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SURFACE EFFECT SHIPS FOR OCEAN COMMERCE

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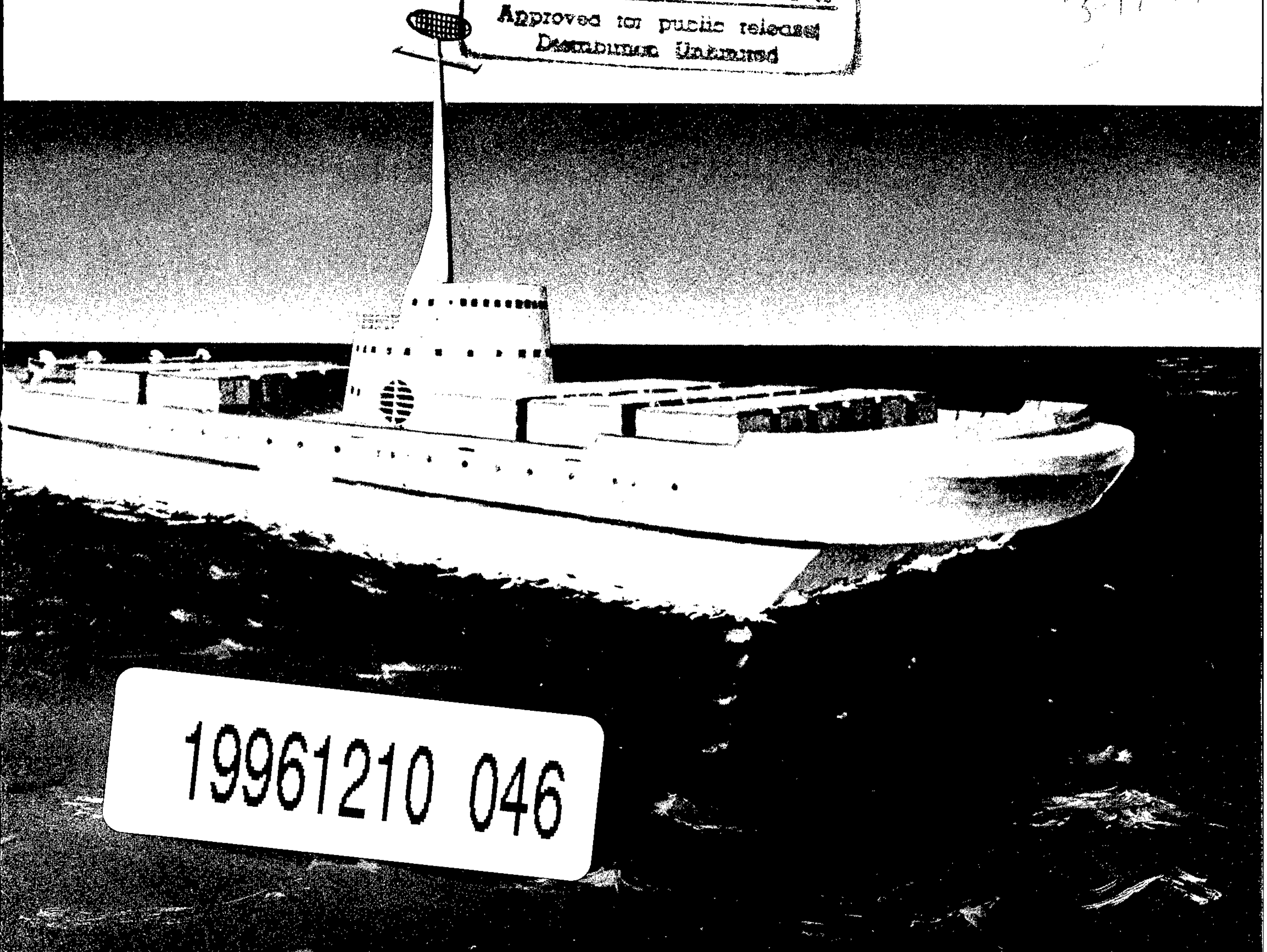

U.S. DEPARTMENT OF COMMERCE

SURFACE EFFECT SHIPS FOR OCEAN COMMERCE
(SESOC)

Final Report on a Study of the
TECHNOLOGICAL PROBLEMS

by the

SESOC ADVISORY COMMITTEE

Convened by the

Commerce Technical Advisory Board

PA 21767

U.S. DEPARTMENT OF COMMERCE
John T. Connor, Secretary
J. Herbert Hollomon, Assistant Secretary
for Science and Technology and Chairman,
Commerce Technical Advisory Board

[illegible]

Washington, D.C., February 1966

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NOTICE

This report contains the results of a study of an advisory committee. Its contents do not necessarily represent the policy or plans of the Department of Commerce or of any other Federal Government agency.

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INTRODUCTION

Ships using the surface effect principle have been suggested as a means of improving the transport of U.S. international commerce. The functional principles of the surface effect ships (SES) appear to offer an avenue for developing transoceanic vehicles potentially capable of filling a gap in the spectrum of services now afforded by displacement ships and aircraft.

The magnitude and complexity of the developments necessary to achieve a full-scale evaluation of the potentialities of large SES prompted the Department of Commerce to conduct a vigorous review of the technological problems involved in such an undertaking.

The study was conducted by the Surface Effect Ships for Ocean Commerce (SESOC) Committee and five supporting Panels. The membership included 40 volunteer scientists and engineers of national stature from industry, education, and Government. The membership is listed in appendix A.

The mission of the study was:

> To determine the research and engineering problems associated with employing the surface effect ship concept in commercial ocean transportation systems.
>
> To recommend a research and development program competent to resolve such technological problems.[1]

The mission was further delineated in a series of notes regarding its scope:

> The study emphasizes the research and engineering aspects of the surface effect ship concept. However, the systems approach will be used, and manning and management will be studied to the extent that they are essential ingredients of engineering an operable system. Similarly, economics will be considered in terms of engineering, construction, and operating costs whereas matters of revenue such as alternate specific routes, cargo availability, and profitability will not be a part of the study.
>
> The study emphasizes commercial transoceanic applications of the surface effect concept. Military application and feeder services by SES will not be studied. The study will concentrate on the captured air bubble (CAB) and channel flow concepts, but other concepts will be screened for the sake of completeness.

The goals for the Committee were set as follows:

1. To identify those technological problems which are important to SES development.
2. To identify and define those technological problems which are crucial to SES development.
3. To rank the crucial problems in order of criticalness to the success of the SES program.
4. To rank the crucial problems in order of difficulty of solution.
5. To recommend the magnitude, time phasing, and scope of an effective R. & D. program to resolve the problems.

The Committee added the following items for its deliberation:

1. Consideration would be restricted to cargo liner systems handling a typical spectrum of high value containerized cargo.
2. The study would include all concepts of SES.
3. The hypothetical SES would have a gross weight of about 5,000 long tons and would cruise at a speed of about 100 knots.

Appendix A contains a statement of the Committee's method of operation. The technical materials which were available to the Committee are also described.

The Committee examined several specific SES configurations. They found that there are two basic types of SES.

1. One type is supported by a cushion of pressurized air which is constrained beneath the vehicle. This type has been designated as a "category I" vehicle (aerostatic lift).
2. The second type of SES is mainly supported by aerodynamics as the vehicle transits at sufficient speed to obtain aerodynamic lift similar to an aircraft. The significant difference from aircraft is that the proximity of the sea surface provides an added degree of lift. This type is called a "category II" vehicle (aerodynamic lift).

A further description of the principles of operation of the SES and of the typical examples examined in this study is found in appendix B. new/;)

The five SESOC Panels identified crucial, important, and improvement problems, performed individual studies, evaluated types of SESOC concepts, and recommended specific research and development. The summary reports of the Panels are included in appendix C, and a consolidated list of the research and engineering problems is included in the Findings section of this report.

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[1] Memorandum from the Assistant Secretary for Science and Technology to the Undersecretary for Transportation, September 14, 1965.

CONCLUSIONS

The SESOC Committee arrived at the following conclusions, which were based on the Panel reports and on an evaluation of all presentations and documents.

The commercial feasibility of the SESOC concept is critically dependent upon the achievement of optimum performance in the following areas: stability and control, effective lift-to-drag ratio, structure, propulsive efficiency, and fuel economy. At the present time, the state of knowledge is not adequate to determine the optimum degree of performance in these areas, either as to what is required or what can be realized.

An improved state of knowledge for the solution of crucial technological problems can be achieved if immediate studies emphasize research rather than the development of scaled prototype vehicles. By the end of about 3 years and with an expenditure of about $10 million, it would be possible, through a coherently organized research program, to know whether the SES concept is technically feasible for ocean operation.

Similarly, by the end of approximately 2 more years and with an expenditure of an additional $60 million, approximate quantitative values could be determined for the preliminary engineering design of commercially feasible ocean transportation systems. If insurmountable technological problems appear to exist, they probably will be discovered early in these studies and the program could be terminated.

If the research program provides a positive indication that commercially competitive performance can be achieved, a continuing program will be required involving larger research craft (on the order of 500 long tons) in order to determine performance data within acceptable engineering tolerances. This extension of the program would involve an increased funding rate as compared to the earlier efforts.

The basic knowledge gained in the research program will contribute to other areas of high-speed transportation regardless of the competitive promise of SESOC. Such areas include the application of the SES principle to ships other than SESOC and the application of SESOC technology to improve components for displacement ship and aircraft systems.

If the United States mounts a development program of the magnitude recommended, it should be monitored by a competent in-house professional staff capable of intelligently assessing the product and of utilizing the data in the economic analyses. During the early stages of the research program, about six professional people would be required. Ideally, the staff should be large enough so that some of the people could be engaged in active technological studies.

RECOMMENDATIONS

In the light of the foregoing conclusions, and to move forward with the evaluation and development of the SES concept for commercial ocean transportation systems, the following recommendations are made.

A two-phase research program should be initiated and implemented as soon as possible to tackle the technological problems involved in SESOC development.

The early effort should define more precisely the parameters of the technological problems through scientific and technologically oriented projects. There should be a relatively minor investment in manpower and facilities.

Priority should be given to projects which will provide a basis for early decisions concerning the technical and commercial feasibility of SESOC. Thus the research program should emphasize the acquisition of basic knowledge and data rather than vehicle development. In terms of both problem priority and technical difficulty of solution, first-rank emphasis should be placed on the areas of stability and control, effective lift-to-drag ratio, structure, propulsive efficiency, and fuel economy.

The mutual interaction and interdependence among these important technological areas are such that they must be studied concurrently in a well-coordinated program. A rational determination of the technological problems and performance criteria can best be achieved through the use of conceptual configuration analysis. By this means, the emergence of general principles, special methods of analysis, and quantitative data for future parametric studies and actual designs will be assured.

Analyses, laboratory tests, component tests, and small-scale research model evaluations should be performed over a period of 3 to 5 years. During this initial research phase, the specimens, components for test, research models, and testing techniques should be no larger nor more complex than necessary to secure significant data regarding the principles under examination. Projects should be selected so as to screen the most crucial potential obstructions to progress with the least cost. Many decision points should be included in the program. The program should be continued only if the forecasts indicate that there is a promise of ultimate development of a commercially competitive transportation system.

A $1 million expenditure for fiscal year 1966 is considered to be reasonable in the light of the usual impediments to initiation of a new research program and because the first year's work would be executed with available talent in existing facilities. This amount could grow reasonably to $2 or $3 million in fiscal year 1967, reaching a total of $10 million for the first 3 years. At this point, it probably will be known whether the crucial phenomenological problems will or will not bar exploitation of the SES concept, and a higher degree of confidence will be available to make a decision regarding the next phase of the program.

The second phase of the program would address itself to solidifying knowledge regarding crucial phenomena and to tackling important technological problems essential to achieving commercially competitive operation of the SES. This phase is estimated to cost about $60 million over a 2-year period.

If the analysis continues to indicate favorable prospects for the SES, these two phases would be followed by larger scale testing. This testing would probably include large seagoing research test bed models (on the order of 500 long tons) which would serve to determine the physical quantities within an acceptable degree of confidence and precision for engineering design purposes.

The current cooperation with the Department of the Navy in the planning of SES research and development programs should be continued. This should be extended to an active coordination between Navy and Commerce Department development programs to ensure full exploitation of the most recent technological advances. Some of the key problem areas should be brought to the attention of the President's Science Advisory Committee.

Transportation system economic analyses, employing marketing appraisals and performance and cost characteristics of the SES, should be performed with the aid of the most recent projections regarding technological capabilities. The mathematical simulation should be extended and refined to perform the required future analyses.

The SESOC study has revealed that we lack knowledge of the technology which dominates the economic input assumptions. During the early years of the research program, data to harden these assumptions will be produced and the formulation of models and the assembly of market-type inputs should be continued so that reliable forecasts can be made as soon as a sufficiently valid prediction of technological capabilities is available. Valid cargo type and quantity forecasts are not now available in terms of ultimate source and destination: these will be required for effective comparison of SES services with those offered by surface displacement ships and aircraft.

The economic analyses should be performed on a continuing basis for monitoring purposes. The results of economic forecasts and analyses would be one of the conditions considered at each decision point in determining the need for continuing the SES development program. The results would also provide economic sensitivity evaluations which will assist in determining proper emphasis for the research effort.

FINDINGS

In arriving at the foregoing conclusions and recommendations, the SESOC Committee findings covered the following:

1. Technological problems.
2. Evaluation of SES concepts.
3. Economic analysis of transportation systems.
4. Research and development plans and costs.

Technological Problems

The five SESOC Panels identified and evaluated the key technological problems which must be solved in the development of competitive SESOC. These problems were categorized as crucial, important, and improvement.

Crucial problems are those which must be solved in order to construct safe and functional SES which meet most performance criteria but do not necessarily have to be economically competitive. These problems include:

1. Inadequate stability and control criteria.
2. Lack of knowledge of stability modes.
   - a. Pitch and heave.
   - b. Yaw and roll.
   - c. Relation to speed, resistance, seakeeping, and lift-power requirements.
3. Need for control systems (concepts, life, reliability).
4. Dynamic loads (and implications of stability solutions) with respect to sea state, speed, resistance, seakeeping, and structural requirements.
5. Overloading sea conditions, waves of unusual heights, damage, and structural failure.
6. Collision avoidance.
7. Need for effective flexible understructures —material and techniques for bubble constraint.

Important problems dominate efficient performance of the vehicles or other parts of the transportation system and must be solved to create economically competitive SESOC systems. These include the need for:

1. Processes to exploit fully our knowledge of the air-sea boundary and to forecast environmental and sea conditions.
2. More adequate formulation of prototype design parameters and criteria.
3. Processes to exploit analytical and experimental methods for prediction, measurement, and simulation of stability and control characteristics.
4. Improved resistance prediction including the interaction of propulsion and resistance.
5. Highly efficient, high powered, lightweight propulsion systems capable of continuous, reliable, and maintenance-free operation without efficiency degradation in the marine environment. This includes gas-turbine engines, transmissions, propulsors, and other system components.
6. Design criteria reflecting spectra of static and dynamic limit loads including criteria for foundations for the novel propulsion systems and for fatigue loading.
7. Further exploration of materials with regard to rupture, stress corrosion, cavitation erosion, and other special properties for SES application.
8. Effective system operational procedures and criteria including fuel margin, failure and survival, manning, maneuverability, and cargo handling.
9. Formulation of an effective mathematical simulation and continuous collection of system performance and economic data to sharpen assumptions and update analyses and evaluations.

Improvement problems involve opportunities to achieve superior performance for economically competitive SESOC transportation systems. Such problems are:

1. Unique structural design requirements and improved structural engineering technology.
2. Port delays.
3. Need for special facilities at terminals to accomplish fueling, servicing, and maintenance.
4. Need for reliability and maintainability.
5. Habitability.
6. Offshore navigation limitations.

The SESOC Committee and Panels have developed present-day capabilities which can be contrasted with projections for 1975 that were made by Booz, Allen Applied Research Inc.[2] The resulting contrast provides a scale for the possible improvements that are necessary. Three broad illustrations follow:

1. A present-day figure for the hull weight of the CAB concept could be 35 to 40 percent of gross weight rather than the 20 percent target for 1975 set by the Booz, Allen studies. This figure reflects our present-day provision for survival criteria, sea forces, and design criteria.

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[2] Booz, Allen Applied Research Inc., Bethesda, Md., performed a series of studies relating to SESOC under earlier contracts with the Maritime Administration.

2. A present-day estimate of the lift-to-drag ratio for the CAB concept is highly speculative when it is considered that full allowance must be made for the probable penalties involved in solving stability problems and for adding certain appendage resistance. The figure used in the Booz, Allen studies could well be increased by a factor of 25 percent or more.
3. In the present state of knowledge, propulsive efficiency probably could be 60 percent instead of 67 percent, as it may be necessary to use water instead of air screws.

At the end of 3 to 5 years of effective research, we should be able to assess expected progress on the problems more confidently and achieve a reasonably realistic projection of the potential performance of the SESOC concepts.

It is clear that vehicle technology dominates the economic future of the SES. The assumptions made by Booz, Allen in assessing the SES systems' economics represent goals such as must be obtained through an aggressive research program. As the research proceeds, it will be possible to provide better input data and to revise the estimates of the projected economic capability of the SESOC systems.

Evaluation of SES Concepts

The Committee has considered the technological problems for both types of SES—the aerostatic and the aerodynamic. The dynamic stability is problematical for each of the five examples of concepts considered. The development of a stability and control system necessary to achieve adequate control and suitable response characteristics in SES of practical design is expected to degrade efficiency.

The achievement of suitable stability characteristics will no doubt result in performance penalties for the aerostatic concepts. It is expected that as each concept is improved, it will take on some of the better features of the other concepts and they will develop toward one common type embodying the best features of each concept.

Of the two aerodynamic types, the state-of-the-art permits a performance assessment of the wing-in-ground effect. In contrast, the channel-flow wing aerodynamics needs much more study. The projected performance of the channel-flow wing craft indicates that it may have considerable promise and therefore merits further study.

Economic Analysis of Transportation Systems

The SESOC Committe considered special reports and presentations on economic analysis, mathematical simulation, and sensitivity studies. The presentations are listed in appendix A along with the reports prepared for the SESOC study.

Research and Development Plans and Costs

In formulating its conclusions and recommendations pertaining to plans and costs of the research and development program required to acquire the capability for building a SESOC transportation system, the SESOC Committee considered several special reports and presentations. The presentations and special reports are listed in appendix A, and the Panel reports are in appendix C.

Air Cushion Vehicle (ACV)

Hovercraft

GEM (Ground Effect Machine)

Volume II of this study (PA 21767) presents additional information on the research and engineering problems involved in the development of the SES.

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APPENDIX A—PARTICIPANTS IN THE SESOC STUDY AND TECHNICAL DATA PROVIDED

Precept and Organization

On July 6, 1965, the Undersecretary for Transportation, Department of Commerce, Mr. Alan S. Boyd, requested that a study be made of the surface effect ship (SES) concept. He addressed his request to Dr. J. Herbert Hollomon, Assistant Secretary for Science and Technology, Department of Commerce and Chairman of the Commerce Technical Advisory Board. Mr. Boyd stated,

> It is my belief that a task force of the Commerce Technical Advisory Board might well be established to study this concept looking toward an integrated research and development program * * *.
>
> In my judgment, such a task force should outline the program and its various segments * * *.

Dr. Hollomon selected Prof. George Maslach, Dean, College of Engineering, University of California, and a member of the Commerce Technical Advisory Board, to lead the advisory task force and he agreed to serve.

Mr. Boyd detailed Mr. E. M. MacCutcheon, Chief, Office of Research and Development of the Maritime Administration, to Dr. Hollomon's office to be full-time manager of this project and work started on September 9, 1965.

Dr. Hollomon appointed 10 scientists and engineers with technical knowledge and national stature to assist Dean Maslach in advising the Department of Commerce on this important subject. The Commerce Technical Advisory Board aided by suggesting qualified advisers and continued its sponsorship through progress reviews, evaluations, and suggestions at its monthly meetings.

The Committee to study Surface Effect Ships for Ocean Commerce (SESOC Committee) consisted of the following men:

Dean George Maslach, Chairman
College of Engineering
University of California

Dr. Francis P. Bundy
Research and Development Center
General Electric Co.

Mr. Phillip Eisenberg
President
Hydronautics, Inc.

Mr. Matthew G. Forrest
Vice President
Gibbs & Cox, Inc.

Mr. Martin Goland
President
Southwest Research Institute

Mr. John B. Parkinson
Chief, Aerodynamics Branch
Aeronautics Division
National Aeronautics and Space Administration

Prof. Willard J. Pierson
Department of Meteorology and Oceanography
New York University

Mr. John D. Reilly, Jr.
Executive Vice President
Todd Shipyards Corp.

Mr. John W. Sawyer
Technical Adviser
Systems Development
Office of Naval Material
Department of the Navy

Dr. Morris A. Steinberg
Deputy Chief Scientist
Lockheed Aircraft Corp.

Mr. Foster L. Weldon
Vice President, Research
Matson Navigation Co.

Coordination with interested branches of Federal agencies was achieved by the appointment of six ex-officio committee members:

Mr. William Hooper
Technical Assistant
Office of Science and Technology
Executive Office of the President

Capt. Michael J. Hanley, USN
CNO Project Officer, SES
Office of Chief of Naval Operations (Op–91)

Mr. Allen G. Ford
Interface Air Vehicles Coordinator
David Taylor Model Basin, U.S. Navy

Dr. Vincent J. Roggeveen
Director, Office of Transportation Research
Office of the Undersecretary for Transportation
Department of Commerce

Lt. Comdr. David J. Linde
Chief, Hull Arrangements Branch
Merchant Marine Technical Division
U.S. Coast Guard

Mr. James A. Higgins
Advanced Ship Specialist
Office of Research and Development
Maritime Administration

The SESOC Committee held its first meeting on October 1, 1965. It was decided that the subjects under study would require technological exploration in greater depth than the Committee could manage. Accordingly, Dean Maslach appointed five Panels, each chaired by a Committee member. The members of the Panels were selected because of their specialized knowledge and national stature and included some of the Committee members. The scope of the Panel responsibilities and the membership are listed below. The results of the Panel studies are contained in appendix C.

Aero-Hydro Dynamics and Control Panel

Aerodynamic stability, hydrodynamic stability, steering, control and forces, excursions, and recovery.

Mr. John B. Parkinson, Chairman

Dr. H. Norman Abramson
Southwest Research Institute

Prof. René H. Miller
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

Prof. Milton S. Plesset
California Institute of Technology

Dr. Harvey R. Chaplin, Jr.
David Taylor Model Basin, U.S. Navy

Mr. Marion O. McKinney, Jr.
Head, Dynamic Stability Branch
Flight Mechanics and Technology Division
NASA Langley Research Center

Mr. Harold Chestnut
General Electric Co.

