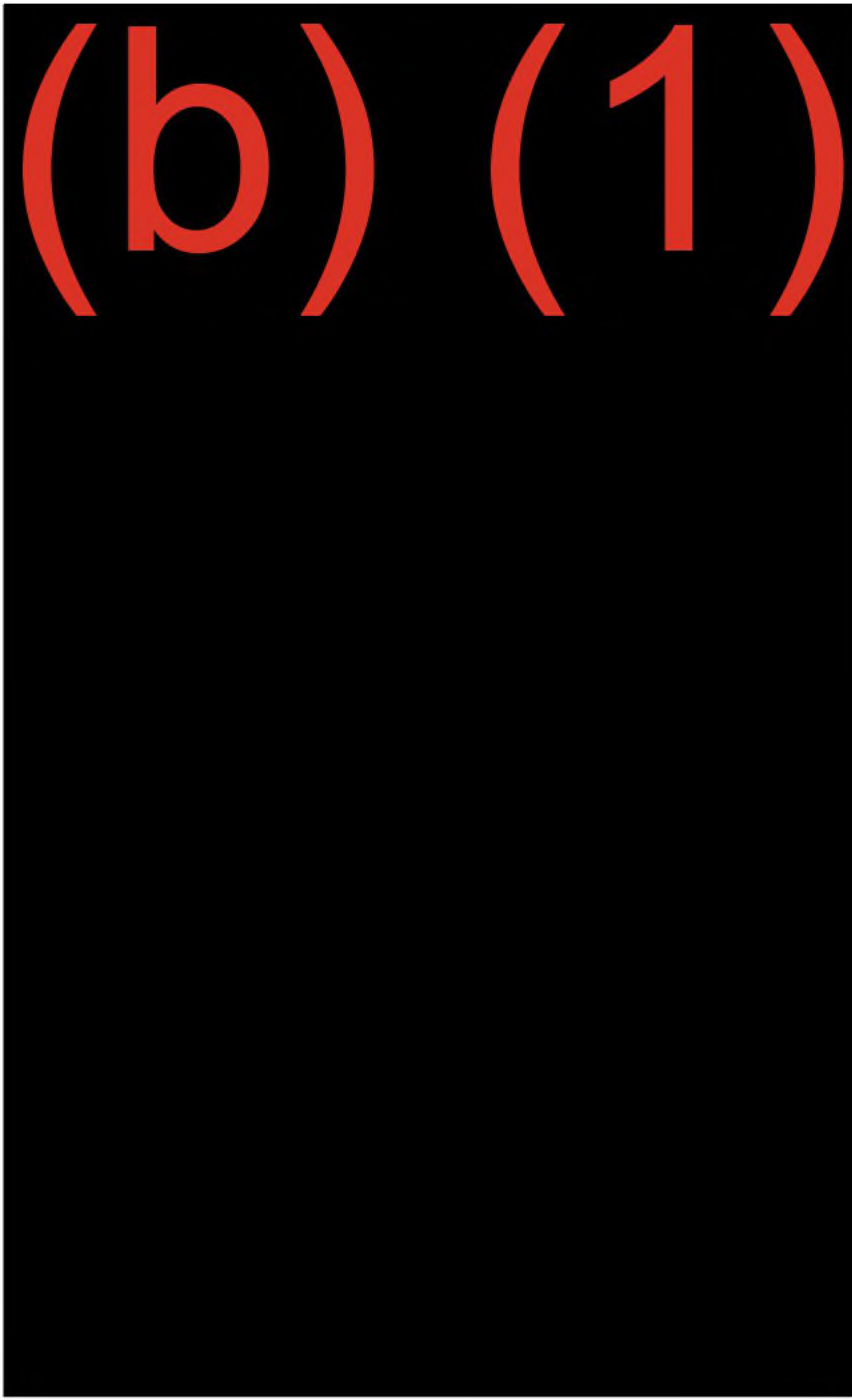


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AVP

(b) (1)



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(b) (1)

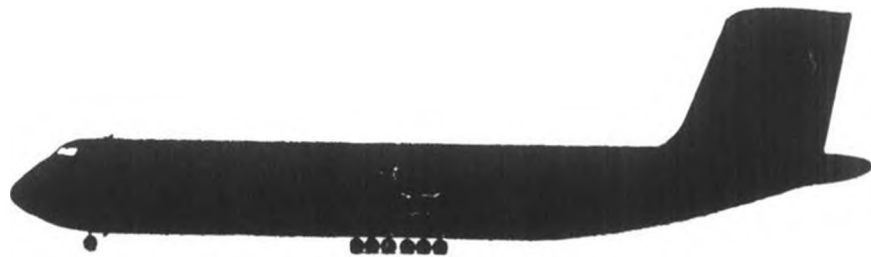
B-231

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UNCLASSIFIED

CXX



LONG RANGE CARGO AIRCRAFT (USAF)

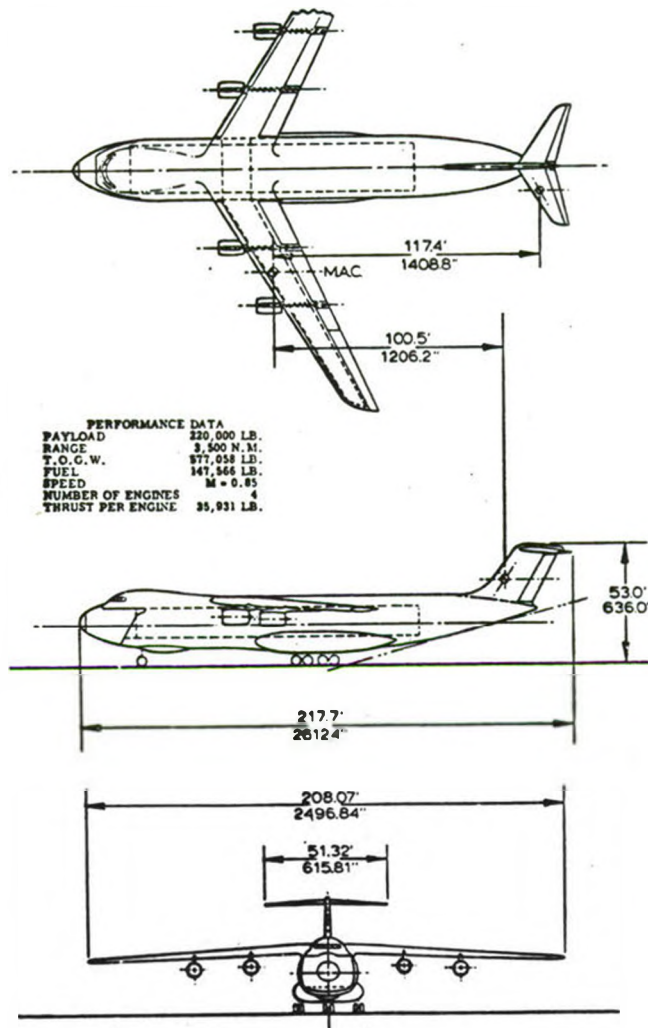
POINT DESIGN SUMMARY

UNCLASSIFIED

B-233

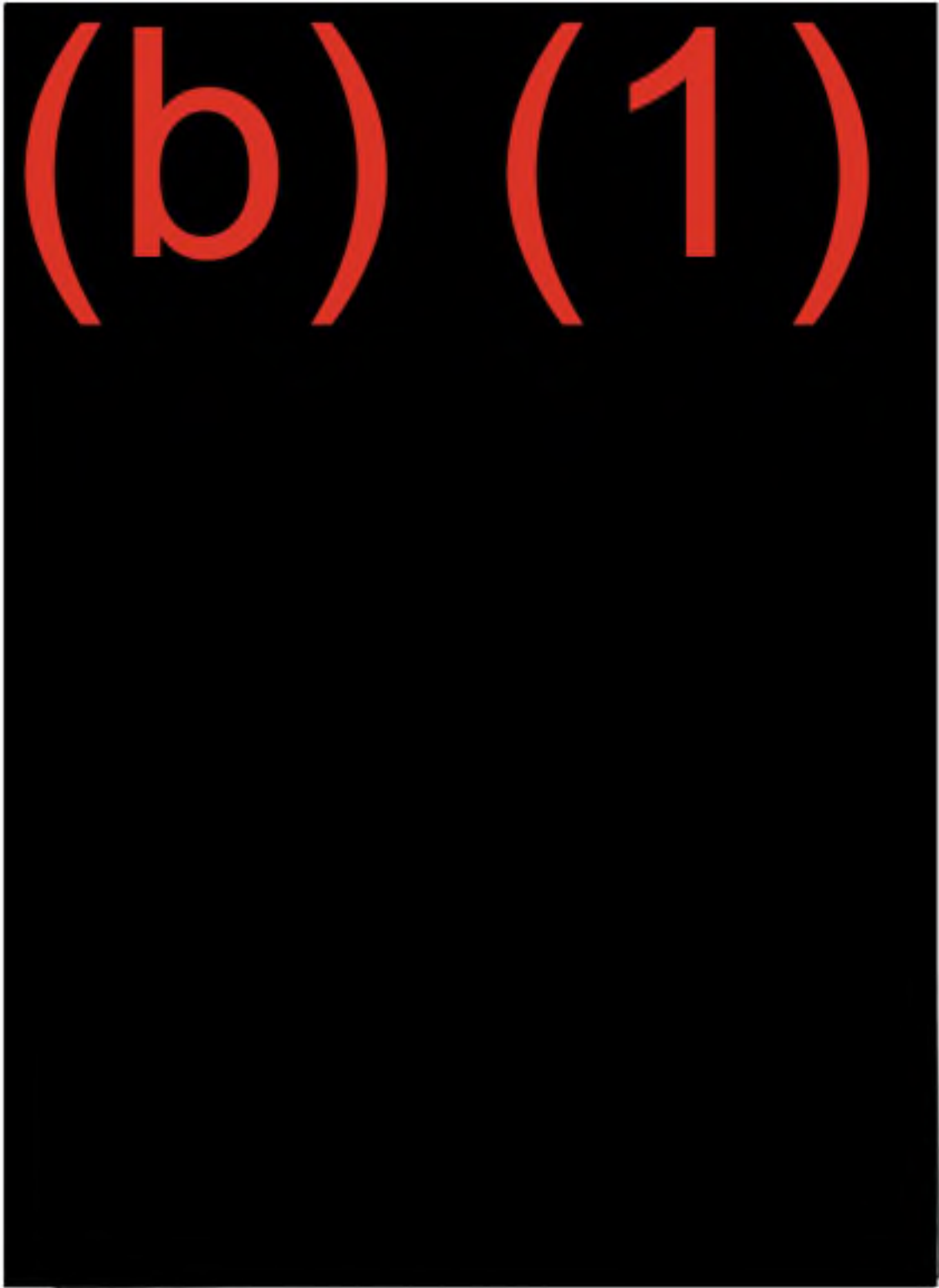
UNCLASSIFIED

CXX-(S)



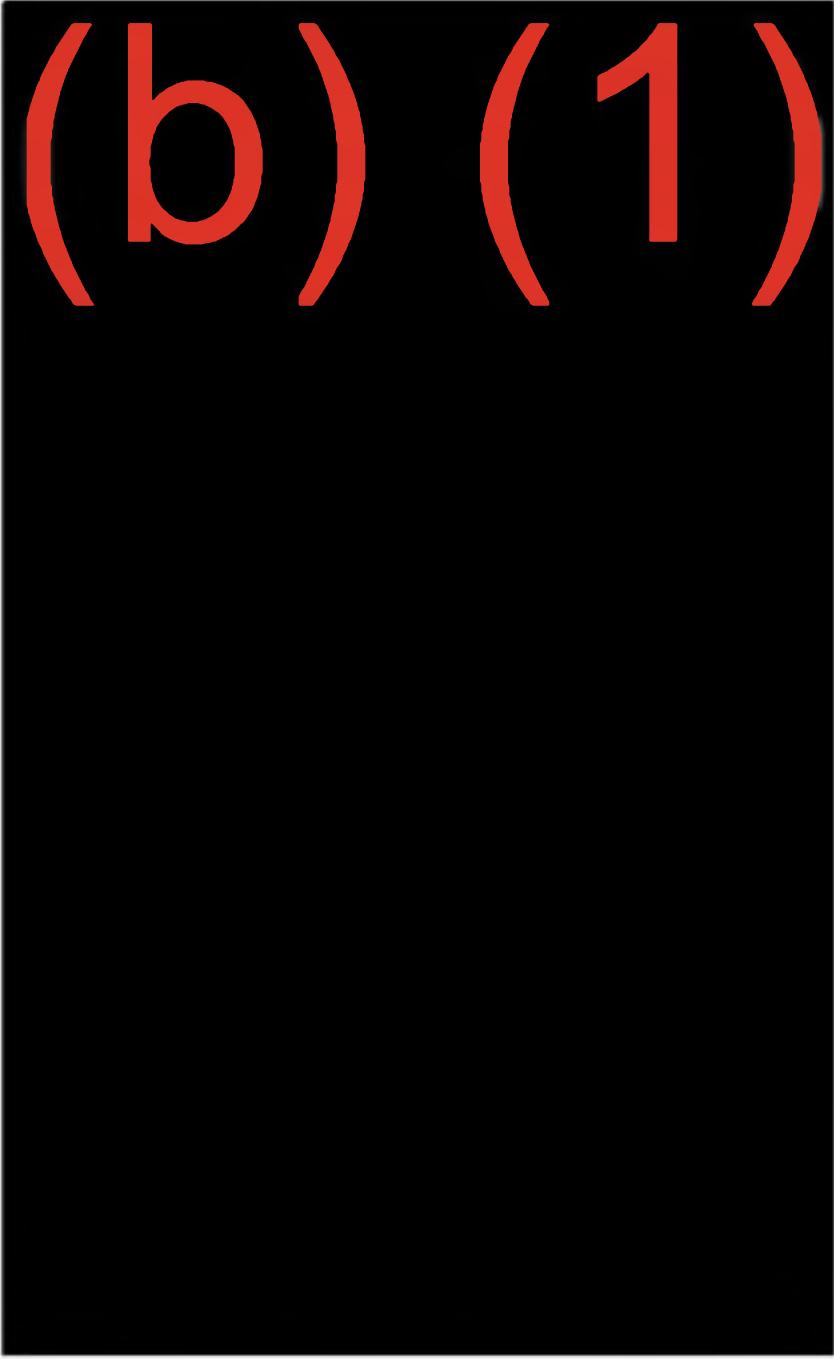
EXTERNAL ARRANGEMENT

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CXX

(b) (1)

