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ADVANCED NAVAL VEHICLES CONCEPTS EVALUATION [ANVCE] PROJECT

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COST ANALYSIS VOLUME 3

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The objective of this volume is to present cost analysis concerning the vehicles addressed in the Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project. Life-cycle costs are presented to provide an estimate of the total cost, in FY-77 dollars, to develop, procure, and operate the individual point designs over a 15-year period.		

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

Encl: (1) ANVCE, Volume II, (Technical Evaluation)
(2) ANVCE, Volume III, (Cost Analysis)

1. The ANVCE project was directed by DDR&E to develop the information needed for a balanced overall advanced naval vehicle research and development program for the 1980-2000 time period. The project involved research, engineering, design and experiment as well as analytic studies to evaluate nine generic classes of advanced vehicles which may have potential application to naval missions. The R&D efforts were mainly technology assessments and point design developments. The analyses involved mission requirements and costing. Enclosures (1) and (2) present the results of the technical evaluation investigation and the cost analysis, respectively. The mission analysis (Volume IV) and the Project Summary (Volume I) which includes the Executive Summary for all four volumes will be promulgated separately.

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

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

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

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

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

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

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

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

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



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

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ADVANCED NAVAL VEHICLES
CONCEPTS EVALUATION (ANVCE) PROJECT

Volume 3

COST ANALYSIS

December 1979

Prepared by:

CHIEF OF NAVAL OPERATIONS (OP-96)

Classified by Chief of Naval Operations (OP-96)

Review on 31 December 1999

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PREFACE

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

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

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

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

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

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PREFACE

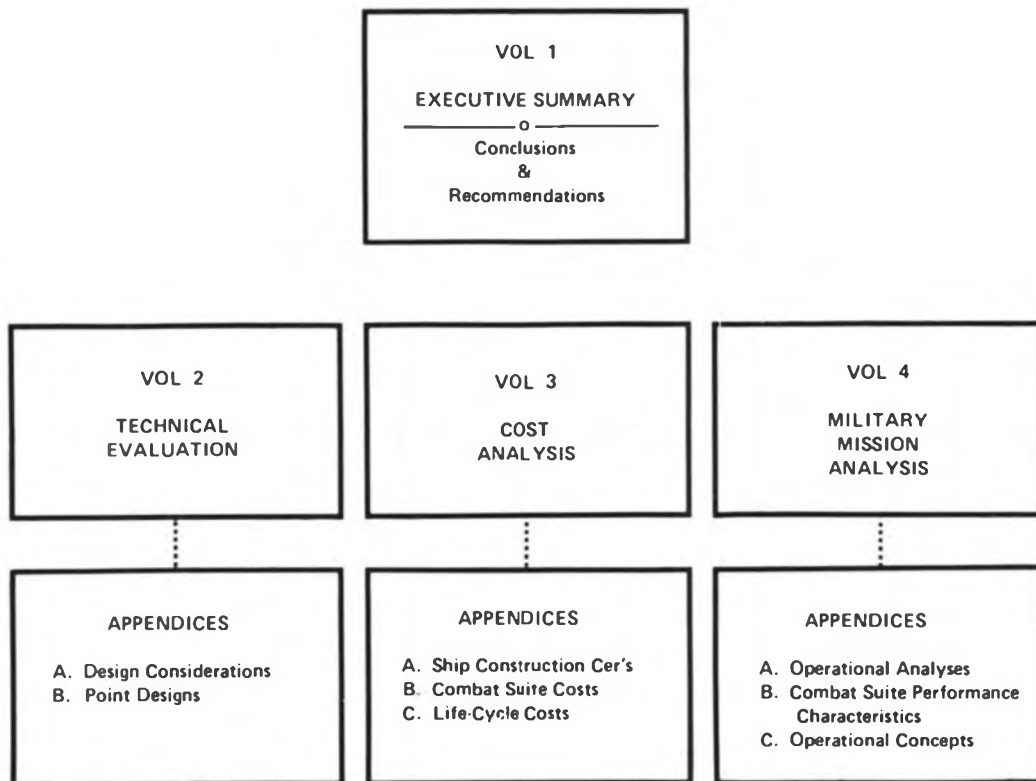
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CAPT Thomas L. Meeks, U.S.N. (OP-96V), Project Officer;
Mr. Peter J. Mantle, Mantle Engineering Company, Technical Director and
Deputy Project Manager;
CDR D. Gray, U.S.N. (OP-96V), Project Staff;
Mr. D. Gicking, SAI, Inc., Project Staff; and
CDR C.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



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CHAPTER I INTRODUCTION

(U) An advanced vehicle concept must satisfy three broad criteria in order to progress in the Navy's research and development (R&D) program:

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

The evaluation has been structured to provide these three elements of information for each vehicle alternative. This volume is concerned solely with the cost analysis of the concepts. The technical volume (Volume 2) and mission analysis volume (Volume 4) are referenced when appropriate for a complete understanding of the material being discussed.

(U) The cost analysis is presented in this volume and its associated appendices (A-C), which are bound separately.

1. OBJECTIVE

(U) The objective of the Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project is to obtain the information necessary for the development of a balanced, overall naval vehicles R&D program for 1980-2000. An R&D program is "balanced" when the three criteria (technical feasibility, cost, and military value) are kept in equilibrium, or proper perspective.

2. SCOPE OF ANALYSIS

(U) Life-cycle costs (LCCs) were derived to provide an estimate of the total cost, in FY-77 dollars, to develop, procure, and operate the individual point designs (developed during the technical analysis, Volume 2) over a 15-year period. The point designs are listed and defined in Table I-1. Table I-2 shows the groupings by type of the point designs developed by the ANVCE Project plus the advanced technology monohull (MONO 3) and the advanced patrol aircraft (AVP) (for comparison purposes). Only the cost results for the point designs listed in Table I-2 are presented in this volume. It is emphasized that these costs were developed specifically for the ANVCE point designs and will differ from estimated costs of similar vehicles costed for budget purposes.

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(U) Table I-1. POINT DESIGNS*

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

THESE VEHICLE POINT DESIGNS ARE DEFINED AND DESCRIBED IN DETAIL IN VOLUME 2, WHICH DISCUSSES THE TECHNICAL FEASIBILITY OF THE ANV CONCEPTS AND DESCRIBES THE DEVELOPMENT OF THE SPECIFIC POINT DESIGNS.

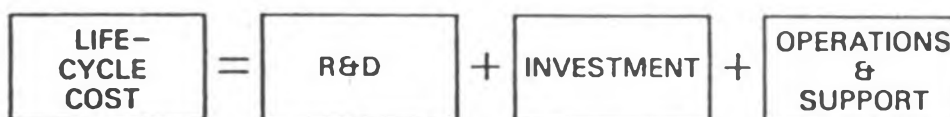
(U) In general, the estimated costs were computed from cost estimating relationships (CERs) derived from historical data, (modified where necessary to reflect technological differences). Time phasing of the costs was also considered for purposes of discounting to present values. Vehicles with service lives longer than 15 years were credited with their estimated residual value at the end of 15 years.

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(U) Table I-2. POINT DESIGN GROUPS DEVELOPED BY ANVCE PROJECT

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

(U) The principal factors that contribute to the LCC are shown schematically in Figure I-1. Each of these major cost elements (and subelements) is defined and discussed in this volume. For each of these cost elements, emphasis was placed on achieving consistency in the cost estimates across all the vehicles being considered. This consistency was achieved by (a) applying the same basic LCC structure to all the vehicles, and (b) formulating the CERs such that cost differences between vehicles would be due solely to differences in the platforms' characteristics.



(U) Figure I-1. COST METHODOLOGY

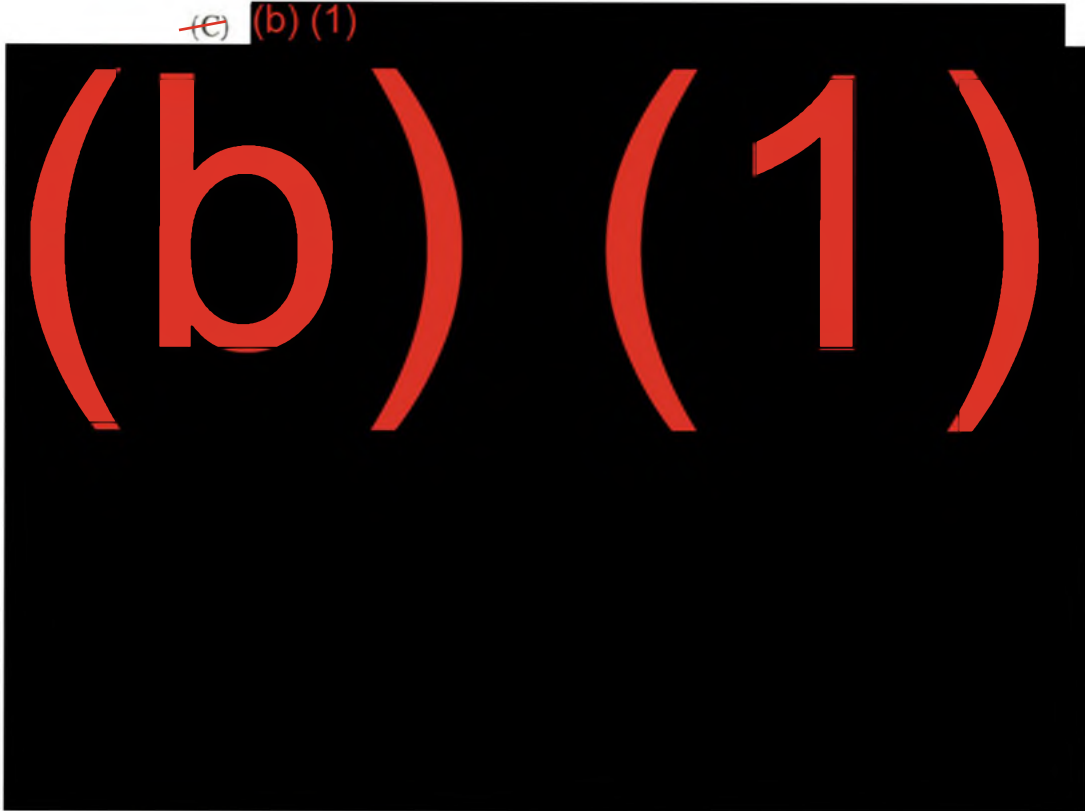
3. ASSUMPTIONS

3.1 General Assumptions

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

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promulgated by the CNO as a definitive Navy position, the Project 2000 study was disseminated to provide a common ground in discussing and analyzing a wide variety of ideas and proposals. In that spirit, the ANVCE Project used the Project 2000 assumptions and findings as a basis for analysis.



3.2 Specific Cost Assumptions

(U) As in all cost analyses, many assumptions and ground rules had to be established. The overall ground rules and key assumptions used in the cost analysis are as follows:

- All costs are expressed in FY-77 dollars unless otherwise stated, and FY-77 dollars are discounted at 10 percent. The use of constant dollars was agreed upon early in the ANVCE study. Care must be taken in making constant force comparisons since two forces that cost the same in constant dollars may require significantly different total-obligational-authority (TOA) funding if they are built at significantly different times.
- A 15-year operating period is assumed for all vehicles. Vehicles with service lives greater than that are credited with their residual value at the end of 15 years.

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- No surface vehicles are purchased solely for R&D purposes. The cost of conducting the required R&D is estimated; however, the cost of the platform used in the research, development, test, and evaluation (RDT&E) is charged against investment costs.
- One air vehicle is purchased out of the R&D appropriation; any other vehicles required for RDT&E are assumed to become operational at some later time and are charged against investment costs.
- For the investment phase of all surface platforms, an identical learning rate of 97 percent was used; for all air platforms the learning rate was 80 percent. These learning rates represent cumulative average learning. While these rates are considered reasonable, it should be noted that the Navy has no experience in quantity production of large advanced vehicles.
- Associated systems costs are charged against any surface vehicle that requires at-sea refueling. These costs are estimated by determining the fraction of an underway replenishment (UNREP) unit required to provide at-sea refueling. The UNREP unit consists of one AOR-7. Both investment and operations and support (O&S) costs of the fractional UNREP unit are considered.
- ANVCE cost estimates include outfit and postdelivery costs that are not usually included in Navy acquisition cost displays.

Most of the specific assumptions are related to the CERs developed and are discussed at the appropriate points in the subsequent chapters.

CHAPTER II PLATFORM COST ESTIMATION PROCEDURE

1. SURFACE PLATFORMS

(U) In this section the process for estimating lead-ship and follow-ship surface platform costs is described. Platform cost is considered to include the installation cost of the combat suite but not the cost of the combat suite itself.* The major inputs to the cost-estimating process are: (a) the CERs for predicting ship detail design and construction contract costs (Reference 1); (b) adjustments to the CERs that reflect differences between the ANVCE point designs and the CER data base (Reference 2); and (c) Naval Sea Systems Command (NAVSEA) planning factors that reflect costs to the Navy above the actual basic construction cost (Reference 3).