Dr. Willard J. Pierson
Department of Meteorology and Oceanography
New York University

Speed, Resistance, and Seakeeping Panel

Resistance—drag, thrust required, speed in rough sea, motions, and accelerations.

Mr. Phillip Eisenberg, Chairman

Mr. Virgil Johnson
Hydronautics, Inc.

Dr. William E. Cummins
Head, Hydromechanics Laboratory
David Taylor Model Basin, U.S. Navy

Mr. Allen G. Ford
David Taylor Model Basin, U.S. Navy

Mr. Leonard Sternfield
Manager, Flight Dynamics Department
The Martin Co.

Propulsion Panel

Air propulsors, water propulsors, powerplants and gear trains.

Mr. John W. Sawyer, Chairman

Mr. Walter C. Bachman
Gibbs & Cox, Inc.

Mr. Herbert R. Hazard
Battelle Memorial Institute

Capt. R. G. Mills, USN
Philadelphia Naval Shipyard

Mr. E. E. Stoeckly
Consulting Engineer, Marine & Industrial
General Electric Co.

Dr. Marshall P. Tulin
Vice President
Hydronautics, Inc.

Mr. Reeves Morrison
Assistant to Chief Scientist
United Aircraft Corp.

Mr. Laskar Wechsler
Technical Director
Machinery Design Branch
Bureau of Ships
Department of the Navy

Hull Panel

Structure, mechanisms, flaps and skirts, metals, fabrics, and cavitation erosion

Mr. Martin Goland, Chairman

Mr. Ira G. Hedrick
Grumman Aircraft Engineering Corp.

Dr. Manley St. Denis
National Engineering Science Co.

Dr. Morris A. Steinberg
Deputy Chief Scientist
Lockheed Aircraft Corp.

Mr. John Vasta
Bureau of Ships
Department of the Navy

Dr. Dana Young
Southwest Research Institute

Mr. Edward W. McCarthy
Chemical Rubber Products Co.

Mr. Glen Wennagel
Assistant Chief, Structural Systems
Engineering Department
Grumman Aircraft Engineering Corp.

Operations Panel

Cargo handling and ports, collision avoidance (surveillance and detection), maneuvering procedures, mooring and docking, maintenance and repair, and manning

Mr. Foster L. Weldon, Chairman

Prof. Harry Benford
Department of Naval Architecture and Marine Engineering
University of Michigan

Capt. L. S. McCready
U.S. Merchant Marine Academy

Mr. A. M. Feiler
Department of Engineering
University of California

Mr. Isaac W. Fuller, Jr.
Head, High Resolution Branch
Radar Division
Naval Research Laboratory

Lt. Comdr. David J. Linde
Chief, Hull Arrangements Branch
Merchant Marine Technical Division
U.S. Coast Guard

Staff

The activities were managed by a small staff in Dr. Hollomon's office. It consisted of:

The SESOC Project Manager
Mr. E. M. MacCutcheon
Chief, Office of Research and Development
Maritime Administration

Mr. Norman K. Walker
President, Norman K. Walker Associates

Mr. Harry M. Simpson
Independent consultant

Mr. R. A. Montes De Oca
Booz, Allen Applied Research Inc.

Dr. Irwin Billick
Research Fellow, National Bureau of Standards
Executive Secretary, Commerce Technical Advisory Board

Acknowledgment is made to Mrs. Marie B. Spence for her effective accomplishment of all secretarial work and a share of the administrative activities during the formative weeks of the study.

Acknowledgment is made to the personnel of Booz, Allen Applied Research Inc., who participated in the contract studies for the Maritime Administration and who provided the bulk of the backup data reviewed during the SESOC study.

Tasks

In carrying out their assignment, the SESOC Committee and Panels found it necessary to focus their attention in a single direction in order to achieve effective results on a compressed time schedule. The initial studies which had highlighted the potentialities of the SESOC were carried out by Booz, Allen Applied Research, under contract with the Maritime Administration. The SESOC studies, therefore, were focused by concentrating on an examination of the assumptions made by Booz, Allen in its studies. This served to accelerate early studies but the overall scope was not confined to the Booz, Allen results. In this manner the seven tasks for the advisory Committee and Panels were established as follows:

1. Evaluate the technological assumptions made by Booz, Allen in determining the functional and economic capabilities of the five SES concepts.

2. Identify the research and engineering problems which should be solved in accomplishing the development of the various SES concepts. Decide which problems could bar successful development and which relate to achieving superior performance of the prospective vehicle. To the extent that time permits, describe the problems, consider the time required for their solution, and suggest approaches to the solution where possible.

3. Considering each concept in terms of the crucial problems and the prospects for their solution, determine, if possible, whether the concept is eligible for early development or barred from early development or whether the evidence is inadequate to make a determination at this time.

4. Affirm, deny, or question the engineering basis for the SES operating costs determined by Booz, Allen for each concept.

5. Consider alternate options for the overall technical development plan and determine which appears best.

6. Determine the approximate cost of development of an operating prototype vehicle.

7. Formulate an adequate research and development program.

The Committee and Panel members each had local resources for obtaining technical information. In addition, there were three sources of information provided as a part of the SESOC study. They were:

1. Presentations to the Committee and Panels.
2. Reports prepared specifically for purposes of the study.
3. Reports, papers, and articles of particular interest which were distributed to the Committee or Panels during the course of the study.

The presentations are listed below followed by a list of all technical documents distributed to the Committee or Panels. The latter list includes the documents prepared specifically for the study.

Presentations to SESOC Committee and Panels

SESOC Committee, October 1, 1965

Mr. Cecil M. Mackey, Department of Commerce, *Statement of Requirement for SESOC Study.*

Mr. Nicholas Johnson, Maritime Administrator, *Opportunities for SESOC.*

Mr. James A. Higgins, Maritime Administration, *SES, A New Era in Commercial Ocean Commerce.*

Comdr. James R. Wiggins, Center for Naval Analyses, *Navy Requirements.*

Mr. Owen H. Oakley, Bureau of Ships, U.S. Navy, *Functional Capabilities of Ships.*

Dr. Harvey R. Chaplin, David Taylor Model Basin, *Technological Problems.*[3]

Mr. Peter G. Fielding, Booz, Allen Applied Research Inc., *Technological Problems.*[3]

Dr. Harvey R. Chaplin and Mr. Owen H. Oakley, *Technological Problems.*

All Panels, October 21, 1965

Mr. Lowell K. Bridwell, Deputy Undersecretary for Transportation, Department of Commerce. *Statement of SESOC Problem.*

Mr. Nicholas Johnson, Maritime Administrator, *Opportunities for SESOC.*

Mr. James A. Higgins, Maritime Administration, *Maritime Administration Interest in SES.*[3]

Mr. Owen H. Oakley, Bureau of Ships, U.S. Navy, *Functional Capabilities of Ship Concepts.*

Dr. Harvey R. Chaplin, David Taylor Model Basin, U.S. Navy, *Technological Aspects of SES.*[3]

Mr. Joseph A. Cannon, Bell Aerosystems Co., *U.S. Operational Experience.*

Comdr. Charles E. Donaldson, Bureau of Ships, U.S. Navy, *Some Impressions of British Hovercraft Programs.*[3]

Aero-Hydro Dynamics Panel, October 21, 1965

Mr. Allen G. Ford, David Taylor Model Basin, U.S. Navy, *Stability of Captured Air Bubble Craft.*

Dr. Scott Rethorst, Vehicle Research Corp., *Stability of Channel Flow Concept.*

Propulsion Panel, October 21, 1965

Mr. Albert A. Koval, Bureau of Ships, U.S. Navy, *Cavitation Problems on PCH Foils and Propellers.*

Comdr. C. E. Donaldson, Bureau of Ships, U.S. Navy, *Power Plant Requirements, Navy.*[3]

Mr. John P. Donnley, Booz, Allen Applied Research Inc., *Power Plant Requirements, Merchant.*[3]

Operations Panel, October 21, 1965

Mr. Joseph A. Cannon, Bell Aerosystems Co., *Crew Training.*

Lt. Comdr. David J. Linde, U.S. Coast Guard, *Safety Problems.*

SESOC Committee, November 5, 1965

Mr. Allen S. Boyd, Undersecretary for Transportation, Department of Commerce, *Amplification of Requirement for Study.*

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[3] Document summarizing presentation distribution to the SESOC Committee.

Mr. **Nicholas Johnson**, Maritime Administrator, *Problems of the Merchant Marine as Viewed by the Interagency Maritime Task Force.*[3]

Mr. **James A. Higgins**, Maritime Administration, *Maritime Administration SES Program.*[3]

Mr. **James L. Schuler**, Bureau of Ships, U.S. Navy, *Thoughts on Navy SES Program.*[3]

Mr. **James W. Grodsky**, Department of Defense, *Comments on Development Plans.*

Hull Panel, November 16, 1965

Dr. **Myron E. Lunchick**, Booz, Allen Applied Research Inc., *Amplification of Booz, Allen Assumptions Regarding Hydrodynamic Loading, Structural Design Criteria for Structural Weights.*

Speed and Resistance Panel, November 22, 1965

Dr. **Edward G. U. Band**, Booz, Allen Applied Research Inc., *Amplification of Booz, Allen Assumptions Regarding Resistance or Drag for Various Speeds and Sea Conditions.*

Propulsion Panel, November 22, 1965

Mr. **Laskar A. Wechsler**, Bureau of Ships, U.S. Navy, *State of the Art in Propulsion Systems and Propulsors.*[3]

SESOC Committee, December 13 and 14, 1965

Messrs. **Jack Jones and Dwight Riley**, North American Aviation, Inc., *Comments on Economic Investigations for Surface Effect Ships for Ocean Commerce.*

Dr. **Morris A. Steinberg**, Lockheed Aircraft Corp., *Lockheed Comments on Booz, Allen Economic Assumptions.*

Messrs. **John H. Kennedy and Peter Mantle**, General Dynamics Corp., *Parametric Evaluation of the Design and Performance of Surface Effect Ships.*[3]

Reports Prepared Specifically for the Study

Booz, Allen Applied Research Inc., *Backup Data for Reports Parts I–IV (Weights and Power vs. Speed Requirements for the Five Types of SES Considered)*, Department of Commerce, SESOC Committee, November 5, 1965:

- Hydrokeel (SESOC 14).
- Annular Jet (SESOC 15).
- Captured Air Bubble (SESOC 16).
- Douglas Aircraft Co. and Vehicle Research Corp. Data regarding Weiland Craft and Channel Flow craft (SESOC 17).

Booz, Allen Applied Research Inc., *Backup Data for 5,000-ton CAB Studies (from an unpublished report to the Maritime Administration)*, Department of Commerce SESOC Committee, November 1965. These backup data comprise the following parts:

- The General Characteristics of the Captured Air Bubble (CAB) Surface Effect Ship (SESOC 18).
- Performance (SESOC 19).
- Drag Components and Propulsive Power Required (SESOC 41).
- Powering and Propulsion (SESOC 20).
- Shaft Horsepower Calculations (SESOC 26).
- Background on Structural Assumptions (SESOC 13).
- Addendum to Background on Structural Assumptions (SESOC 81).
- Basis for the Structural Weight Assumptions on the 5,000-ton CAB (SESOC 42).
- Outfit and Auxiliary Systems (SESOC 21).
- Operations (SESOC 24).
- Weights (SESOC 23).
- Cost Methodology (SESOC 22).
- Economic Analysis (SESOC 25).

David J. Linde, *Technological Problems.* Letter report to Operations Panel, SESOC Committee, December 3, 1965 (SESOC 27).

Harry Benford, *SESOC Manning Problems.* Letter report to Operations Panel, SESOC Committee, November 24, 1965 (SESOC 28).

I. W. Fuller, *Comments on SESOC Operations Committee.* Letter to F. L. Weldon, Chairman, Operations Panel, December 3, 1965 (SESOC 29).

I. G. Hedrick, and **G. Wennagel**, Grumman Aircraft Engineering Co., *Structural Design Loading Conditions and Preliminary Structural Weight Estimate.* Hull Panel, SESOC Committee, November 1965 (SESOC 30).

R. G. Mills, *Important Problems in the Propulsion Area.* Letter to J. W. Sawyer, Chairman of the Propulsion Panel, November 19, 1965 (SESOC 31).

C. E. Donaldson, *Some Impressions of British Hovercraft Programs.* Presentation to SESOC Committee, October 21, 1965 (SESOC 32).

Harvey Chaplin, *ACV Technology.* Presentation to SESOC Committee, November 3, 1965 (SESOC 33).

Harvey Chaplin, *Key Stability and Control Problems.* Letter report to Aero-Hydro Dynamics and Control Panel, SESOC Committee, November 2, 1965 (SESOC 34).

H. C. Mason, Department of the Navy, Bureau of Ships, *Air Cushion Ship (ACV) Development Program.* Memo for Assistant Secretary of the Navy (Research and Development), November 1, 1965 (SESOC 35).

J. A. Higgins, *MARAD SES Program Technical Development Plan.* Maritime Administration Planning Document, November 1965 (SESOC 36).

L. A. Wechsler, Department of the Navy, Bureau of Ships, *State-of-the-Art in Propulsion Systems and Propulsors.* Presentation to Propulsion Panel, November 22, 1965 (SESOC 43).

M. A. Steinberg, *Materials for GEM Hulls.* Memorandum to Hull Panel, November 22, 1965 (SESOC 46).

North American Aviation, Inc., *Comments on Economic Investigations of Surface Effect Ships for Ocean Commerce.* For Department of Commerce SESOC Committee, December 10, 1965, NA 65–1065 (SESOC 63).

H. Benford, *Potential Economics of the Surface Effect Ship in Ocean Transport, a Brief Approximation.* Department of Commerce, SESOC Committee, December 18, 1965. (SESOC 64).

R. F. Stoessel, Lockheed Interdepartmental Communication, *Additional Comments on Booz, Allen Report—Surface Effect Ship*, to M. A. Steinberg, Hull Panel, November 26, 1965 (SESOC 65).

R. F. Stoessel, Lockheed Interdepartmental Communication, *Additional Comments on Booz, Allen Report—Surface Effect Ship,* to M. A. Steinberg, Hull Panel, December 7, 1965 (SESOC 66).

W. P. Kennedy, Lockheed Interdepartmental Communication, *Comments on Booz, Allen Report—Surface Effect Ship,* to M. A. Steinberg, Hull Panel, October 7, 1965 (SESOC 67).

Aerojet-General Corp., *SES Technological Problems,* letter to Project Manager, November 29, 1965, SESOC Committee (SESOC 68).

Bell Aerosystems Co., *Overall requirements for the Surface Effect Ship and Industry Participation.* Letter to Project Manager, SESOC Committee, December 2, 1965. (SESOC 70).

A. M. Feiler, *Problem Areas Affecting SESOC Design and Systems Criteria,* Letter to Project Manager, SESOC Committee, November 18, 1965 (SESOC 72).

F. P. Bundy, General Electric Co., *Problems Involved in SESOC.* Letter to Project Manager, SESOC Committee, January 4, 1966 (SESOC 74).

The Boeing Co., *Technological Problems.* Letter to Project Manager, SESOC Committee, January 4, 1965 (SESOC 75).

J. L. B. Selwood, Selwood Research, Inc., *Miscellaneous Notes on Surface Effect Ships.* Letter to Project Manager, SESOC Committee, January 14, 1966 (SESOC 76).

Marshall P. Tulin, *Problems Relating to Propulsors.* Letter report to SESOC Committee, January 28, 1966 (SESOC 78).

SESOC Committee Staff, *Economic Analysis, Mathematical Simulation and Sensitivity Studies.* January 1966 (SESOC 92).

SESOC Committee Staff, *Transportation System Development Plans and Costs.* January 1966 (SESOC 93).

Northrop Corp., *Technological Problems.* Letter to Project Manager, SESOC, December 10, 1965 (SESOC 80).

P. J. Mantle, Electric Boat Co., General Dynamics Division, *Parametric Evaluation of the Design and Performance of Surface Effect Ships.* Presentation to SESOC Committee, December 13, 1965 (SESOC 79).

J. Scherer and W. Webster, Hydronautics, Inc., *Preliminary Investigations of 3,000-Ton CAB Ship.* Prepared for SESOC Committee, February 1966 (SESOC 82).

Newport News Shipbuilding & Drydock Co., *SESOC Technological Problems as Observed by Newport News Shipbuilding & Drydock Co.* SESOC staff memo to file January 6, 1966 (SESOC 83).

M. St. Denis, *Some Suggestions on Criteria for the Design of Surface Effect Ships for Ocean Commerce.* Report to Hull Panel, January 5, 1966 (SESOC 84).

J. Vasta, *Problem Areas Needing Investigation.* Report to the Hull Panel, January 5, 1966 (SESOC 85).

E. W. McCarthy, *Skirt Material Problems.* Report to the Hull Panel, January 5, 1966 (SESOC 86).

Lockheed Aircraft Corp., *Surface Effect Ship Studies.* SESOC staff memo to file, January 5, 1966 (SESOC 87).

Peter G. Fielding, Booz, Allen Applied Research Inc., *Technological Problems.* October 1965 (SESOC 89).

John P. Donnely, Booz, Allen Applied Research Inc., *Propulsion Problems.* October 1965 (SESOC 90).

W. C. Bachman, Gibbs & Cox, Inc., *Comments on Proposed Development of Surface Effect Ships for Ocean Commerce.* Letter to J. W. Sawyer, Chairman, Propulsion Panel, December 10, 1965 (SESOC 94).

SESOC Propulsion Panel, *Minutes of Propulsion Panel Meeting.* November 22, 1965 (SESOC 95).

Documents Distributed

James A. Higgins, Surface Effect Ships, *A New Era in Commercial Ocean Transportation.* Maritime Administration, U.S. Department of Commerce, April 14, 1965 (SESOC 1).

Booz, Allen Applied Research Inc., *The Surface Effect Ship in the American Merchant Marine—Parts I through V.* U.S. Department of Commerce, Maritime Administration.

Part I—An Economic Feasibility Study of the 100-Ton MARAD Surface Effect Ship. November 1965, PB 181676 (SESOC 3).

Part II—The Technical and Economic Feasibility Study of a Nuclear-Powered Surface Effect Ship. February 1964, PB 181677 (SESOC 4).

Part III—Comparative Performance and Cost Characteristics of Four Types of Surface Effect Ships. February 1964, PB 181678 (SESOC 5).

Part IV—A Comparative Study of the Economic Feasibility of Two Sidewall Concepts with Other Surface Effect Ships. March 1965, PB 167990 (SESOC 6).

Part V—Comparison of Transport Economy of Surface Effect Ships vs. Large Aircraft and Displacement Ship. July 1965, PB 168486 (SESOC 7).

Peat, Marwick, Livingston & Co., *Why Contract Definition?* 1965 (SESOC 8).

Department of Defense directive: *Initiation of Engineering and Operational Systems Development.* Number 3200.9, July 1, 1965 (SESOC 9).

Peat, Marwick Management Systems Co., *Lessons Learned From Contract Definition.* Office of Secretary of Defense, Director of Defense Research and Engineering, August 16, 1965 (SESOC 10).

Ford Park, *Near-Surface Vehicles.* International Science and Technology. February 1962 (SESOC 37).

Booz, Allen Applied Research Inc., *Summary of State-of-the-Art in SES.* Distributed to SESOC Committee, October 1, 1965 (SESOC 38).

Harvey Chaplin, *The New Trend in Ground Effect Machines.* Aeronautics and Astronautics, October 1965 (SESOC 39).

Helge Norstrud, *Wind Tunnel Tests with a Blowing Channel Flow Model in Ground Effect.* Vehicle Research Corp. Working Paper No. 70, July 1963 (SESOC 44).

Helge Norstrud, *Wind Tunnel Tests with a Blowing Channel Flow Model in Ground Effect.* Vehicle Research Corp. Working Paper No. 57, February 1963 (SESOC 45).

NORMAN K. WALKER, *Stability Control and Maneuver Characteristics of the Martin Research Vehicle.* (SESOC 47).

GLENN L. MARTIN report to Bureau of Ships, Department of the Navy, *Hydrofoil Ship Structural Design Criteria Study.* February 1965 (SESOC 48).

AEROPHYSICS CO., *A Study of Radial-Flow Fans for GEM Propulsion System Applications.* U.S. Army Transportation Research Command, Fort Eustis, Va., July 1964, AD 610–522 (SESOC 49).

NORMAN K. WALKER Associates, Inc., *Some Preliminary Tests on the Effects of Spray Generated by Ground Effects Machines.* Bureau of Ships, Department of the Navy, September 1965 (SESOC 50).

NORMAN K. WALKER Associates, Inc., *Roll Stability of Ground Effect Machines—Thick Annular Jet-Plenum Types.* U.S. Army Aviation Materiel Laboratories, Fort Eustis, Va., June 1965 (SESOC 51).

NORMAN K. WALKER Associates, Inc., *Heave Stability and Heave Damping of Ground Effect Machines—Thick Annular Jet and Plenum Types.* U.S. Army Aviation Materiel Laboratories, July 1965 (SESOC 52).

E. M. MACCUTCHEON, JR., *A Summary of David Taylor Model Basin and Alcoa Notch-Tensile Tests and Observations on Engineering Applications of Fracture Mechanics.* Ship Structure Committee Report SSC 69, May 17, 1954 (SESOC 73).

KAREN CHASE, *A Selected Bibliography on Air Cushion Vehicles and Ground Effect Machines.* Institute of Transportation and Traffic Engineering, University of California, April 1965 (SESOC 77).

INTERAGENCY MARITIME TASK FORCE. *The Merchant Marine in National Defense and Trade—A Policy and a Program.* Department of Commerce, October 1965 (SESOC 88).

W. J. PIERSON and L. J. TICK, *The Accuracy and Potential Uses of Computer-Based Wave Forecasts and Hindcasts for the North Atlantic.* Proceedings of the Second Symposium on Military Oceanography with Willard J. Pierson letter of October 19, 1965, to SESOC (SESOC 40).

APPENDIX B—DESCRIPTION OF SURFACE EFFECT SHIP CONCEPTS

Introduction

The purpose of this appendix is to define the physical nature of the different surface effect ship (SES) concepts evaluated in the SESOC study.

There are two types of SES or ground effect machines (GEM). One type is supported by a cushion of pressurized air which is constrained beneath the vehicle. This type has been designated as a category I vehicle (aerostatic lift). The second type is mainly supported by aerodynamics as the vehicle transits at sufficient speed to obtain aerodynamic lift similar to an aircraft. This type is called a category II vehicle (aerodynamic lift).

The potentialities of these two types of SES for ocean commerce were examined by Booz, Allen through studies of five illustrative SES craft selected to best typify the useful capabilities of all SES concepts.

Figure B–1 shows the relation of the various SES concepts. Studies and tests have been made on concepts of practically every branch of the functional principle network. Only the five representative vehicles reviewed in this report have been named.