B-237
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UNCLASSIFIED

MONO 3



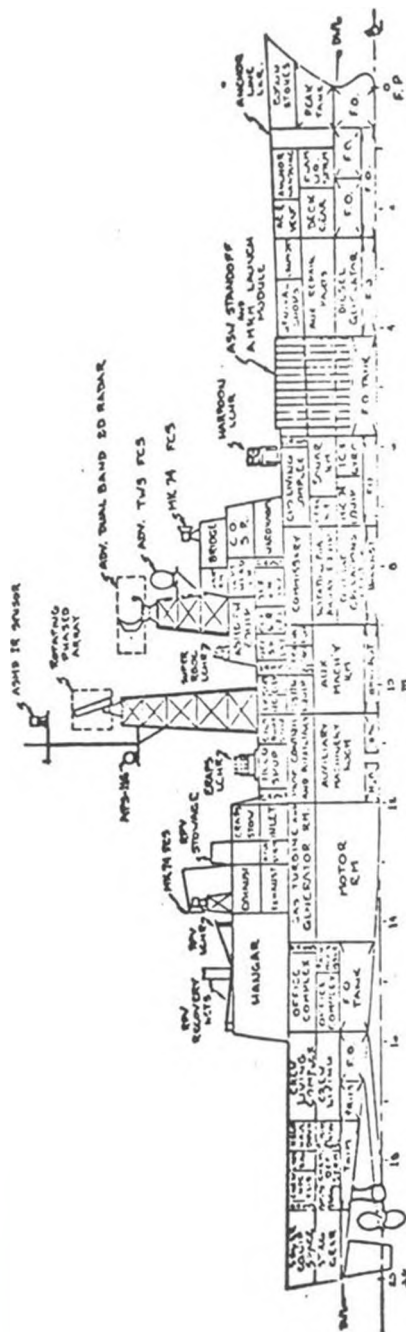
NOMINAL 3000-TON ADVANCED TECHNOLOGY MONOHULL
POINT DESIGN SUMMARY

B-239

UNCLASSIFIED

UNCLASSIFIED

MONO 3



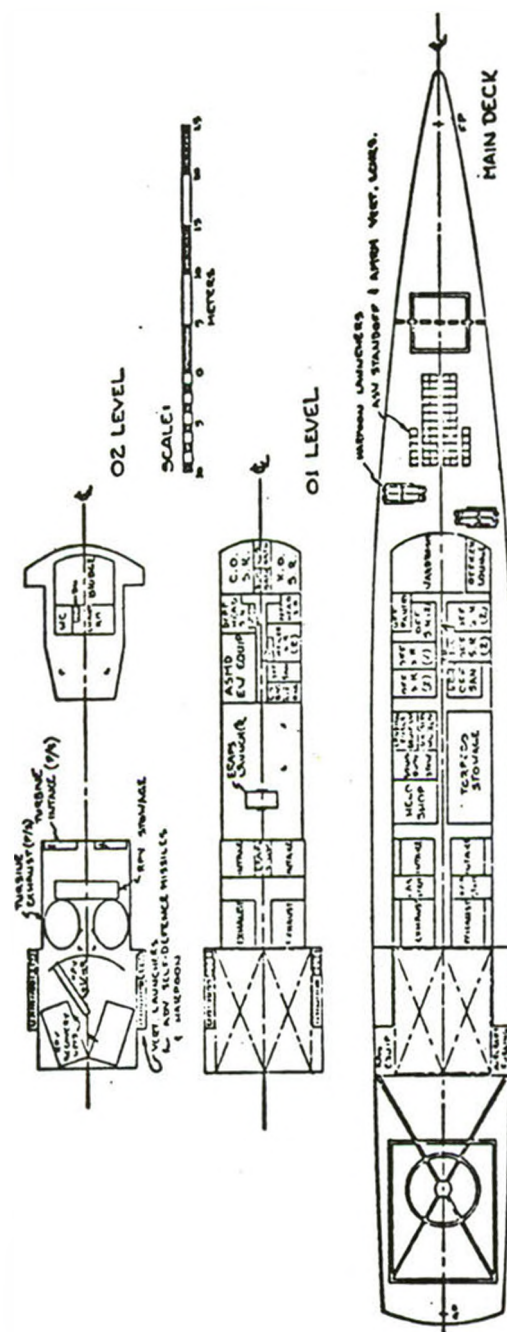
INTERNAL ARRANGEMENT

B-241

UNCLASSIFIED

UNCLASSIFIED

MONO 3



INTERNAL ARRANGEMENT

B-242

UNCLASSIFIED

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(b) (1)

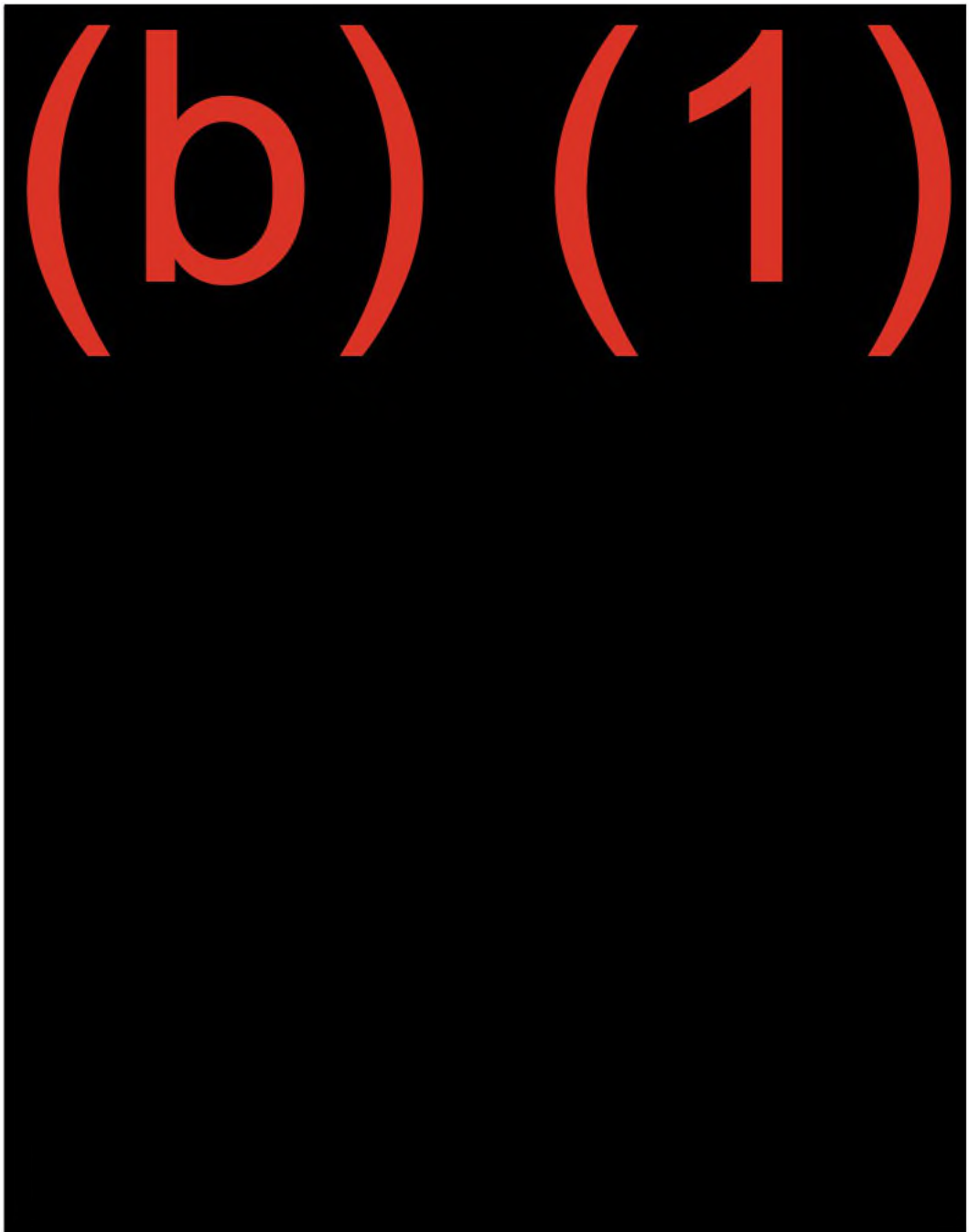
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MONO 3

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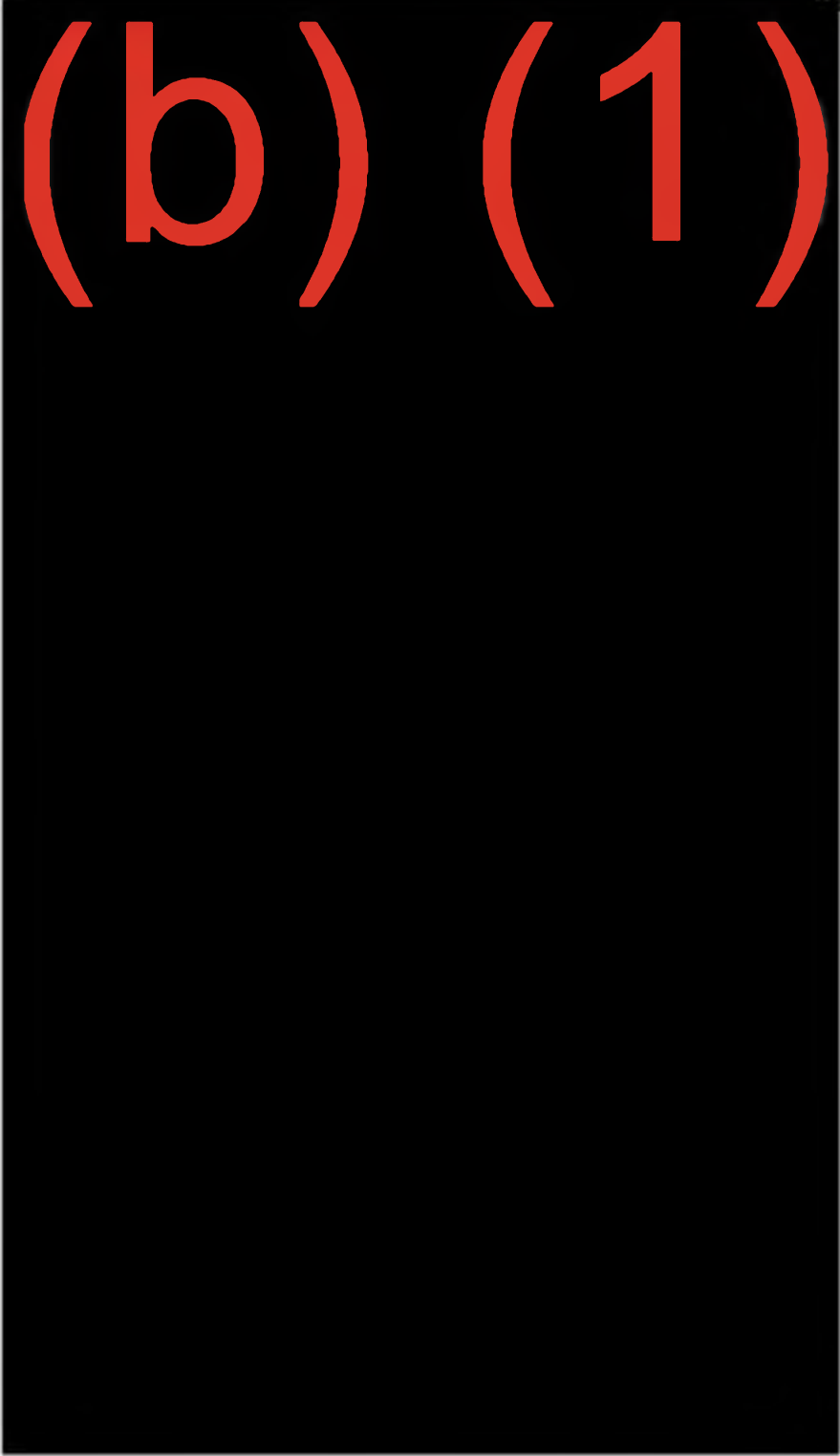
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MONO 3

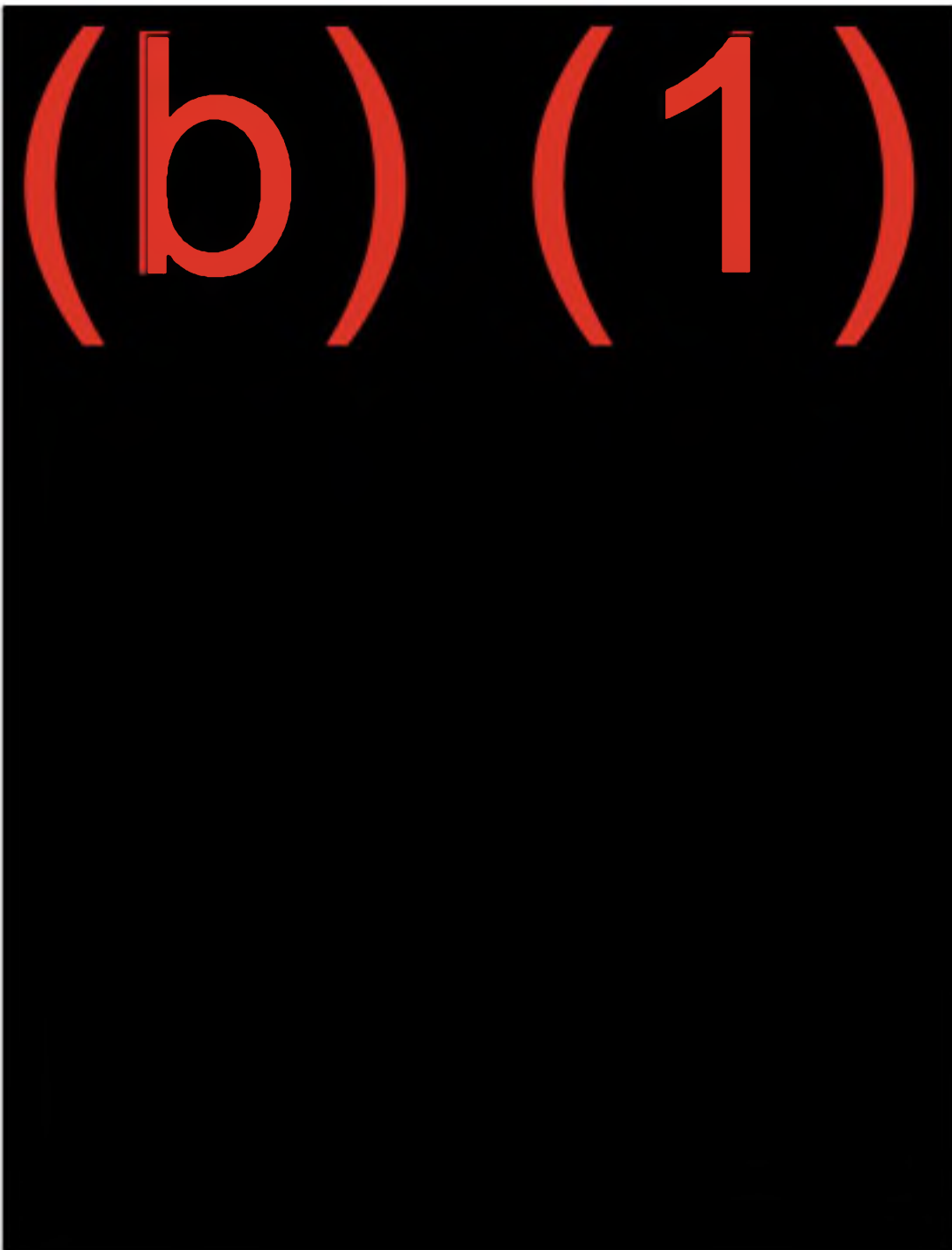
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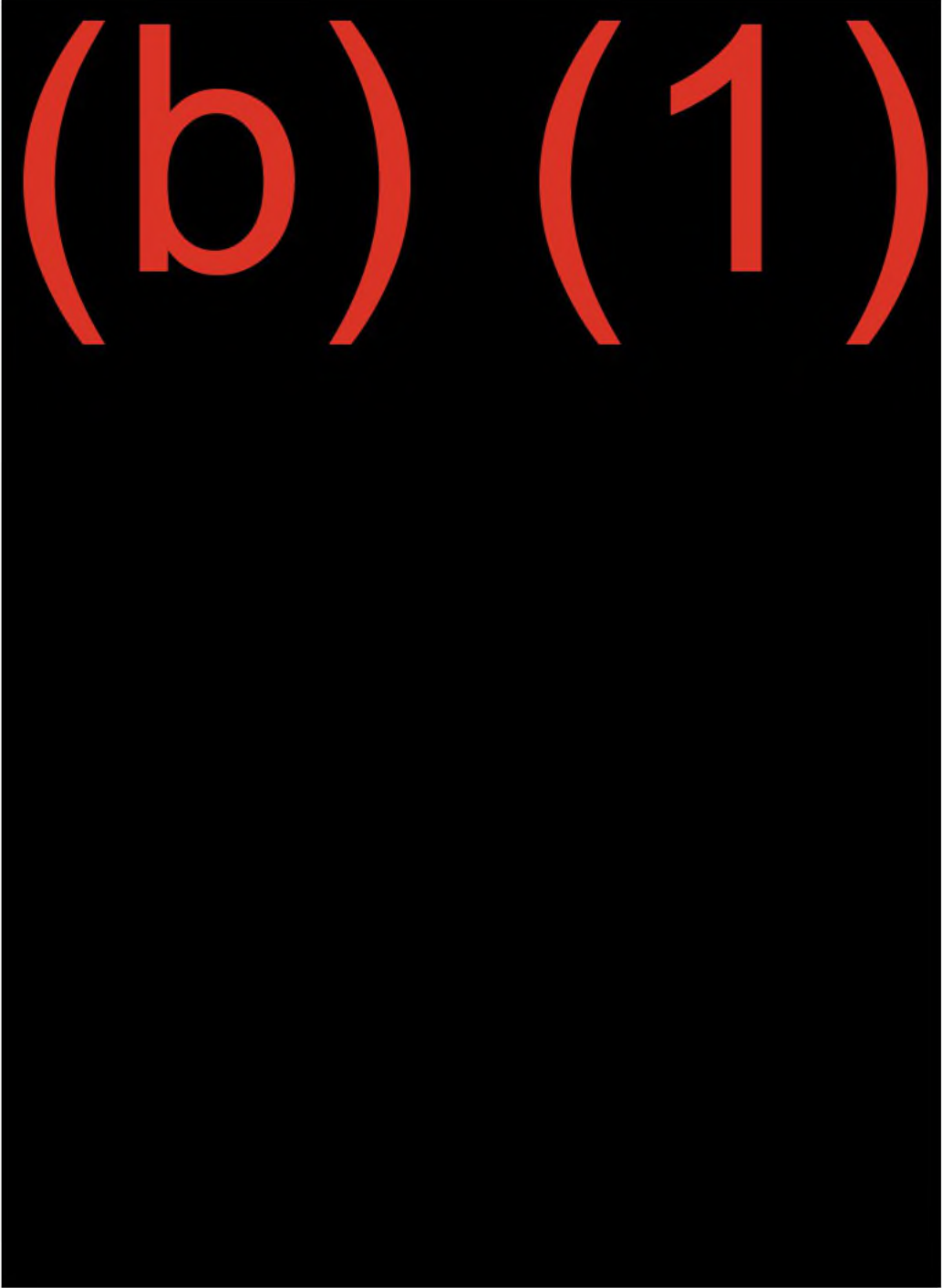
(b) (1)