1.1 Lead-Ship Platforms

1.1.1 General

(U) The process used to estimate lead-ship platform costs consists of three steps:

- Step 1. The lead-ship construction cost is estimated from the CERs for each of the nine Ship Work Breakdown Structure (SWBS) cost groups defined in Table II-1.
- Step 2. Profit is added to the construction cost to obtain the construction price.
- Step 3. Other (than profit) NAVSEA planning factors and government-furnished equipment (GFE) costs† are then applied to the construction price to obtain the estimated total cost of the platform.

* The cost of the combat suite is included in the vehicle cost, as discussed in Chapter IV, Section 2; combat suite costs are given in Appendix B.

† For the purposes of the ANVCE Project, the only GFE cost included was that of the nuclear plant for the nuclear-powered vehicles.

(U) Table II-1. DEFINITIONS OF NINE SWBS GROUPS

GROUP	DESCRIPTION	DEFINITION
1	HULL STRUCTURE	SHELL PLATING OR PLANKING; LONGITUDINAL AND TRANSVERSE FRAMING; INNERBOTTOM PLATING; PLATFORMS AND FLATS BELOW LOWERMOST CONTINUOUS DECK; FOURTH DECK, THIRD DECK, SECOND DECK, MAIN DECK OR HANGAR DECK; FORECASTLE DECK (INCLUDING PLATFORMS, FLATS, AND DECKS BETWEEN MAIN AND GALLERY DECK); GALLERY DECK; FLIGHT DECK; LANDING PLATFORMS AND SPECIAL PURPOSE DECKS ABOVE WEATHER DECK (INCLUDES CATAPULT TROUGHS); SUPERSTRUCTURES; FOUNDATIONS FOR MAIN PROPELLING MACHINERY; FOUNDATIONS FOR AUXILIARIES AND OTHER EQUIPMENT; STRUCTURAL BULKHEADS; TRUNKS AND ENCLOSURES; STRUCTURAL SPONSORS; ARMOR; AIRCRAFT FUEL SADDLE TANK STRUCTURE; STRUCTURAL COSTINGS, FORGINGS, AND EQUIVALENT WELDMENTS; SEA CHESTS; BALLAST AND BUOYANCY UNITS; DOORS AND CLOSURES, SPECIAL PURPOSE; DOORS, HATCHES, MANHOLES, AND SCUTTLES, NONBALLISTIC; DOORS, HATCHES, MANHOLES, AND SCUTTLES, BALLISTIC; MASTS AND KING POSTS; COMPARTMENT TESTING
2	PROPULSION	BOILERS AND ENERGY CONVERTERS; PROPULSION UNITS; MAIN CONDENSERS AND AIR EJECTORS; SHAFTING, BEARINGS, AND PROPELLERS; COMBUSTION AIR SUPPLY SYSTEM; UPTAKES AND SMOKE PIPES; PROPULSION CONTROL EQUIPMENT; MAIN STEAM SYSTEM; FEEDWATER AND CONDENSATE SYSTEMS; CIRCULATING AND COOLING WATER SYSTEM; FUEL OIL SERVICE SYSTEM; LUBE OIL SYSTEM
3	ELECTRIC PLANT	ELECTRIC POWER GENERATION; POWER DISTRIBUTION SWITCHBOARDS; POWER DISTRIBUTION SYSTEM (CABLE); LIGHTING SYSTEM - DISTRIBUTION AND FIXTURES
4	COMMUNICATION AND CONTROL	NAVIGATIONAL SYSTEM AND EQUIPMENT; INTERIOR COMMUNICATIONS SYSTEMS; ARMAMENT CONTROL SYSTEMS; COUNTERMEASURE AND SHIPS' PROTECTIVE SYSTEMS (EXCEPT ELECTRONIC); ELECTRONIC SYSTEMS INCLUDING ELECTRONIC COUNTERMEASURES
5	AUXILIARY SYSTEMS	HEATING SYSTEM; VENTILATION SYSTEM; AIR-CONDITIONING SYSTEM; REFRIGERATING SPACES, PLANT AND EQUIPMENT; GAS, HEAF, CARGO PIPING, OXYGEN-NITROGEN, AVIATION LUBE OIL SYSTEMS; PLUMBING INSTALLATIONS; FIREMAIN, FLUSHING, AND SPRINKLER SYSTEM; FIRE EXTINGUISHING SYSTEMS; DRAINAGE, TRIMMING, HEELING, AND BALLAST SYSTEMS; FRESHWATER SYSTEM; SCUPPERS AND DECK DRAINS; FUEL AND DIESEL OIL FILLING, VENTING, STOWAGE AND TRANSFER SYSTEMS; TANK HEATING SYSTEMS; COMPRESSED AIR SYSTEMS; AUXILIARY STEAM, EXHAUST STEAM, AND STEAM DRAINS; BUOYANCY CONTROL SYSTEM (FLOODING AND VENTING - SUBMARINES); MISCELLANEOUS PIPING SYSTEMS; DISTILLING PLANT; STEERING GEAR SYSTEM; RUDDER; WINCHES, CAPSTANS, CRANES, AND ANCHOR-HANDLING SYSTEM; ELEVATORS; MOVING STAIRWAYS, AND CARGO HANDLING EQUIPMENT; OPERATING GEAR FOR RETRACTABLE ELEVATING UNITS; AIRCRAFT ELEVATORS; AIRCRAFT ARRESTING GEAR BARRIERS AND BARRICADES; CATAPULTS AND JET BLAST DEFLECTORS, HYDROFOILS AND LIFT SYSTEMS
6	OUTFIT AND FURNISHING	HULL FITTINGS; BOATS, BOAT STOWAGE AND HANDLING; RIGGING AND CANVAS; LADDERS AND GRATINGS, NON-STRUCTURAL BULKHEADS AND NONSTRUCTURAL DOORS; PAINTING; DECK COVERING; HULL INSULATION; STOREROOMS, STOWAGES, AND LOCKERS; EQUIPMENT FOR UTILITY SPACES; EQUIPMENT FOR WORKSHOPS; EQUIPMENT FOR GALLEY, PANTRY, SCULLERY, AND COMMISSARY OUTFIT; FURNISHINGS FOR LIVING SPACES; FURNISHINGS FOR OFFICE SPACES, ELECTRONIC, AND RADAR; FURNISHINGS FOR MEDICAL AND DENTAL SPACES
7	ARMAMENT	GUNS, MOUNTS, AND LAUNCHING DEVICES; AMMUNITION HANDLING SYSTEMS; AMMUNITION STOWAGE; SPECIAL WEAPON STOWAGE AND HANDLING
8	DESIGN AND ENGINEERING SERVICES	DESIGN AND ENGINEERING SERVICES
9	CONSTRUCTION SERVICE	STAGING, SCAFFOLDING, AND CRIBBING; LAUNCHING; TRIALS AND DOCKING; TEMPORARY UTILITIES AND SERVICES; MATERIAL HANDLING AND REMOVAL; CLEANING SHIP SERVICES

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II-2

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1.1.2 Construction Cost

(U) The general format for each major cost group CER is

$$C_i = K_i KN_{ij} X^A,$$

where

C_i = cost of Group i ,

K_i = constant associated with Group i ,

KN_{ij} = constant to reflect the scaling of the cost of Group i according to the unique design features of Vehicle j ,

X = independent variable as follows:

- group weight for Groups 1, 3, 4, 5, 6, and 7;
- propulsion power for Group 2 (non-nuclear propulsion);
- Group 2 weight for nuclear-powered platforms; and
- cost of Groups 1 through 7 for Groups 8 and 9; and

A = exponent to which the variable X is to be raised.

The term KN_{ij} reflects further subdivisions within the cost groups. For example, for Group 1, hull structure, four baseline KN values were developed: (a) conventional steel hull ($KN = 1.000$), (b) high-strength steel hull ($KN = 1.570$), (c) conventional aluminum hull ($KN = 2.192$), and (d) high-strength aluminum hull ($KN = 5.587$). The values are explained and discussed in detail in Appendix A. The CERs are summarized in Table II-2. For the nuclear and nonnuclear vehicles, the complete CERs are given in Appendix A.

(U) For Groups 1 through 7, the values for KN_{ij} were determined by comparing the individual platform group characteristics to the data base and making the appropriate adjustments. The complete details of this process are discussed in Appendix A. The complete set of KN_{ij} values used for ANVCE are given in Table II-3.

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(U) Table II-2. LEAD-SHIP PLATFORM CER'S

PLATFORM ^a	VALUES FOR KN _{I,J}								
	GP 1	GP 2	GP 3	GP 4	GP 5	GP 6	GP 7	GP 8	GP 9
ACV 1	5.87	1.8	3.72	6.91	5.37	1.86	3.4	26.064	4.255
HYD 7	6.00	1.5	2.04	6.91	8.52	2.17	3.4	26.064	4.255
PC 1	5.51	1.5	2.87	3.15	5.00	2.17	3.4	26.064	4.255
WIG(S)	5.87	1.8	3.72	6.91	5.37	1.86	3.4	26.064	4.255
ACV 3	6.02	1.5	3.72	6.91	5.37	2.17	3.4	26.064	4.255
HYD 2	7.37	1.5	3.72	6.91	6.78	2.17	3.4	26.064	4.255
SES 3	5.59	1.5	3.72	6.91	5.37	2.17	3.4	26.064	4.255
SWA 4	2.92	2.75	1.00	3.15	2.50	1.60	3.4	26.064	4.255
MONO 3	3.43	2.75	2.04	3.15	2.50	1.60	3.4	26.064	4.255
SES CV	6.31	2.0	2.04	6.91	4.00	1.86	3.4	26.064	4.255
SES CVN	6.31	b	2.04	6.91	4.00	1.86	3.4	26.064	4.255
SWA CVN	1.25	b	1.0	3.15	1.53	1.00	1.0	26.064	4.255
LCAC	5.81	1.8	3.72	6.91	5.37	1.86	3.4	12.888	4.255
LCPC	2.68	1.0	2.04	1.00	1.53	1.31	1.0	12.888	1.0
SWA MCM	1.45	2.75	1.5	3.15	1.53	1.0	1.0	12.888	4.255

^a PLATFORMS GROUPED ACCORDING TO TABLE I-2.

^b NUCLEAR POWERED

1.2 Follow-Ship Platforms

1.2.1 General

(U) The first follow-ship cost is estimated using a process that parallels the one employed for the lead ship and includes the following three steps:

- Step 1. The first follow-ship construction cost is estimated from the CERs for the major cost groups.
- Step 2. Profit is added to the construction cost to obtain the construction price.
- Step 3. Other (than profit) NAVSEA planning factors and GFE costs are then applied to the construction price to obtain the estimated total cost of the platform.

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(U) Table II-3. LEAD-SHIP PLATFORM KN VALUES

GROUP	CER	
1	$C_1 = 22.543$	$\left(KN_{1,J} W_1^{0.772} \right)$
2	$C_2 = 1.236$	$\left(KN_{2,J} P_2^{0.808} \right)$, NONNUCLEAR
	$C_2 = 92.02$	$\left(W_2^{0.765} \right)$, NUCLEAR
3	$C_3 = 49.727$	$\left(KN_{3,J} W_3^{0.910} \right)$
4	$C_4 = 72.269$	$\left(KN_{4,J} W_4^{0.617} \right)$
5	$C_5 = 62.983$	$\left(KN_{5,J} W_5^{0.782} \right)$
6	$C_6 = 65.450$	$\left(KN_{6,J} W_6^{0.784} \right)$
7	$C_7 = 5.542$	$\left(KN_{7,J} W_7^{0.987} \right)$
8	$C_8 = 0.019$	$\left[KN_{8,J} \left(\sum_{I=1}^7 C_I \right)^{1.099} \right]$
9	$C_9 = 0.385$	$\left[KN_{9,J} \left(\sum_{I=1}^7 C_I \right)^{0.839} \right]$

NOTE:

- C_i = COST OF GROUP I (\$ THOUSANDS),
 W_i = WEIGHT OF GROUP I (TONNES)
 P = POWER (MAX. HP), AND
 $KN_{i,J}$ = REFERS TO THE UNIQUE CONSTANT TO BE APPLIED TO GROUP I FOR VEHICLE J.

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(U) Subsequent follow-ship costs are estimated by applying a learning rate to the total first follow-ship cost. Therefore, if B_1 is defined by the cost of the first follow-ship platform, the total cost, C_Q , for Q follow-ship platforms is

$$C_Q = B_1 \left(\frac{\ln(2R)}{Q^{\ln 2}} \right)$$

where R is the learning rate (assumed to be 0.97 for surface ships). The total platform procurement cost (PPC) includes the cost of the lead-ship platform (C_{LS}) plus the cost of the follow-ship platforms, or $PPC = C_{LS} + C_Q$.