Category I Vehicles (Aerostatic Lift)

This group of vehicles has been called "air cushion vehicle" (ACV).

In the cruise condition, the major proportion of the weight is borne by a cushion of air constrained in some way beneath the hull. Since this cushion can be present even when the craft is not in motion, this class may be said to depend on aerostatic lift. Concepts of particular interest in this study are described.

Free Leakage (Plenum Chamber)

The simplest form of ACV is the open plenum (fig. B–2a) in which a fan forces air into a large base, from which it leaks out at the edges. Since the air flows slowly below the base, almost the whole of the total head of the fan is available to produce a large lift by acting over the whole base area. Additional clearance between the water and the "hard" structure has been achieved by adding a flexible skirt which constrains the air cushion (fig. B–2b).

Fluid Constraint (Annular Jet)

Air Jet

The annular jet is an improved application of the air cushion principle. The power required to support a vehicle at a given height from the water can be reduced by supplying the cushion air through an annular jet around the periphery which improves the constraint of the air cushion as shown in figure B–2c. A combination of the two improvements was achieved by adding an inflated flexible fabric sidewall or "trunk" as illustrated in figure B–2d. This results in still greater economy at the effective operating clearance because the benefits of the annular jet and flexible skirt or trunk are additive.

The effectiveness of flexible understructure is best illustrated by an example: A flexible 3-foot trunk coupled with a 2-foot air gap will permit clearance of 4-foot solid obstructions, whereas a similar craft without the trunk would require a 4-foot air gap and hence more than double the lift power.

Water Jet

It is theoretically possible to replace the air curtain of the annular jet by a wall of water. Such a vehicle would only be practical over water, and in addition, the weight of water and ducting which must be carried by the craft renders this design unattractive. (This type not illustrated.)

Structural Constraint (Captured Air Bubble, CAB)

An alternative form of ACV was studied in 1960 at the David Taylor Model Basin. The contraint along the side was provided by solid sidewalls which dipped into the water effecting a seal. In early models, the ends were sealed with air

FUNCTIONAL PRINCIPLES of SURFACE EFFECT SHIPS

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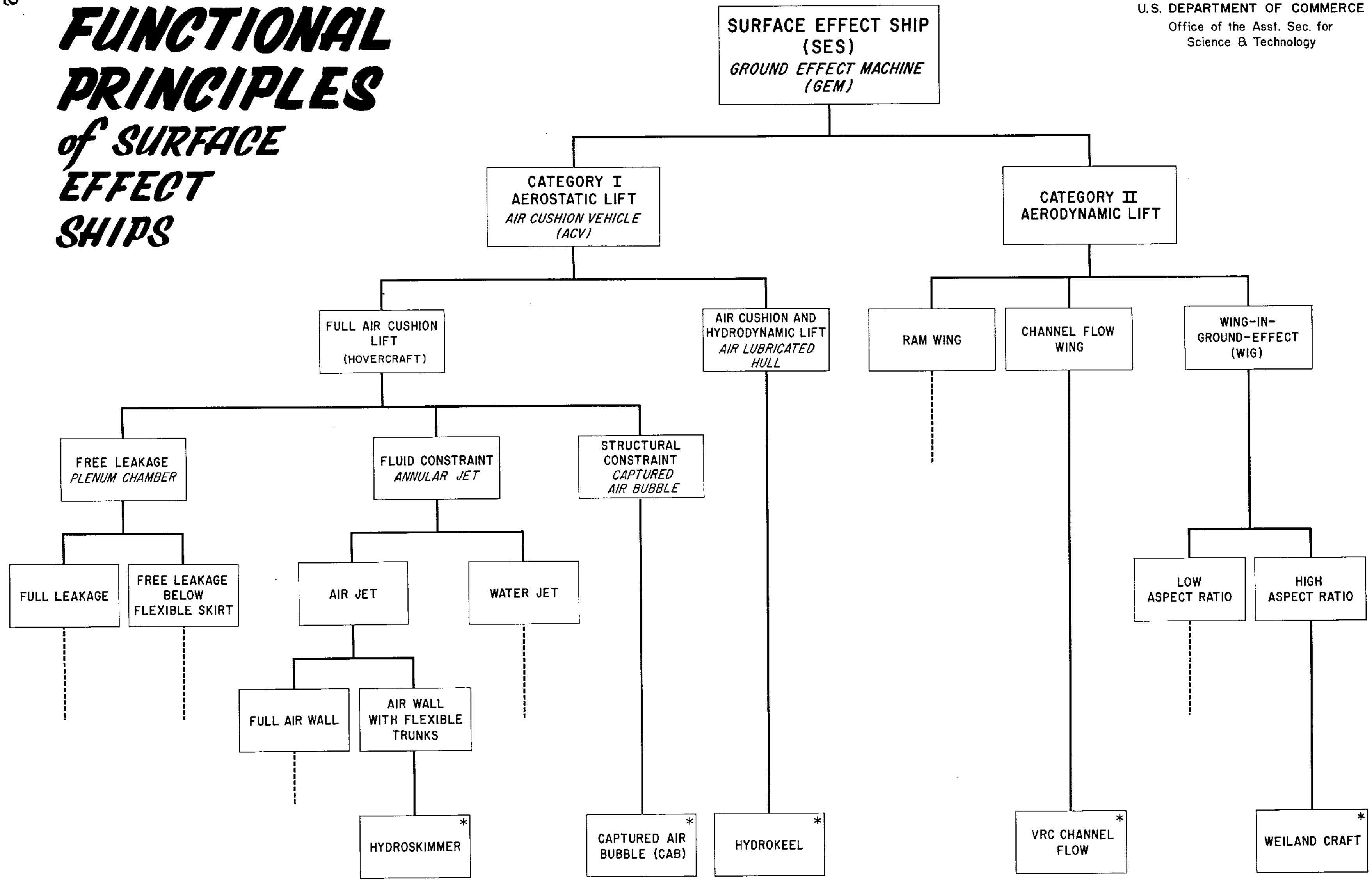

*Representative Vehicle Investigated by BOOZ, ALLEN Applied Research Inc.

walls, but in a new concept—the captured air bubble (CAB) (fig. B–2e)—the constraint at bow and stern is provided by solid structures called skis. The skis lightly brush the surface of the water and minimize air leakage so that the required lift power is drastically reduced.

Air Lubricated Hull

The solid sidewall ACV initially met with roll stability problems and these were solved in a special case—the air lubricated hull—by retaining the flexible bow ski, but permitting the craft to plane on the bottom of the hull at the rear. The rear planing surface serves the dual purpose of air seal and lift (fig. B–2f).

In later forms of the craft, the sidewalls have been made thicker to provide buoyant lift and stability at low speeds, and planing lift at high speeds.

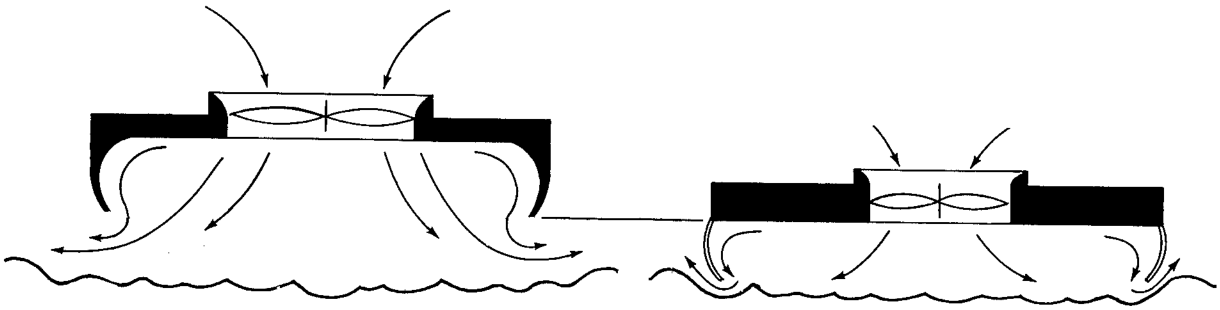

Fig 2a. The Plenum Chamber

Fig 2b. The Plenum Chamber with 'SKIRT'

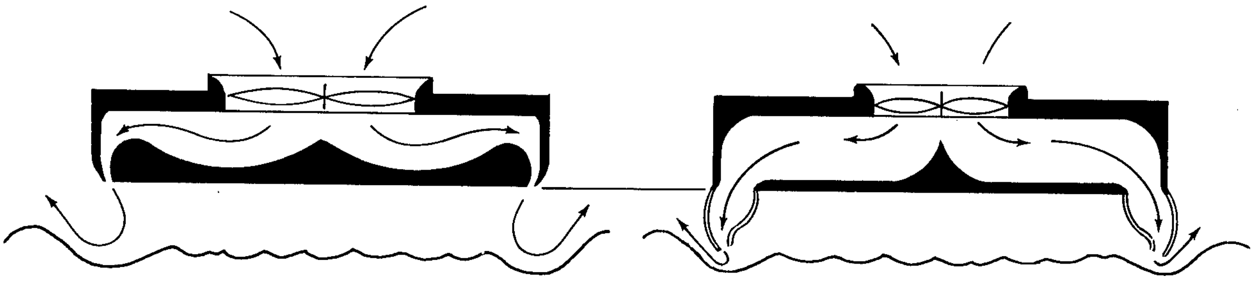

Fig 2c. The Annular Jet

Fig 2d. The Hydroskimmer
(Annular Jet with 'TRUNKS')

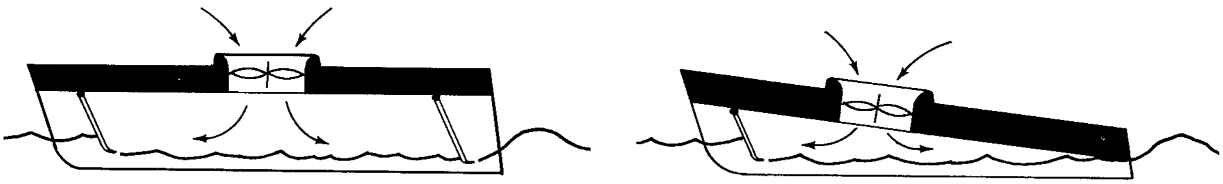

Fig 2e. The Captured Air Bubble

Fig 2f. The Hydrokeel

Figure B–2.—*Various concepts illustrating the aerostatic lift principle.*

Category II Vehicles (Aerodynamic Lift)

In the cruise condition, the major part of the weight is borne by the resultant force of aerodynamic lift on the upper and the lower surfaces of wings due to the forward motion and the vehicle cannot hover.

For category I vehicles, the ratio of the weight divided by the aerodynamic lift ranges ($P_{b/q}$) from 2 to 50. For category II vehicles, it would be about 1.

Ram Wing

The simplest category II vehicle is the ram wing (fig. B–3a). An open-ended scoop, sealed along the sides and rear, is propelled forward. Air enters the scoop and builds up an internal pressure equal to the dynamic stagnation pressure and this provides most of the lift. Additional lift is generated from a suction which is developed on the upper surface. Some small craft of this type have been built, but there are stability problems, and the drag is relatively high.

Channel Flow Wing

The channel flow wing SES (fig. B–3b) is similar in concept to the ram wing, except that an opening is left at the stern forming a channel. By correctly designing the cross section of the craft, it is possible to realize a pressure increment beneath it, with a suction of almost equal magnitude on the upper surface. Provided that the flow remains streamlined and that the sides are sealed, there will be little or no induced drag.

Wing-In-Ground Effect (WIG)

It is possible to take the channel flow concept still further, and ignore leakage at the sides by making the span so great in relation to the length that the losses can be neglected (fig. B–3c).

This is simply an airplane flying in ground effect. It has been known since 1929 (DoX) that a great improvement in performance could be realized by this means.

The Weiland craft is a special form of WIG with tandem wings intended to provide inherent dynamic stability in ground effect.

Representative Surface Effect Ships Studied by Booz, Allen Applied Research Inc.

General details of the five representative craft studied by Booz, Allen are listed in tables I, II, and III. These data are derived from tabulations in the various Booz, Allen studies, Parts I, III, and IV, and the Booz, Allen backup data. For the sake of direct comparison, all of the sketches prepared by Booz, Allen for the five typifying configurations apply to 1,000-long-ton gross weight vehicles.

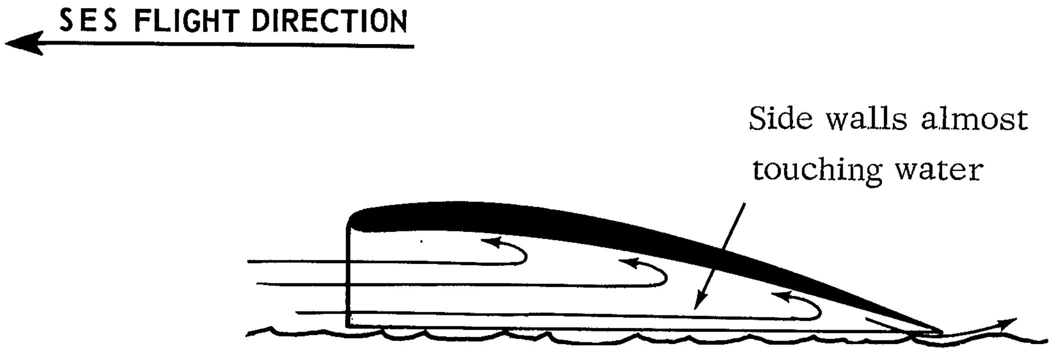

Fig 3a. The Ram Wing

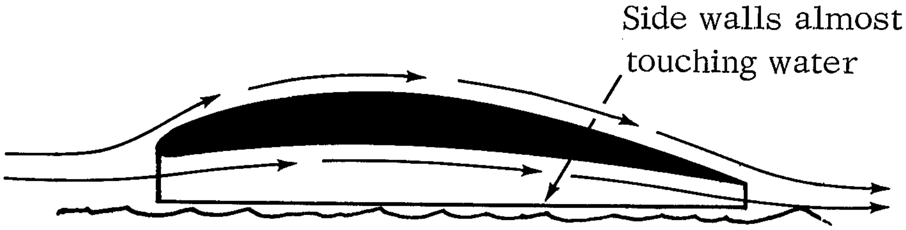

Fig 3b. The Channel-Flow Wing

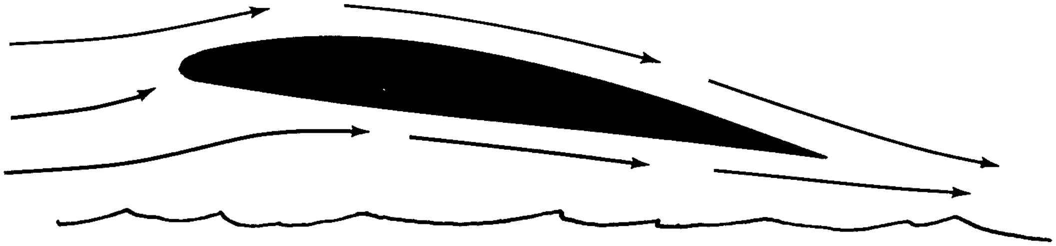

Fig 3c. The Wing-in-Ground Effect

FIGURE B–3.—*Various concepts illustrating the aerodynamic lift principle.*

TABLE I.—*Vehicle characteristics*

Concept	Gross weight (long tons)	Dimensions L x B x H (feet)	Maximum horsepower	Disposable load / (gross weight)	Estimated base pressure, p.s.f.	Vmax. knots	$P_{b/q}$
Hydroskimmer	100	77 x 38 x 21	35, 000	0. 500	[1] 81	100	2. 4
	400	122 x 61 x 35	105, 000	. 600	126	100	3. 7
	1, 000	166 x 83 x 40	214, 500	. 640	162	100	4. 8
CAB	100	100 x 40 x 25	8, 500	. 644	[2] 62	58	5. 4
	500	200 x 80 x 45	26, 000	. 691	78	65	5. 4
	1, 000	270 x 110 x 65	50, 000	. 718	84	74	4. 5
	2, 500	352 x 149 x 80	125, 000	. 720	119	100	3. 5
	5, 000	445 x 188 x 90	250, 000	. 726	149	112	3. 5
	10, 000	500 x 215 x 10	500, 000	. 726	232	129	4. 1
Hydrokeel	100	90 x 20 x 20	8, 500	. 495	[3] 153	33½	40. 0
	500	160 x 30 x 30	36, 000	. 518	285	46	40. 0
	1, 000	205 x 37 x 40	70, 000	. 561	370	50	44. 0
VRC channel flow [5]	100	140 x 62 x 38	16, 900	. 500	[4] 36	100	1. 05
	500	310 x 156 x 80	40, 500	. 580	32	100	0. 95
	1, 000	440 x 220 x 100	63, 500	. 603	32	100	0. 95
	2, 000	620 x 310 x 120	99, 700	. 621	32	100	0. 95
Wieland craft	100	215 x 150 x 48	19, 500	. 500	N.A.	N.A.	N.A.
	500	370 x 280 x 68	63, 100	. 562			
	1, 000	600 x 500 x 100	105, 000	. 684			

[1] Assuming length of base is 95%— L.O.A.
[2] Assuming length of base is 90%— L.O.A.
[3] Assuming length of base is 82%— L.O.A.
[4] Assuming length of base is 71%— L.O.A.
[5] VRC—Vehicle Research Corp.
N.A.—Not available.
L. O. A. Length Over All

TABLE II.—*Effect of wave height on power*

Concept	Gross weight	Required power (horsepower)		Speed in 8-foot waves (knots)
		2-foot wave height	8-foot wave height	
Hydroskimmer	100	13, 000	28, 000	100
	400	48, 000	84, 000	100
	1, 000	118, 000	170, 000	100
CAB	100	3, 400	6, 800	58
	1, 000	27, 800	40, 000	74
	2, 500	68, 000	100, 000	100
	5, 000	148, 000	200, 000	112
	10, 000	298, 000	400, 000	129
Hydrokeel	100	4, 300	6, 800	[1] 33. 5
	500	22, 000	37, 000	46
	1, 000	45, 500	56, 000	50
VRC channel flow	100	3, 500	9, 300	100
	500	10, 300	23, 800	100
	1, 000	17, 200	36, 700	100
Wieland craft	1, 000	------------	------------	100

[1] 5-foot waves.

NOTE.—(1) Data abstracted from tables of variable input data such as tables IIIa, IIIb, and IIIc.
(2) In early programs, speed was held constant and power reduced for lower wave height. In later programs, the power was fixed and speed varied.

TABLE IIIa—*Variable input data*

(Data for the 100-ton vehicles)

		Hydroskimmer	VRC channel flow	Wieland craft
Power requirements at 100 knots:				
Operating height of:				
1 foot	hp	13, 000	3, 500	4, 300
2 feet	hp	18, 000	5, 200	4, 550
3 feet	hp	23, 000	7, 100	4, 800
4 feet	hp	28, 000	9, 300	5, 000
Power requirements at 1 foot:				
Velocity:				
0 knot	hp	5, 000	3, 300	[1] 0
5 knots	hp	5, 000	3, 300	[1] 100
20 knots	hp	5, 100	3, 300	[1] 4, 900
50 knots	hp	6, 800	3, 500	[1] 7, 800
Nominal empty weight	lb	112, 000	112, 000	112, 000
Equipment weight	Percent empty weight	14	14	14
Propulsion system weight	Percent empty weight	44	20	15
Structure weight	Percent empty weight	42	66	71
Number of engines		4	6	3
Horsepower per engine		7, 000	2, 250	5, 200

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[1] In water, not flying.

TABLE IIIb.—*Variable input data*

(Data for the 400- and 500-ton vehicles)

		400	500	500
		Hydroskimmer	VRC channel flow	Wieland craft
Power requirements at 100 knots:				
Operating height of:				
1 foot	hp	46, 000	10, 300	15, 700
2 feet	hp	59, 000	14, 500	16, 350
3 feet	hp	72, 000	18, 600	17, 050
4 feet	hp	84, 700	23, 800	17, 750
Power requirements at 1 foot:				
Velocity:				
10 knots	hp	13, 000	7, 900	[1] 344
20 knots	hp	14, 000	8, 900	[1] 19, 600
50 knots	hp	20, 000	10, 700	[1] 26, 800
80 knots	hp	33, 400	11, 600	17, 200
Nominal empty weight	lb	358, 400	470, 400	490, 560
Equipment weight	Percent empty weight	11. 0	9. 5	9. 2
Propulsion system weight	Percent empty weight	41. 5	12. 5	10. 3
Structure weight	Percent empty weight	47. 5	78. 0	80. 5
Number of engines		6	6	4
Horsepower per engine		14, 000	5, 400	12, 600

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[1] In water, not flying.

TABLE IIIc.—*Varible input data*

(Data for the 1,000-ton vehicles)

		Hydroskimmer	VRC channel flow	Wieland craft
Power requirements at 100 knots:				
Operating height of:				
1 foot	hp	105, 000	17, 200	23, 900
2 feet	hp	127, 500	22, 200	25, 100
3 feet	hp	149, 600	29, 400	26, 400
4 feet	hp	172, 000	36, 700	27, 600
Power requirements at 1 foot:				
Velocity:				
10 knots	hp	22, 700	11, 800	[1] 546
20 knots	hp	25, 000	13, 600	[1] 26, 800
50 knots	hp	40, 000	17, 900	[1] 42, 600
80 knots	hp	73, 000	20, 500	26, 200
Nominal empty weight	lb	806, 400	891, 000	940, 800
Equipment weight	Percent empty weight	9. 2	8. 0	7. 6
Propulsion system weight	Percent empty weight	38. 5	10. 1	8. 6
Structure weight	Percent empty weight	52. 3	81. 9	83. 8
Number of engines		11	6	6
Horsepower per engine		15, 600	8, 740	14, 000

[1] In water, not flying.

The Hydroskimmer

The Bell Aerosystems Corp. supplied Booz, Allen, through the Maritime Administration, with design data on three annular-jet SES of 100-, 400-, and 1,000-long-ton gross weight. An artist's conceptual illustration is shown in figure B-4, along with a dimensioned sketch. The ships would be similar in concept to the U.S. Navy SKMR-1, as shown in figure B-5, with 4-foot rubberized fabric trunks installed.

Booz, Allen found that the designed air wall clearance was only 2 feet, and the maximum speeds were 65, 85, and 100 knots, for the 100-, 400-, and 1,000-long-ton sizes, respectively. To provide a design comparable to the VRC channel flow ship studied in Part I, Booz, Allen engineers assumed additonal power to give an air wall clearance of 4 feet (believed necessary at that time to negotiate 8-foot waves without loss of speed) and a uniform maximum speed of 100 knots. Corresponding corrections were made to the disposable load and cost.

The CAB

Design data for CAB's weighing from 100 to 10,000 tons were provided by Mr. Allen Ford of David Taylor Model Basin. The performance data were provided to or generated by Booz, Allen.