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MONO 3

(b) (1)

B-249
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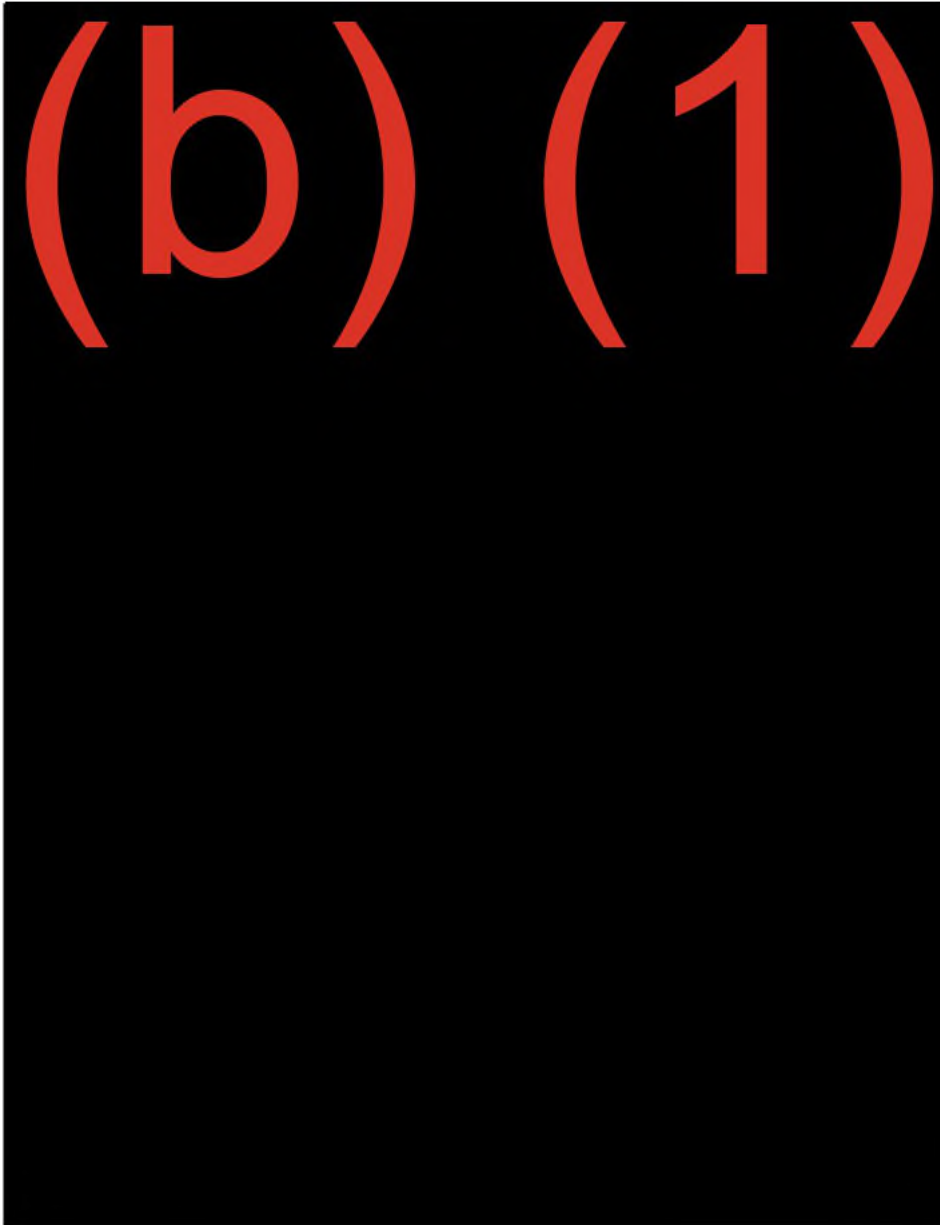
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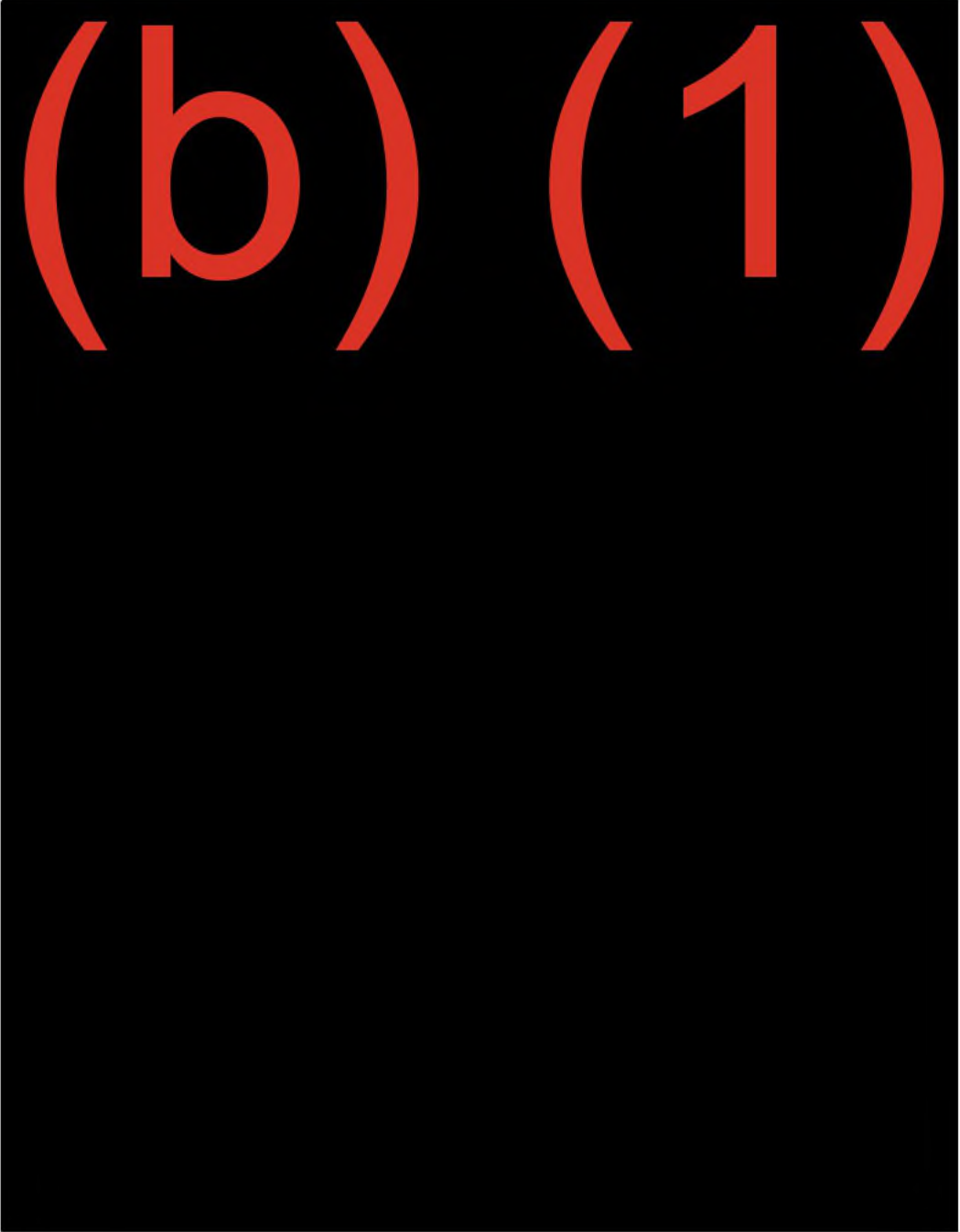
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VSS

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VSS

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B-255
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V. COLLECTED EXISTING DESIGNS

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CPIC

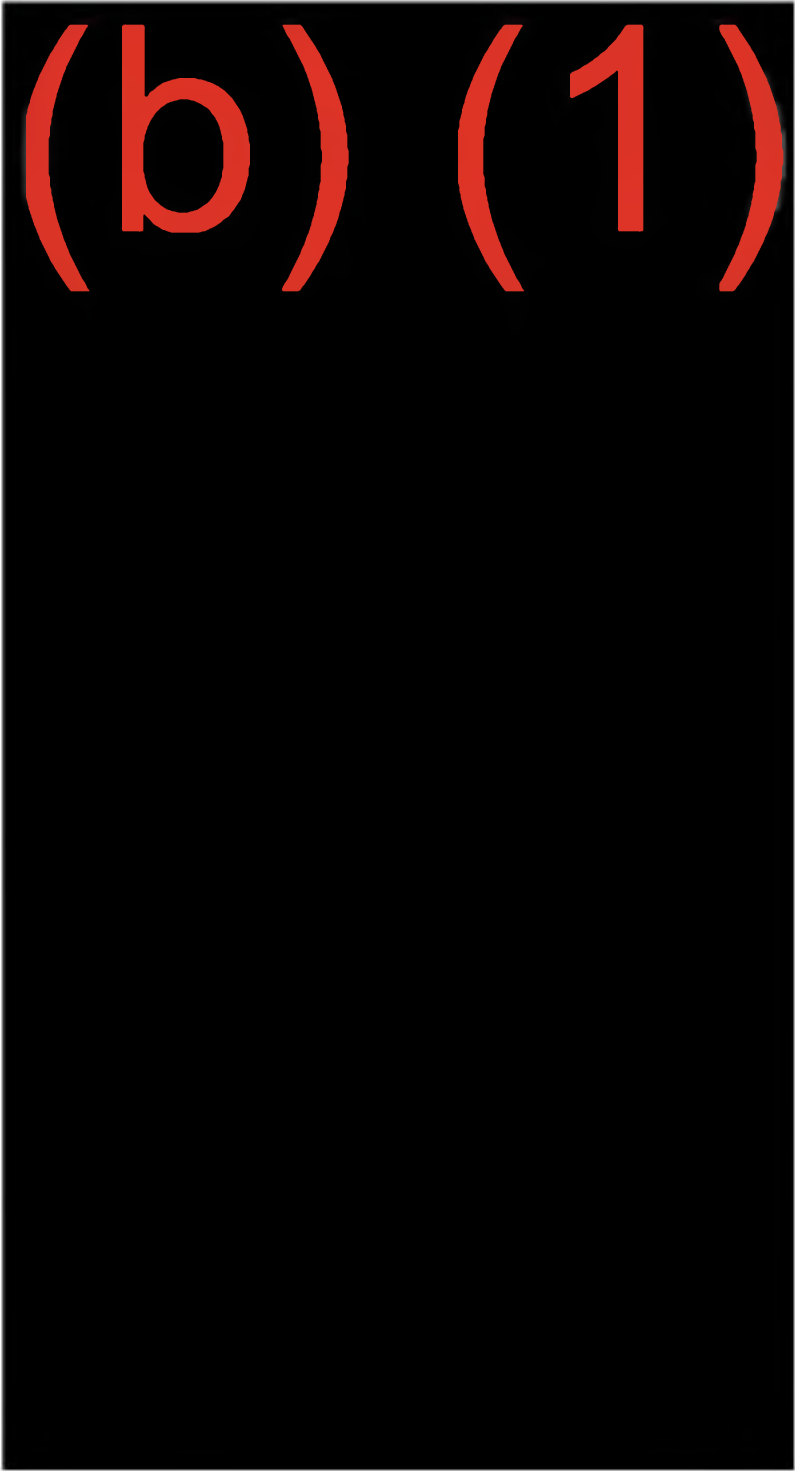
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CPIC

(b) (1)