1.2.2 Construction Cost

(U) The general format for each major cost group CER is the same as that for the lead-ship platform, i.e.,

$$C_i' = K_i' KN_{ij}' X'^A$$

where

C_i' = follow-ship platform cost of Group i ,

K_i' = constant associated with Group i ,

KN_{ij}' = constant to reflect the scaling of Group i costs according to the unique design features of Vehicle j ,

X' = independent variable, and

A = exponent to which the variable X' is to be raised.

For the follow-ship platform, the cost for Groups 1 through 7 is assumed to be 94 percent of the cost of the lead-ship platform for Groups 1-7. This assumes a cumulative learning rate of 97 percent.* Group 8 and Group 9 costs are derived using the CERs shown in Table II-4; the KN_{ij}' used are given in Table II-5. *for group 9*

* That is, the average Group 1-7 cost for the first two platforms (lead-ship and first follow-ship) is 97 percent of the cost for the lead-ship platform in Groups 1-7.

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(U) Table II-4. FOLLOW-SHIP PLATFORM CER'S

GROUP	CER
8	$C_8 = 0.019 \left[KN_{8,J} \left(\sum_{I=1}^7 C_I \right) 1.099 \right]$
9	$C_9 = 0.94 (0.385) \left[KN_{9,J} \left(\sum_{I=1}^7 C_I \right) 0.839 \right]$

NOTES:

C_I = FOLLOW-SHIP PLATFORM COST OF GROUP I (\$ THOUSANDS) AND

$KN_{I,J}$ = THE UNIQUE CONSTANT TO BE APPLIED TO THE FOLLOW-SHIP PLATFORM GROUP I FOR VEHICLE J.

THE 0.94 IN THE CER EQUATION FOR GROUP 9 IS DERIVED FROM THE LEARNING RATE OF 97 PERCENT, WHICH ALSO APPLIES TO THE GROUP 9 COST.

(U) Table II-5. FOLLOW-SHIP PLATFORM KN VALUES FOR GROUPS 8 AND 9

PLATFORM*	VALUES FOR $KN_{I,J}$	
	GP 8	GP 9
ACV 1	2.882	4.255
HYD 7	2.882	4.255
PC 1	2.882	4.255
WIG(S)	2.882	4.255
ACV 3	2.882	4.255
HYD 2	2.882	4.255
SES 3	2.882	4.255
SWA 4	2.882	4.255
MONO 3	2.882	4.255
SES CV	2.882	4.255
SES CVN	2.882	4.255
SWA CVN	2.882	4.255
LCAC	2.882	4.255
LCPC	2.882	1.0
SWA MCM	2.882	4.255

* PLATFORMS GROUPED ACCORDING TO TABLE I-2.

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1.3 Application of NAVSEA Planning Factors to Lead- and Follow-Ship Platform Construction Cost

(U) NAVSEA planning factors are used to obtain the total estimated cost (less GFE) of the platform. The first factor to be considered is the profit to be applied to the construction costs.

(U) The construction price (lead or follow ship) is defined to be the construction cost plus profit. For the ANVCE Project, the guidance received from NAVSEA (Reference 3) was that a profit of 15 percent was to be assumed. Thus,

$$\text{Construction Price} = 1.15 (\text{Construction Cost}).$$

(U) The other NAVSEA factors are then to be applied to the construction price. These factors, given in Table II-6, yield additional costs to the platform of 33.5 and 29.5 percent of the construction price for the lead- and follow-ship platform, respectively.

(U) Table II-6. NAVSEA PLANNING FACTORS FOR LEAD-SHIP AND FOLLOW-SHIP PLATFORMS (OTHER THAN PROFIT)

COST ELEMENT	LEAD-SHIP FACTOR (%)	FOLLOW-SHIP FACTOR (%)
CHANGE ORDERS	12	8
GOVERNMENT SUPPORT SERVICES	2.5	2.5
POSTDELIVERY CORRECTIONS	5	5
OUTFITTING MATERIAL	4	4
HULL/MECHANICAL/ ELECTRICAL EQUIPMENT	10	10
TOTAL	33.5	29.5

(U) Including all NAVSEA factors, the total platform costs, less GFE, are

$$\begin{aligned} \text{Lead-ship platform cost} &= 1.335 (\text{lead-ship construction price}) \\ &= 1.535 (\text{lead-ship construction cost}) \end{aligned}$$

$$\begin{aligned} \text{Follow-ship platform cost} &= 1.295 (\text{follow-ship construction price}) \\ &= 1.489 (\text{follow-ship construction cost}). \end{aligned}$$

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(U) The only GFE costs added to the platform cost were those representative of the nuclear power plant. For the conventional pressurized-water reactor (PWR) used in the SWA CVN, the cost was derived from the information presented in Reference 2.

(U) The basic CER for Group 2 (nonnuclear) is given in Table II-2 as

$$C_2 = 1.236P^{0.808}(KN),$$

For nuclear steam propulsion, Norris (Reference 2) recommends that a KN value of 9.52 (rather than the 3.44 value recommended in Appendix A) be used to reflect the cost of the reactor. If it is assumed that the KN of 3.44 represents the installation cost of the reactor and the KN of 9.52 includes the installation cost plus the reactor cost, then

$$1.236(3.44P^{0.808}) + \text{Reactor Cost} = 1.236(9.52P^{0.808}),$$

or

$$\text{Reactor Cost} = 7.52P^{0.808}.$$

For the lightweight nuclear reactor used on the SES CVN, the only cost information available was that from Westinghouse (Reference 4). Using these estimates, the cost of the nuclear power plant for the lead-ship SES CVN is \$275 million and the cost of the power plant for the first follow-ship SES CVN is \$190 million.

2. AIR PLATFORMS

(U) First-unit costs of air platforms were estimated in terms of airframe, power plant, and flight avionics costs. In preparing the estimates, several different CERs were used, and heavier-than-air (HTA) and lighter-than-air (LTA) airframes were treated separately because of the very different manufacturing methods and methodologies involved.

(U) Three power-plant CERs were used, one for turbojet/fan engines, one for turboshaft engines, and one for turboprop engines. Manufacturers' costs were used for diesel engines, and flight avionics costs were provided by the Naval Air Development Center (NADC).

(U) The CERs for airframes and engines are generally expressed in terms of cumulative cost for a given quantity, and, therefore, a learning rate is applied to calculate the first-unit cost. For airframes, the cumulative average learning rate is 75 percent, and for engines it is 90 percent; flight avionics packages are treated as "off-the-shelf" items that require no production learning.

2.1 Airframe Production CER'S

2.1.1 HTA Airframes

(U) To estimate the production costs of HTA airframes, a CER was derived from the production cost data shown in Table II-7. These data, obtained from the *Aircraft Cost Handbook* (Reference 5), includes AMPR ("Aeronautical Manufacturers' Planning Report") weight (also referenced to the DCPR weight, after the "Defense Contractors' Planning Report," or in more recent sources as airframe weight), maximum speed at best altitude, maximum thrust at sea-level standard, and the airframe cumulative average production cost at production quantity 100. AMPR weight is defined in the "Aeronautical Manufacturers' Planning Report" as the empty weight of the airplanes less

- wheels, brakes, tires, and tubes;
- engines;
- starter;
- cooling fluid;
- rubber or nylon fuel cells;
- instruments,
- batteries and electrical power supply and conversion equipment;
- electronic equipment;
- turret mechanism and power-operated gun mounts;
- remote fire mechanism and sighting-and-scanning equipment;
- air-conditioning units and fluid;
- auxiliary power plant unit; and
- trapped fuel and oil.

(U) The production costs in Table II-7 include

- sustaining engineering, including redesign;
- tooling;
- quality control in support of the production of complete units;
- manufacturing of all completed units, including flight test airframes
- purchased equipment for installation into complete units;
- material overhead;
- training all service personnel to operate and maintain equipment; and
- reproduction and updating of technical data and manuals.

The cost data are expressed in millions of FY-75 dollars, and an inflation factor of 1.2526 (Reference 6) must be applied to bring costs to FY-77 dollars.

(U) The CER used to estimate HTA airframe production cost is

$$AFPC = KN (0.000155W^{0.413}S^{0.202}F^{0.548}) ,$$

where

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(U) Table II-7. AIRCRAFT AND AIRFRAME COST DATA

AIRCRAFT	W ^a	S	F	T	PRODUCTION COST ^b
A-3	24,040	556	20,000	3	6.7
A-4	5,072	578	7,700	3	2.8
A-5	22,800	1,147	34,000	3	9.3
A-7A/B	11,621	595	11,350	3	2.8
A-10	14,842	450	19,800	3	4.3
B-47	52,280	528	34,020	2	11.8
B-52	112,500	551	64,000	2	25.7
B-58	32,300	1,147	62,000	2	20.1
B-66	30,500	548	20,400	2	11.1
C-5A	279,145	496	164,000	1	44.5
C-124	78,900	274	32,500	1	8.1
C-130	51,479	326	40,500	1	8.2
C-133	95,500	309	58,000	1	13.4
C-141	104,308	496	84,000	1	14.0
E-2C	23,100	319	18,775	3	6.0
EA-6B	24,191	539	22,400	3	6.5
F-3	13,788	553	14,500	3	4.2
F-4	17,320	1,220	34,000	3	9.7
F-14	26,016	1,370	40,000	3	11.3
F-15	20,000	1,500	48,000	3	10.3
F-84	6,523	543	4,900	3	1.7
F-86	6,715	590	6,000	3	1.7
F-86D	8,755	602	7,500	3	2.2
F-89	18,119	546	13,600	3	4.3
F-100	12,118	713	14,800	3	2.6
F-101	13,146	873	30,000	3	5.8
F-102	12,026	677	16,000	3	6.9
F-104	7,954	1,150	14,800	3	3.3
F-105	19,439	1,195	24,500	3	9.3
F-106	14,805	1,153	24,500	3	8.0
F-111	32,458	1,262	37,000	3	15.9
KC-135	70,500	527	55,000	1	11.7
S-3A	18,536	434	18,000	3	7.5
T-38	5,346	750	7,950	3	2.7

^a W = AMPR WEIGHT (LB);
S = MAXIMUM SPEED AT BEST ALTITUDE (KT);
F = MAXIMUM THRUST AT SEA LEVEL STANDARD (LB);
T = AIRCRAFT TYPE: 1 = CARGO, 2 = BOMBER, 3 = FAS.

^b PRODUCTION COST IS CUMULATIVE AVERAGE COST
AT QUANTITY 100 (FY-75 \$ MILLIONS)

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AFPC = airframe cumulative average production cost at quantity 100 (FY-77 \$ millions);

KN = 0.682 for cargo aircraft,
= 1.166 for bomber aircraft, and
= 1.0 for fighter/attack/surveillance (FAS) aircraft;

W = AMPR weight (lb);

S = maximum speed at best altitude (kt);
and

F = maximum thrust at sea-level standard (lb).

The cumulative average cost at quantity 100 is then adjusted to first-unit production cost.

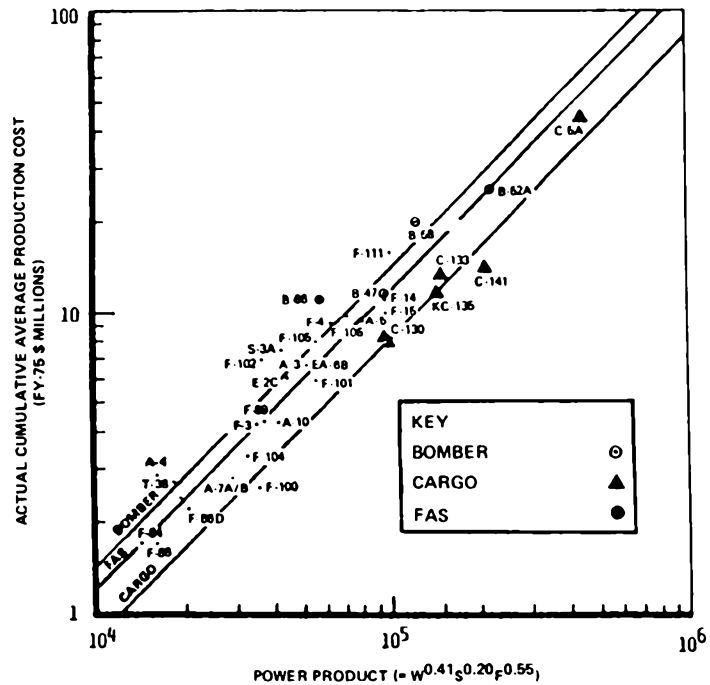
(U) Figure II-1 shows the actual airframe production cost and a power product based on the weight, speed, and thrust of the aircraft. The power product is merely the CER calculated without including either the leading coefficient of the CER or any adjustments to cost for aircraft type, i.e., the preceding equation without the term $0.000155KN$. The lines labeled bomber, FAS, and cargo represent the regression equations for each type of aircraft. Where actual airframe cost for an aircraft is shown near the line for the corresponding type of aircraft, a close estimate can be derived with the CER. Where the actual cost is above or below the line corresponding to its type, the CER estimate is high or low, respectively.