An artist's concept is shown in figure B-6 along with a sketch showing the dimensions. These craft feature fairly thin side walls and spring flaps at bow and stern to seal the ends.

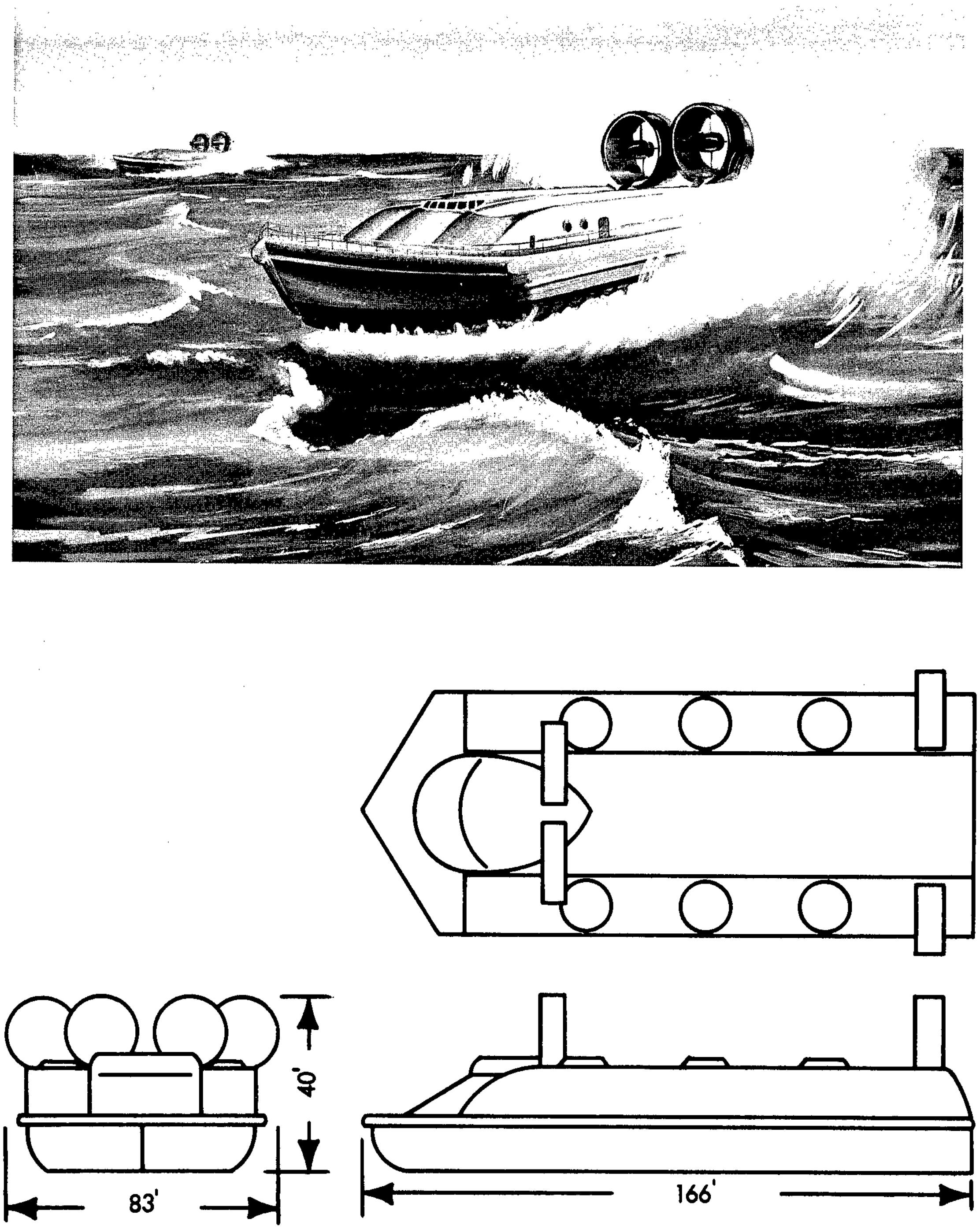
Curves were provided for a change of speed or power with wave height. These resistance curves were based on the assumption that the added resistance was simply due to the added wetted area of the side walls, it being assumed that the clearance of the base was sufficient in all cases to prevent contact with 8-foot waves.

A man-carrying model of the CAB constructed by the Naval Air Development Center is shown in figure B-7.

The Hydrokeel

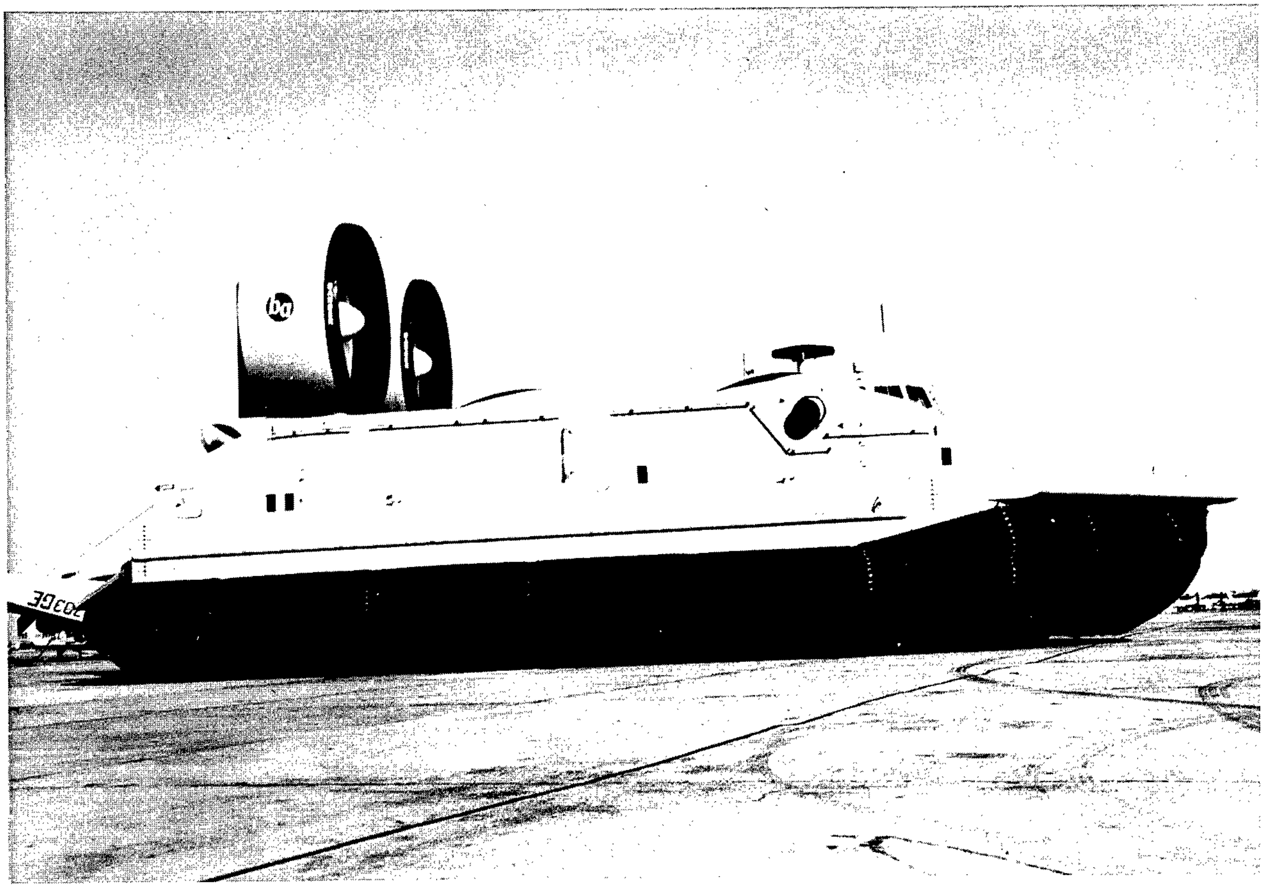
Data for the Hydrokeel were supplied by Bell Aerosystems through the Maritime Administration for craft of 100-, 500-, and 1,000-long-ton gross weight. An artist's concept and dimensions are illustrated in figure B-8.

The designs use a spring or air loaded flap to close the bow as in the CAB, but the sidewalls are of appreciable thickness to give buoyant and planing lifts to stabilize the craft in roll. Furthermore, the lower surface of the hull is substantially flat, and planes on the water at the stern, forming the rear seal and providing lift. An early form of Hydrokeel with thin sidewalls, the U.S. Navy LCVP(K) of 1962, is shown in figure B-9.



Booz, Allen illustration.

FIGURE B-4.—*The hydroskimmer 1,000 long tons gross weight size.*



U.S. Navy photo

FIGURE B-5.—*U.S. Navy annular jet, SKMR-1, with 4-foot trunks.*

This concept suffers a considerable reduction of speed in rough water since the waves sweep an increasing proportion of the hull as the wave height increases, and the aft planing surface causes the stern of the craft to follow nearly the contour of the waves, producing greater accelerations than occur with the CAB concept. However, the present Hydrokeel designs appear to be stable under any sea condition.

The VRC Channel Flow

The channel flow data were supplied by Vehicle Research Corp. and Douglas Aircraft Corp. and are included in the Booz, Allen report, Parts I and III.

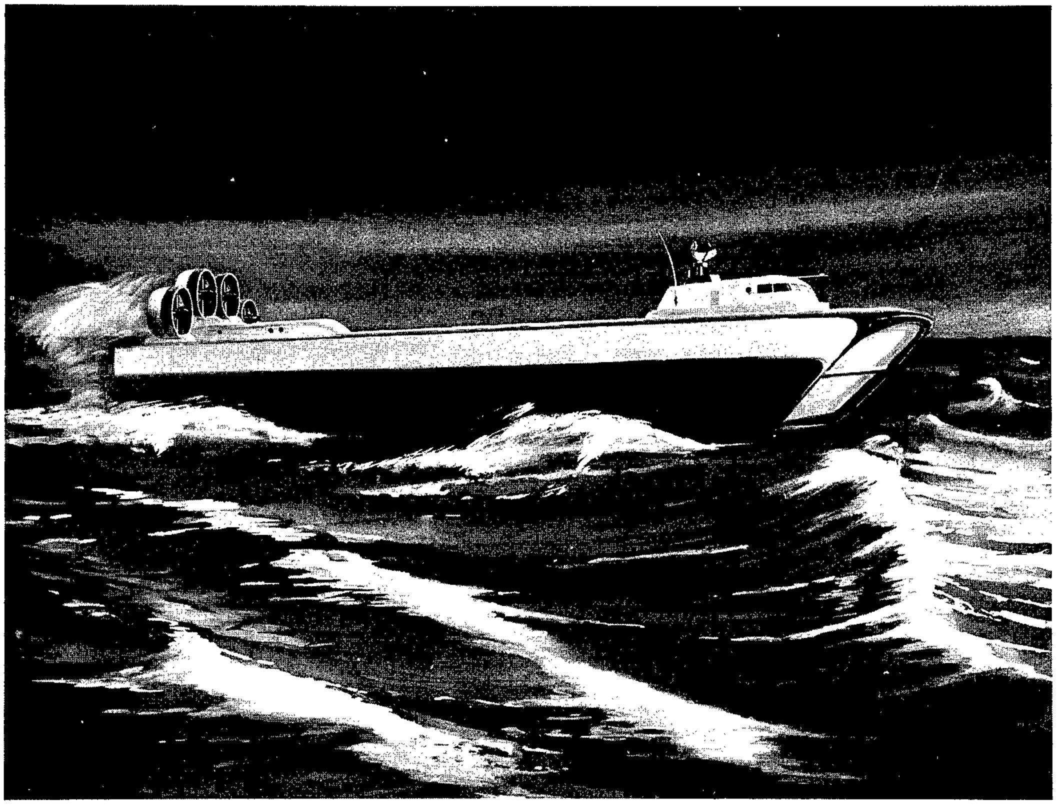
The VRC machines were designed with sufficient lift power to hover with an air wall clearance of 4 feet beneath the side floats, to enable the vehicle to negotiate waves up to 8 feet without slowing down. To reduce the lift power in the hover condition, retractable closures with nozzles were provided at bow and stern. These closures reduce the clearance in way of the "channel" to 4 feet and convert the vehicle to an annular jet with 4 feet clearance all around.

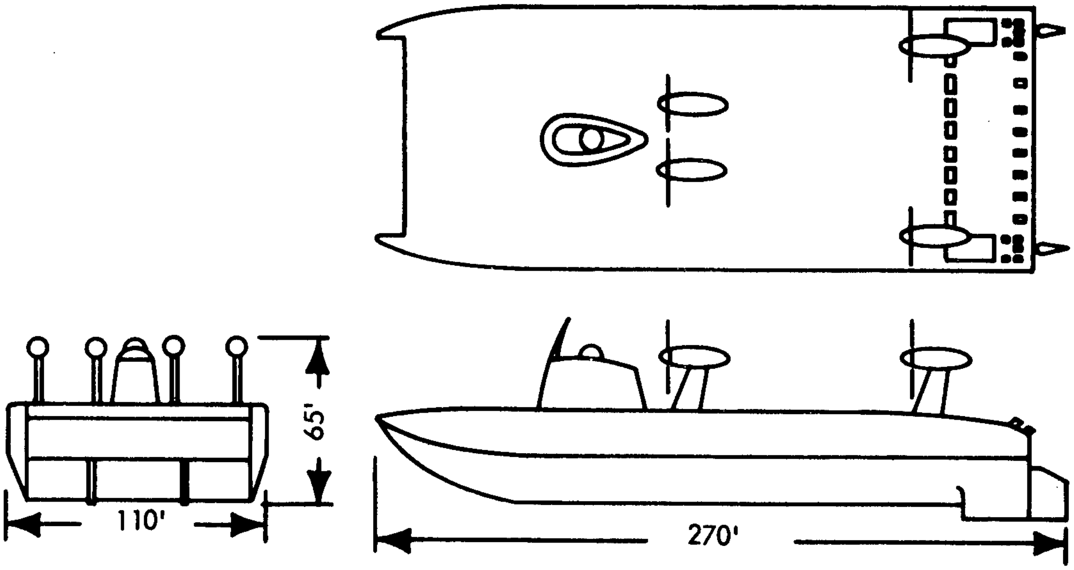
An artist's concept and a sketch giving dimensions are shown in figure B-10.

It was assumed that, as speed increased, these bow and stern jets would be progressively retracted and sealed and transition made to channel flow. A man-carrying model test vehicle was built by the Vehicle Research Corp. under a Maritime Administration contract. As of this writing, the vehicle has hovered but has not flown in dynamic lift. See figure B-11.

The Weiland Craft

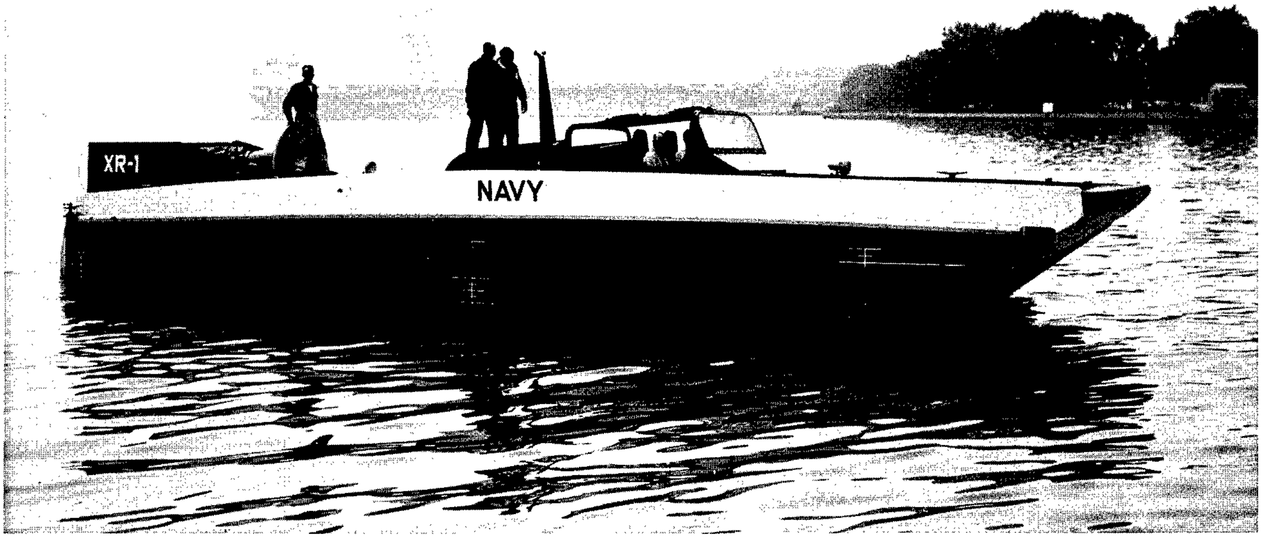
Data on this machine were supplied by the Douglas Aircraft Co. This machine features tandem wings, intended to provide inherent altitude stability and pitch stability relative to the surface. It cannot hover so must take off like a flying boat (figs. B-12 and B-13).





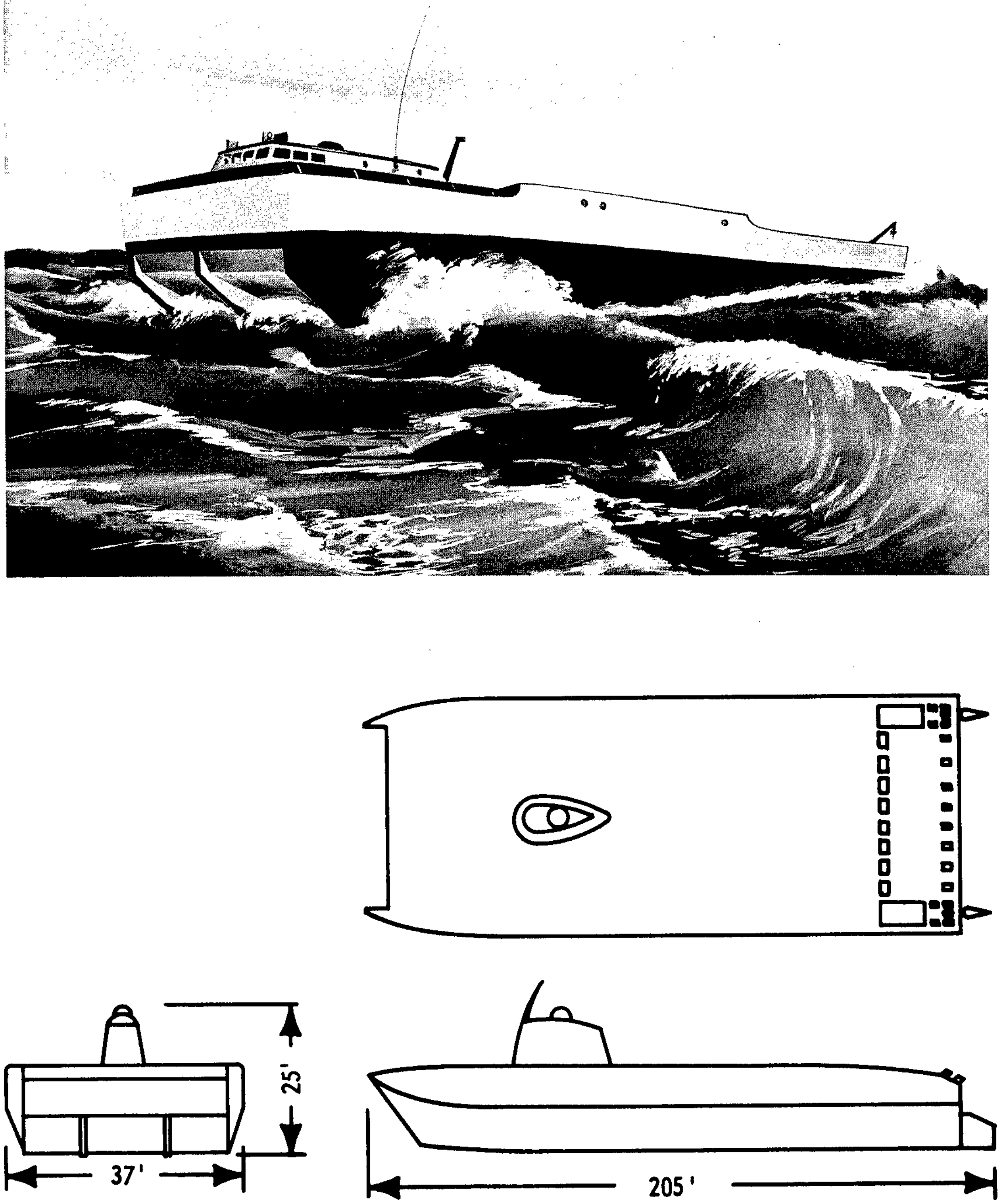
Booz, Allen illustration.