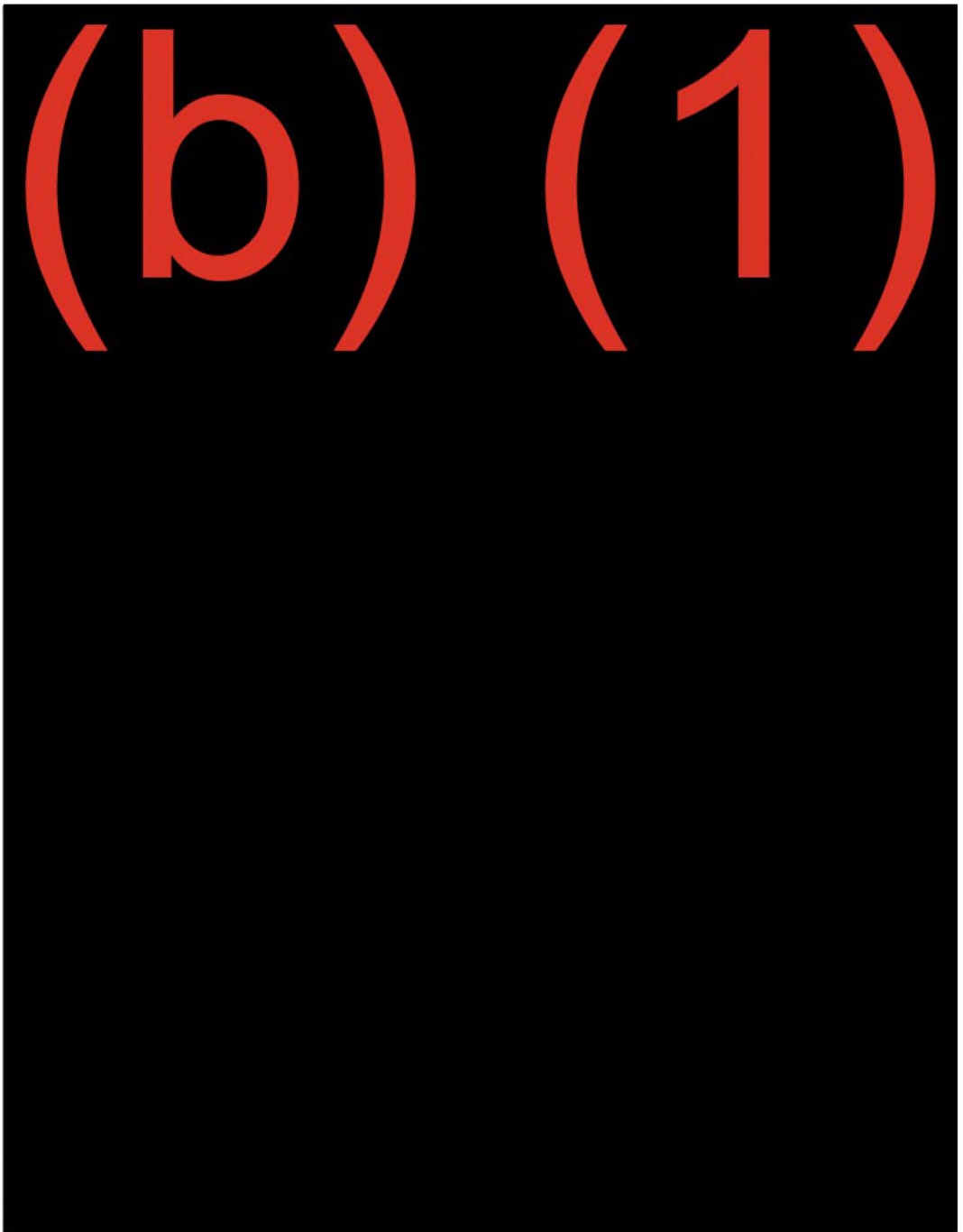


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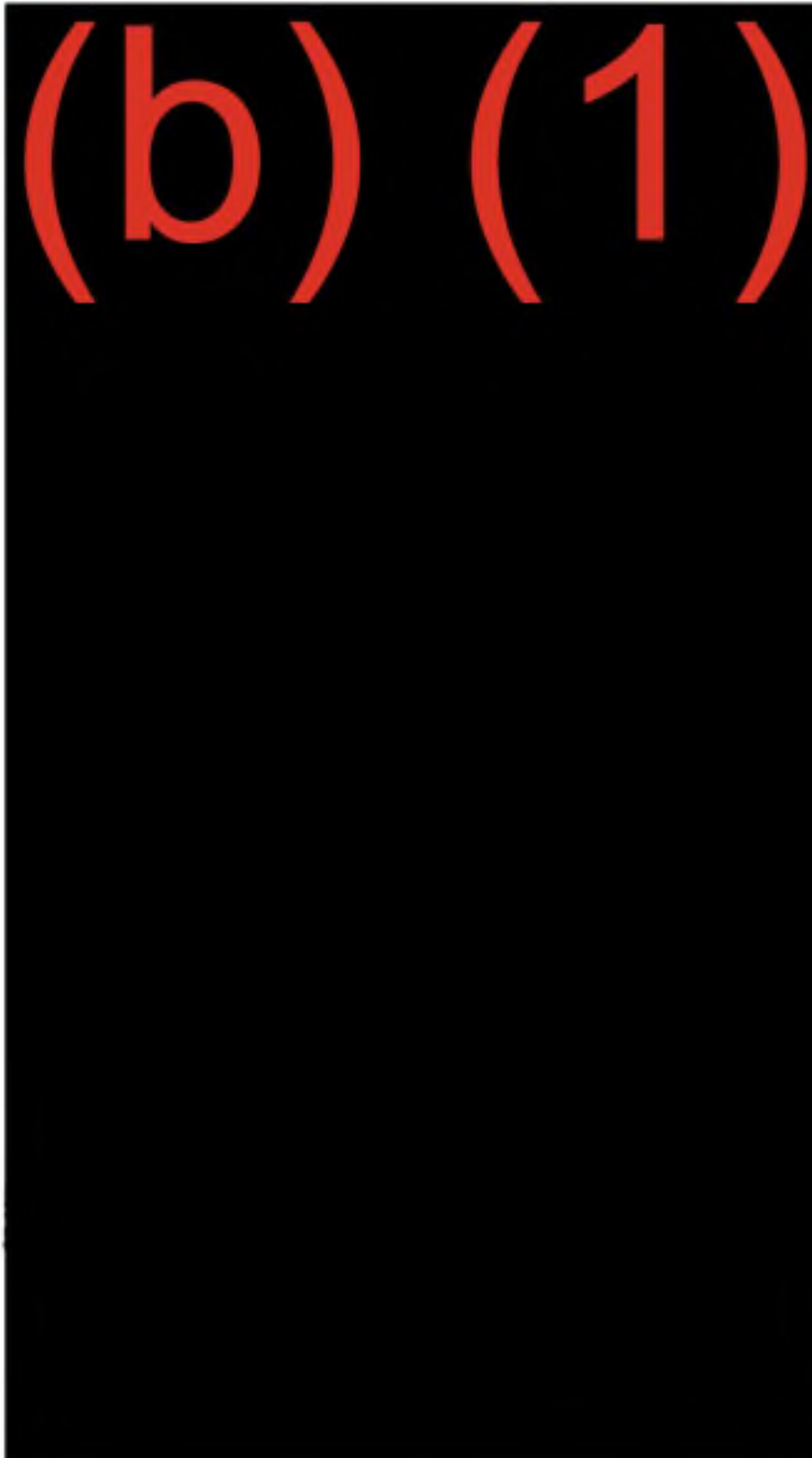
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CPIC

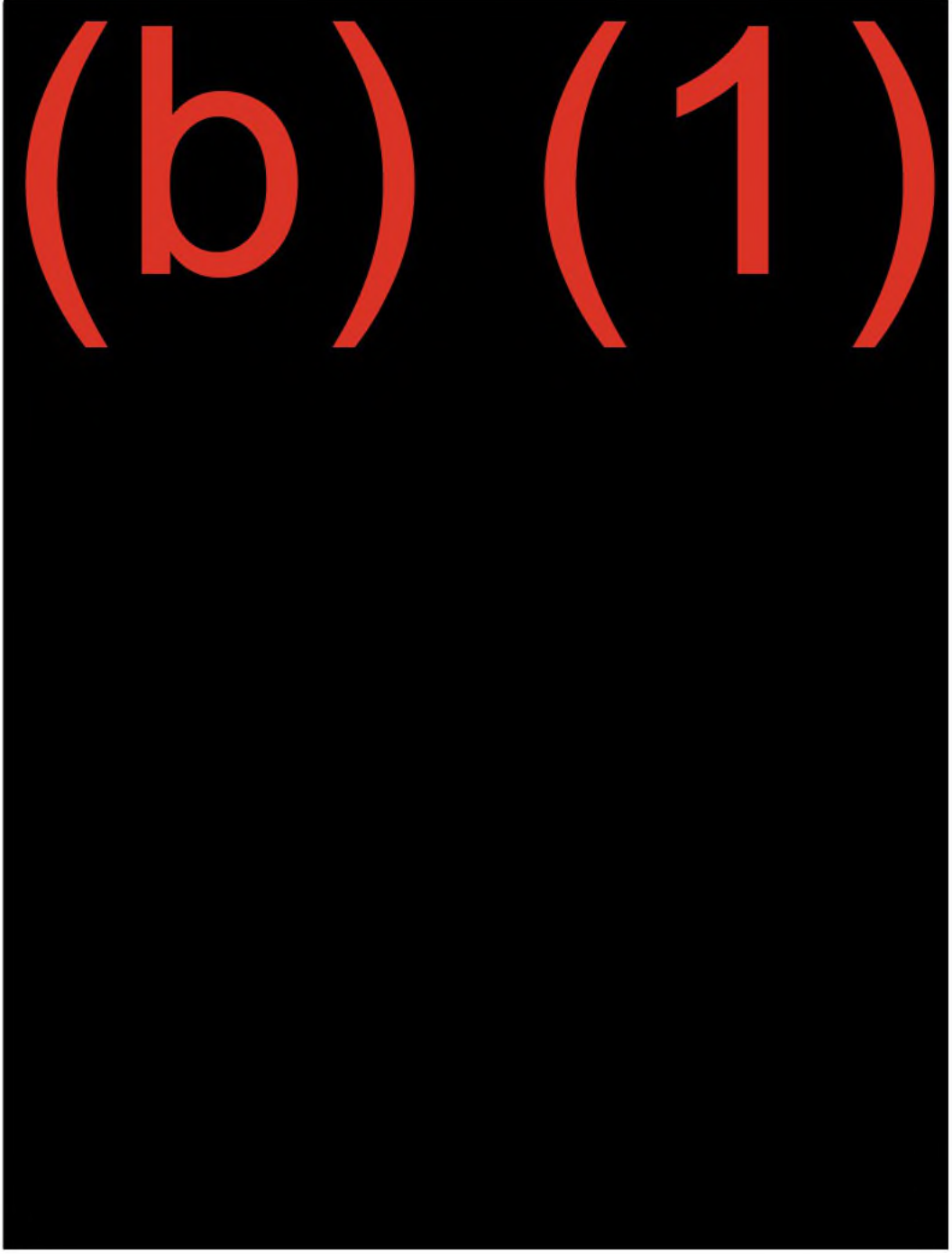


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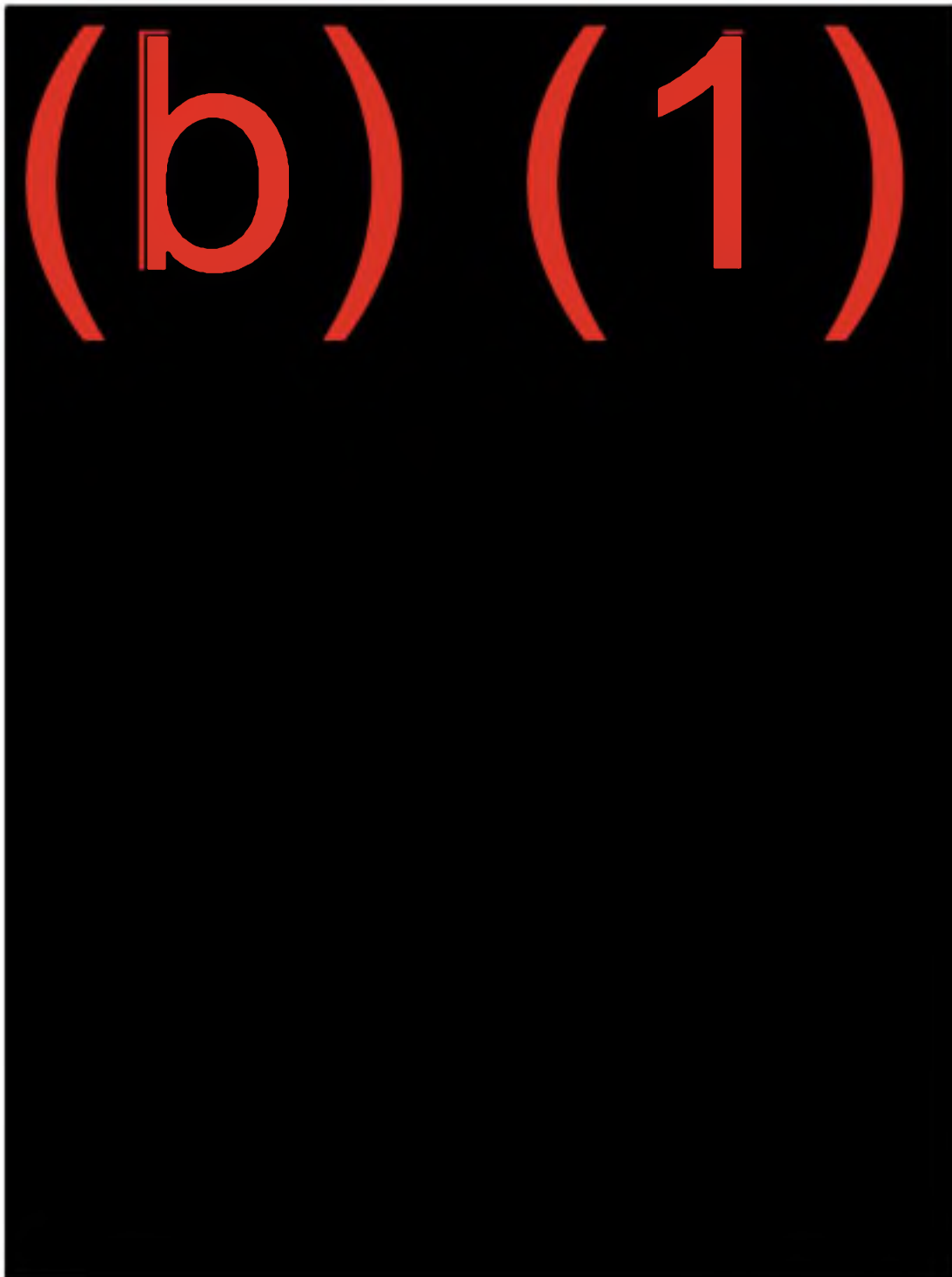
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B-263

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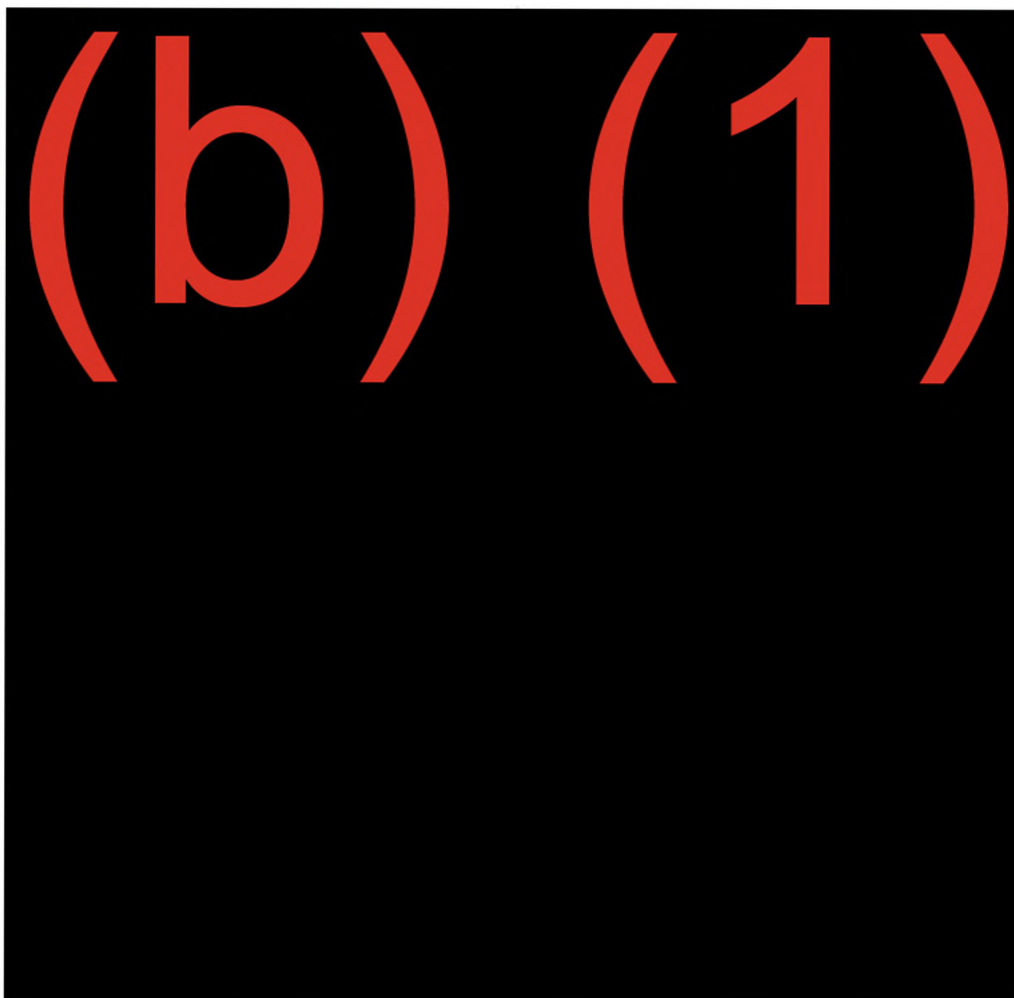
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CPIC



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B-265
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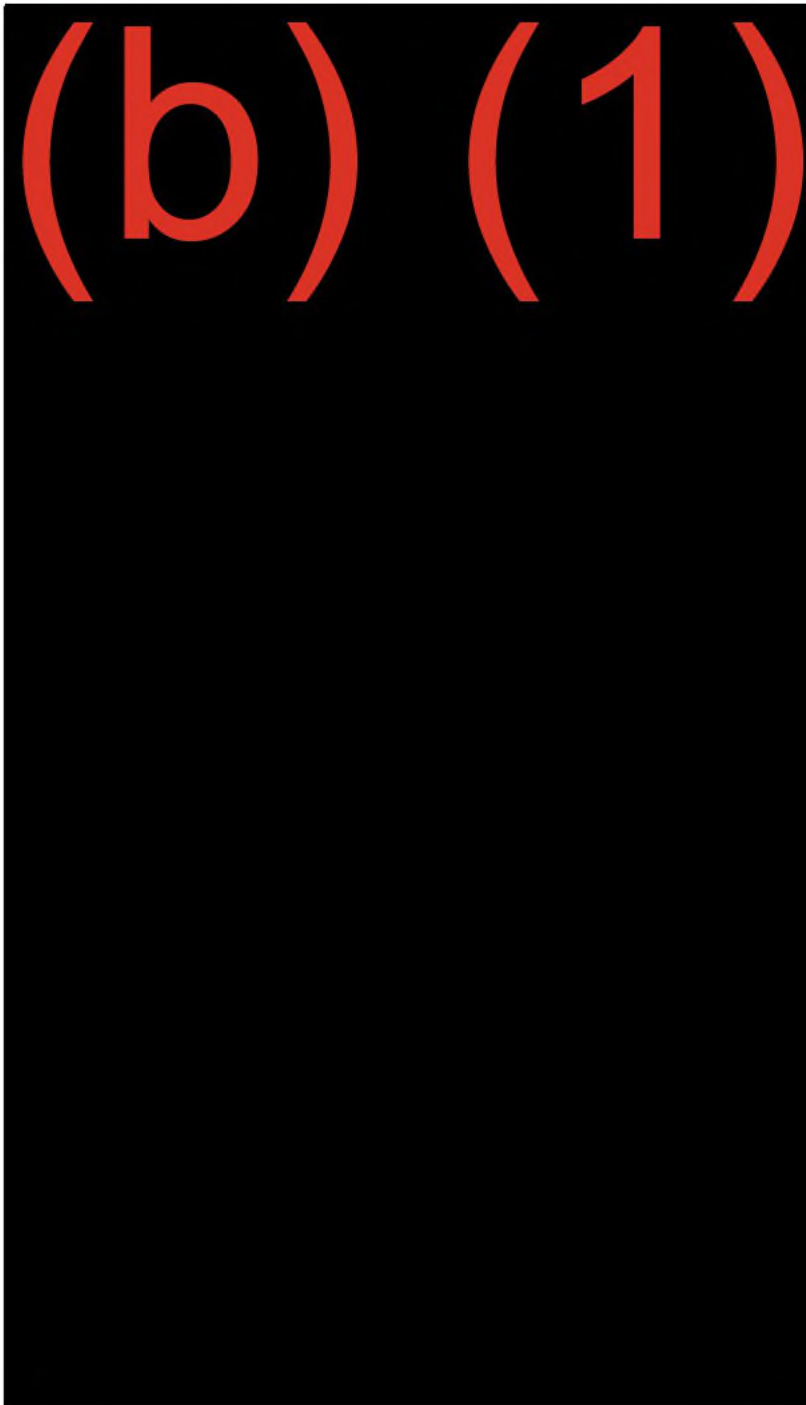
(b) (1)