(U) The air ANVs were categorized as either cargo, bomber, or FAS aircraft. Because the ANVs are far removed from current aircraft, care must be taken in their categorization if the cost estimates are to approximate actual airframe costs. Table II-8 shows the categories in which the HTA ANV aircraft were placed.

2.1.2 LTA Airframes

(U) Costs for LTA airframes were derived by direct scaling of the labor and material costs incurred in the construction of the AKRON airship in 1931. The data were scaled on a cost-per-unit, light-vehicle-weight basis. These data, shown in Table II-9 result in an estimated cost for the AKRON, if built in 1977, of

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(U) Figure II-1. AIRFRAME PRODUCTION COST

(U) Table II-8. HTA AIRFRAME PRODUCTION COST*

AIR ANV APPLICABILITY			DATA BASE	
KN VALUE	TYPE INTERPRETATION	AIR ANV	NUMBER	CASES USED
0.682	CARGO	WIG(H)	6	C-5A, C-124, C-130, C-133, C-141, NC-135
1.166	BOMBER	A/L, A'L(N), S/L(L), S/L(S), WIG(O), WIG(S)	4	B-47, B-52, B-58, B-66
1.0	FAS	AVP, S/L(V)	24	A-3, A-4, A-5, A-7/B, A-10, E-2C, EA-68, F-3, F-4, F-14, F-15, F-84, F-86, F-86D, F-89, F-100, F-101, F-102, F-104, F-105, F-106, F-111, S-3A, T-38

* EQUATION CITED PREVIOUSLY

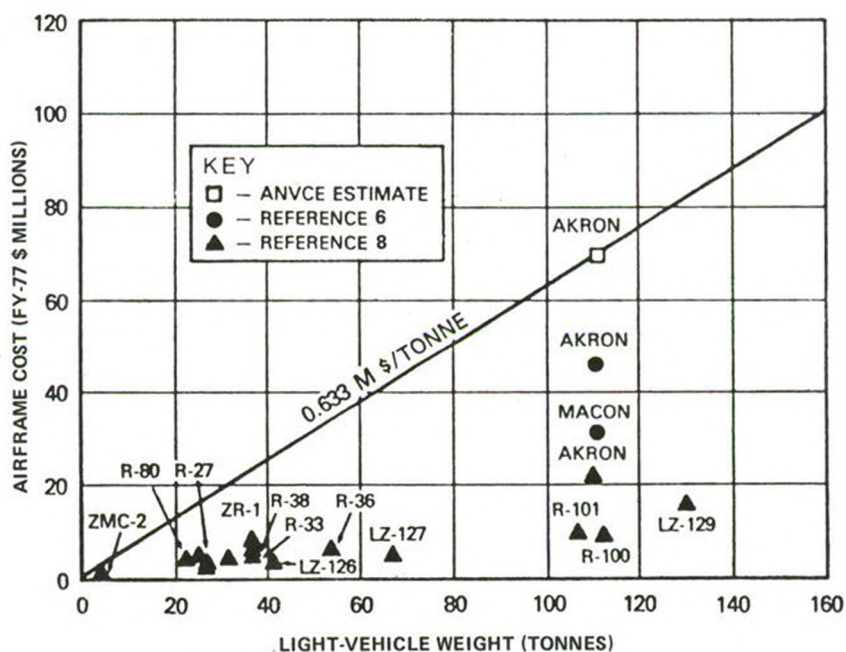
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(U) Table II-9. AKRON COST DATA*

COST ELEMENT	1931 DATA		LABOR RATE (FY-77 \$/HR)	COSTS (FY-77 \$ MILLIONS)		
	LABOR HOURS	MATERIAL COST		LABOR	MATERIAL	TOTAL
LABOR						
PRODUCTION	1,506,940		27.56	41.53		
ENGINEERING	417,842		27.24	11.38		
TOOLING	254,190		28.50	7.24		
TOTAL	2,178,972			60.15		
MATERIAL		\$1,381,339			9.85	
LABOR + MATERIAL						70.00

* DATA AND SCALING FACTORS FROM REFERENCE 6.

\$70 million. This translates to a cost of \$0.633 million/tonne when applied to the AKRON's light vehicle weight of 110.52 tonnes (Reference 7). This approach was selected since the AKRON data were the most complete and thus could be used as the most confident cost estimate for a rigid airship. The AKRON data also provided the highest cost estimate, as shown in Figure II-2, which shows plots of estimates derived from other investigators for the AKRON and other rigid airships.



(U) Figure II-2. LTA AIRFRAME COST AS A FUNCTION OF LIGHT-VEHICLE WEIGHT FOR RIGID AIRSHIP

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2.2 Power-Plant Production CERs

(U) Several types of nonnuclear engines are used on the air vehicle designs. The production costs of turbojet/turbofan, turboprop, and turboshaft engines are estimated using CERs; the production costs of diesel engines were obtained from an engine manufacturer (Detroit Diesel - Allison); and cost of light-weight, nuclear propulsion (LWNP) used on the A/L(N) was estimated by Westinghouse (Reference 4).

2.2.1 Turbojet/Turbofan Engines

(U) Turbojet and turbofan engine production costs are treated by the same CER. Previous research indicates that turbojet and turbofan engines come from the same statistical population, and thus, the data can be consolidated to derive CERs.

(U) The CER selected for estimating the costs of turbojet/turbofan engines was derived by J.R. Nelson and F. S. Timson (Reference 9). The CER for subsonic vehicles is

$$C_P = (5.014 \times 10^{-4}) Q^{0.84172} F^{0.84755} ,$$

where

C_P = engine cumulative production cost (\$ million),

Q = cumulative quantity of engines produced, and

F = maximum thrust at sea-level standard (lb).

2.2.2 Turboshaft and Turboprop Engines

(U) Separate CERs were developed for turboshaft and turboprop engines. While the engines are similar, turboshaft engines generally are used to power helicopters and turboprop engines are used on fixed-wing, propeller-driven aircraft. The engines differ in that the gearbox for a turboprop engine is an integral part of the engine, while turboshaft engines connect to an independent transmission. Because of this, cost data on turboprop engines include the cost of the gearbox; turboshaft cost data exclude that cost.

(U) The CER selected to estimate turboshaft engine production cost, developed by D.G. Cruden (Reference 10), estimates the cost of the engine only; the costs of gearboxes and rotors are included as part of the airframe cost.

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(U) The turboshaft CER is

$$C_P = (1.655 \times 10^{-3})P^{0.79734}Q^{0.76553} ,$$

where P is power (shp). For turboprop engines a CER developed by A. F. Watts (Reference II) was selected for use. This CER is

$$C_P = (6.8558 \times 10^{-3})P^{0.45873}Q^{0.89055}$$

2.2.3 Diesel Engines

(U) In addition to four turboprop engines, the power plant of the FAB includes one small diesel engine and one larger one. The estimated costs for these engines were obtained from Detroit Diesel - Allison, manufacturer of comparably powered diesel engines.

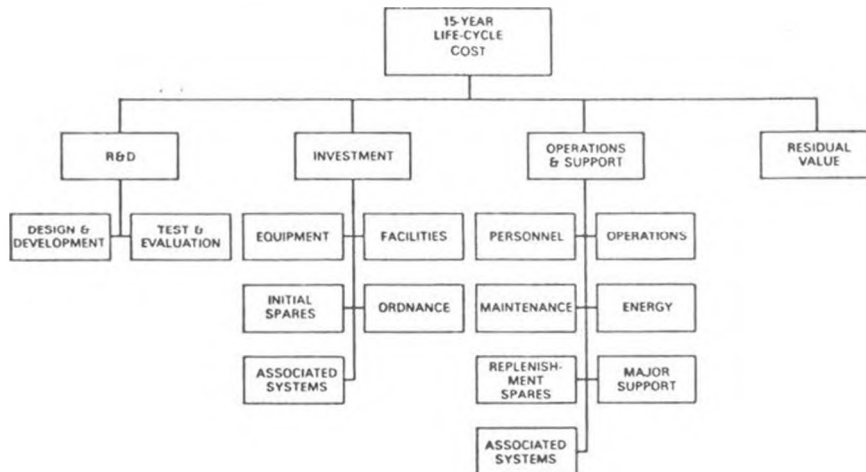
2.3 Avionics

(U) Command, control, communications, and navigation (C³&N) costs for all air vehicle designs except the WIG(S) were developed by NADC. The WIG(S) C³&N cost were taken from the ACV 1 combat suite costs, which were developed by NAVSEA.

CHAPTER III LIFE-CYCLE COST ESTIMATING PROCEDURES

I. INTRODUCTION

(U) Life-cycle costs were derived to provide an estimate of the total cost to develop, procure, and operate each of the point design vehicles over a 15-year period. A 15-year period was selected because 15 years is the shortest service life of any advanced vehicle considered.* The three major cost elements (R&D investment, and operations and support) and subelements shown schematically in Figure III-1 are defined and discussed in this chapter.



(U) Figure III-1. MAJOR LIFE-CYCLE COST ELEMENTS

(U) Reference 6 contains additional background information on the equations presented in this chapter. Table III-1 presents definitions of the terms used in the equations given in this chapter; each definition is given again as it is first used in the text which follows. All costs are given in FY-77 dollars unless otherwise indicated.

* All vehicles were credited with their appropriate residual value at the end of the assumed 15-year operating period.

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(U) Table III-1. DEFINITIONS OF TERMS

TERM	DEFINITION
A	AVERAGE VEHICLE COST (\$ MILLIONS)
ADC	AIRFRAME DEVELOPMENT COST (FY-77 \$ MILLIONS)
AV	AVERAGE NUMBER OF VEHICLES OPERATED
A2	COMPONENT TECHNOLOGY D&D COST (\$ MILLIONS)
A6	NUMBER OF FLIGHT TEST AIR VEHICLES
A7	1 FOR AIR PLATFORMS, OTHERWISE, 0
BO	AIR PLATFORM DESIGN MULTIPLE (RATIO OF PLATFORM D&D COST TO PLATFORM FIRST-UNIT PRODUCTION COST)
B1	SURFACE VEHICLE FOLLOW-SHIP PLATFORM COST (\$ MILLIONS)
B2	AIR VEHICLE PLATFORM FIRST-UNIT COST (\$ MILLIONS)
B2	SERVICE LIFE (YEARS)
B5	1 FOR NUCLEAR PLATFORMS, OTHERWISE, 0
C _D	ENGINE D&D COST (FY-77 \$ MILLIONS)
C1	PAYLOAD T&E COST (\$ MILLIONS)
C2	LEAD-PAYLOAD COST (\$ MILLIONS)
C3	FOLLOW-PAYLOAD COST (\$ MILLIONS)
C5	ANNUAL COST OF TRAINING ORDNANCE (\$ MILLIONS)
D1	NUMBER OF OFFICERS PER VEHICLE
D2	NUMBER OF ENLISTED MEN PER VEHICLE
D3	ANNUAL OPERATING HOURS PER VEHICLE
D5	FUEL PER OPERATING HOUR PER VEHICLE (TONNES)
D6	FUEL PER OPERATING HOUR PER PAYLOAD (TONNES)
D7	1000 MHP-HR. PER OPERATING HOUR (NUCLEAR)
D8	COST OF NONNUCLEAR FUEL PER MILLION BTU'S (\$ MILLIONS)
ENERGY	ENERGY COST (\$ MILLIONS)
E1	WEEKLY ADDITIONAL MAINTENANCE (MAN-HOURS)
E2	ADDITIONAL FACILITIES COST (\$ MILLIONS)
F	MAXIMUM TOTAL THRUST (LB)
GW	GROSS WEIGHT (LB)
H	MONTHLY OPERATING HOURS
IASOC	ASSOCIATED SYSTEMS INVESTMENT COST (\$ MILLIONS)
ISL	INITIAL SPARES COST FOR PAYLOAD (\$ MILLIONS)
ISP	INITIAL SPARES COST FOR PLATFORM (\$ MILLIONS)

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(U) Table III-1. DEFINITIONS OF TERMS (CONTINUED)