FIGURE B-6.—*The CAB 1,000 long tons gross weight size.*



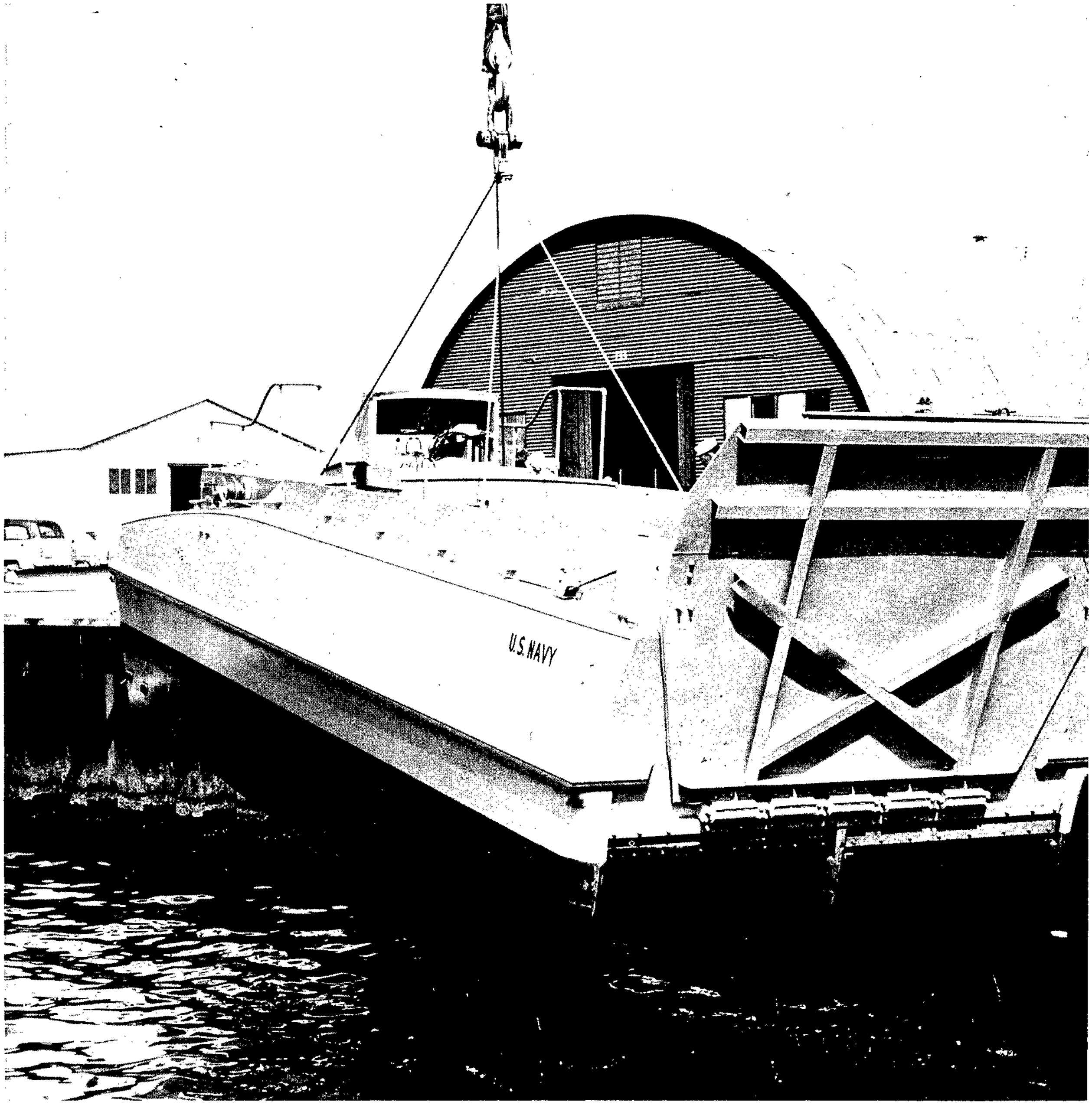
U.S. Navy photo

Figure B-7.—*CAB Test Craft.*



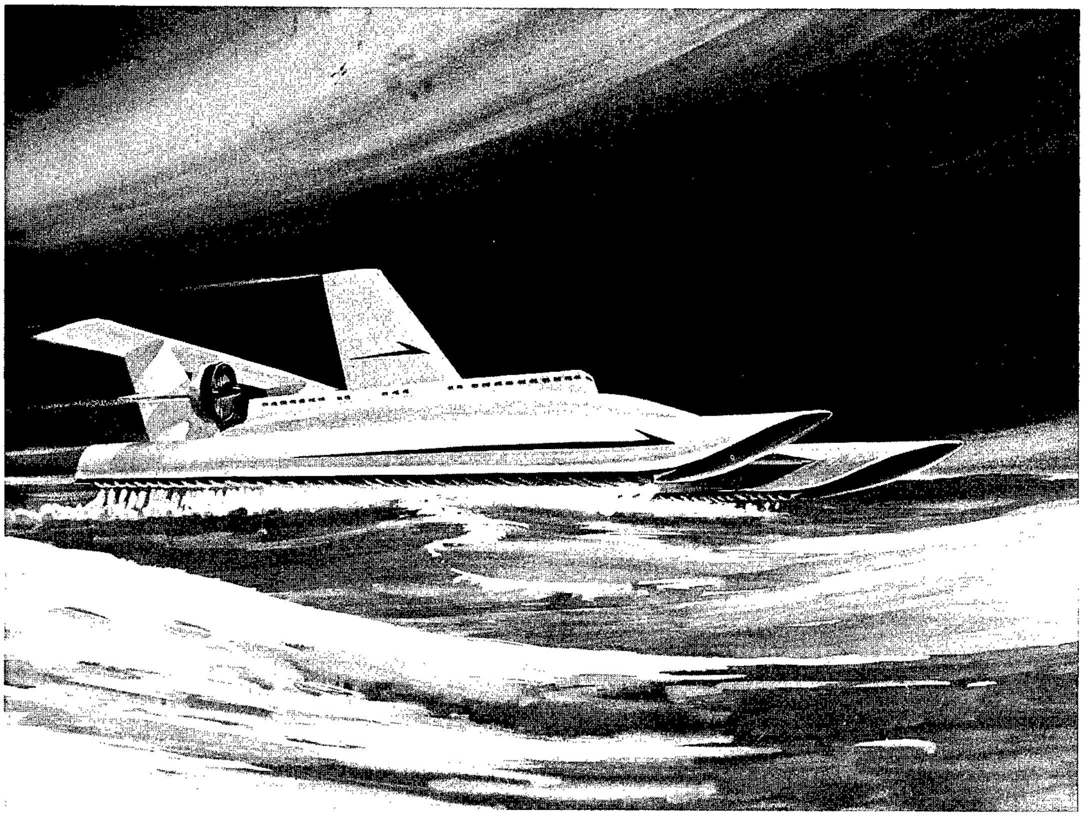
Booz, Allen illustration.

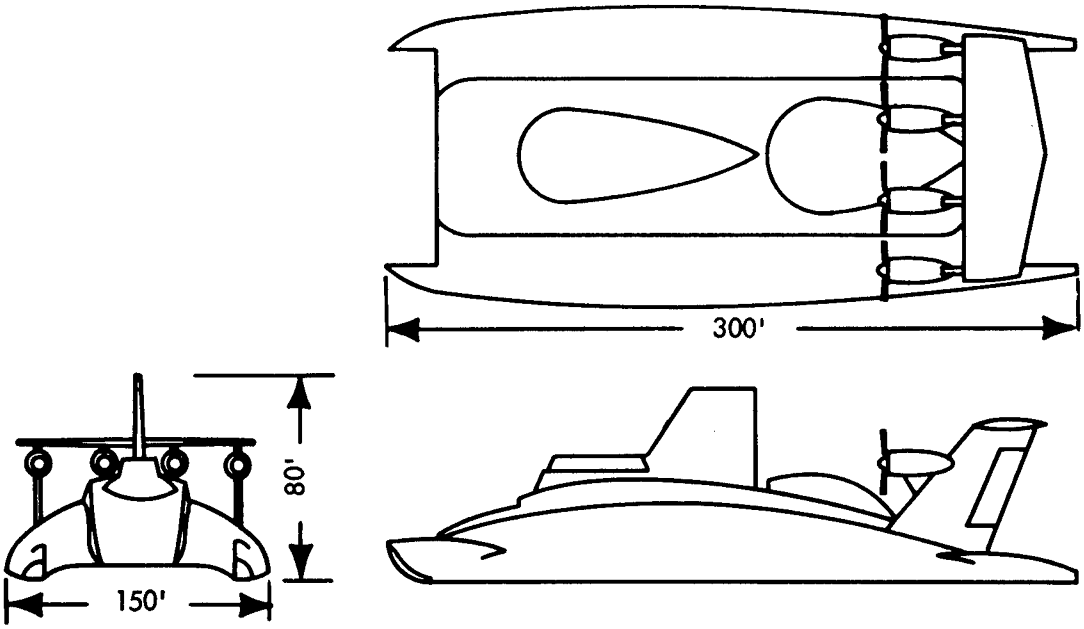
FIGURE B-8.—*The Hydrokeel 1,000 long tons gross weight size.*



U.S. Navy photo

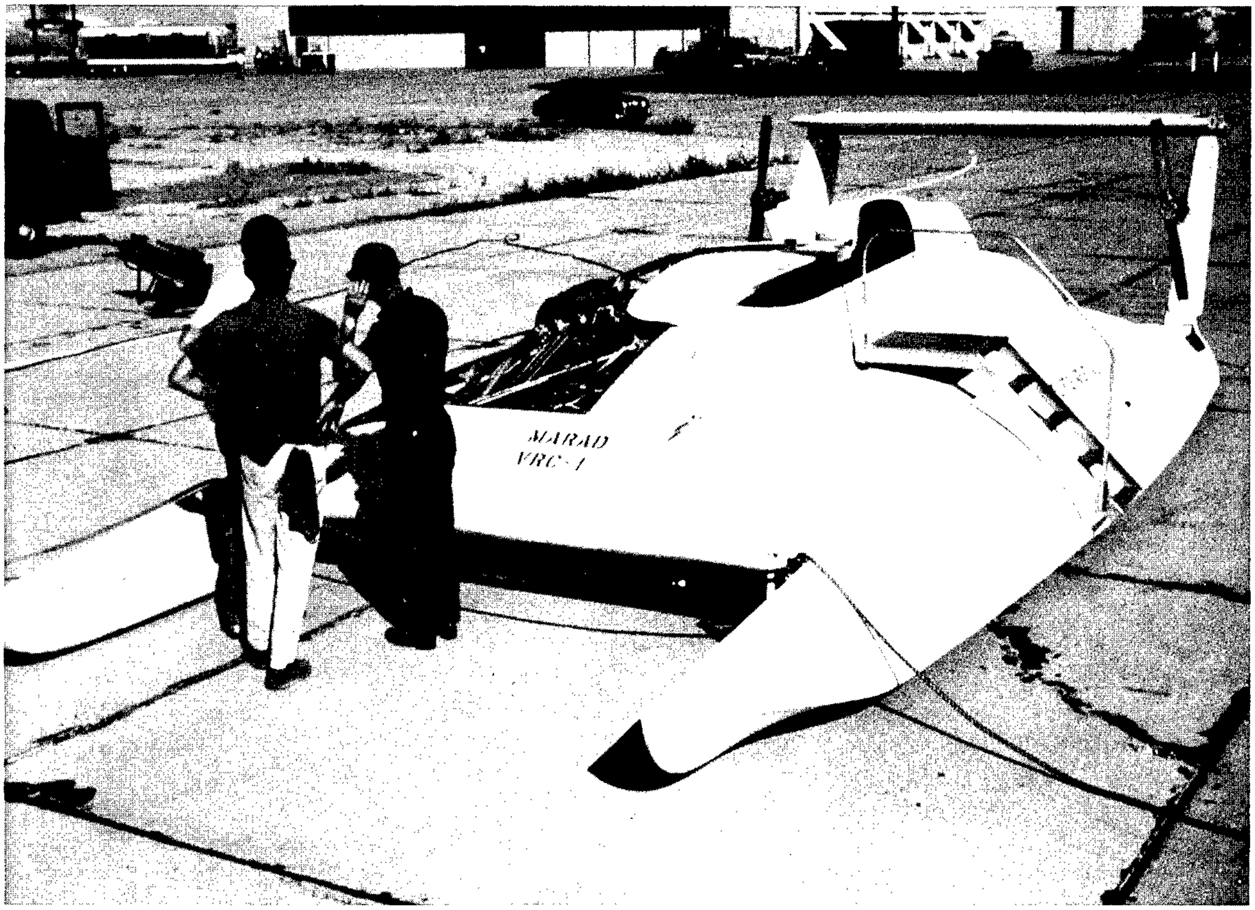
FIGURE B-9.—*An early Hydrokeel—The LCVP(K) of 1962.*





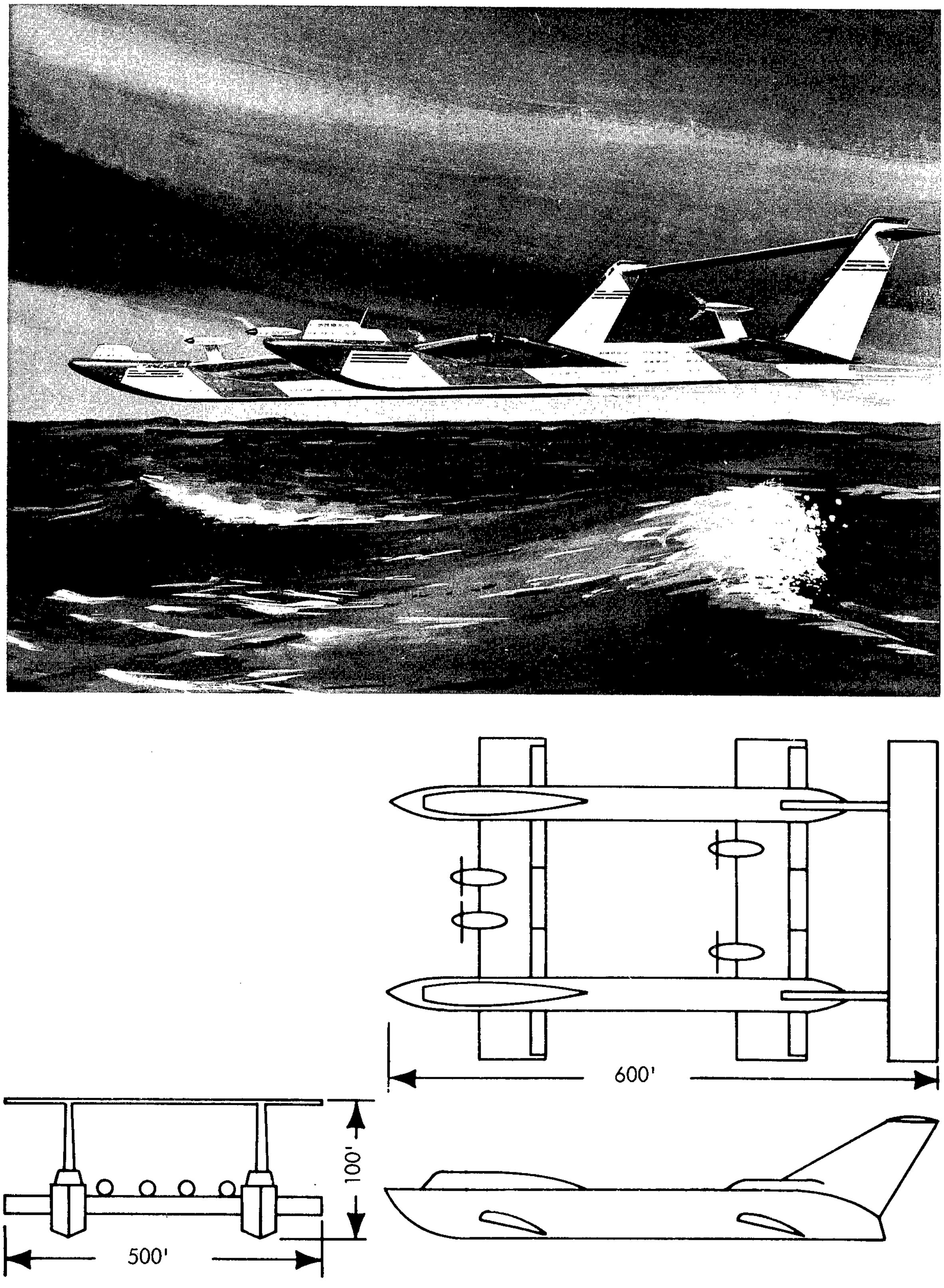
Booz, Allen illustration.

FIGURE B-10.—*The VRC 1,000-ton channel flow SES.*



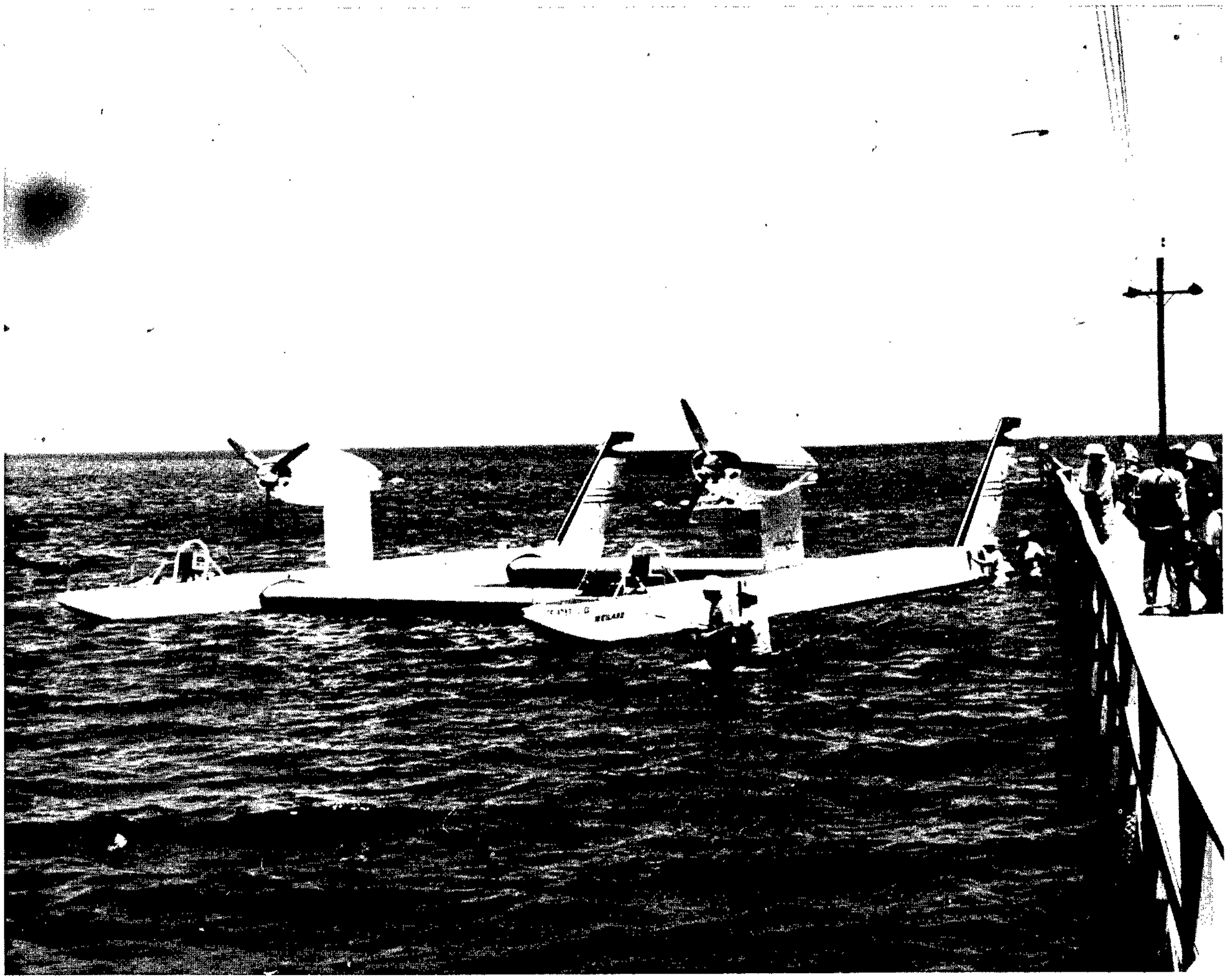
Vehicle Research Corp. photo

FIGURE B-11.—*VRC channel flow test craft.*



Booze, Allen Illustration

FIGURE B-12.—*The Weiland airfoil type SES (wing-in-ground effect).*



Douglas Aircraft Co. Photo

FIGURE B–13.—*Man-carrying model of Weiland Craft.*

APPENDIX C—PANEL REPORTS

Introduction

Establishment of Panels

The SESOC Committee approach to achieving its missions as spelled out by the Assistant Secretary for Science and Technology, Department of Commerce, was to make a critical survey of the whole problem area, using the Booz, Allen reports as a partial input, but not allowing the previous work to restrict the scope of the inquiry in any way.

This new survey was to draw on the most expert advice available in the various technological fields. To this end, five Panels were appointed to assist the main SESOC Committee, each Panel chairman being a member of the main Committee, and each Panel consisting of persons particularly qualified to address a particular technological problem area.

The Panels and their scopes were:

1. *Aero-Hydro Dynamics and Control Panel*
    - Aerodynamic stability
    - Hydrodynamic stability
    - Steering
    - Control
    - Forces, excursions and recovery
2. *Speed, Resistance, and Seakeeping Panel*
    - Resistance, drag
    - Thrust required
    - Speed in rough sea
    - Motions and accelerations
3. *Propulsion Panel*
    - Air propulsors
    - Water propulsors
    - Powerplants
    - Gear trains
4. *Hull Panel*
    - Structure
    - Mechanisms
    - Flaps and skirts
    - Metals
    - Fabrics
    - Cavitation erosion
5. *Operations Panel*
    - Cargo handling and ports
    - Collision avoidance (surveillance and detection)
    - Maneuvering procedures
    - Mooring and docking
    - Maintenance and repair
    - Manning

It was appreciated that there would be areas of overlap among the various Panels, but some logical grouping was necessary to permit a manageable organization. During the course of the Panel work, there was a desirable and sufficient interchange of information among the various groups.

The final coordination of the Panels' findings was eased by requesting each Panel to submit its report in a prescribed format.

Approaches were also made to industry for assistance in the project and in every case a positive, and in some cases extremely generous, response was forthcoming.

Panel Approach

At the first Panel meeting the Panels all agreed that the original task statement was too broad to tackle in the time available. Instead, they suggested that the most profitable approach would be to start by considering the assumptions and conclusions contained in the Booz, Allen reports prepared for the Maritime Administration.

As a result, the following set of Panel tasks was subsequently approved by the SESOC Committee.

1. Evaluate the technological assumptions made by Booz, Allen in determining the functional and economic capabilities of the five SES concepts.

2. Identify the research and engineering problems which should be solved in accomplishing the development of the various SES concepts. Decide which problems could bar successful development and which relate to achieving superior performance of the prospective vehicle. To the extent that time permits, describe the problems, consider the

time required for their solution, and suggest approaches to the solution where possible.

3. Considering each concept in terms of the crucial problems and the prospects for their solution, determine, if possible, whether the concept is eligible for early development or barred from early development or whether the evidence is inadequate to make a determination at this time.

The major part of the Booz, Allen reports, staff papers, other technical reports, and inputs from industry were distributed to the various Panels, which, in subsequent meetings and correspondence, accumulated criticisms, comments, and suggestions.

Information Supplied to the Panels

The Booz, Allen Reports to the Maritime Administration

The Maritime Administration sponsored the development of a new type of surface effect ship, the channel flow wing concept which had originally been considered by the Office of Naval Research. A parallel series of studies was initiated, with Booz, Allen as contractor, to examine the potential economic role of various concepts of SESOC.

Booz, Allen Reports Released

The following reports have been released:

Part I—"An Economic Feasibility Study of the 100-Ton Maritime Administration Surface Effect Ship." Begun February 1963, issued November 1963.

Part II—"The Technical and Economic Feasibility Study of a Nuclear-Powered Surface Effect Ship." Begun August 1963, issued January 1964.

Part III—"Comparative Performance and Cost Characteristics for Four Types of Surface Effect Ships." Begun October 1963, issued January 1964.

Part IV—"A Comparative Study of the Economic Feasibility of Two Sidewall Concepts With Other Surface Effect Ships." Begun November 1964, issued March 1965.

From these four studies, a conclusion was drawn that the captured air bubble (CAB) type SES appeared to be the most favorable for development, and further studies were launched to explore the CAB concept.

Part V—"The Economic Potential of the CAB Type SES in the Market of 1975." Begun March 1965, issued July 1965.