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FEG 7

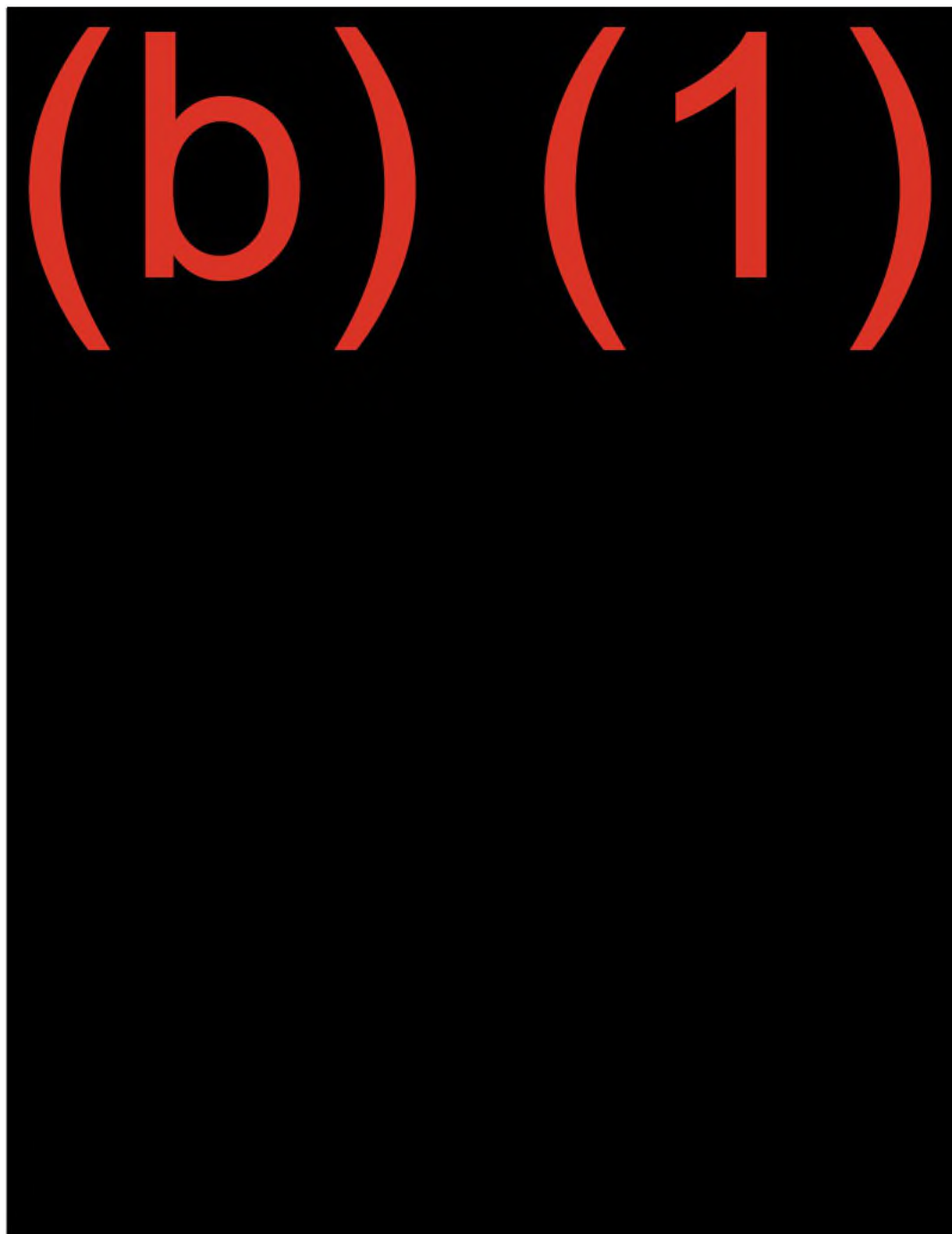
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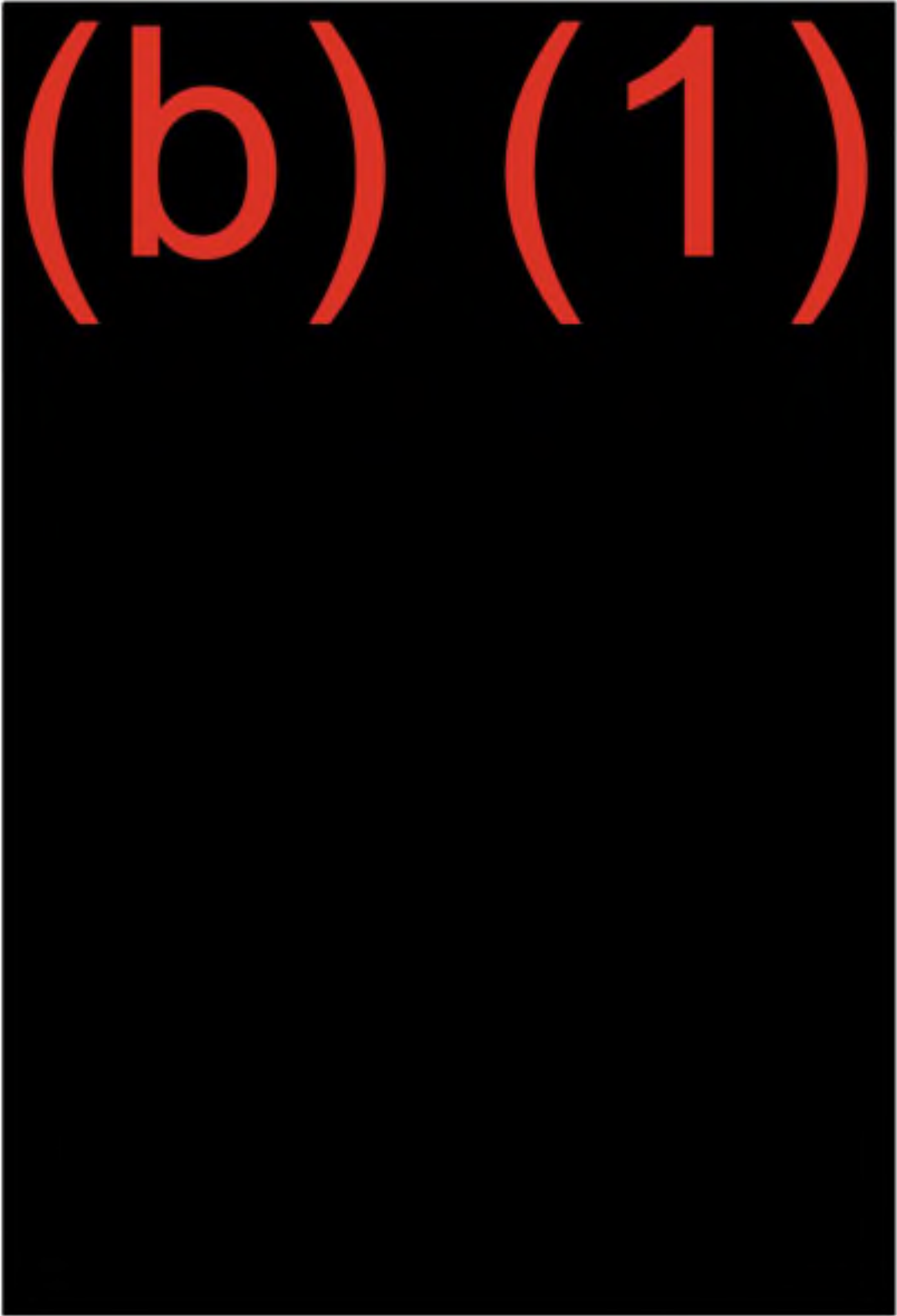
FFG 7



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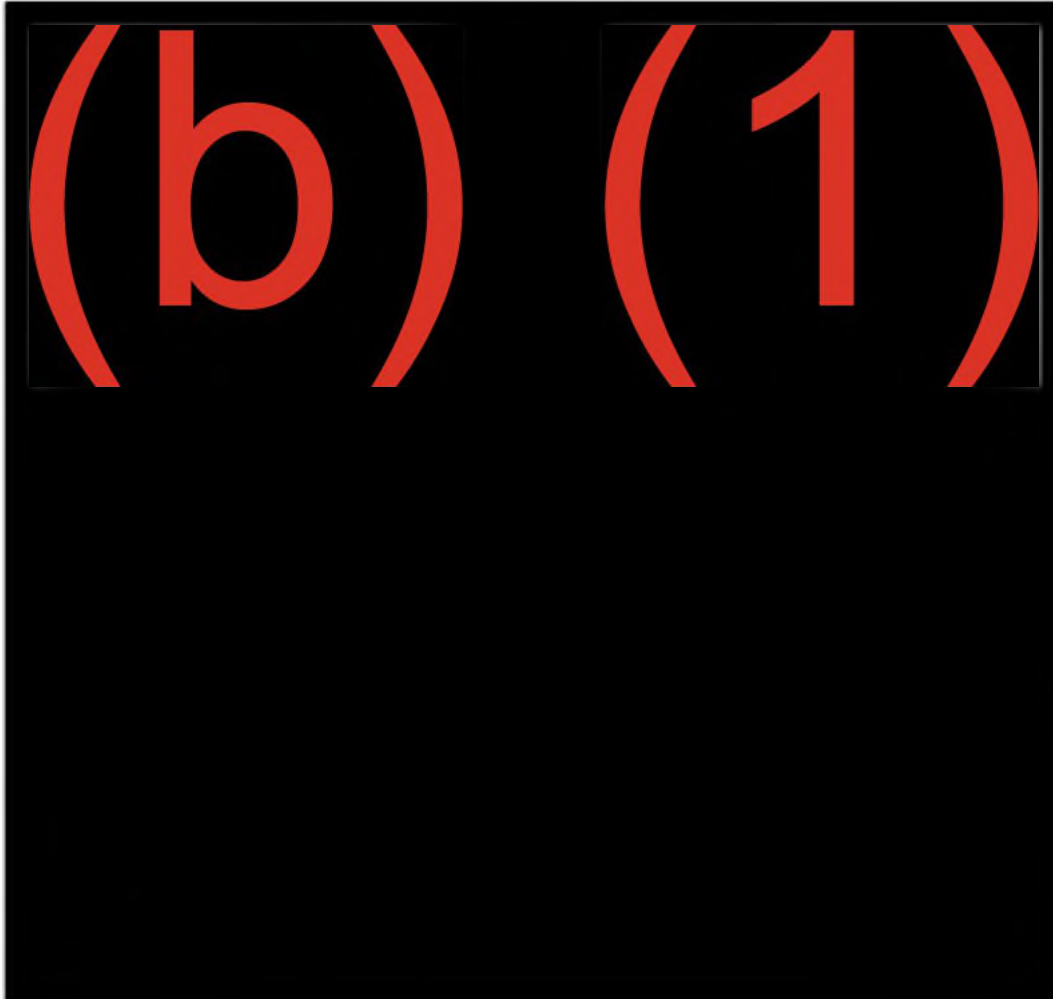
(b) (1)



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FFG 7



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FPG 7

(b) (1)

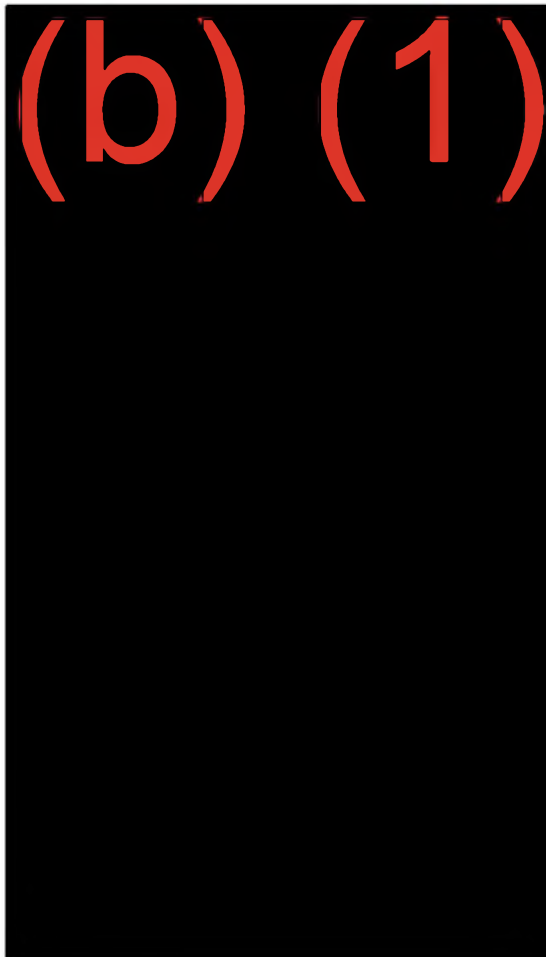
B-272

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FFG 7

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B-273

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FEG 7

(b) (1)

B-274

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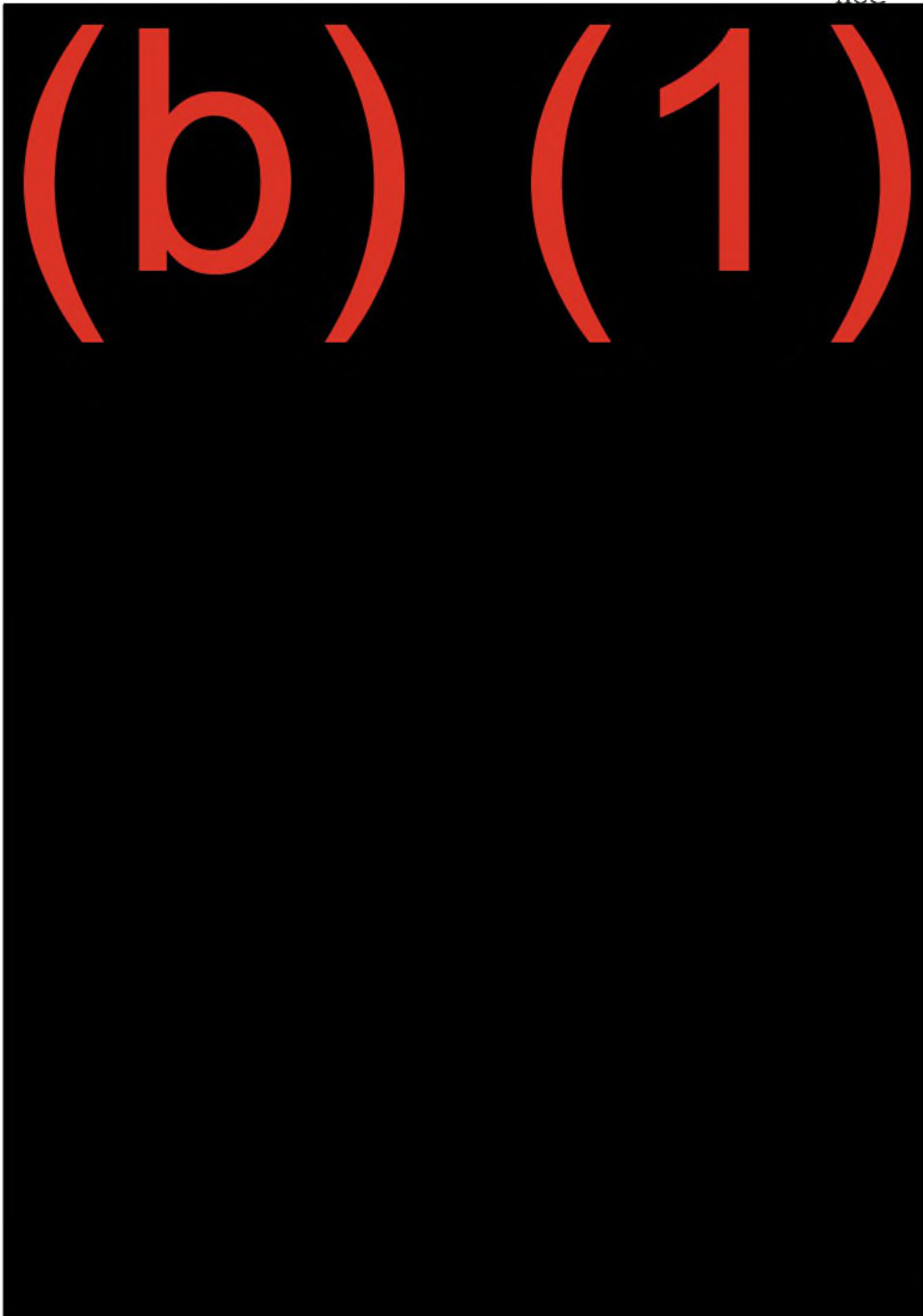
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HQC