TERM	DEFINITION
LO&S	LENGTH OF O&S PERIOD (YEARS, NORMALLY 15)
LPE	PAYLOAD PRIME EQUIPMENT COSTS (\$ MILLIONS)
LSE	PAYLOAD SUPPORT EQUIPMENT COSTS (\$ MILLIONS)
LTE	PAYLOAD T&E COST (\$ MILLIONS)
L1	LEAD-PLATFORM COST (\$ MILLIONS)
MSUP	MAJOR SUPPORT COST (\$ MILLIONS)
MTC	MAINTENANCE COST (\$ MILLIONS)
OASOC	ASSOCIATED SYSTEMS O&S COSTS (\$ MILLIONS)
O&S	SYSTEM O&S COSTS (\$ MILLIONS)
ODD	OTHER D&D COSTS (\$ MILLIONS)
OPS	OPERATING COST (\$ MILLIONS)
OTE	OTHER T&E COSTS (\$ MILLIONS)
P	POWER (SHP)
P&A	P&A COST (\$ MILLIONS)
PDD	PLATFORM D&D COST (\$ MILLIONS)
PPE	PLATFORM PRIME EQUIPMENT INVESTMENT COST (\$ MILLIONS)
PSE	PLATFORM SUPPORT EQUIPMENT COST (\$ MILLIONS)
PTE	PLATFORM T&E COST (\$ MILLIONS)
P5	R&D PAYLOAD REQUIRED
R	LEARNING RATE FOR CONSTRUCTION (0.97 FOR SURFACE VEHICLES, 0.80 FOR AIR VEHICLES)
RES VALUE	RESIDUAL VALUE AT END OF OPERATING PERIOD (\$ MILLIONS)
REPL	REPLENISHMENT SPARES COST (\$ MILLIONS)
R4	NUMBER OF VEHICLES TO BE ACQUIRED
S	MAXIMUM SPEED AT BEST ALTITUDE (KT)
S1	UNDERWAY REPLENISHMENT UNIT CAPACITY (TONNES/YEAR)
S2	UNDERWAY REPLENISHMENT UNIT INVESTMENT COST (\$ MILLIONS)
S3	UNDERWAY REPLENISHMENT UNIT ANNUAL O&S COST (\$ MILLIONS)
TAD	TEMPORARY ADDITIONAL DUTY COST (\$ MILLIONS)
TI	TECHNOLOGY INDEX
VOY	NUMBER OF VEHICLE OPERATING YEARS OBTAINED IN THE O&S PERIOD
V9	COST OF NUCLEAR FUEL PER MILLION BTU'S (\$ MILLIONS)
W	AMPR WEIGHT (LB)
W'	DRY WEIGHT OF THE ENGINE (LB)
WE	LIGHT-VEHICLE WEIGHT (MILLIONS OF LB)

2. RESEARCH AND DEVELOPMENT

(U) The major components of the R&D costs are shown in Figure III-1. The methodology for estimating the two main cost elements—design and development (D&D) and test and evaluation (T&E)—is described in the following sections.

2.1 Design and Development

(U) D&D costs include those for preliminary research and design studies, development engineering and fabrication of test articles, development instrumentation, component test operations, industrial facilities required to proceed through a development program, and the necessary fuels and lubricants used during laboratory, in-plant, and component testing. Added to those costs are the costs of development and qualification of specific component technologies not currently available as state of the art.

(U) The D&D cost estimates for both surface and air vehicles are based on platform (vehicle without payload) first-unit cost, lead-payload cost, specific component technology development costs, and facility costs. The D&D cost estimating equation is

$$\text{D\&D} = \text{Platform D\&D} + \text{Other D\&D}.$$

The method used to estimate the surface platform D&D, air platform D&D, and other D&D is described in the next three subsections.

2.1.1 Surface Platform D&D

(U) For surface vehicles, the platform D&D cost was estimated from the following equation

$$\text{PDD} = 1.1(0.63\text{B1} + 0.165\text{C2} + \text{A2}),$$

933
1.1
339.6
123.9
380
239
751
385

where

- PDD = platform D&D cost (\$ millions),
- B1 = follow-ship platform cost (\$ millions), *229*
- C2 = lead-payload cost (\$ millions), *751*
- A2 = component technology D&D cost (\$ millions). *385*

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(U) The factor 0.63 on B1 for surface platforms approximates the percentage of follow-ship platform cost equal to costs of platform-specific D&D. The factor is based on FFG-7 program experience and is applied to all surface vehicles.

(U) The factor 0.165 on C2 platforms approximates the percentage of lead-payload cost equal to the cost of payload-related platform D&D cost. This factor is also derived from FFG-7 program experience.

2.1.2 Air Platform D&D

(U) For air vehicles, the platform D&D cost was estimated from the following equation:

$$PPD = 1.1[B_0(B_1) + 0.165C_2 + A_2],$$

where B_0 is the air platform design multiple. The term B_0 is simply the ratio of platform D&D cost to platform first-unit production cost.

(U) The platform D&D cost consists of the airframe D&D cost plus the power-plant D&D cost. The equation for the airframe development cost (ADC), in FY-77 \$ millions, for HTA airframes (based on Reference 5) is

$$ADC = (4.03 \times 10^{-6})W^{0.49}S^{0.58}GW^{-0.74}F^{0.95}TI^{1.66}.$$

where

W = AMPR weight (lb),

S = maximum speed at best altitude (kt),

GW = gross weight (lb),

F = maximum total thrust (lb), and

TI = technology index

This CER is then

- multiplied by 1.89 for bomber airframes not requiring a major technology advance (MTA),
- multiplied by 3.11 for bomber airframes requiring an MTA, and
- multiplied by 2.29 for nonbomber airframes requiring an MTA.

For LTA vehicles, the airframe development cost was estimated to be twice the first-unit cost (Reference 6).

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(U) CERs for engine D&D cost (C_D), in FY-77 \$ millions, were derived from three generic engine types: turbojet/turbofan, turboprop, and turboshaft.* For turbojet/turbofan engines, the CER appropriate to the ANVCE air vehicles (derived from a general CER developed in Reference 9) was

$$C_D = 3.968F^{0.4761}$$

For turboprop engines, the CER (derived from Reference 11) was

$$C_D = 6.1789P^{0.35497}$$

where P is power (shp). For turboshaft engines, the CER (derived from Reference 12) is

$$C_D = 15.707 + 1.278P(W'^{0.5}),$$

where W' is the dry weight of the engine (lb).

2.1.3 Other D&D

(U) Other D&D costs reflect the estimated additional facilities required for the D&D effort. The CER is

$$ODD = 1.1 (0.6E2),$$

where

$$\begin{aligned} ODD &= \text{other D\&D costs (\$ millions), and} \\ E2 &= \text{additional facilities cost (\$ millions).} \end{aligned}$$

The leading coefficient of 1.1 reflects a 10 percent allowance for cost of management, administration, and technical direction. The factor 0.06 on E2 reflects assumed architectural and engineering fees associated with facilities investment for D&D activities.

2.2 Test and Evaluation

(U) The T&E cost element includes the cost of test vehicles and payloads required during the R&D phase as well as spares to support major subsystems during test operations. Operational activities associated with systems testing, test equipment and test facilities, test instrumentation, additional fuels and lubricants, data reduction and analysis, maintenance, supply, and miscellaneous items necessary for the conduct of systems test are also included in this element.

* For the diesel engines used on the FAB, no additional D&D effort is required.

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(U) The T&E cost was estimated from the following equation:

$$\text{T\&E} = \text{Platform T\&E Cost} + \text{Payload T\&E Cost} \\ + \text{Other T\&E Costs.}$$

The method used to estimate each of these costs is described in the following subsections.

2.2.1 Surface Platform T&E

(U) For surface vehicles, the platform T&E cost was estimated from the following equation:

$$\text{PTE} = 1.2 [0.785\text{B1} + 1.481\text{C2} + 0.001 \text{O\&S}],$$

where

PTE = platform T&E cost (\$ millions),

C2 = lead-payload cost (\$ millions), and

O&S = system O&S costs (\$ millions),

The leading coefficient of 1.2 reflects a 20 percent allowance for management, administration, technical direction, systems engineering, and facilities utilization. The factor 0.785 on B1 approximates the percentage of follow-ship platform cost equal to platform-specific T&E cost. The factor 1.481 on C2 approximates the percentage of lead-payload cost equal to the cost of payload-related platform T&E cost. Both factors are derived from FFG-7 program experience. The factor 0.001 on O&S approximates the percentage of total system O&S costs equal to the O&S costs of the T&E program.

2.2.2 Air Platform T&E

(U) For air vehicles, the platform T&E cost was estimated from the following equation:

$$\text{PTE} = 1.2 \left[(\text{B1} + 0.6\text{C2})\text{A6}^{\frac{\ln(2\text{R})}{\ln 2}} + 0.001(\text{O\&S}) \right]$$

where

B1 = platform first-unit cost (\$ millions),

A6 = number of flight-test air vehicles, and

R = learning rate for construction (0.80 for air vehicles).

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The leading coefficient of 1.2 reflects a 20 percent allowance for management, administration, technical direction, systems engineering, and facilities utilization. The factor 0.6 on C2 approximates the percentage of lead-payload cost equal to the payload-related platform T&E cost; a full-payload test is not required for all test vehicles. The factor of 0.001 on O&S costs approximates the percentage of total system O&S costs equal to the O&S costs of the T&E program.

2.2.3 Payload T&E

(U) Payload T&E costs were estimated from the following equation:

$$LTE = 1.2 \left[C1 + P5(C2) + 0.2C3 \right] ,$$

where

LTE = total payload T&E cost (\$ millions),

C1 = payload hardware T&E cost (\$ millions),

P5 = R&D payloads required, and

C3 = follow-payload cost (\$ millions).

The leading coefficient of 1.2 reflects a 20 percent allowance for management, administration, technical direction, systems engineering, and facilities utilization. NAVSEA and NADC provided the cost inputs (C1, C2, and C3) for surface vehicles and air vehicles, respectively. The last term in the equation is included to account for the additional development effort required for application to weight-critical ships.

2.2.4 Other T&E

(U) Other T&E (OTE) costs, in \$ millions, were estimated by

$$OTE = 1.2 (0.02E2).$$

The leading coefficient of 1.2 reflects 20 percent allowance for management, technical direction, and systems engineering. The factor 0.02 on E2 approximates the percentage of additional facilities cost equal to the cost of T&E-related facilities investment.

3. INVESTMENT COSTS

(U) The components of investment cost are shown in Figure III-1. The definitions of these elements and the appropriate CERs are discussed in the following sections.

3.1 Equipment

(U) Two types of equipment are associated with a new system, prime and support. Investment costs are primarily the acquisition costs of these types of equipment.

(U) The costs of conversions and modernizations, which entail major changes to vehicle configuration and which alter the military characteristics of a vehicle, are not included in the 15-year LCCs. Costs of such modifications are beyond the scope of incremental improvements of subsystem modernization done during periodic overhauls or reworks. As evidenced by both past and current air and surface vehicle programs, major conversions or modernizations may not occur during vehicle service lifetimes; only incremental modifications may take place.

(U) Prime equipment costs include the estimated initial cost of the required number of platforms, payloads, and other installed equipment items (including the GFE) necessary to operate a vehicle (platform and payload). A cost quantity production rate relationship is used to derive the total cost of platforms.

3.1.1 Platform Prime Equipment Costs

(U) The key parameter in the prime equipment CERs for surface and air platforms is the platform cost. The methodology for estimating surface lead-ship and follow-ship platform costs is discussed in Chapter II.

(U) For surface platforms, platform prime equipment (PPE) total costs were determined from the following equation:

$$PPE = L1 + B1(R4 - 1)(\ln(2R)/\ln 2)$$

where

L1 = lead-platform cost (\$ millions),

B1 = follow-ship platform cost (\$ millions)

R4 = number of vehicles to be acquired, and

R = learning rate for construction (0.97 for surface vehicles).

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(U) For air platforms, the equation used to estimate platform prime equipment was

$$PPE = B1 \left[(A6 + R4) \left(\frac{\ln(2R)}{\ln 2} \right) - A6 \left(\frac{\ln(2R)}{\ln 2} \right) \right],$$

where

B1 = platform first-unit cost (\$ millions), and

A6 = number of flight-test air vehicles.

3.1.2 Payload Prime Equipment Costs

(U) Payload prime equipment (LPE) costs, in \$ millions, was derived using the following CER:

$$LPE = C2 + (R4 - 1) C3.$$

3.1.3 Platform Support Equipment Costs

(U) Support equipment costs include the costs of both peculiar and common support equipment that must be procured to perform all three levels of maintenance for the platform and the payload. Peculiar support equipment includes tools and test equipment that have maintenance applications only to a particular class of platform. Common support equipment includes tools and test equipment that are necessary for maintaining a platform but that are applicable to other classes of platform as well.

(U) Platform support equipment (PSE) costs, in \$ millions, were estimated using the following equation:

$$PSE = 0.05 (PPE).$$

The factor 0.05 on PPE approximates the percentage of air and surface platform prime equipment cost equal to the cost of platform peculiar and common support equipment.

3.1.4 Payload Support Equipment Costs

(U) Payload support equipment (LSE) costs, in \$ millions, were estimated using the following equation:

$$LSE = 0.2(LPE).$$

The factor 0.2 on LPE approximates the percentage of air and surface payload prime equipment cost equal to the cost of payload peculiar and common support equipment. No hard data are available on these (PSE and LSE) estimates and the equations represent the best judgments of the ANVCE Project analysts.