These five issued reports, along with the Booz, Allen backup data on the design study of a 5,000-long-ton CAB, formed a partial basis for the Panel studies of the Booz, Allen assumptions.

The Panels began their work by considering the underlying fundamental assumptions. To some extent, they concentrated on the 5,000-long-ton CAB design as a suitable example for detailed investigation.

Ground Rules Applicable to All Reports

The fundamental assumptions made in the course of the Booz, Allen studies are described in the "Discussion and Findings" of this appendix. In addition, three procedural rules were followed:

(1) The engineering data for any particular type of SES would be generated for Booz, Allen by the designers of the craft. If modifications to the engineering data were needed to provide uniformity of performance, these could be made by Booz, Allen with advice from the appropriate designer.

(2) Sufficient lift power would be installed to give an air wall clearance on hard standing (i.e., over land) of 4 feet, which according to the experience available in 1962 would permit operation in waves of 8 feet without loss in speed.

(3) If the wave height were less than 8 feet, the lift power used would be reduced to give an air-wall clearance of 50 percent of the wave height, down to a minimum wave height of 2 feet.

Part I Report

Part I is a general economic study of the usefulness of a particular type of SES, the 100-long-ton channel flow machine developed for Maritime Administration, using engineering data supplied by Vehicle Research Corp. (VRC).

Booz, Allen investigated in detail the regions of the world where such a ship might be useful, and the most promising types of cargo that could be shipped by this means. They used an economic model and an environmental sea state in which sea conditions typified by a significant wave height of 5 feet or more occurred 10 percent of the time. If the wave height exceeded 8 feet, service was suspended, or the craft was permitted to detour the storm center at the 8-foot wave height contour. It was assumed this amounted to a 50-percent increase in distance.

The study concluded that the potentialities of this particular size of SES were marginal.

Part II Report

Part II was an economic and technical feasibility study of a nuclear-powered annular-jet-type SES.

This report is of interest in that Booz, Allen generated a great deal of technical data for large SES's especially on structural weights, but the power requirements were still essentially based on 1963 practice as provided to the Maritime Administration by Bell Aerosystems.

Since this form of SES was intended for transoceanic use, the air wall clearance was raised to 8 feet, permitting waves 16 feet high to be negotiated without loss of speed or the need for a detour.

No further discussion of this report is warranted here since this particular ship was intended for passenger service and was not considered in this study.

Part III Report

In Part III, Booz, Allen compared four examples of SES types:

1. The original VRC channel flow.
2. The nuclear-powered annular jet.
3. The conventional-powered annular jet.
4. The Douglas-Weiland wing-in-ground effect (WIG).

Data were obtained for all designs up to 1,000 or more long ton gross weight.

The same basic pattern of assumptions made for the Part I report was followed for the two additional designs, but minor modifications were made to the basic design data as needed. For example, the data for the annular jet as provided by Bell Aerosystems, were for an air wall clearance of 2 feet. Booz, Allen engineers modified the data to allow sufficient power for an air wall clearance of 4 feet, to maintain comparable performance with the VRC design, and verified their estimate by reference to Bell data.

Part III concluded that the cost in dollars per ton-mile varied with the gross weight and the range in much the same way for each design. For any particular gross weight there was an optimum range at about one-fifth of the ultimate range which gave minimum cost. (Ultimate range implies that fuel replaces all payload.) Furthermore, at the optimum range, the larger the ship, the lower the cost. However, in all cases the costs for the annular jet, at optimum range, were much greater than for either of the other designs. The optimum range itself was much less, restricting the annular jet to ranges of the order of 200 nautical miles at 1,000 long tons gross weight.

Part IV Report

The study in Part III was now extended to cover two additional types of SES supported by air cushions contained by solid sidewalls. They were:

1. The air lubricated hull or Hydrokeel. (Design data supplied through Maritime Administration by Bell Aerosystems.)
2. The captured air bubble or CAB. (Design data supplied by Mr. Allen Ford of David Taylor Model Basin; no commercial data were available.)

The study showed that the Hydrokeel appeared to involve even higher unit costs than the Hydroskimmer, but that the characteristics of the CAB appeared to be much better and were quite comparable with those of the VRC channel flow and Weiland WIG design.

Since the CAB appeared to offer fewer development problems than the channel flow design and was much more reasonable in overall size than the WIG, Booz, Allen extended the CAB study to cover longer ranges with large ships, and also to include realistic wave conditions for actual transoceanic routes. (Previous cost studies were made on rather smooth conditions typical of short runs in sheltered water.)

The results showed that further investigation of the CAB would be justified.

Part V Report

Part V consisted of a marketing type survey which was not germane to the issues before the Committee. No further comment is therefore warranted.

Booz, Allen Backup Data

In the absence of any commercial designers of the craft, Booz, Allen, with assistance from Mr. Allen Ford, investigated the detailed characteristics of a 5,000 long ton gross weight CAB SES. These data are referred to generally as the "Booz, Allen assumptions backup data," and were made available to the Committee and Panels.

Canvass of Private Enterprise

In addition to the direct work with Booz, Allen, the Committee sent a general letter, dated November 17, 1965, to several companies requesting their independent appraisal of the crucial technological problems in the development of the SES. The companies solicited were:

General Dynamics Corp., Electric Boat Division
The Boeing Co.
Lockheed Aircraft Corp., Lockheed California Co.
The Aerojet General Corp.
Bell Aerosystems Co.
Newport News Shipbuilding & Drydock Co.
North American Aviation, Inc.
Northrop Corp.

It was believed that each of these companies had information of value to the Panels, because they were understood to be actively studying the SES. A useful response was received in every case. Some companies gave presentations, some returned written statements on problem areas, and others undertook, at their own expense, a detailed written investigation of some problem areas. These were made available to the Committee and Panels.

Some of the Committee and Panel members were drawn from private industry, and the Panel reports drew heavily upon internal reports produced by these various companies at their own expense.

Other Technical Documents

Many additional documents of particular importance to Panel members were obtained or duplicated by the Department of Commerce, and distributed by the staff to the Committee or Panels as appropriate. These documents are listed in appendix A.

Ranking of Technological Problems

As a part of the formulation of the research and development program which was a mission of the SESOC study, the Committee had the goal of ranking the technological problems in order of criticalness to the success of the SES program. To accomplish this part of the task, the Panels have considered each of the problems in terms of three levels of impact on the ability to create successful SES. These three levels are:

1. *Crucial problems* which must be solved in order to construct safe and functional SES which meet most performance criteria but do not necessarily have to be economically competitive.
2. *Important problems* which dominate efficient performance of the vehicle or other parts of the system and must be solved to create economically competitive SESOC systems.
3. *Improvement problems* involving opportunities to achieve superior performance for economically competitive SESOC transportation systems.

Aero-Hydro Dynamics and Control Panel Report

Booz, Allen Assumptions

The Booz, Allen technological assumptions of concern to this Panel are implicit in the economic studies. They can be reduced to the generality that the various craft examined will be stable and controllable about all axes in the specified sea states. If not, artificial stability means can be used and these are within the state-of-the-art. The Booz, Allen studies assumed the vehicles will have stability, control, and response characteristics which will permit safe operation in the environmental conditions of waves and wind for the trade routes of interest. Apparently no account was taken of various penalties to be paid in structural weight fractions, performance, and utility to achieve these necessary characteristics, except insofar as they may have been included by the designers who supplied the original data to Booz, Allen.

The Panel concurs in the necessity for the assumptions outlined in accomplishing the purpose of the Booz, Allen studies, i.e., to get a first approximation to the economics of SES. However, the Panel is strongly of the opinion that the technology for large 100-150 knot SES is not sufficiently available at this point to assure adequate stability, control, and response characteristics for practical vehicles intimately associated with the surface of the sea.

A second closely associated area of concern is the implicit assumption that the dynamic motions and loads in a seaway can be defined accurately enough to permit rational design of an efficient and safe structure. Obviously, the motions of the ship and its response to rough water will have major effects on the dynamic loads imposed on the structure. These in turn will be critically dependent on the detailed configuration, and on the stability and control built into the craft.

Technological Problems

There is one all-encompassing problem in the dynamics area, which is to provide the technology required to assure dynamic characteristics that will permit a SES to operate safely in the required sea and wind conditions, and to provide adequate manueuverability (excluding the WIG configuration). This problem has been subdivided into the following areas which indicate the approaches to individual parts of the problem:

1. Stability and control criteria.
2. Stability modes:
   a. Pitch—Heave stability.
   b. Yaw—Roll stability.
3. Control systems, concepts, reliability, and life.
4. Dynamic loads implications of stability solutions.
5. Use of knowledge of air-sea boundary.
6. Lack of prototype parameters.
7. Availability of analytical and experimental methods for prediction, measurement, and simulation of stability and control characteristics.

The first four areas are considered crucial in the sense of precluding immediate development of any large vehicle. The remaining areas are not crucial in this sense but are included for proper attention in any next phase of the SESOC program.

Consideration of SES Concepts

In evaluating the concepts presented to it, the Panel eliminated the WIG and channel flow configurations.

1. *WIG Configuration*

Past studies of this type of craft and experience of Panel members have indicated that the most promising solutions resemble conventional aircraft. Hence, they become more efficient when cruising high and fast than when flying near the surface in ground effect. In any event, the technology is available for the comparative assessment of such vehicles and for their design, construction, and operation. This point of view is broader and is considered preferable to that of MARAD and Booz, Allen in which the concept is set aside because of the size of the Weiland craft and its incompatibility with existing marine terminals.

2. *Channel Flow Configuration*

This concept is at too early a stage of development to permit detailed evaluation. It seems to offer some promise of superior performance and should be pursued on a research basis until it can be defined more closely and evaluated more rationally.

3. *Other Configurations*

The remaining three aerostatic concepts (air-lubricated hull, CAB, and annular jet) are all known to have performance, stability, control, and response problems that can be serious. It is believed that as each concept is improved, it will take on some of the better features of the other concepts and they will develop toward one common type embodying the best features of each concept. Consequently, the Panel has reviewed the various problems in an overall sense and has not differentiated among the three schemes, considering all of them as forerunners of a common descendant.

Development Program Considerations

The Panel is unanimously of the opinion that all of the concepts have aero-hydro dynamic stability, control, and response problems potentially serious enough to preclude the actual development of a large prototype SES at the present time.

The Panel strongly recommends an exploratory approach which includes the construction and evaluation of several man-carrying scale vehicles in the 5- to 25-long-ton size range to deal adequately with the problems outlined by testing in a scaled-down sea. An example of an operating area in which 5- or 10-long-ton vehicles could be evaluated with some validity would be Buzzards Bay, where facilities for measuring the sea characteristics may still be available. Modification of these vehicles or construction of additional ones should be anticipated as the necessary preliminary research and development progresses. This work should be augmented and guided by intensive experimental research with laboratory models, theoretical analyses, and simulator investigations.

The Panel's estimates for the time and money required to define adequately solutions to the problems and provide the necessary technology in the stability and control field varies from 5 years and $15 million to 10 years and $50 million. This spread may be attributed to differences of opinion as to how soon the state of the SES design can be brought to a level where realistic time and cost estimates can be made.

Because of the exploratory nature of the program, it should be set up with frequent decision points at which times the program can be reoriented technically and increased or decreased as necessary.

Speed, Resistance, and Seakeeping Panel Report

Booz, Allen Assumptions

In general, the Speed, Resistance, and Seakeeping Panel agrees with the smooth water resistance estimates made by Booz, Allen *if* no consideration is given to achieving stability of the craft. We believe, however, that resistance estimates which disregard stability can only be considered as the minimum possible magnitudes of resistance. When provisions are made for stabilizing the craft by utilizing buoyancy or dynamic lift on the sidewalls, dynamic lift on the seals, or differential pressures achieved within the bubble by compartmentation, the resistance of the craft will almost certainly be greater than the estimates made in the Booz, Allen study. Little or no data currently exist to aid in estimating these resistance increases.

Solution of the stability problem through an adequate research and development program should be directed at minimizing the resistance increase caused by providing stability for the craft, and the smooth water lift-to-drag ratios given in the Booz, Allen study should be treated as the goals to be desired in a stable craft. Without such research, it is very probable that early designs of stable craft will have lift-to-drag ratios *substantially* less than the Booz, Allen predictions.

In the Booz, Allen study, the increase in resistance of the craft due to operation in a seaway is treated as well as can currently be expected. However, there are essentially no existing data on this subject. Clearly, the magnitude of resistance increase in a seaway is dependent on the motion of the craft in a seaway, which is not treated at all in the Booz, Allen study. The increase in resistance when operating in a seaway is very much dependent on the means used to stabilize the craft. Information on increased flap drag and blower power required in rough water does not exist.

An important preliminary conclusion which resulted from our evaluation is that it seems logical that vorticity is left behind in the water wake of CAB-type vehicles. The resistance associated with this vorticity (that is, induced drag) is not taken into account in any current analyses. Preliminary estimates indicate that this component of resistance may be comparable to the wave drag as presently computed.

The Booz, Allen study shows that the cost per ton mile for CAB vehicles is *extremely* sensitive to the lift-to-drag ratio of the craft. Since changes in lift-to-drag ratio influence the cost per ton mile in exactly the same way as the propulsive efficiency, it can be seen in figure 3 of the Booz, Allen backup data, "Economic Analysis," that a reduction in the estimated lift-to-drag ratio of only 25 percent will result in a 130-percent increase in the cost per ton-mile. In view of the areas of ignorance which presently exist in any attempt to estimate the resistance of CAB-type vehicles, an error of only 25 percent seems almost to be expected. A stable craft (in any size) built within the present state of knowledge is almost certain to fall short of the lift-to-drag ratios predicted in the Booz, Allen studies. However, after carrying out an extensive research and development program, it is conceivable that the lift-to-drag performance estimates presented in the Booz, Allen study can be approached.

A more detailed discussion of the assumptions relating to speed, resistance, and seakeeping is presented in the following sections.

Technological Problems

1. *Smooth Water Resistance*

The results were presented by Booz, Allen in greater detail for the CAB than for other craft. In general, in smooth water they were found to be satisfactory as projections, but they must be recognized as projections with confirmation of them high on a priority list. The drags presented were not without conservative elements (such as use of full specific loading used for bubble pressure), but these factors could be overshadowed possibly by penalties.

The one area that was found wanting in the drag projections was the effect of stabilizing schemes in degrading performance. While the numbers used may be a legitimate projection for establishing an upper limit of performance (with the exception of the omission of possible induced drag), it should be recognized that the stabilization schemes could penalize performance. Possible roll, yaw, pitch, and heave stabilization methods are considered as they affect performance.

a. *Roll*

(1) Wider beam: Minimum penalty. Fairly broad beam vehicles (e.g., length/beam=2) were shown by Booz, Allen roughly to optimize performance.

(2) Sidewall dynamic lift: Depending on added wetted areas (particularly in waves) this would have rough water penalties.

(3) Centerboard partitioning: Adds wetted areas particularly in waves and degrades performance by 1.5 times present sidewall drag penalty taken in waves.

(4) Effect of buoyancy: Depending on design, this could result in increased water wetting drag.

(5) Flap dynamic lift: Flap drag in smooth water and in waves was taken by Booz, Allen as 50 percent of the corresponding annular jet skirt or trunk drag at zero daylight clearance based on Republic Aviation (Office of Naval Research) tests of the Vickers VA–3 ACV SES. Since this performance included penalties varying approximately linearly with wave height and with velocity squared, it is probably the best available predictive method, and could even be conservative. It emphasizes, however, that much harder data on specific test vehicles of the type under investigation are mandatory as part of a development program.

b. *Yaw*

Effect of tail fins and control elements could add detrimental drags to the extent of the increased wetted area.

c. *Pitch*

Motions in pitch (particularly in a seaway) could cause increased wetting drags and other drags.

d. *Heave*

Contouring waves would cause drag reductions relative to the platforming assumptions made because of decreasing wetted sidewall area.

2. Seakeeping Considerations

The Booz, Allen study does not treat the seakeeping problems of CAB-type vehicles. The design of such craft obviously will be greatly influenced by a desire to achieve acceptable motions in a seaway based on considerations of crew comfort, structural dynamic loads, and increases in resistance. Practically no data currently exist to aid in rationally evaluating the problem. For example, the influence on craft motions of (1) geometry, (2) buoyancy of the sidewalls, (3) dynamic lift of the sidewalls, (4) bubble-blower-flap dynamics, and (5) the interactions of waves with bubble is essentially unknown.

In order to attain some quantitative estimate of the motions of a CAB vehicle in a seaway, a study was carried out at Hydronautics, Inc., by J. Scherer and W. Webster, "Preliminary Investigation of a 3,000 Long Ton CAB Ship." This study of the motions of a buoyancy-stabilized CAB vehicle in a seaway shows that the response of the vehicle at various speeds and sea states is highly dependent on the sidewall buoyancy and bubble dynamics. One important result of this study is that very high bubble leakage rates (back through the blower and flap seals) will be required at speeds of 100 knots in seaways greater than sea state 3, if heave accelerations associated with the bubble compressibility are to be kept within human tolerance levels. These results point out the importance of developing flap seals which will provide the necessary stiffness for stability while simultaneously properly assisting in the regulation of the bubble pressure and providing adequate sea state alleviation. In passive seals, the probable direction of development is to have low weight/strength seals to achieve high frequency response characteristics. Such complex flap seal requirements may lead to actively controlled flaps rather than the preferred passive flap systems. Futhermore, these results suggest the need for the development of blowers with characteristics which will tend to alleviate the motions associated with bubble compressibility.

3. Rough Water Performance

The Booz, Allen assumptions on increased resistance due to waves are quite crude, and in some ways optimistic.

(1) It is assumed that the vehicle platforms. In higher sea states it is essential that the vehicle contour, which would tend to reduce the increase in drag due to waves.

(2) The application of usual skin friction formulas to the drag on a flat plate in waves needs justification. Since this frictional drag is important to overall performance, a moderate change could be significant.

(3) Flap drag has been estimated crudely on the basis of skirt drag data at zero clearance. Only a very rough attempt was made to allow for increases when flaps are subjected to dynamic lift. There will be an effective increase in drag when flaps move away from their stops because of wave action. Effect of impacts of waves on flaps has yet to be established.

(4) No allowance has been made for increase in blower power required to make up air lost due to large motions. In heavy seas this could be critical, particularly near synchronism of the bubble-vehicle system since, in this case, air leakage is the primary mechanism by which motions are limited.

(5) The assumptions with respect to air drag are generally valid. However, this is an important percentage of the total drag at high speed (100 knots) and deserves to be estimated accurately. Winds associated with high sea states will result in significantly larger power demands.

Required tests include measurement of drag of typical sidewalls in waves, drag or flaps under various loading conditions in waves, magnitude of impacts on flaps, and the relation between motions and drag. Wind tunnel tests of proposed configurations are essential for estimation of air drag.

One encouraging aspect of air cushion vehicle (ACV) performance is shown by extrapolation of Office of Naval Research-Republic Aviation tests of the British VA-3 annular jet with skirts or trunks (RAC Report 2612, October 1964). The envelope of experience and the envelope of acceptable performance is shown to be generally less than average-wave-height/vehicle-length ratio of 0.1 with speed/length ratio (V_k/L) from 8 at zero wave heights to speed/length ratios of 6 at the higher (about 0.1) wave height/length ratios.[4] The point here is that this experience provides projections of acceptable performance of large craft to quite high sea states (when one projects these results by Froude scaling laws). For instance, in the case of a 9,400-long-ton scale model of the VA-3, 100 knots at 30 feet average wave height is within this "experience range."

These data are, of course, directly applicable to the annular jet, but they also hold out a possible promise of *good sea state alleviation* characteristics for ACV of other types. This is not to say that the CAB type of ACV will show the same (more or less) promise.

In summary, the technological problems in the area of speed, resistance, and seakeeping are:

Crucial

Influence of achieving stability on speed, resistance, and seakeeping:

Geometry of sidewalls and overall geometry factors.

Design of active and passive seals.

Compartmentation: blower-bubble-water surface dynamics.

Motion in a seaway and the relation to speed resistance and seakeeping:

Interaction of propulsion and resistance.

General resistance problems, component drags.

Important

Influence of achieving stability on speed resistance and seakeeping.

Control surface configuration and design.

Consideration of SES Concepts

After examination of the various candidate vehicle types, our attention focused on aerostatic vehicles on the basis of the following considerations. The WIG machine was excluded because:

1. It is evidently much too large when practical payloads are considered.
2. Relative to the other types of machines, there are no unknown or uncertain technical factors.
3. If, for any reason, such machines find an application, working designs can be prepared on the basis of presently available information and data.

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[4] H. Chaplin and A. Ford, *Elementary Fluid Dynamic Design Principles of Ground Effect Machines*, Section L, "Seakeeping," DTMB Report, 1965.

The channel flow machines were excluded because:

1. They are essentially very low aspect ratio wings which must operate within what appear to be impractically small distances from the water surface to overcome the inherent inefficiency of low aspect ratio wings.
2. They must be very low density machines.
3. They are very large compared with aerostatic machines of equivalent payload capacities.

Although it was suggested to the Panel that air lubricated hull, CAB, and annular jet machines be treated separately, it should be recognized that these vehicles are very closely related, especially when the sizes approach those being proposed for ocean commerce. In fact, the air lubricated hull and the annular jet machines may be considered as special cases of the CAB type of vehicle in certain respects. For example, the air lubricated hull is simply a CAB with rigid rear seal; the annular jet machine with skirts has features of a CAB with flexible sidewalls and bubble leakage. Except for the air lubricated hull, the aerostatic machines, based on present knowledge and information, tend to approach each other in performance in a seaway. Actual details of performance will differ, of course, and must be examined ultimately when making decisions in selection of specific designs. We believe that the problem areas described in the following proposed development program correctly reflect these conclusions and are, at the present stage of knowledge, sufficiently inclusive as well as pivotally important to provide the data that are needed for early decisions concerning the types of designs, sizes, and speeds that will be successful for ocean commerce applications.

Development Program Considerations

Serious thought was given to the directions, types, and methods of research and data acquisition that would accomplish the program objective. It is clear that laboratory model studies and manned models will provide efficiently and economically, the information now critically needed. The scaling laws are well understood and model testing techniques are of sufficient sophistication for these purposes. Intelligent division and coordination of experimental studies must, of course, be made among components and complete models, model basin and cavitation tunnel studies, and manned models in small sizes.