(b) (1)

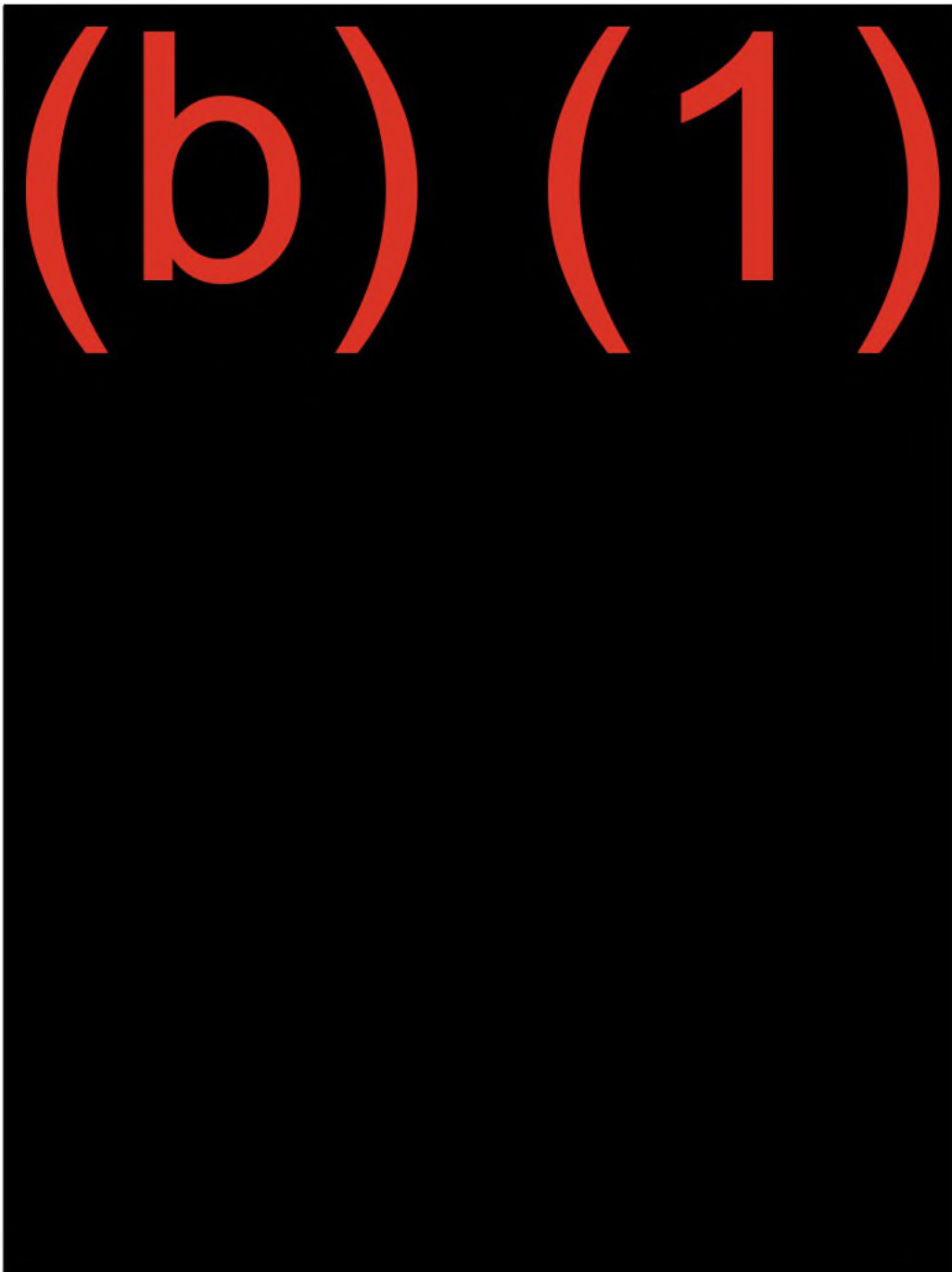


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HOC

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HOC

(b) (1)

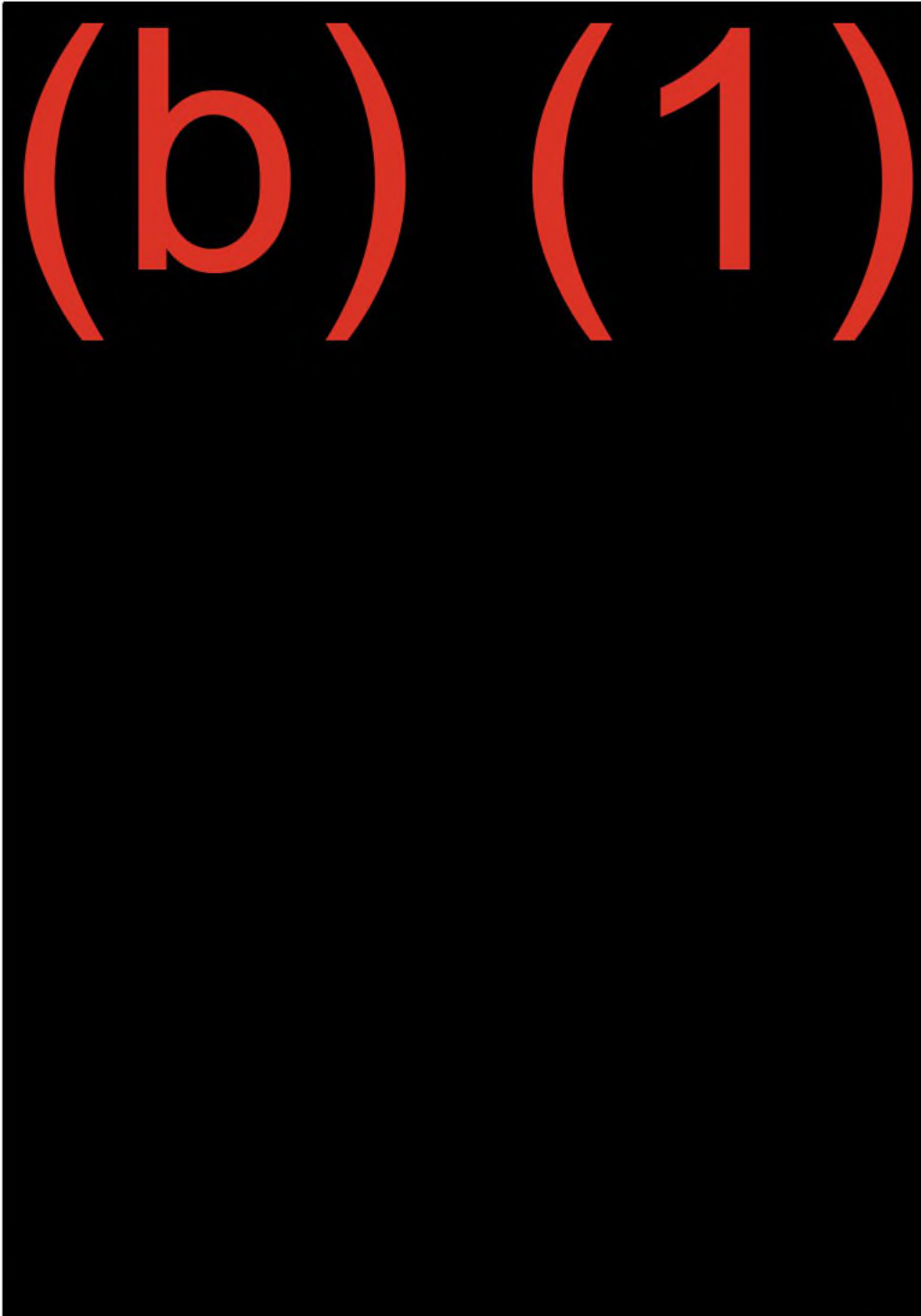


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HOC

(b) (1)

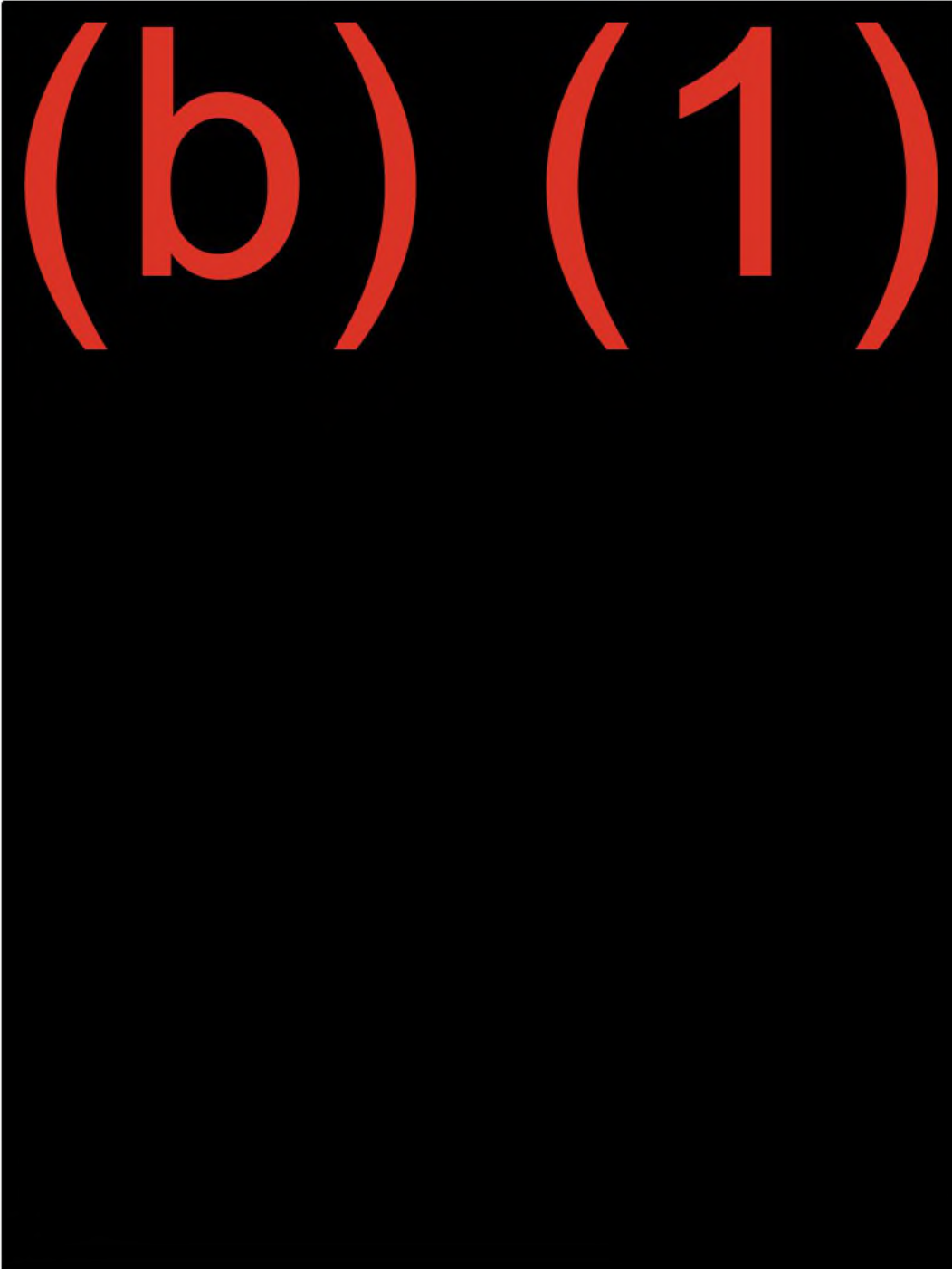


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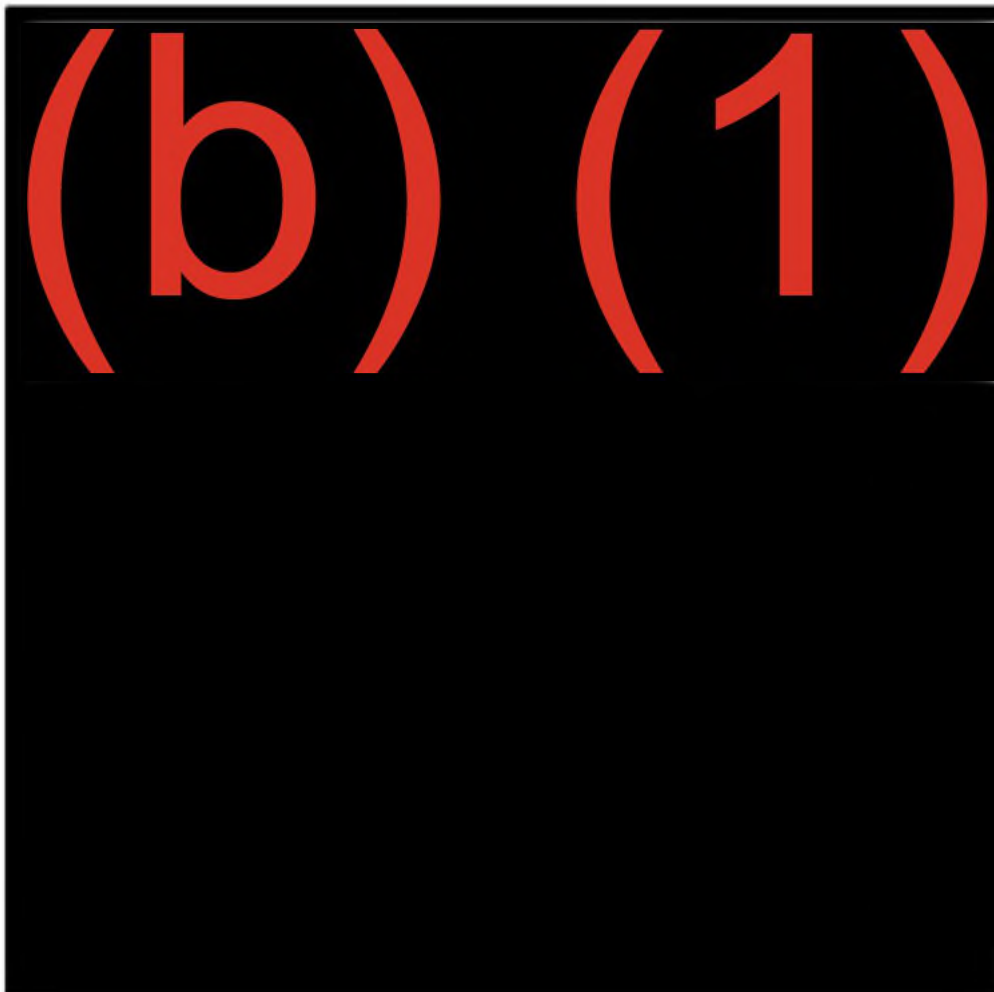
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(b) (1)