3.2 Facilities

(U) This cost element includes the cost of constructing, converting, altering, or modifying facilities dedicated to the maintenance, training, and logistic support of given ANVs. The facilities may include intermediate and depot-level maintenance facilities, naval shipyards, and aircraft rework facilities as well as piers, docks, anchorages, runways, hangars, fuel storage sites, and ammunition depots.

(U) A review of each ANV point design led to a first-order identification of unique facilities required and their associated costs. Although this investigation into unique facilities costs was not all-inclusive, further refinement of these cost estimates was not made since the estimated facilities costs were typically much less than 1 percent of the total 15-year system LCC. The description of the unique facilities identified and their estimated costs are given in Appendix G of Reference 6.

3.3 Initial Spares and Repair Parts

(U) This cost element includes the cost of initial spares and repair parts required to be stocked for the service and repair of an ANV. Spares are recoverable components, assemblies, subassemblies, equipments, or end items that are installed or placed in use while replaced items are undergoing maintenance, repair, or overhaul. Repair parts are those individual parts required for the maintenance or repair of installed equipments or spares but that are not themselves considered repairable.

(U) The investment cost of initial spares and repair parts is assumed to be a percentage of platform and payload prime equipment cost. For platforms, the initial spares and repair parts are assumed to be 3 percent of the platform prime equipment cost; for payloads, the corresponding figure is assumed to be 13 percent. The initial spares for an ANV were arbitrarily set to last for the first 4 years of vehicle operations. Thereafter, the replenishment spares cost element in O&S consists of spares designed to last the remainder of the 15-year operating period. Repair parts, on the other hand, are an annual recurring cost accounted for under the operating cost element of the O&S category.

3.4 Ordnance

(U) Included in the ordnance cost element are costs of the expendable ordnance, ammunition, pyrotechnics, missiles, ballistic weapons, guided weapons, torpedoes, mines, depth charges, and sonobuoys required to initially fill vehicle magazines. The detailed costs for these payload items are taken from estimates for individual items made by SEA-06 for the surface platform and NADC for the air platform.

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3.5 Associated Systems

(U) Associated systems investment costs for ANVs are based on annual refueling consumption from an UNREP unit. In this analysis, an UNREP unit has been defined as one UNREP ship, the AOR-7.

(U) Associated systems costs are derived as an annual cost for each ANV having an at-sea refueling requirement. This includes all surface ANVs except the LCAC and LCPC, which are carried by a host ship. The associated systems investment calculation is based on the annual usage by an ANV of the UNREP unit annual fuel capacity. The following CER is used:

$$IASOC = 0.85AV(D3) (D5 + D6) \left(\frac{S2}{S1} \right) \left(\frac{LO\&S}{30} \right) ,$$

where

IASOC = associated systems investment cost (\$ millions),

AV = average number of vehicles operated,

D3 = annual operating time per vehicle (hr),

D5 = fuel per operating hour per vehicle (tonnes),

D6 = fuel per operating hour per payload (tonnes),

S2 = UNREP unit investment cost (\$ millions),

S1 = UNREP unit capacity (tonnes/year), and

LO&S = length of O&S period (years, normally 15).

The factor 0.85 reflects the assumed percentage of annual refuelings that take place at sea and for which ANVs must bear the UNREP unit investment burden. The LO&S reflects the 15-year period of operations for which the ANVs are responsible; it is divided by 30 to reflect the 30-year service life of the UNREP unit, 15 years more than required by the ANVs. Thus, the ANVs are only charged for that portion of IASOC that will be utilized over the 15-year period.

4. OPERATIONS AND SUPPORT

(U) The major elements of O&S costs are shown in Figure III-1. The definitions of these elements and the appropriate CERs are discussed in the following sections.

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4.1 Personnel

(U) The personnel cost element includes two subelements, pay and allowance (P&A) and temporary additional duty (TAD).

4.1.1 Pay and Allowances

(U) The P&A cost element includes the cost for all active vehicle personnel and consists of basic pay, quarters, subsistence, clothing allowances, incentive and special pay, and miscellaneous expenses.

(U) The "Navy Program Factors Manual (NAEM)" (Reference 13) was used to derive the average annual pay and allowances for officers and enlisted men. For officers, the average annual P&A was found to be \$21,427. For enlisted man on surface ships, the average annual P&A was derived as a function of the number of men aboard the ship; this approach for enlisted men was taken in an attempt to reflect the implicitly higher skills required on the smaller, high-performance ships. For enlisted men on air vehicles, the average annual P&A of \$10,489 appears to be independent of crew or squadron size. The resulting equations (from Reference 6) are

for surface platforms:

$$P\&A = \frac{VOY}{10^6} \left[21,427D1 + [1 + 0.03(B5)] [12,950D2 - 675 (\ln D2) D2] \right],$$

For air platforms:

$$P\&A = \frac{VOY}{10^6} \left[21,427D1 + (1 + 0.03B5) 10,489D2 \right],$$

where

P&A = P&A cost (\$ millions)

VOY = number of vehicle operating years obtained in the O&S period;

D1 = number of officers per vehicle;

B5 = 1 for nuclear platforms; otherwise, 0; and

D2 = number of enlisted men per vehicle.

The factor 0.03 on B5 reflects an estimated 3 percent increase in average enlisted P&A for nuclear platforms over nonnuclear platforms.

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4.1.2 Temporary Additional Duty

(U) The TAD cost element represents the cost, in \$ million, associated with the temporary assignment of vehicle personnel away from the vehicle for training, administrative, or other purposes. Based on the NARM, an average of \$40 per person was selected as the representative annual TAD cost. An additional assumption made was that 65 percent of the total crew would be expected to be assigned to TAD. Thus, the resulting equation becomes

$$\text{TAD} = \frac{\text{VOY}}{10^6} [0.65 (40)] (D1 + D2).$$

Including TAD money in the LCC is an attempt at completeness rather than absolute precision since its impact on LCC is negligible. In fact, TAD costs are less than 1 percent of the total personnel costs.

4.2 Operations

(U) This element is defined to include part of the direct costs associated with operating a vehicle.* Included are the costs of utilities, repair parts, other vehicle consumables, and training expendable ordnance as defined below.

(U) Utilities costs include the cost of energy used to power a vehicle that is not provided by the vehicle itself. For example, surface vehicles require utilities from shore facilities when not underway.

(U) The repair parts cost includes the cost of repair parts used in the organizational maintenance of the vehicle. Repair parts are those individual parts used for equipment repair and not themselves repairable.

(U) Supplies include consumable and equipage items of a general nature, e.g., janitorial supplies, office material, personnel support supplies, medical and dental material, etc., that are not directly related to the support of specific equipment or vehicle systems.

(U) Training expendable ordnance cost includes the cost of the expendable ordnance, ammunition, pyrotechnics, missiles, ballistic weapons, guided weapons, torpedoes, mines, depth charges, sonobuoys, etc., used by the vehicle in training exercises.

(U) With the exception of training ordnance costs, the operating costs were derived from NARM data and correlated according to average vehicle cost, light-vehicle weight, monthly operating hours, type of power (nuclear or non-nuclear), and type of vehicle (aircraft or surface ship). The training ordnance costs

* Energy, which is also a direct operating cost, is treated as a separate cost element and is discussed in Section 4.4 of this chapter.

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were calculated on the basis of estimated annual usage rates for each type of ordnance (missiles, torpedoes, sonobuoys, etc.). The NARM data and the derivation of the CER for operations may be found in Appendix R of Reference 6; the training ordnance costs derivation may be found in Appendix Q of Reference 6.

(U) The equation used is

$$OPS = \frac{VOY}{10^3} \left[9.119A^{0.016} We^{0.213} (D1 + D2)^{0.56} \right. \\ \left. H^{0.141} 1.116^{B5} 1.808^{A7} + C5(10^3) \right],$$

where

- OPS = operating cost (\$ millions);
- A = average vehicle cost (\$ thousands);
- We = light-vehicle weight (millions of lb);
- H = monthly operating hours;
- A7 = 1 for air platforms; otherwise, 0; and
- C5 = annual cost of training ordnance (\$ millions)

4.3 Maintenance

(U) The maintenance cost element includes the cost of intermediate and depot (industrial) maintenance for air and surface vessels. (Organizational maintenance is covered by the personnel and operations cost elements).

(U) The intermediate maintenance cost includes direct labor and material, supplies, and repair parts expended during intermediate maintenance activities. For example, the cost of direct labor and materials expended by tenders and repair ships for a surface ANV represents an intermediate maintenance activity.

(U) The depot (industrial) maintenance includes the cost of direct labor, material, other direct costs, and applied overhead chargeable to job orders for overhaul, progressive maintenance, analytical rework, modification, repair, inspection and test, manufacture, reclamation, and storage of vehicle subsystems, components, parts, and support equipment at naval shipyards and aircraft reworks facilities, commercial facilities, and any other industrial facilities that perform depot-level maintenance. For surface vehicles, depot (industrial) maintenance includes regular vehicle overhaul; nonscheduled ship repair (i.e., restricted or technical availability, RA/TA); Fleet Modernization Program (i.e., SHIPALTS, ORDALTS, etc.); recore (if applicable); and scheduled ship repair (i.e., selected restricted availability, SRA).

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(U) The CER for maintenance was derived from NARM data using the same vehicle-related parameters as the operations CER plus an additional cost factor to represent any weekly additional maintenance hours required to perform deferred maintenance. Additional maintenance hours arise for certain of the ANV surface vehicles where manning levels were considered insufficient to provide the estimated required organizational-level maintenance. The methodology by which these additional maintenance man-hours were estimated is discussed in Chapter VI of Volume 2.

(U) The CER for ANV maintenance is

$$MTC = \frac{VOY}{10^3} \left[3.77 A^{0.298} W e^{-0.214} (D1 + D2)^{0.633} \right. \\ \left. + H^{0.100} 1.187 B^{0.155} A^7 + 0.52 E1 \right]$$

where

MTC = maintenance cost (\$ millions), and

E1 = weekly additional maintenance man-hours.

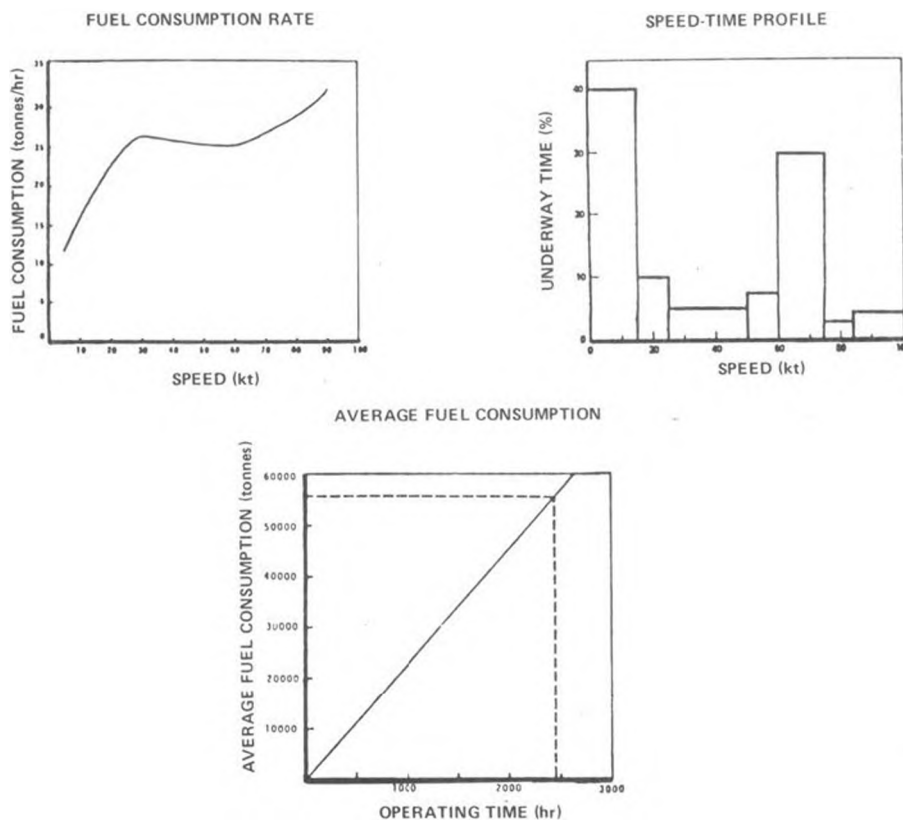
4.4 Energy

(U) The energy cost element includes the annual cost of fuel, nuclear or fossil, consumed by an ANV, including the fuel consumed by any subvehicles. Since the cost of such fuel is an increasingly important operational consideration for the Navy, vehicle fuel consumption and operating profiles have received considerable attention in the ANVCE Project.