The problem areas which have been disclosed as a result of our studies lead to the conclusion that immediate initiation of a program of design studies for 1,000- or 5,000-long-ton vehicles with research only in a supporting role is premature. We believe that laboratory studies backed up by manned model research and development are essential to provide the firm data upon which to base decisions concerning the type and size of SES to be pursued. Such research and development studies should, of course, be carefully addressed to the problems of large ships for commercial application. A carefully designed research and development program will provide data for renewed emphasis on actual design and application of oceangoing ships. We urge that such a program be pursued vigorously to realize the promise of SES. The specific problem areas to which a development program related to speed, resistance, and seakeeping should be directed are:

1. Influence of stability on speed, resistance, and seakeeping:
   a. Geometry of sidewalls (including flexible skirts) and overall geometry factors (length/beam, height/beam).
   b. Design of active and passive seals.
   c. Compartmentation, blower-bubble-water surface dynamics.
   d. Control surface configuration and design.
2. Motion in a seaway and the relation to speed, resistance, and seakeeping.
3. The interaction of propulsion and resistance.
4. General resistance problems:
   a. Wave making, skin friction, and possible sidewall induced drag.
   b. Wave profiles are related to skin friction, induced effects, and overall vehicle drag.
   c. Flap drag in smooth and rough water.
   d. Aerodynamic drag.
   e. Required cushion fan power.

Propulsion Panel Report

Booz, Allen Assumptions

The Panel finds the Booz, Allen assumptions within the realm of feasibility for the 1975 time frame, but considerably optimistic even if an aggressive development program were to be followed. The assumptions of most concern involve the ability to design a practical ship with reasonable life and reliability expectancy within the projected weight range. The performance of the SES is shown by these studies to be particularly sensitive to the following parameters:

1. Propulsive efficiency.
2. Fuel performance.
3. Machinery weight.

Most of the assumptions in the Booz, Allen studies have been developed realistically, but they are not backed up by detailed design studies, which, of course, were outside the basic scope of work. Without the benefit of such studies it is practically impossible either to identify the necessary components and their technical and operational requirements or the effect of these installations on the ship structure and size characteristics.

It is implicit in the Booz, Allen studies that all of these problems can be solved so that a high performance ship can be built that would also be fully competitive with other systems. The assumptions made with respect to the propulsion systems are optimistic in all of the three categories. Meanwhile, it is evident that insufficient data are available to predict accurately the power requirements and speed performance. The ultimate decision to proceed with the development of a commercial ship will no doubt depend on whether or not the assumptions can be substantiated, and, if not, whether the combined effects diminish the overall effectiveness of these craft to an unacceptable point for commericial service.

The Propulsion Panel has addressed its specific evaluations of the Booz, Allen assumptions relating to the 5,000 long ton CAB, since the earlier Booz, Allen studies do not endeavor to define the actual propulsion systems.

The following evaluations of the Booz, Allen assumptions are submitted.

1. *Type of Powerplant*

The simple open-cycle aircraft gas turbine is the most suitable prime mover available for all types of SES. No amount of practical improvement in specific fuel consumption (SFC) could offset the advantage in machinery weight that this type of gas turbine offers for the SES. Regenerative gas turbines do not offer enough improvement to justify their weight.

2. *Engine Availability*

Engines exist which provide the approximate thermodynamic performance assumed by Booz, Allen, but they have not demonstrated their ability to produce the high power level required for continuous operation.

3. *Fuel Type*

Aircraft fuels are acceptable. Turbines have demonstrated their ability to develop high powers on No. 2 grade fuels.

4. *Engine Performance*

The study was based on the SFC operating characteristics, and growth potential of the Pratt and Whitney FT4A–2. This engine has not demonstrated its ability to produce high power in the 30,000 horsepower range for extended periods, although it has demonstrated its ability to achieve these approximate power levels for short periods. Development to this point appears feasible.

5. *Engine Performance and Environment (Natural and Installed)*

The installed engine power and SFC assumed appear optimistic. The following considerations would result in greater specific weight and SFC:

a. To avoid exceeding 6 percent power degradation, it may be necessary to shut down each engine periodically for water washing. This would require about 10 minutes per engine. The use of abrasives may circumvent the need for washing and engine shutdown. However, neither the magnitude of these effects nor the solution of these problems has been determined in large engines at sea. The Booz, Allen estimates of a 6 percent power loss are considered conservative.

b. Pressure drop for inlet air water separation and exhaust ducting must be considered.

c. De-icing of air inlet must be provided.

d. The present status of the sulfidation problem is such that there is no assurance that turbine inlet temperatures can be extended beyond 1530° F. without added maintenance, the extent of which cannot be determined at this time. This temperature limitation can result in larger engines, greater weight, and higher fuel consumption. Feasibility of the SES with this engine should be studied.

e. Booz, Allen assumed that the turbine horsepower changed an average of 0.005 HP/HP/degrees F. in ambient temperature. Although not stated by Booz, Allen, this is approximately true if the firing temperature is held constant. In the route analysis, an engine SFC of 0.55 was assumed plus a correction for change in ambient temperature. For ease of calculation, the effect of temperature variations which occur on various routes was assumed to change SFC, rather than HP by a factor of ± 0.005 HP/HP/degrees F. from an assumed mean average of 60° F. Further, the SFC was increased by 0.06 to account for salt fouling. What appears to have been overlooked is that the factor of 0.005 HP/HP/degrees F. applies only at a constant firing temperature. When a fixed horsepower is required of a fixed geometry turbine it is obtained by varying the firing temperature with changes in ambient. The effect is to give almost constant SFC with variations in ambient at a fixed power output.

6. *Transmissions*

The problems of transmission system development vary in degree with the various propulsor systems:

a. Water screw with inclined shaft. The gear development appears within the state-of-the-art.

b. Water screw with right-angle drive and retractible nacelle. Gear development requires considerable extension of the state-of-the-art and may have unacceptable life.

c. Water jet system. Gearing is within the state-of-the-art. May even avoid gears and go to direct drive.

d. Air screw. No insurmountable problem, but requires considerable development and may still have unacceptable life. Unit power outputs require considerable extension of the state-of-the-art for planetary gears.

7. *Lift Fans and Ducts*

These are within the state-of-the-art.

8. *Overhaul Intervals and Maintenance Schedule*

Overhaul intervals are determined by experience and cannot be accurately predicted in advance. Aircraft experience cannot be projected accurately into the SES use as the Booz, Allen method implies. Systems will be required to operate for extended periods in marine environment which is very severe. Pods, struts, ducts, and propulsors will be subject to erosion. The projected maintenance schedule of 1,760 hours would provide for a 7-day quarterly docking and 1 full day scheduled maintenance after every round voyage. Such routine would appear essential in the operation of these craft until operating experience can be gained.

9. *Propulsors and Propulsive Efficiency*

Propulsive efficiency of 67 percent is assumed in the economic analysis. This value may be achievable for airscrews. With the recommended water screw or water jet system, the assumed efficiency of 60 percent may be optimistic. In such a case, the economics would be less attractive than those shown by Booz, Allen.

10. *Machinery Weights*

The propulsion machinery weights for all systems are underestimated. A figure of 2 pounds per installed horsepower appears more realistic for each of the three systems.

11. *Auxiliary Power*

The Panel has no comment.

Technological Problems

The critical parameters defined by the Booz, Allen studies identify problems that must be solved in order to develop an economically competitive transportation system. There appear to be no propulsion problems however that would bar the early development of an operable, seaworthy craft for limited use as a test vehicle, but systems developed for such a craft would not be applicable in a commercially competitive ship. A comprehensive design, research, and development testing program would be required before the construction of a large SES for commercial service could be undertaken with confidence.

The power requirements for SES cannot be projected accurately at this time because of the lack of experience and data on their drag characteristics and speed performance. Nevertheless, certain conclusions can be drawn with respect to the required machinery characteristics and performance by considering the effect of the more critical parameters on the payload characteristics of these ships.

The power requirements will depend fundamentally upon the drag characteristics, the propulsive efficiency, and the design speed. Machinery weight will, of course, depend on the power requirements and the unit weight characteristics of the machinery.

The total fuel requirements, and hence the fuel weight, will also depend on the drag characteristics, the propulsive efficiency, the endurance range, and the SFC rather than the speed, although the drag characteristics will be a function of speed.

The basic importance of propulsive efficiency and SFC in SES results from their effect on total fuel weight requirements. Because the fuel weight for a 5,000 long ton CAB equates to a greater fraction of the total ship weight than any other single weight group, it follows that a percentage change in either factor would result in a proportionately greater change in the payload capacity. Also, there will be a compounding effect of these factors on the economic characteristics of the ship due to the payload reduction and the fuel cost increase.

Most of the SES built so far have utilized aircraft type engines in order to reduce the machinery weights to practical proportions. The Propulsion Panel concurs with this approach because no amount of practical reduction in the fuel consumption of other marine powerplants could possibly offset the weight advantage offered by aircraft type components. The use of conventional marine powerplants, for instance, would dictate machinery weights of the same order of magnitude as the fuel weight and would result in no payload capacity. There is little doubt, therefore, that lightweight powerplants must be used in SES in transoceanic service. The use of such powerplants minimizes the importance of machinery weight, so there would appear to be some margin for growth over the minimal values projected in the Booz, Allen studies if required. The critical question will be whether or not powerplants of sufficient life and reliability can be developed even within this expanded weight range.

No engines are available today that have achieved Booz, Allen projections of either fuel performance or power output for extended periods in the marine environment. Engines do exist which, through further design development, could meet these requirements. An extensive development effort would be required however, because a temperature barrier to the improvement of the thermodynamic performance occurs at approximately 1530° F. because of sulfidation corrosion which is to be expected in the marine environment. Other corrosion problems arise in this environment too, due to the deposition of salt in various parts of the engine, but their solution will require less development effort and will involve either materials development or the perfection of blade coatings.

Engine performance is also subject to deterioration in the marine environment due to the deposition of salt in the compressor. Therefore, careful attention must be given in the engine installations to the removal of salt water in the air intakes and the minimization of both the intake and exhaust pressure losses. Also, operating regimes will need to be established that will permit water washing of the engines. Although these are practical considerations, a certain weight and space penalty will result from these provisions and acceptable operating regimes may determine the actual number of engines required.

In the absence of detailed design studies it is not possible to identify either the technical or operational requirements of the propulsion system components. The transmission problems, for instance, will differ for each type of propulsion system. The need for clutches, reduction gears, right-angle drives, and combining gears cannot be established without detailed design studies, nor can the life and reliability of these systems or the scope of required development programs be evaluated.

Air screw propulsion offers not only the best immediate prospects for high efficiency with fewer development problems, but also the best long-range prospects, if the trend is toward higher speeds, i.e., in the 125- to 150-knot range. Even so, this system requires the development of planetary gears and propellers beyond the state-of-the-art. Air propulsion also offers a further possible advantage in the location of the complete propulsion system outside of the basic structure which may permit smaller structures and lower structural weights. Other problems associated with this system will involve the structural design of the supports, support drag, crosswind, and interference effects.

Water screw or water jet propulsion systems impose, in addition to the difficult problem of designing an efficient and reliable propulsor, a number of difficult mechanical and structural design problems and consequently more development problems than the air systems. The efficiency of water propulsion systems will also be less than the air propulsion system at 100 knots and even lower still in the 125- to 150-knot speed range. Both types of water propulsion systems require the machinery to be installed inside of the basic structure and will therefore influence the overall size characteristics of the ship as well as the configuration of the sidewalls or other appendages resulting in added appendage drag. Since the influence of cavitation will become evident at ship speeds above 50 knots, it is to be expected that appendage drag will become increasingly important and should be evaluated in tunnel tests. A certain amount of detailed design work will need to be undertaken in order to develop practical configurations of the appendages. It will also be important to determine whether or not induced effects are produced by the water propulsion system, e.g., added spray or wave drag. The design of the intakes for the water jet system is identified as the most significant single problem while a similar problem would be involved in the supercavitating propeller system of insuring minimum interference and proper flow to the propulsor.

The position of the center of thrust will vary widely among the different types of propulsion systems. This too may bear an important relationship to the pitch stability of the ship and will need to be evaluated in early test programs. Similarly, the appendages required by the different systems will have an important effect on the yaw-roll stability.

The present resurgence of interest in the SES stems from the favorable experience with various types of flexible understructures which make it practical to reduce the air gap area and thereby the power required to sustain the air cushion.

The ultimate lift power requirements will result from a compromise between air gap area and rough water drag penalty caused by the understructure. The Booz, Allen studies indicate that the lift power requirements would not exceed 10 percent of the propulsion power requirements. Because of the many uncertainties involved, it is entirely possible that these power requirements may be two or three times this value. It is noteworthy that a relative increase of lift in relation to propulsion power will produce an effect equivalent to a reduction in the propulsive efficiency and the effect will be magnified by any increase of rough water drag. Thus, while no important problems will be associated with the development of lift power, lift power requirements could determine the commercial competitiveness of the ship.

The technological problems in the development of propulsion systems for large surface effect ships for ocean commerce are summarized as follows:

Crucial

Propulsion system development for large-scale test vehicles.[5]

Important

Engine availability.

Fuel economy in the marine environment.

Propulsion transmission systems (life and reliability).

Propulsive efficiency—propulsors.

Related structural and mechanical problems that influence ship performance, stability, and drag characteristics.

Improvement

Lift power requirements (fan characteristics and controls).

Related structural and mechanical design problems for the propulsion system installations.

Harbor propulsion and maneuvering system.

Consideration of SES Concepts

The Propulsion Panel has not considered the propulsion problems for each of the various types of SES, but has considered both air and water propulsion systems for the CAB-type ship.

It is fairly evident that only air propulsion would be applicable for the annular-jet ship and either of the category II ships, i.e., the channel flow and WIG concepts. The problem in these systems would likewise be similar to those in the CAB.

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[5] Although engines are available that may be adapted to this purpose, the power requirements for test craft of the order of 500 long tons are such that complete propulsion systems will have to be developed which are beyond the state-of-the-art. The critical requirements involve the complete system, i.e., engines, transmissions, and propulsors.

Development Program Considerations

Little, if any, meaningful information applicable to these systems can be developed from model tests, except for the propulsors. Full-scale developmental testing will be required for both the engine and transmission systems.

It is not practical to define either the technical or operational requirements for the propulsion systems unless detailed design studies are carried out beforehand. Also, the related mechanical and structural design problems cannot be fully defined without such studies. Since the latter will have an important effect on the overall performance of the ship it would appear desirable to implement further design studies at an early time.

Propulsion system development will be required for a large-scale test vehicle as well as the ultimate size commercial ship. The Panel's estimates for the time required to develop the propulsion system are 3 years for the large-scale test vehicle and 5 years or more for the 5,000 long ton ship.

Since the design work may be carried on for relatively low costs, it would appear desirable to implement design studies as soon as possible so that these results may be applied in the planning of future programs and in the development of a better basis for continued appraisal and refinement of economic studies.

Hull Panel Report

The Hull Panel has examined the following areas relating to the design of SES:

1. Design philosophy.
2. Design criteria, both static and dynamic, for the primary and secondary structure.
3. Structural materials and fabrication procedures.
4. A typical, feasible structural configuration for a 1,000 long ton CAB vessel.
5. The associated structural weight.
6. A cursory examination of the influence of size and bubble pressure on structural weight.

Members of the Hull Panel have prepared reports covering these areas. It is to be understood that the Hull Panel findings are preliminary in nature in view of the limited time and effort available for the studies.

Booz, Allen Assumptions

In addition to its own independent studies, the Panel has reviewed the structural weight estimates employed in the Booz, Allen studies, as well as the methods by which they were obtained.

The conclusions of the Panel are as follows:

1. For a 1,000 long ton gross weight CAB, designed for a 138 pounds per square foot (psf) bubble pressure and built with aluminum alloy having a 39,000 pounds per square inch (psi) yield (5456 alloy), the structural weight is estimated to be in the range of 35–40 percent of the gross weight.
2. In the range of 1,000–5,000 long tons, with the bubble pressure rising as the cube root of the weight, it is expected that the structural weight requirements will remain in the 35–40 percent gross weight range.
3. Substantial reductions in structural weight appear possible through substantial increases in bubble pressure, leading to a smaller, more compact ship. The amount of weight saving possible through this approach has not been pursued, since it represents a trade-off with propulsion requirements.
4. The use of high-strength aluminum alloys and/or steel may offer a weight advantage. Further study of fabrication problems, structural design, materials performance in the ocean environment, and maintenance factors are required before this can be decided.
5. Original Booz, Allen estimate of structural weight for the 5,000 long ton CAB operating at 280 psf bubble pressure was 34 percent of gross weight. Through refined design, Booz, Allen personnel believed that this could be reduced to 25 percent of gross weight. (In the Booz, Allen economic studies, structural weight is assumed to be 20 percent of gross weight.)

The Panel is of the unanimous opinion that the figure of 20 percent is far too optimistic for use as a basis for economic studies. The Panel also doubts that the 25 percent level for structural weight can be achieved in practice.

Technological Problems

The following major problem areas standing in the way of early SES development relate specifically to the CAB concept, since this is the vessel type considered in greatest detail by the Panel. Many of the listings apply equally well, however, to the air lubricated hull, annular jet, and channel flow concepts.

The listing is given roughly in the order the problems would be encountered in the design process. Notes are appended regarding the severity and degree of difficulty anticipated in arriving at acceptable solutions.

1. *Design Philosophy*

The philosophy of displacement ship design is to provide sufficient structural strength to avoid serious structural damage under all conditions of operations. In severe storms, however, a certain amount of repairable damage is permitted.

In the case of SES vessels, it is generally agreed that no structural damage can be tolerated under all possible conditions of "on-bubble" operation. A critical design condition, however, relates to the emergency circumstance when the ship must withstand a heavy seaway in the displacement condition. It is agreed that if SES design criteria require structural integrity to the extent now embodied in displacement ship design, the resulting structure will be too heavy to permit practical SES designs. However, a substantial margin of structural integrity will be required, but not necessarily as much as for a conventional ship.

A variety of studies must be made to clarify questions such as:

a. In the "on-bubble" configuration, structural requirements will impose an envelope of speed versus sea state. What is an acceptable envelope from the operational viewpoint, and what are the associated structural problems?

b. What is the relation between severity of damage and the various sea conditions? What structural criteria shall be imposed on the craft bearing in mind this relationship?

c. In light structures subjected to dynamic loads, fatigue is a severe structural problem. In the case of the CAB, what spectrum of dynamic loadings shall be the basis for fatigue-resistant design?

d. What is the spectrum of static and dynamic limit loads to be used in CAB design?

A considerable body of related experience in answer to these questions can be drawn from displacement ship and aircraft design procedures. For large SES vessels however, the lack of model or prototype data precludes intelligent decisions on important matters of design. It is probable that theoretical and model studies will be a minimum requirement for solution of these and related questions. Seagoing operations with a test vehicle may also be needed in order to arrive at acceptable design criteria which afford adequate safety margins without excessive structural penalty.

2. *Fore and Aft Ski Design*

It is generally agreed that a successful CAB design must employ fore and aft skis which contain the bubble with relatively small clearance at the waterline. Simple calculations quickly show that, for operations in a seaway at speeds up to 100 knots, the potential water loads on a hinged, but otherwise rigid, ski are enormous. In addition to intolerable structural loads, large longitudinal (fore and aft) accelerations would be imparted to the craft in even modest seaways.

The ski design must therefore combine adequate bubble containment with a design concept which avoids water loads transfer to the main hull. A flexible "balloon" type of ski at once suggests itself, but the design loads imposed on such a configuration are unknown. From the design, materails, and maintenance viewpoints, the practicality of flexible fabric skis cannot be appraised at this time.

Save for the concept of employing fabric ski structures, no promising avenues of approach to the problem of ski design have yet been advanced.

Even if an ingenious and inventive concept for ski design is proposed in the near future, the current level of technical knowledge of CAB behavior in seaways would preclude an intelligent evaluation of the suitability of the concept. Theoretical analyses of CAB dynamics and response in seaways, model studies, and perhaps some form of prototype experience will be required before the problem of ski design can be formulated within a reasonable engineering framework.

The Panel believes this entire problem area to be a major hurdle which must be overcome before serious CAB development can be undertaken. The practicality of the entire project may well hinge on whether reasonable solutions can be found to the problems of ski design.

3. *Dynamic Loads*

The ability of the CAB design to withstand the static loads encountered in the on-bubble and displacement configurations is a problem which appears to be of a straightforward nature.

This type of vessel will, however, be subject to a variety of dynamic loading conditions which require further engineering clarification. The dynamic loading on the fore and aft skis has already been mentioned as one such problem.

Other problems requiring research attention in order to arrive at suitable design procedures are the dynamic responses of the overall craft in seaways, the dynamic loads on the sides of the craft (including the skegs) in beam seas, and the dynamic loads and local pressures exerted on the bottom plating in the bubble area. These problem areas are present both in the on-bubble and displacement conditions.

It is evident that structural weights are strongly dependent on the loads envelope specified for the design. The determination of critical dynamic loads depends on the methods used to derive the loads and on the assumed severity of the load-inducing parameters (in this case, the design sea states). In both these areas, current knowledge is deficient for the purpose of optimum design. At least some seagoing experience with a prototype vessel will doubtless be required before many of the questions regarding dynamic loads can be resolved.

4. *Structural Materials*

The qualities which make up an ideal material for CAB structures (and many other structures as well) are high strength-to-weight ratio, high modulus of elasticity-to-weight ratio, good ductility, good formability and machinability, resistance to fatigue damage, high fracture toughness, good weldability, high corrosion resistance, and low cost. In general, the achievement of high strength-to-weight ratio is associated with a relative degradation of many of the remaining performance parameters of a structural material.

A preliminary study of the special circumstances connected with SES design indicates that aluminum alloys hold the most immediate promise for use as a structural material. Alloy 5456 has been used with considerable success in marine structures.

However, before a final choice of materials for the various SES structural components can be made, considerable further analysis and laboratory study are required. It is possible that substantial weight savings can be effected through the use of high-strength steels or high-strength aluminum alloys as structural materials. Candidate materials would almost certainly be drawn from the newer alloys, so that substantial experience in their use would not be available. A considerable body of trade-off studies and laboratory investigations to compare one alloy with others would be required before a final choice could be made for an optimum SES structure.

5. *Structural Design*

The present concepts for the CAB main hull design entail box-like structures with a maximum of clear internal cargo space. The proportions of the box elements would be such as to exhibit pronounced shear lag effects and other structural complications.

Moreover, in the displacement condition, the CAB resembles a catamaran-type vessel with a long span between the hulls (the buoyancy afforded by the side skegs is of the order of the ship's displacement). Little experience is available in the design of such configurations.

Research will thus be required to clarify certain of the essential structural mechanisms connected with CAB design. When these mechanisms are understood, design and optimization of the overall structure will become possible through normal engineering procedures. Although some model studies may be required for verifying the structural behavior of SES, it is not considered that the uncertainties in the design problem by themselves are such as to provide a hindrance to initiating the project.

6. *Fabric Development*

It has already been pointed out that successful CAB designs will very probably require the use of fabric structures for the fore and aft skis. For annular-jet designs, fabric curtains appear to be the essential key to the development of acceptable designs.