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HOC



B-281

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LSES

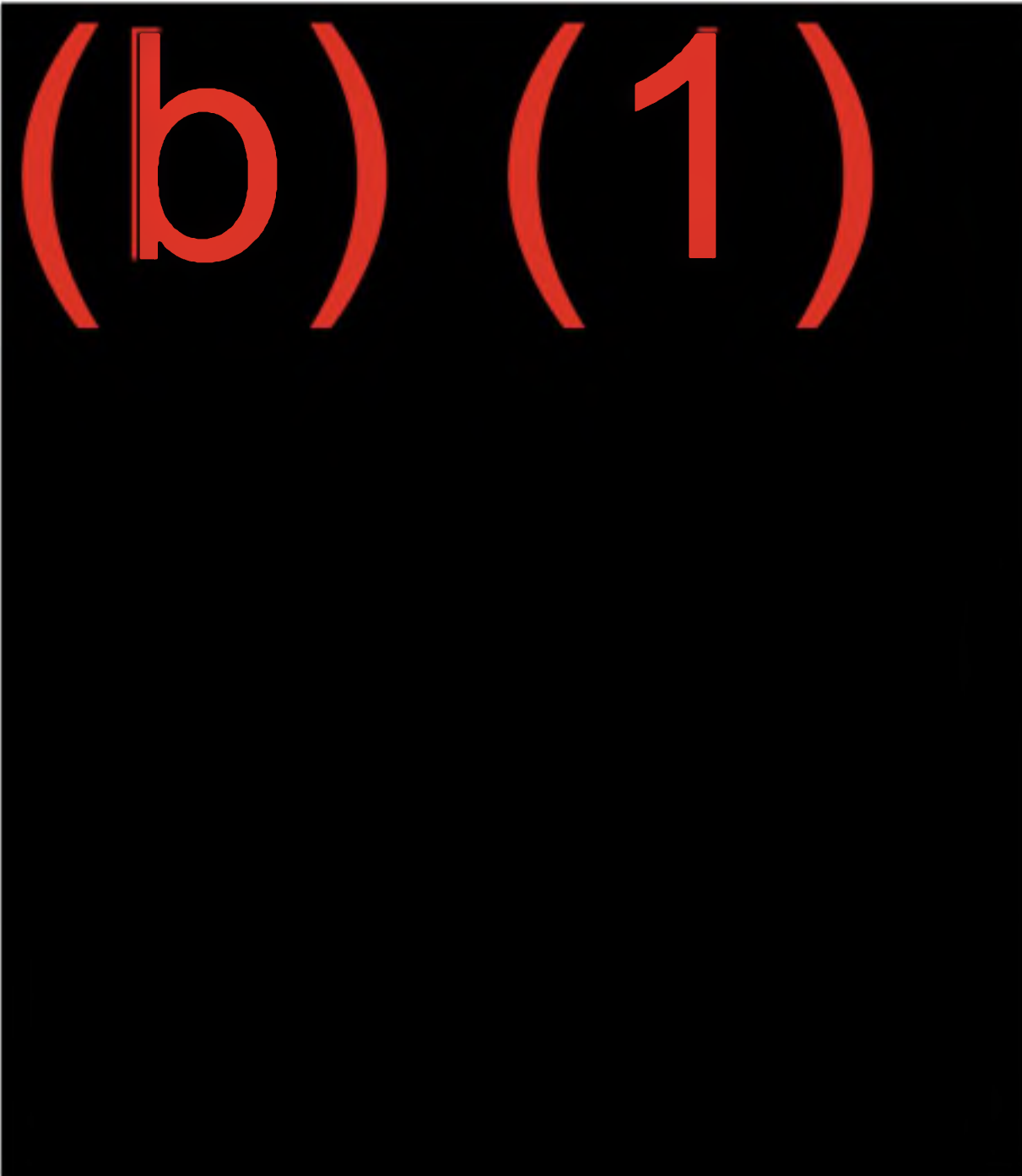
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(b) (1)



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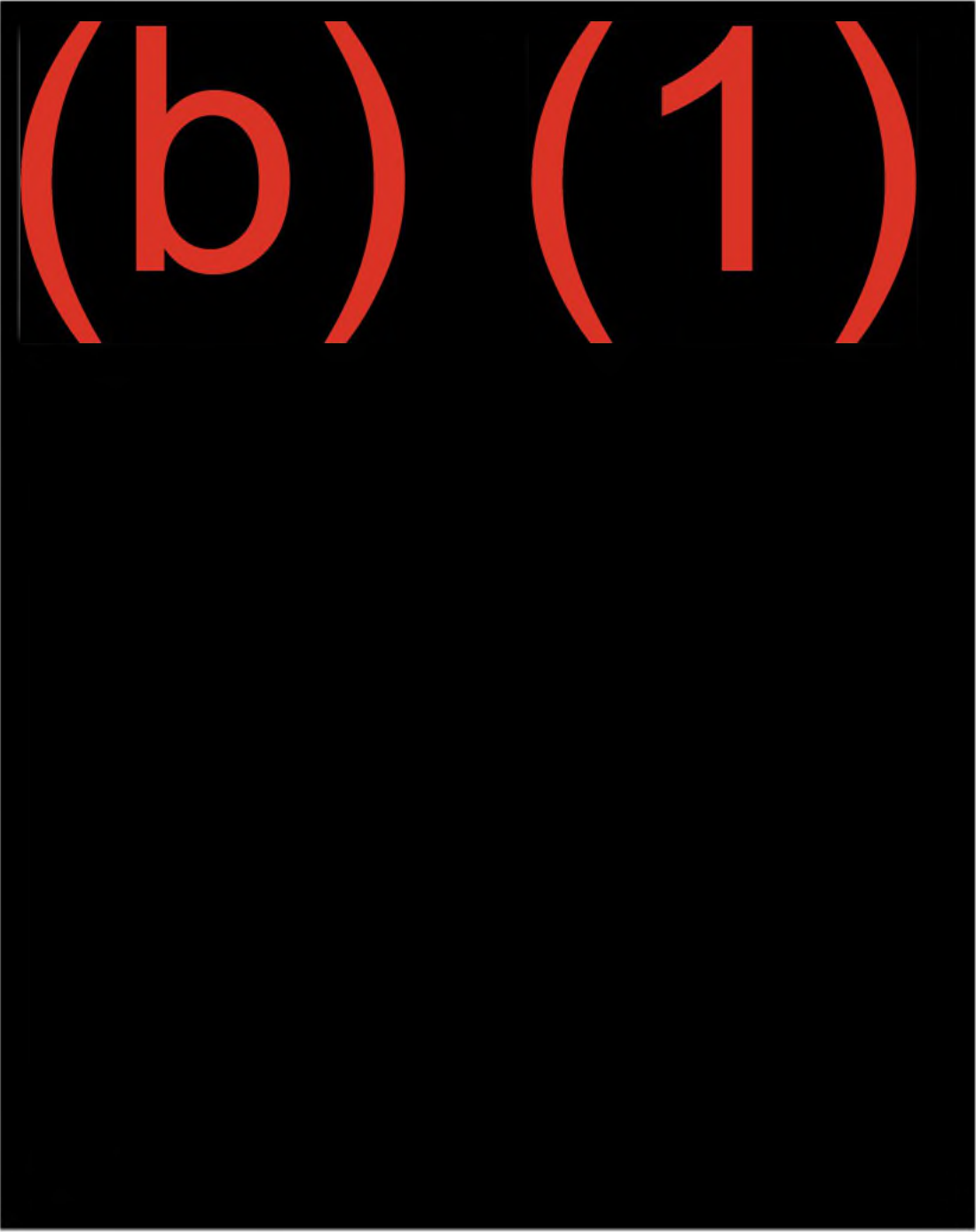


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LSES

(b) (1)



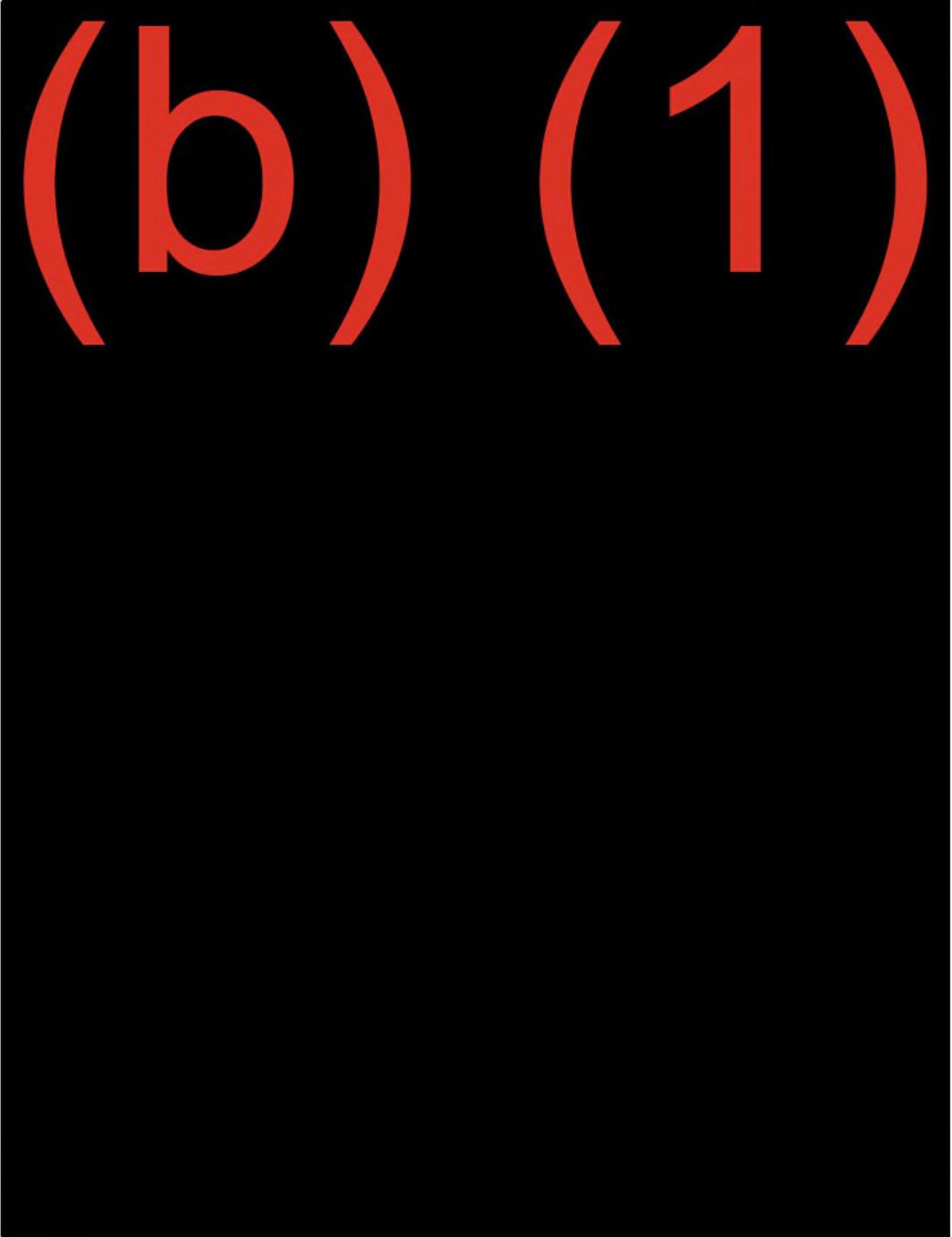
B-287

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LSES

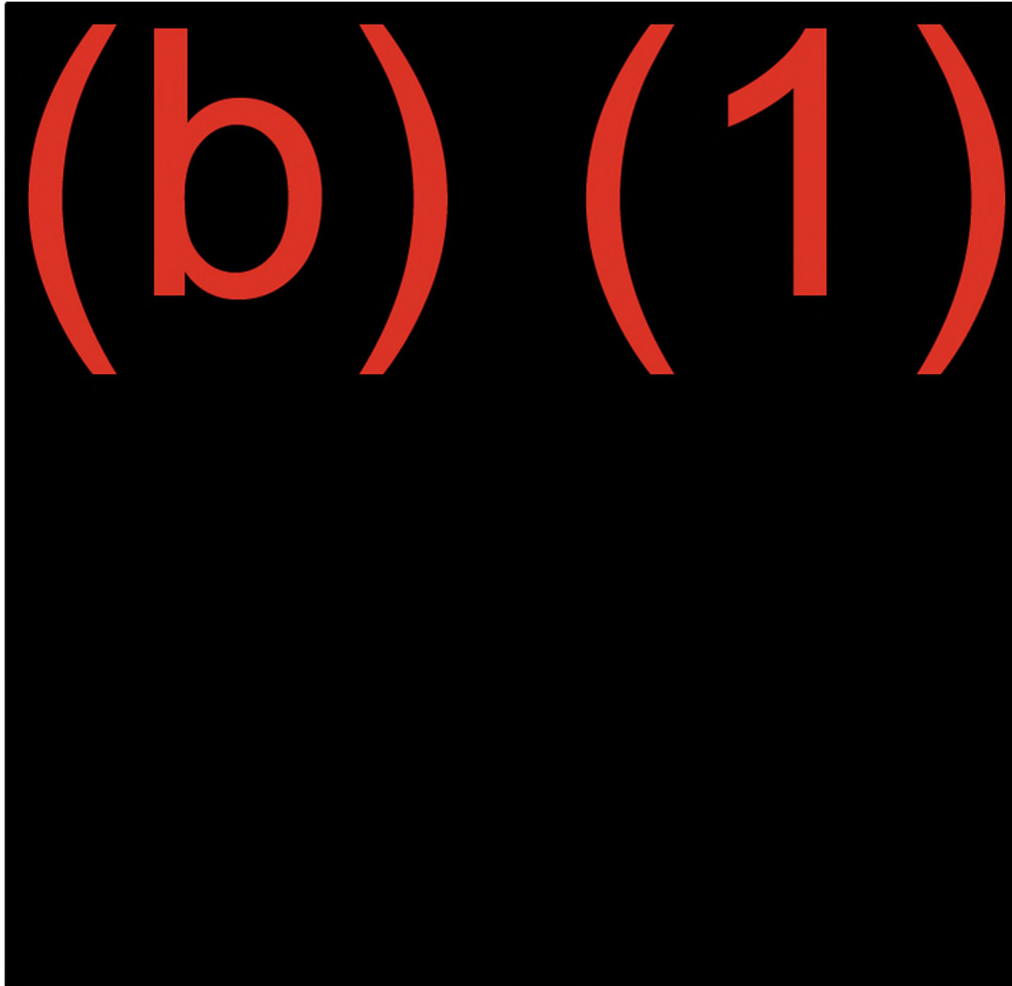
(b) (1)



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~~CONFIDENTIAL~~

LSES



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(b) (1)