(U) For surface vehicles, fuel consumption was determined from the speed/time profiles and fuel consumption characteristics of the individual vehicles. Illustrative charts of the technique used are shown in Figure III-2. Peacetime speed/time profiles were derived for each vehicle to reflect the expected vehicle operational usage. From the characteristic fuel consumption/speed characteristic and the speed/time profile, it is possible to estimate the average platform fuel-usage rate (or average reactor power for nuclear-powered vehicles). The subvehicle fuel consumption must then be added to this platform fuel consumption. For purposes of the ANVCE Project, the only subvehicles that were considered to expend signif-

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icant fuel were helicopters and vertical/short takeoff and landing (V/STOL) aircraft. The fuel consumptions of these subvehicles were computed under the assumption that a helicopter was utilized 32 hr per month and a V/STOL was utilized 30 hr per month.



(U) Figure III-2. ENERGY COST

(U) A mission profile was similarly derived for air vehicles; in conjunction with the fuel consumption representative of each mission phase, it yielded an average fuel consumption, or average nuclear power for the A/L(N).

4.4.1 Nonnuclear-Powered Vehicles

(U) The energy cost equation for nonnuclear-powered vehicles is

$$\text{ENERGY} = \frac{\text{VOY}}{10^6} \left[D3(D5 + D6)41.9D8 \right],$$

where

ENERGY = energy cost (\$ millions) and

D8 = cost of nonnuclear fuel per million Btu's (\$ millions).

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The factor 41.9 converts the tonnes of fuel to millions of Btu's. The cost of non-nuclear fuel was assumed to be \$3.42/million Btu's (corresponding to \$0.44/gal in FY-77 dollars).

4.4.2 Nuclear-Powered Vehicles

(U) The energy cost equation for nuclear-powered vehicles is

$$\text{ENERGY} = \frac{\text{VOY}}{10^6} (\text{D3}) \left[2.5098 \text{D7 (V9)} + \text{D6 (41.9D8)} \right],$$

where

D7 = 1000 max. hp-hr per operating hour (nuclear) and

V9 = cost of nuclear fuel per million Btu's (\$ million).

The equation includes the average reactor core cost per hour and the average sub-vehicle fossil-fuel cost per hour. The factor of 2.5098 converts the max. hp-hr per operating hour to millions of Btu's per operating hour. The cost of nonnuclear fuel, assumed to be \$0.80/million Btu's (in FY-77 dollars), included the cost of fuel fabrication, reprocessing, and residual value. Note also that for the A/L(N), the fossil-fuel costs incurred for takeoff and landing must be added to the energy cost.

4.5 Replenishment Spares

(U) Replenishment spares cost includes the cost of recurring procurement of spares required to replenish rotatable pools of repairable components depleted through abandonment, loss, or survey. Spares are recoverable components, subassemblies, assemblies, equipments, or end items that are installed or otherwise placed in use while items are undergoing maintenance, repair, overhaul, or salvage at other than the organizational level.

(U) Both surface and air ANVs are assumed to have sufficient initial platform and payload spares to meet the first 4 years of vehicle operation. Thereafter, vehicle replenishment spares must be accounted for as a recurring O&S cost. The replenishment spares cost element calculates the accumulated cost of these spares on the basis of the total number of vehicle operating years, minus the 4 years for which initial spares are provided. The equation for this cost is

$$\text{REPL} = \left(\frac{\text{VOY}}{\text{R4}} - 4 \right) \left(\frac{\text{ISP+ISL}}{4} \right)$$

where

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REPL = replenishment spares cost (\$ millions),
ISP = initial spares cost for platform (\$ millions), and
ISL = initial spares cost for payload (\$ millions).

4.6 Major Support

(U) The major support costs include the indirect operating cost of an ANV, i.e., training, indirect personnel, support, and logistics.

(U) The training cost includes the cost of providing all vehicle personnel with both general and specialized training and includes O&S costs of the training facilities and staff that are allocated over trainees.

(U) The indirect personnel support cost is the cost of such indirect support to vehicle personnel as medical, recruiting and examining, transient and prisoner billets, and permanent change of station (PCS).

(U) Included in the logistics cost is the cost of base operating support; second-destination transportation of material required for the vehicle subsequent to its initial receipt by the government; engineering and technical services not supplied by intermediate or depot (industrial) maintenance activities; proportional operating costs of inventory control points (ICPs), supply depots, other field support; technical documentation updating; and other logistics activities.

(U) The CER for major support was derived from the NARM data base used for the O&M CERs previously described. The major support cost (MSUP), in \$ millions, was derived by

$$\text{MSUP} = \frac{\text{VOY}}{10^3} \left[3.274 A^{0.120} W e^{-0.045} (D1 + D2)^{0.847} \right. \\ \left. H^{0.103} 0.988 B^5 0.731 A^7 \right].$$

4.7 Associated Systems

(U) The same methodology described for calculating associated systems investment costs applies to associated systems O&S costs, i.e., ANVs pay for that share of UNREP unit O&S costs based on the ANV consumption of fuel delivered by the UNREP unit. The CER for associated systems O&S costs (OASOC), in \$ million, is

$$\text{OASOC} = \text{VOY}(D3) (D5 + D6) [0.85(S3/S1)],$$

where S3 is the UNREP unit annual O&S cost (\$ millions).

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(U) The factor 0.85 approximates the percentage of total operating hours for which there is an at-sea refueling requirement. The UNREP unit annual O&S cost was given in the NARM to be \$15.029 million (FY 77); the UNREP unit capacity was derived to be 206,621 tonnes per year.

5. RESIDUAL VALUE

(U) Residual values are seldom treated in systems analyses within the Department of Defense, primarily because many studies involve only competing systems with nearly equal lifetimes. That is not the case in the ANVCE Project. Conventional displacement ships have expected lifetimes as long as 30 years; aircraft have service lifetimes of about 15 years; advanced naval vehicles such as the SES and hydrofoil have lifetimes of about 20 years.

(U) Residual values of the platform only, i.e., the vehicle without the payload, are calculated and subtracted from the total of other 15-year systems costs. A 15-year period was selected because 15 years is the shortest service life of any ANV point design. The method by which these residual values are calculated is taken from principles of accounting. The declining balance method most closely approximates the decline in value of capital assets that are not worn out at the end of a nominal service life but are capable of being restored, modernized, and/or converted to other uses. A good reason for using the declining balance method is that platforms reaching their final years of nominal life are sometimes employed in a standby or other secondary status.

(U) With the declining balance method, a given rate is applied each year to the unamortized cost (i.e., that portion of original cost not already written off). The rate is sometimes expressed as a multiple of the straight-line rate. For example, a vehicle with an estimated life of 20 years and zero salvage value has a straight-line rate of 5 percent per year (100 percent/20 years); the double declining balance method applied a rate, r , of 10 percent for that asset. Unlike the other methods of depreciation, the declining balance method does not write off all the original cost of the vehicle but instead subjects its value to an exponential decline. The residual value equation is

$$\text{RES VALUE} = \text{PPE} \left(1 - \frac{2}{B2}\right)^{\frac{\text{VOY}}{R4}},$$

where RES VALUE is the residual value at end of operating period (\$ millions), and B2 is the service life (years) and R4 is the number of vehicles to be acquired.

(U) Using this method in the context of 15-year systems costs, even vehicles having a 15-year service life will be estimated to have a residual value. Vehicles having a service life longer than 15 years will have a larger residual value. No vehicles are now assigned a shorter service life than 15 years, but if a shorter life is assigned, a reacquisition would have to be made to fulfill the mission requirement over the 15-year period selected for costing.

CHAPTER IV RESULTS

(U) Although most cost/effectiveness analyses focus on LCC, a significant part of the ANVCE effort was devoted to platform cost development in order to better understand what factors were important in determining the cost of advanced vehicles. Therefore, this chapter presents platform and vehicle costs for those interested in the acquisition cost of these advanced vehicles as well as the estimated LCCs.

1. PLATFORM COSTS

1.1 Introduction

(U) The terminology and methodology for estimating platform costs were different for surface and air platforms. For surface platforms, the significant terms are lead-ship platform cost and follow-ship platform cost. The lead-ship platform cost includes the detailed design cost, the construction cost attributed to each SWBS group, GFE costs, and appropriate NAVSEA planning factors to account for such items as profit, change orders, government laboratory support, and outfitting and furnishing. A learning rate of 0.97 is applied to the first follow-ship platform cost. In the ANVCE Project, it was assumed that no surface platform would be procured from the RDT&E appropriation; thus, the first operational platform is the lead-ship platform.

(U) For air platforms the significant term is the first-unit production cost, which includes the cost of the airframe, engines, and avionics but does not include the combat suite items or detailed design costs. The first-unit production cost figure applies to the first vehicle, which in the ANVCE Project was designated as the R&D vehicle. A learning rate of 0.80 is applied to the first-production-unit cost. Thus, the first operational platform (and the first platform to be charged against investment costs) is the second platform procured.

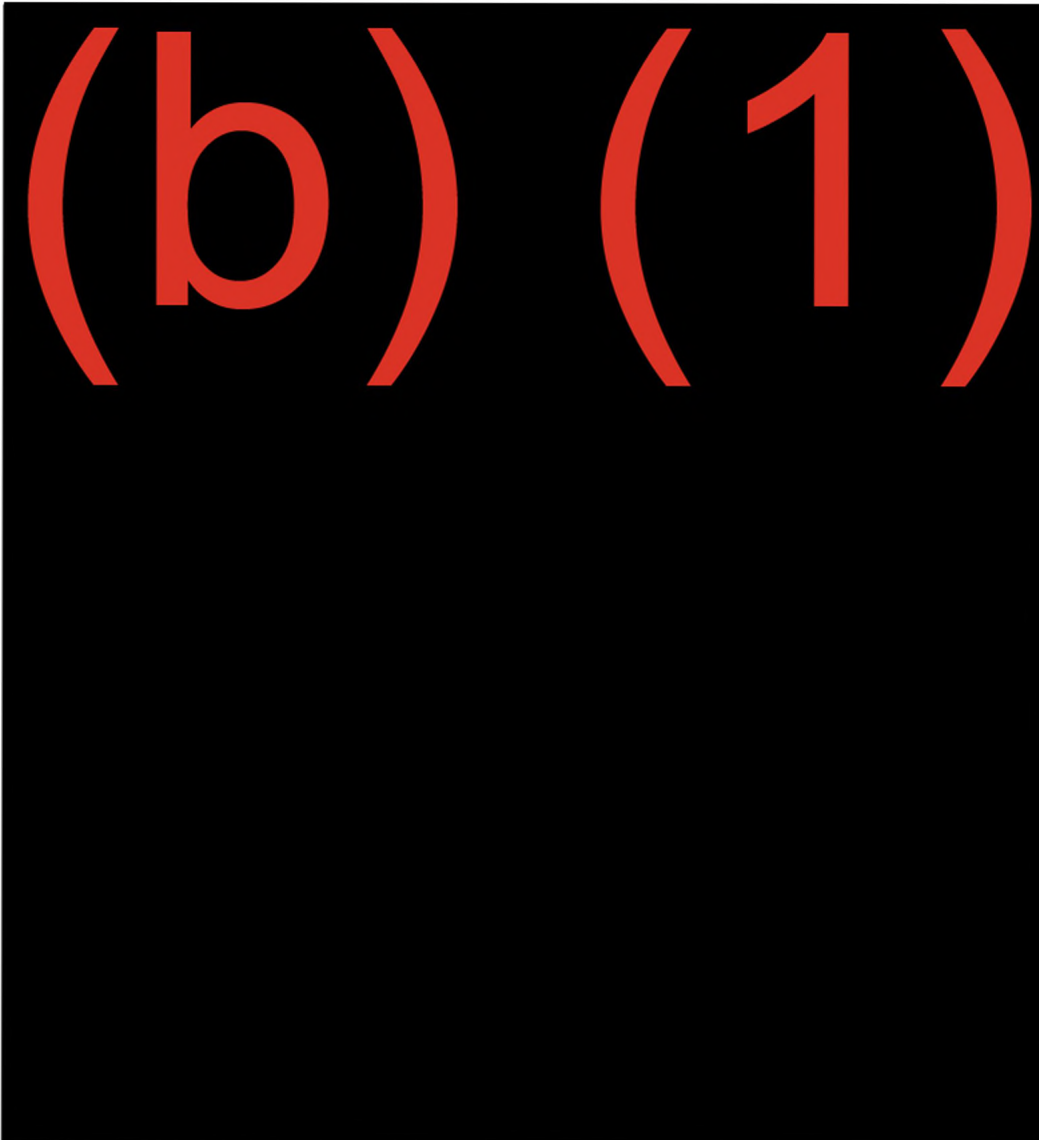
1.2 Cost Summary

(U) The estimated costs of the first and second platform constructed are summarized in Table IV-1. Second-platform costs* were included in the table since this is the first stage at which detailed design costs are not included in either the surface or air cost estimates.