The fabric requirements include light weight, a high degree of flexibility, high tensile strength, high tear strength, abrasion resistance, chemical resistance to the marine operational environment, and the development of suitable joining techniques for attaching the fabric structure to the supporting structure. Maintenance and repair-at-sea characteristics will also be important.

It was mentioned earlier that sufficient knowledge is not presently available for the estimation of the design loads on the fabric structures. Determination of loads is complicated by the fact that the skirt shape changes drastically under load and this change in shape will in turn affect the loads. This Panel is not aware of analytical methods that would yield skirt loads for a high confidence design. Some experimental work will undoubtedly be necessary to arrive at a skirt that performs well on a 100-knot vehicle.

In any event, it is clear that fabrics of unusual strength and performance characteristics will be required. A considerable research and development program will be required to produce fabric designs adequate for SES service.

The chronology and methodology followed by the Hull Panel are mentioned in appendix A and specific reports by individual panel members are listed.

The hull problems are summarized as:

Crucial

Dynamic loads and accelerations.

Overloading sea conditions, damage, and structural failure.

Fore and aft skis for CAB.

Fabric for pliable structure.

Important

Fluctuating loads and fatigue criteria.

Design criteria for spectra of static and dynamic limit loads.

Rupture, stress corrosion, and cavitation erosion.

Improvement

Structural materials.

Unique structural design problems.

Consideration of SES Concepts

The air lubricated hull, annular jet, and channel flow concepts may offer some structural advantage over the CAB, but it is not expected that such advantage will be of major significance.

The design of WIG-type SES, which are essentially large aircraft operating in the ground-effect region, is within the current state-of-the-art as regards structural design. Structural weights in the vicinity of 25 percent of gross weight can probably be achieved in large aircraft of this type providing emergency survival in heavy seas in the displacement condition is not a design requirement. If survival in emergency landings at sea is required, the structural weight ratio is estimated to be 30 percent or more.

Development Program Considerations

The members of the Hull Panel endorse an active program aimed toward the development of successful SES vessels. However, until more supporting technology is available for engineering purposes, the programming should be on the basis of research and advanced development.

In the context of DOD directive No. 3200.9, July 1, 1965, the Panel is of the unanimous opinion that the CAB concept is not yet ready for Contract Definition (Project Definition) action.

Operations Panel Report

Booz, Allen Assumptions

There are notable voids in the assumptions relative to economic analysis and justification of SESOC concepts.

1. Lack of supporting analysis on which to assess the need for development of a SESOC.
2. Need for a thorough study of system requirements and competitive merits of the SESOC versus other transport modes for the type of cargo being considered.
    a. Cargo handling system is a major and critical factor in the economics of the SESOC transportation concept. Its design will greatly affect or dictate that of the SESOC vehicle.
    b. Comparison of transport modes should be made on a total systems cost basis, not on direct operating cost alone.
    c. It is mandatory that a system analysis program be carried on simultaneously with the technological development program on the SESOC.

The Panel takes exception to the Booz, Allen assumptions as follows:

1. The identification of SESOC support facilities as a percentage of direct operating cost is considered inappropriate. Each concept will have distinctly different cargo handling system and support facilities. The amortization of each of these

systems and facilities will represent a rather large cost although differing in amount. This cost should be considered as an indirect cost, but be included in comparisons made between the SESOC and other modes of transportation.

2. The stated utilization figure of 7,000 hours per year is unrealistic. From experience with other systems of similar structure, a downgrading of 25 percent to 5,250 hours per year, is considered reasonable. The 5,250 hours of utilization would require a proportionate increase in fleet size for a given cargo tonnage movement.
3. The assumption that required equipment for collision avoidance is within the state-of-the-art is not completely concurred in. The detection of small craft or other objects which offer a poor visual or radar target represents a serious safety problem to SESOC operations. The final solution appears to rest in a composite approach consisting of:
   a. Use of radar.
   b. Visual detection.
   c. Establishment of separated "sea lanes" in heavy traffic areas.
   d. Speed reduction when circumstances or conditions so dictate.

The following discussion of specific Booz, Allen assumptions is also submitted.

1. *Load Factor*

It is understood that Booz, Allen assumed a cargo load factor of 85 percent for the 5,000 long ton CAB. This figure is not specifically supported within their analysis.

A detailed market analysis should be made to predict as accurately as possible the actual demand for the proposed service. In this analysis, cognizance should be taken of the following points:

a. High-value cargo will tend to be transported by readily available and reliable means.
b. There will be a seasonal fluctuation in high-value cargoes. This would preclude a continuous high load factor.
c. High-value cargo of inland origin will tend to be attracted to aircraft movement because it offers more of a point-to-point transit. Any higher air cargo rates would be compensated for by the reduction in transit time and elimination of the additional handling cycles of the SES.
d. A certain degree of unreliability, due to weather conditions, structural and mechanical limitations, and system delays is inherent in the SES concept. This would tend to discourage use or reuse of SES for high-value cargo.

2. *Utilization*

The selection of 7,000 hours per year utilization for the 5,000 long ton CAB appears unrealistic, if based on the typical 55-hour one-way trip schedule of table 2 (Booz, Allen Backup Data, "Operations").

While the assumed times for the individual activities may be reasonable at mean values, this method of approach does not allow for the highly variable and random nature of each activity. This randomness will result in delays due to congestion and asynchronization which are not accounted for under a deterministic or mean time approach. From experience with other systems of similar structure, a downgrading of about 25 percent would appear to be reasonable. This would reduce the 7,000-hour utilization figure to 5,250 hours and proportionately increase the fleet size to haul the same amount of cargo tonnage.

It is recommended that a stochastic systems analysis be immediately conducted to approximate this factor more closely.

It is estimated that such analysis can be conducted within a 4-month period for an amount of $25,000, utilizing available analytical state-of-the-art.

3. *Terminal Facilities*

We concur with the Booz, Allen assumption that special terminal facilities will be necessary. Location of terminals away from congested areas may be necessary. We want to point out that, while such arrangements are reasonable, they are also expensive. Estimates of indirect operating costs should therefore recognize higher-than-normal terminal charges in order to amortize the high cost of facilities. Some factors entering into these high costs are:

a. Home-port terminal should have complete repair facilities. These would include:
   (1) Quick-acting drydock or marine railway for frequent inspection and

repair of underwater structure and appendages.

(2) Elaborately equipped and suitably staffed electronics repair shops as well as complete machine shops and metal fabricating shops.

b. The out-port terminal should have emergency repair facilities including a quick-acting drydock or marine railway.

c. The real estate for the proposed terminals will presumably be difficult to find and expensive to procure. Feeder lines (roads and railroads) will have to be provided, probably at considerable cost.

d. The high-capacity fuel bunkering systems will require high first costs and high operating costs because of the inherent hazards involved.

e. Pierside mooring and un-mooring systems can be developed without extensive research and development. Although Booz, Allen has apparently not detailed a solution to this problem, we believe any practical, fast-operating system will be expensive to build, to operate, and to maintain. The proposed 5,000 long ton CAB is a large and awkward, but delicate, structure and will require sophisticated hardware and skillful operation if excessive repair bills are to be avoided. The problem of mooring is greatly facilitated for SES concepts having amphibious capability.

4. *Navigation Facilities*

The Operations Panel concurs with the assumption that advanced navigation equipment must be available both on board and ashore.

This equipment has to provide rapid and automatic determination and printout of vessel position. Navigation equipment and associated systems having sufficient geographical coverage and accuracy should be available by 1970. The cost of this equipment will, however, be high compared to systems now in use. Suitability of equipment for motion and acceleration loads associated with SES operations has to be evaluated.

5. *Collision Avoidance*

Radar offers the only practical means to avoid collision when visibility is limited. There may be a serious problem with respect to small craft and other vessels which present a poor visual or radar target. Reduction of harbor-approach speed increases the port time while continued high speed implies greater likelihood of collision.

The establishment of lanes to separate directional traffic in congested areas is gaining support and adoption. Separation of traffic is practiced in the English Channel and is being proposed for the approaches to New York Harbor.

Present thinking is reflected in the following proposed revision of Rule 20(c) of the Inland Rules of the Road:

> Seaplanes on the water and all nondisplacement craft operating at high speed shall, in general, keep well clear of all vessels and avoid impeding their navigation. In circumstances, however, where risk of collision exists, they shall comply with these rules.

6. *Systems Analysis*

While there is no doubt that, with application of sufficient resources, the SES can be developed as an operational vehicle, the question remains, "Should it be done?" To answer this question it is necessary to study thoroughly the system requirements and the competitive merits of the SES versus other modes for the types of cargo traffic under consideration.

Comparisons should be made between the SES and other transport modes on a total systems cost basis, not direct operating costs alone. This will provide a more realistic basis for evaluating the competitive merit of the SES. Such comparisons should be based on simulation techniques which take into account the variability of vehicle and other system element performance and their effects on total system performance.

Competitive modes being analyzed should include the state-of-the-art, as well as technological improvements which can feasibly occur within the time span of development of the SES to an operational state.

The systems analysis should also be directed toward optimization of design and performance criteria for system and component development.

It is mandatory that this systems analysis program be carried on simultaneously with the technological development program. It would then be possible to benefit from the feedback of results of one or the other.

Such a systems simulation analysis in its initial version could be conducted within a 6-month period, for an estimated $50,000 using available analytical state-of-the-art. An amount of $5,000 per year is estimated to update the analysis results to keep pace with technological developments as they occur.

7. *Shipboard Manning*

The Panel agrees in general with pages 7–9 of the Booz, Allen Backup Data, "Operations." Further aspects should also be considered.

The service on one of these craft can be expected to be arduous, i.e., something of a noisy, rough ride. This suggests the advisability of designing for shock mounting in general, and in particular for the electronics, control, and navigational apparatus carried.

We propose "auto-pilot" control for guiding the craft most of the time. Manual control would be assumed only in restricted waters or rough weather.

Quarters and operating stations for personnel should be very carefully designed for habitability, attractiveness of decor, quietness, and perhaps proofing against shock and vibration. Control layout will need study facilitated by full-scale mock-ups. The entire habitability question, in fact, could well stand intensive study.

It would be expected, and most desirable to ensure steady progress of the project, to seek guidance and reactions from the Coast Guard and other regulatory agencies. The thinking incorporated within the recent change proposed by the United States to the 1960 Safety of Life at Sea Convention should be actively supported and encouraged.

Emergency routines should be well developed. These would cope with fire, collision, flooding, mechanical breakdowns, electronics failures, and SOS and abandon ship measures.

Training programs, following initial recruitment of well-educated marine personnel, will have to be extensive and thorough. Part of the training should be given ashore at a qualified institution and the balance conducted on an on-the-job basis in one of the craft.

8. *Fuel Availability*

The Panel agrees with the basic assumption that fuel will be available at the terminal points of operation. It is an important assumption.

Booz, Allen has apparently assumed that fueling would proceed concurrently with cargo handling. This could impart a measure of hazard due to the increased probability of sources of ignition being present.

If the craft is fueled over a 10-hour period at a separate facility, or at a time when no cargo is being handled, a delay on the order of 18 percent of an average one-way trip time would ensue.

Since neither JP–4 nor JP–5 fuel is as safe to handle as bunker C or diesel oil, safety precautions comparable to aircraft and airport practices should be planned with existing regulations as a guide.

Fast loading rates, under automatic control, can be expected. Loading 2,500 long tons of fuel at 6.4 lb/gal, in an assumed loading time of 10 hours, requires a loading rate of about 1,450 gallons per minute. This seems reasonable.

9. *Anchoring System*

Booz, Allen assumes that a testing and development program will be required to determine suitable anchor and line characteristics. Booz, Allen expects that the SES will have high-holding power anchors and synthetic fiber lines to minimize weight compared to the medium-holding power anchors and heavy chain on conventional ships, and that there will be no spare anchor.

It should be noted that lightweight anchoring systems have been under development by the Navy and others for many years.

10. *Regulations*

Booz, Allen assumes that existing rules and regulations will be revised to encompass the SES concepts which are developed. Present thinking is pointed toward providing more flexibility within existing rules and regulations to permit the operation of the SES in their early stages of evolution. The aims of this approach are to encourage their development and to provide a source of necessary data and experience for drafting intelligent and informed revisions to regulations.

In the revision of rules and regulations major emphasis would be given to the need for providing equivalency of safety in relation to the degree of safety achieved by other modes of transportation.

Technological Problems

The Panel's approach is aimed at identifying and developing problem definitions common to all five SESOC concepts. Exceptions to applicability of these problems to certain of the concepts are specifically noted. Problem identification is oriented with respect to operational aspects. Upon development of specific concepts and prototype vehicles, existing problems can be better delineated and additional problems will become apparent.

The identified problems are classified as:

Crucial

Ocean waves of unusual height.
Mode of response to waves.
Collision avoidance.

Important

Forecast of route environmental and surface conditions.
Fuel margin.
Failure modes and survival.
Manning.
Maneuverability.

Improvement

Port delays.
Fueling.
Habitability and control layout.
Geographical navigation.

Problems identified as "improvement" are considered to fall into the category of administrative solution. The state-of-the-art or technology is in hand for solving these four problems. However, care will have to be exercised to insure that they are considered in development programs since they are not related to conventional vessels.

Consideration of SES Concepts

The Operations Panel has identified specific technical and operational problems applicable to each of the SESOC concepts. The applicability and importance of certain of these problems are dependent on the characteristics of the supporting surface and the proximity of the vehicle to the surface.

The SESOC concepts fall into three groups with respect to proximity to this surface:

Group 1, WIG.
Group 2, channel flow and annular jet.
Group 3, air lubricated hull and the CAB.

Each group has certain advantages and disadvantages relative to problem applicability, shift in emphasis on problems, and approaches to solutions.

Selection of the WIG concept would eliminate or markedly reduce the magnitude of problems associated with ocean waves of unusual height and mode of response to waves.

Selection of the WIG would be faced with the increased importance or complexity of problems associated with "Survival" and "Maneuverability." Doubt exists as to the survival of the vehicle during forced landings or survival in the displacement mode under other than calm or very moderate sea conditions. This should not be a deterrent to its development. Its large size and unwieldy configurations dictate that terminals be removed from harbor or other congested areas but this could be a distinct advantage.

Groups 2 and 3 concepts can be evaluated together with recognition of the following comments applicable to the channel flow and annular jet.

1. Lower hull flexible structure offers an approach or hope toward absorbing or dampening forces associated with vehicle response, waves of unusual height, and hull collision with floating foreign objects.
2. The directional stability and maneuvering characteristics and problems become more complex.
3. Their amphibious capability permits relatively easy movement ashore for cargo handling, servicing, and maintenance.

Proper selection of routes and adequacy of forecasts of route environmental and surface conditions enhance the economic and technical feasibility of the SESOC concepts.

Development Program Considerations

A determination by the Operations Panel of specific development projects was a difficult task. This difficulty stemmed from the fact that our projects encompass operational considerations and the economic aspects of the SESOC concepts. Upon development of specific concepts and prototype vehicles, certain additional technological problems will become apparent.

The solution to a number of our defined problems are within the state-of-the-art or technology in hand. These problems, which are not related to conventional type vessels, require administrative follow-up to assure successful solution. The following problems are grouped in this category:

1. Port delays.
2. Fueling.
3. Habitability and control layout.
4. Geographical navigation.

To a certain degree, administrative follow-up is also required for portions of the following specific problems:

1. Forecast of route environmental and surface conditions.
2. Fuel margin.
3. Failure modes and survival.
4. Manning.

Relative to the economic foundation or justification of SESOC concepts, certain studies and analysis should go hand in hand with technological programs and progress. The following continuing studies and analyses are considered necessary:

1. Systems analysis throughout all design phases to assure that the ultimate function of the vehicle—loading, transport, and discharge of cargoes and/or passengers—is implemented in an optimal manner.
2. Careful determination of probable utilization factors.
3. Determination of overall systems cost and comparison to other transport modes.

Discussion and Findings

A summary of Committee discussions and findings based on the Panel reports follows.

Booz, Allen Assumptions

General Assumptions

There are inherent limitations in the various studies completed by Booz, Allen which result from the way the work evolved over a sizable time period. During this time, important innovations were being incorporated in the annular-jet craft, and the other types were in the process of exploratory design and development. The results of the Booz, Allen studies, Parts I through IV, therefore depend on broad assumptions which were made at the time of the study so that an approximate economic comparison of various SES could be made. These broad assumptions generate important implications as far as design and performance are concerned. They are summarized as follows:

1. At the particular time of writing, sufficient data existed for persons skilled in the art to produce technical performance input data on each of the five illustrative types of SES.
2. No catastrophic problems existed, or if they did, their solution would not seriously alter the input data through a performance penalty.
3. No assessment of the relative accuracy or validity or adjustment of the input data, as provided by vehicle designers, would be made.
4. All input data were comparable as representing to an equal degree the state-of-the-art at the time of receipt.
5. The relative results produced from a series of comparative studies based on the state-of-the-art in period 1963–64 would reflect the state-of-the-art applicable to 1970–75.

Thus, certain assumptions are implicit in the studies that will no doubt influence the realism of the assumed performance of the SES since the assumptions reflect either the status of development at the time of the study or the availability of applicable technology for accurate estimation of design and performance characteristics. In this regard, the Panels consider that adequate applicable technology is available to assess the performance of the WIG type of SES and projections of the design and performance characteristics of other concepts are less certain. Since the design data for other types had not been developed in detail, the Parts I through IV studies are subject to limitations, and it is doubtful that any one of the SES concepts should be excluded on the strength of these studies alone.

The later studies performed by Booz, Allen consist of a first-stage preliminary design of the 5,000-long-ton CAB type SES. These studies incorporate more refined design and performance estimates for the 1975 time frame. Most of the Panels devoted more attention to the evaluation of the CAB studies than they did to the earlier studies, although some of the Panels gave almost equal consideration to the other SES concepts.

Other Assumptions

The Committee's and Panels' reviews of the other more explicit assumptions of technological and operational data indicate that the achievement of the projected performance will require extraordinary skill in the application of current engineering knowledge and will require technological development work in several areas to extend the available skill to an acceptable point even within the 1975 objective. The most important areas in question are summarized.

1. *Stability, Control, and Lift-to-Drag Ratio*

It is the consensus of the Committee and Panels that the most serious deficiency in information needed to perform a comparison of the various types of SES is the lack of knowledge of the phenomenological factors associated with the stability and control requirements and consequent effect on performance.

Booz, Allen has assumed that all of the SES will be stable, controllable, and have acceptable response characteristics so that they will be safe in the weather and sea conditions prevailing on the intended routes. Furthermore, they have included no performance penalties to accommodate inefficiencies arising from subsystems necessary to provide the required performance.

The rough water drag characteristics have been projected without adequate information on the degradation of speed performance that may be expected in real-life environments, or sufficient knowledge of the interaction of stability requirements on the resistance characteristics.

The seakeeping qualities of the SES remain unknown and will be a strong function of the stability and control solutions. There will be an important effect of ship motions on both the drag characteristics and the lift power requirements. The Committee considers that these combined effects might result in a reduction of lift-to-drag ratio by as much as 25 percent below that assumed in the studies.

In a similar manner Booz, Allen has assumed that the SES hull will effectively platform with the resulting accelerations and motions being acceptable to crew and cargo. There will be no unusual loadings consequent to the high speed of these ships over rough seas or to the ensuing motions of the vehicles as they proceed in this manner. No studies are available to verify the validity of these assumptions.

2. *Structural*

The structural weight of the SES is one of the principal determinants of the payload characteristics because of the power required to provide the lift. Consequently, SES require lightweight structures. The Booz, Allen studies assume structural weights as 20 percent of the gross weight in order to be economically feasible, as opposed to estimates by the Hull Panel of 35–40 percent presently achievable. The lack of model or prototype design data imposes a serious limit of confidence in this area, and hence on the economic consequences of alternate assumptions.

The overall size and structural weight of the aerostatic SES will depend ultimately on the effectiveness of new techniques being evolved for bubble containment since they will determine the upper limit of cushion pressure considered practical for larger SES.

There are several questions unanswered which make it difficult to give firm predictions. These include technical questions, such as the allowable bubble pressure and special materials problems, and institutional questions such as survival criteria. The maximum bubble pressure is a function of overall vehicle density and bubble leakage in a seaway, the latter being largely unknown. The cruciality of structural weight makes aluminum alloys seem desirable, but they present an undetermined jeopardy of catastrophic rupture, stress corrosion, and cavitation erosion for vehicles of such large size traveling at such high speeds over or through the sea. Safe solutions to materials problems may limit hull weight reduction.

The requirement that the hull survive on the surface of the sea is an institutional requirement traditional in the maritime industry. On the order of 20 percent of the structural weight may be attributable to the requirement for survival on the surface of the sea.

3. *Propulsive Efficiency and Fuel Economy*

The inherent characteristics of SES necessitate the use of lightweight machinery components and the achievement of good fuel performance including high efficiency transmission systems and propulsors all of which are beyond the state-of-the-art.

The Booz, Allen assumptions appear feasible within the 1975 time frame, but would require intensive development effort.

Achievement of the assumed requisite fuel performance will depend on the availability of high-performance engines and will also require extraordinary skill in the application of existing knowledge to minimize degradation of fuel economy for engines in the marine environment. The realization of low machinery weight will depend on our ability to develop propulsion systems with sufficient life and reliability in an acceptable weight range.

The Booz, Allen studies project a 67 percent propulsive efficiency which could only be achieved by the use of air propulsion; 55–60 percent seems more realistic for water propulsion systems.

4. *Utilization and Operational Considerations*

A crucial assumption in the operations area is that a solution to the collision problem is available. Actually, we have no assurance that we can devise systems to avoid collisions involving a high-speed SES. Three prominent quantitative assumptions also have been challenged:

a. The number of voyages per annum is too high, because there is no allowance for delay and schedule dislocation.
b. The assumed cargo load factor is optimistic for the introduction of such a novel system.
c. The fuel margin is too low. Prudence would dictate a margin of the order of 25 percent rather than 10 percent.

Summarization

The Booz, Allen economic studies substantiate the importance of all of these parameters. Therefore, it is the conclusion of the Panels that lack of information on the weight and performance penalties which will result from the solution of stability and control problems and the reduction of lift power requirements is probably the greatest deficiency in the existing technology for these ships. These factors have far-reaching effects in determining the structural weight, power requirements, and speed performance which, in turn, establish the machinery and fuel weights. The Committee concludes that an inadequate input data base and related assumptions preclude assessment of the commercial effectiveness of any particular type of SES.

Technological Problems, Consideration of SES Concepts, and Development Program Considerations

An overall summarization and ranking of technological problems, based in part on the foregoing discussion of Booz, Allen assumptions, appear in the findings section of the main report along with the overall evaluation of SES concepts. Therefore, neither subject is discussed further here.

Similarly, the development program considerations have been synthesized into a research and development program proposal which is covered in its entirety in the recommendations of the SESCO report body and is not treated here.

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