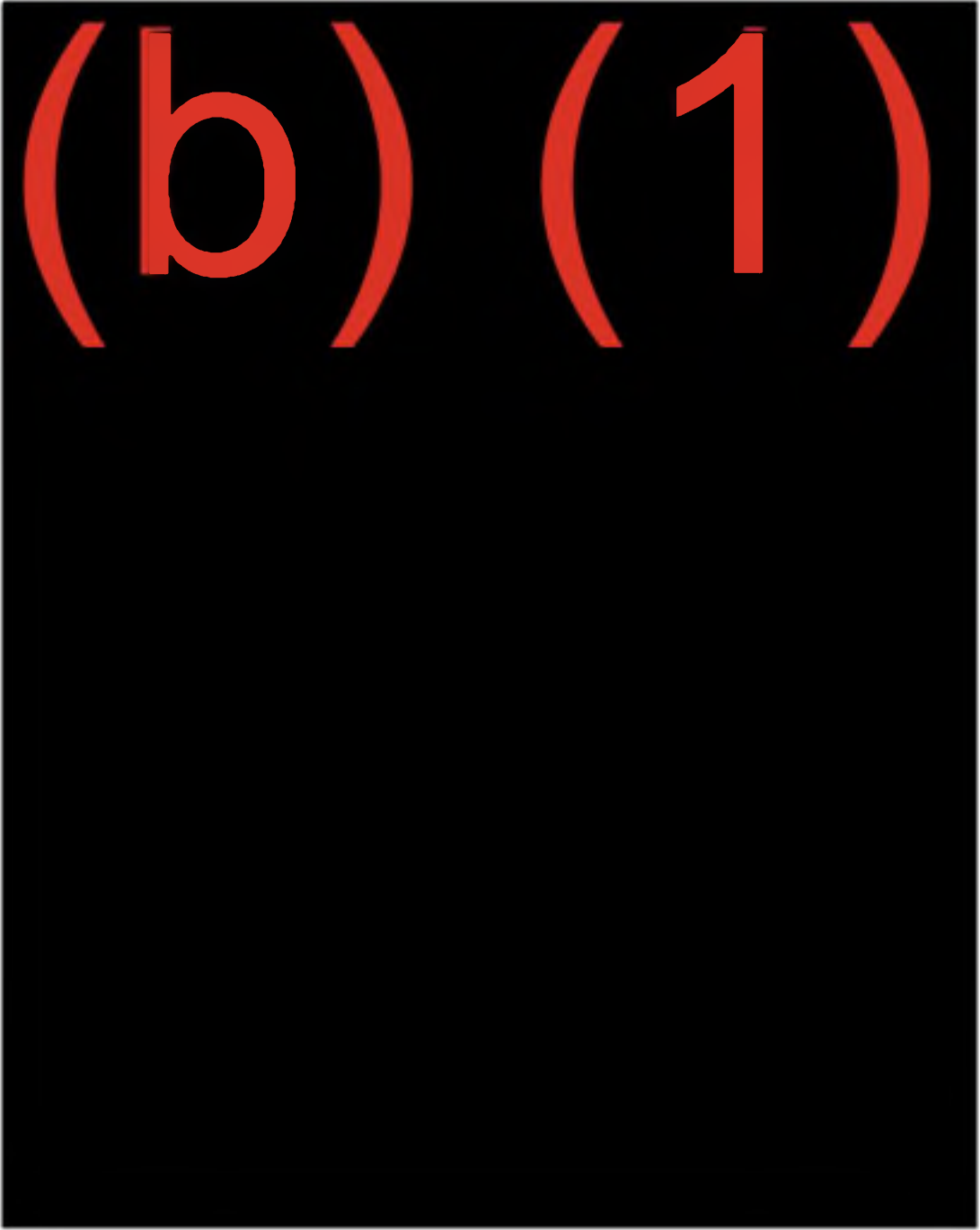
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PHM

(b) (1)

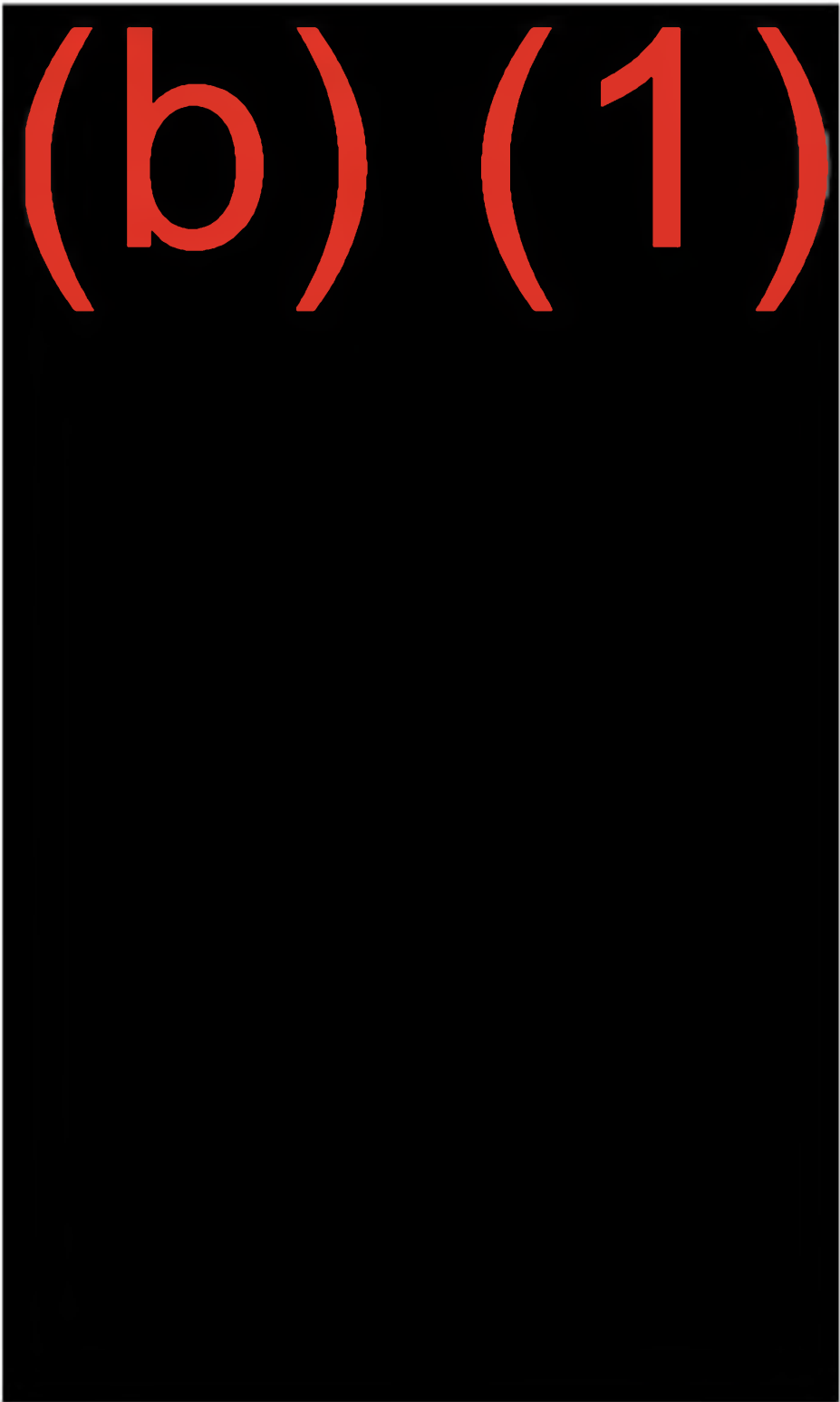


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PHM

(b) (1)



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PHM

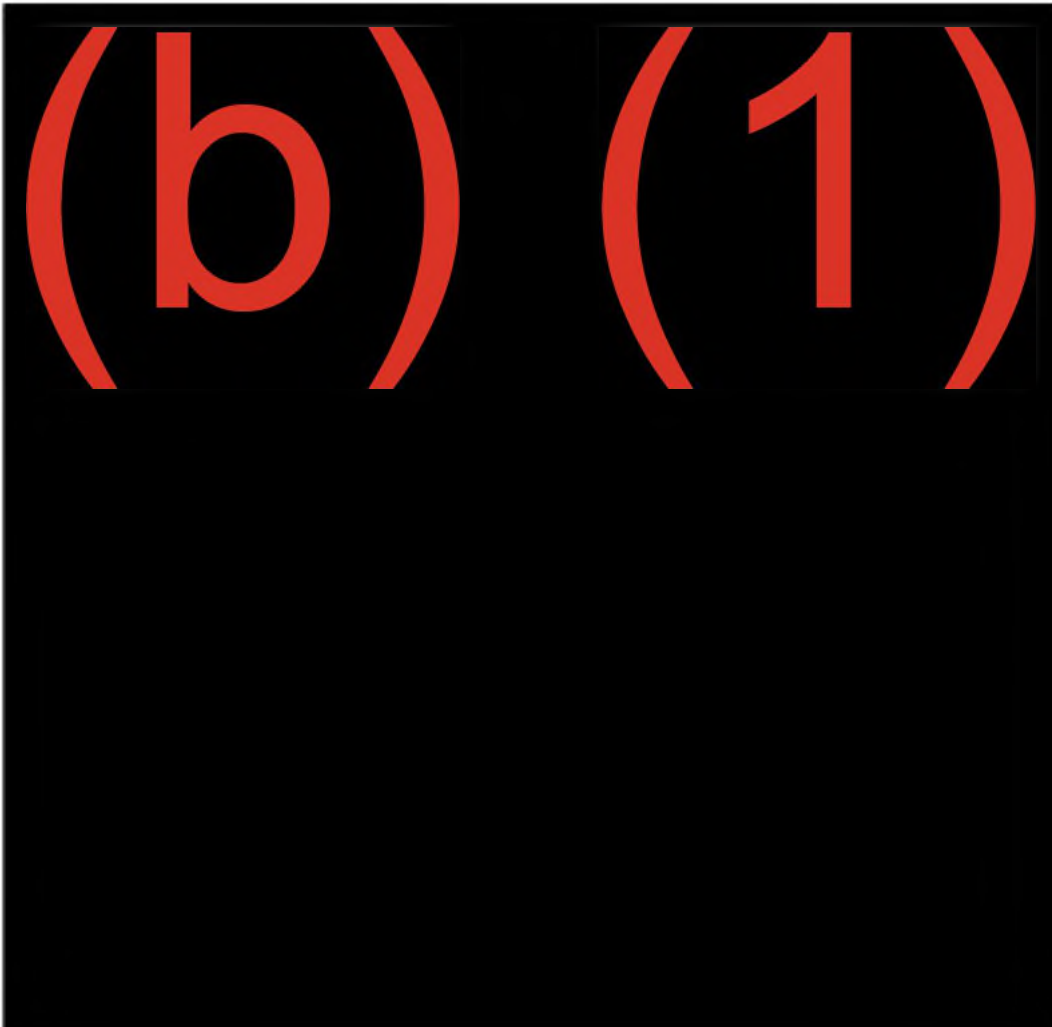
(b) (1)



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PHM



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UNCLASSIFIED

ZPG



PATROL LTA VEHICLE
POINT DESIGN SUMMARY

UNCLASSIFIED

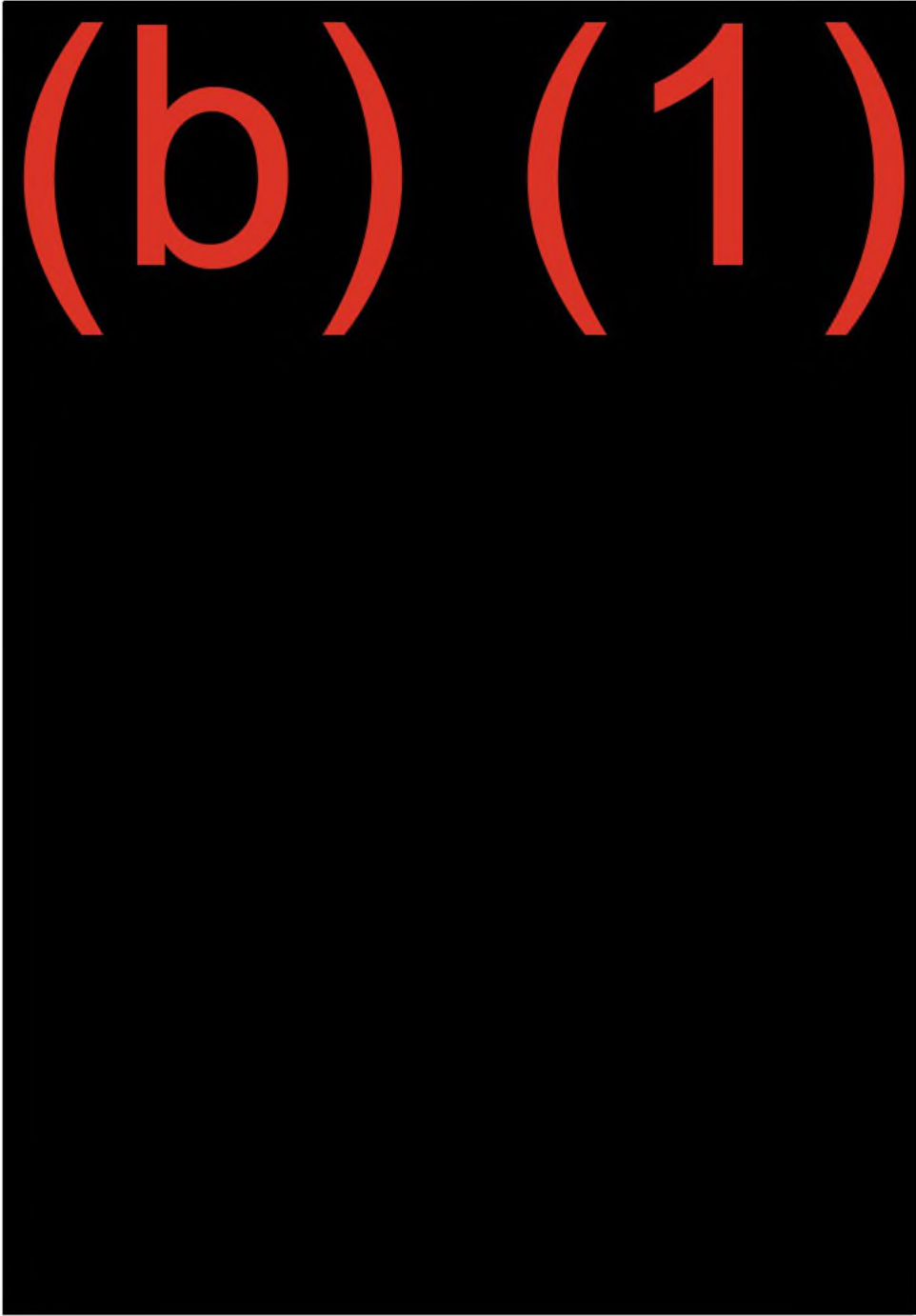
B-297

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(b) (1)

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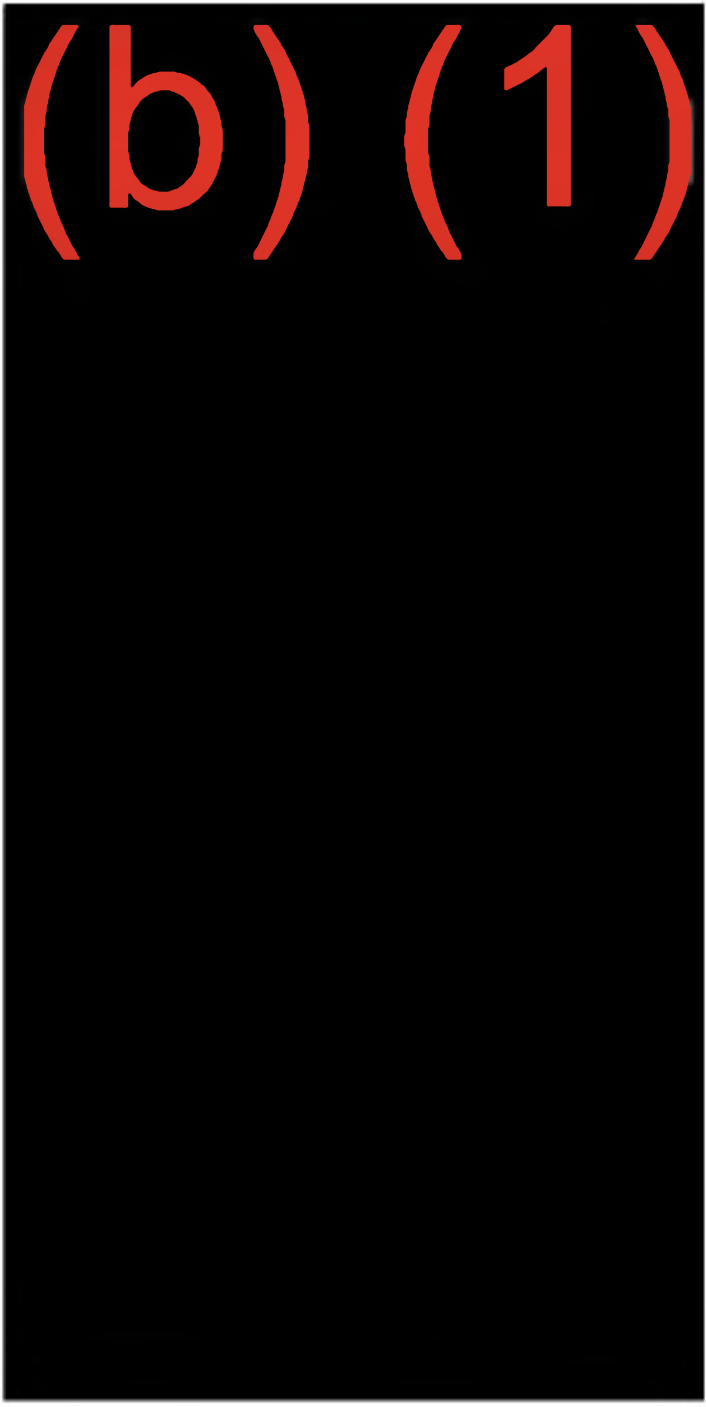
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