* First follow-ship platform cost for surface vehicles; second-production-unit cost for air vehicles

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~~(C)~~ Table IV-1. SUMMARY OF SURFACE AND AIR
PLATFORM COSTS (U)



(U) For the surface platforms, nearly all of the differences between the platform costs for the lead ship and follow ship are due to the inclusion of the detailed design cost in the lead-ship platform construction cost estimate. For the air platforms, the large difference between the costs of the first and second production unit is caused by the assumed cumulative learning rate of 80 percent.

(U) As expected, unit cost tends to increase with size and speed for both surface and air platforms. However, the most significant result is the relatively low cost of the LTA vehicles. Although confidence in the absolute value of the LTA vehicle costs is low, the relative results are credible.

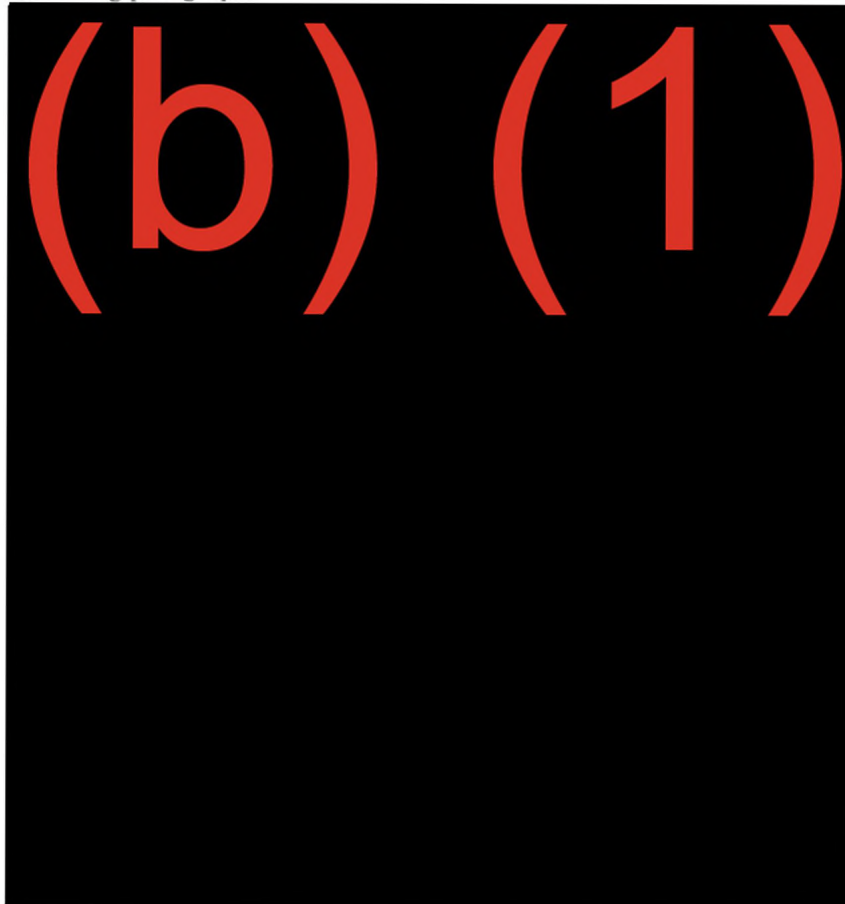
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(U) For small buys, the platform unit cost of the multimission, air combatants (except for the FAB) is comparable to or greater than the unit cost of the air-capable surface combatants. The learning rate for air platforms brings the average cost per platform down quite rapidly as the size of the buy increases. For example, for a buy of 25 air platforms, the average air platform cost is about 35 percent of the first-unit cost; if the learning rate were that of surface platforms, the average cost of the 25 platforms would be about 87 percent of the first-unit cost.

1.3 Surface Platforms

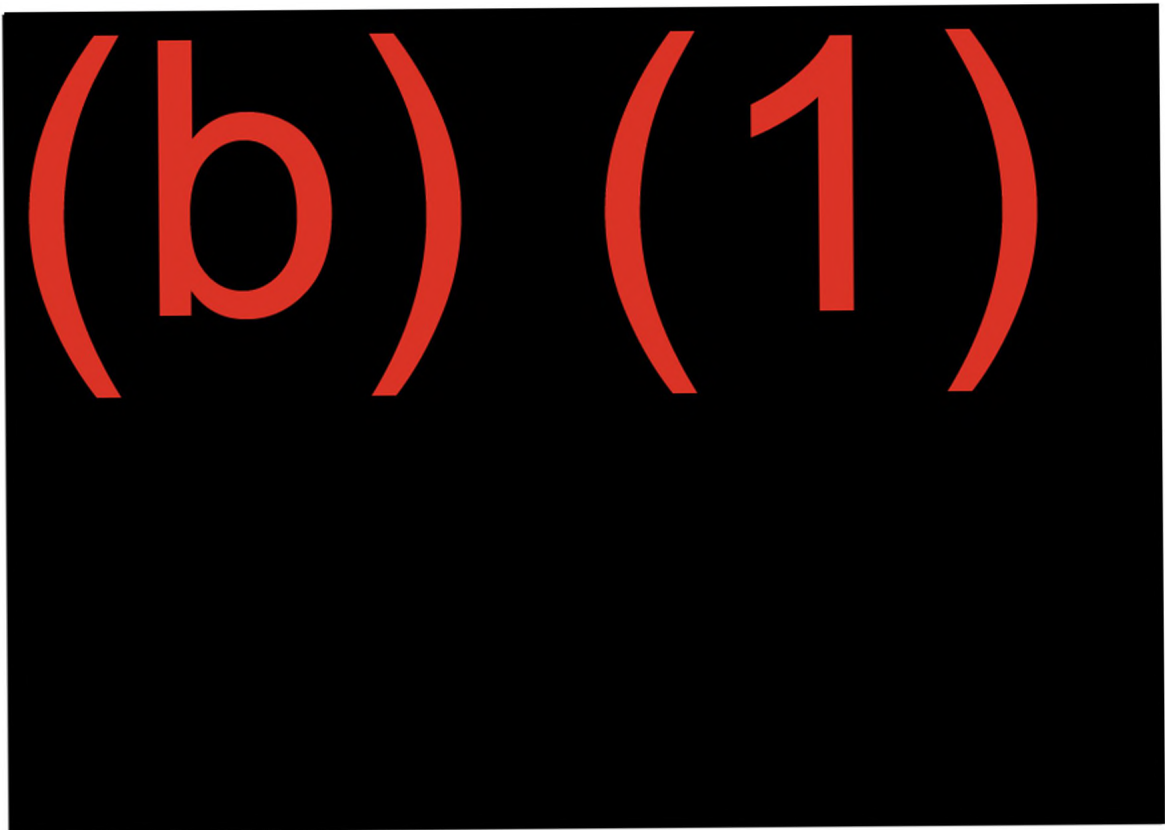
(U) As stated previously, the large difference between the cost of the lead-ship and follow-ship platforms (Table IV-1) is caused primarily by the inclusion of detailed design cost in the lead-platform cost estimate.

(U) Average platform cost as a function of the size of the buy is shown in Figure IV-1 for each of the surface point design groups. As expected, cost increases as platform size increases. Further observations on Figure IV-1 are discussed in the following paragraphs.



~~(C)~~ Figure IV-1. AVERAGE SURFACE PLATFORM COST AS A FUNCTION OF BUY SIZE (U)

(U) First, the dynamic-lift platforms (cushion and foil platforms) cost more than the displacement platforms, but the increased cost differential diminishes as advanced technology is incorporated into the displacement platform. Figure IV-2 shows a breakdown of the first follow-ship platform cost, by SWBS group, for the air-capable, surface combatant group. The higher cost of the ANVCE point designs in comparison with a typical monohull of similar displacement can be attributed to Groups 1 and 2, and for dynamic-lift vehicles, Group 5. The increase in Group 1 costs is caused by the use of aluminum structures; the increase in Group 2 costs is caused by the relatively high propulsion system power in the ANVCE point designs. However, within the ANVCE point design group, the higher cost of dynamic-lift platforms is mostly attributable to Group 5 rather than Group 2 costs. In fact, the highest Group 2 cost is associated with the MONO 3. The implication is that the cost differences among high-performance platforms of a given tonnage are primarily the result of the differences in the concepts and to a lesser extent by specific design differences.

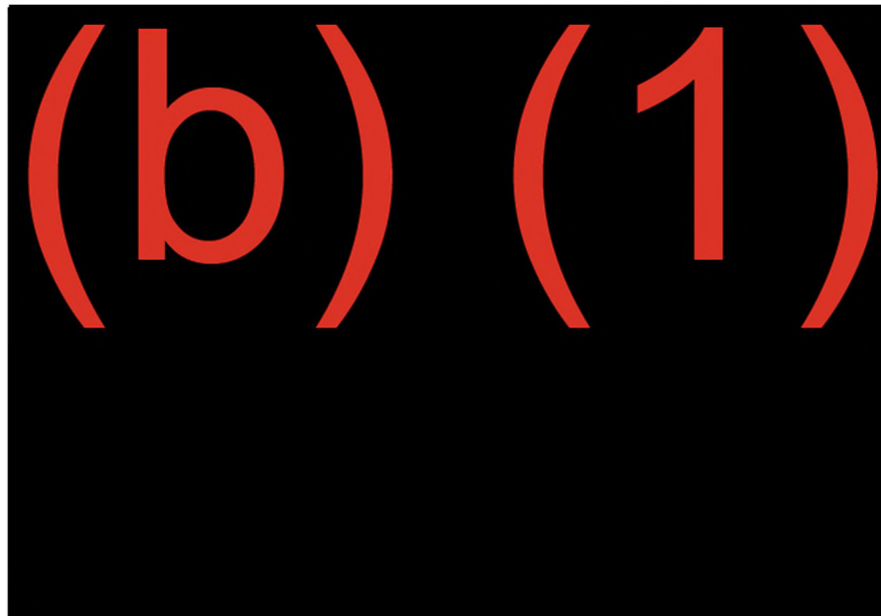


~~(C)~~ Figure IV-2. FIRST FOLLOW-SHIP PLATFORM COST FOR AIR-CAPABLE, SURFACE COMBATANTS

(U) Second, the impact of a change in the cost of any given SWBS group on the total cost is not clear. It was previously shown that the costs of Group 8, Group 9, and the NAVSEA factors are directly related to the sum of the costs of Groups 1 through 7. This formulation does not permit an accurate assessment of the sensitivity of platform cost to individual group cost changes that might occur during the design/construction process. It is not obvious that design changes that affect the cost of a given group would result in cost differences that would have the multiplicative effect indicated by the CERs. For example, how would a 10 percent change in the cost of Group 1 affect the estimated cost of the NAVSEA factors (outfitting and furnishing, etc.)? In fact, a 10 percent reduction in cost of a given group might be offset by an increased cost elsewhere (e.g., Group 9). The only conclusions that can be drawn are that (a) the current cost estimating methodology (which is derived primarily from bid data) is strongly affected by the estimated cost of the SWBS Groups 1 through 7, and (b) the costs of Groups 1, 2, and 5 are the dominant contributors to the sum of the costs of Groups 1 through 7.

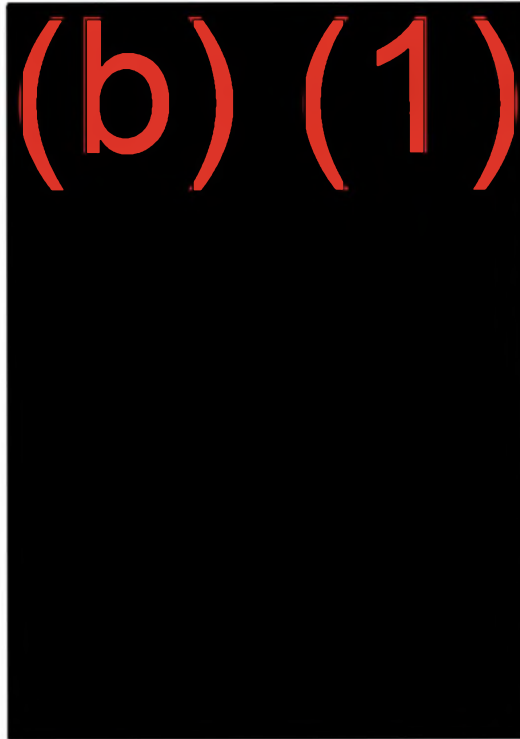
(U) Third, confidence in the cost estimates needs to be addressed from both an absolute and relative standpoint. Confidence in absolute costs can best be assessed by comparing the estimated costs with actual costs. However, the fragmented cost data on advanced vehicles do not permit such a comparison.

(U) For ANVCE purposes, the confidence in the relative costs is a more important consideration. Although it is important to use a consistent cost methodology, achieving accurate relative costs is not assured since errors in the individual group cost estimates are not likely to be offsetting, even in a relative sense. The extrapolation required for each point design provides an indication of how good the individual SWBS group cost estimates are. Figure IV-3 through IV-11 show the data-base CER and the points corresponding to the ANVCE point designs.



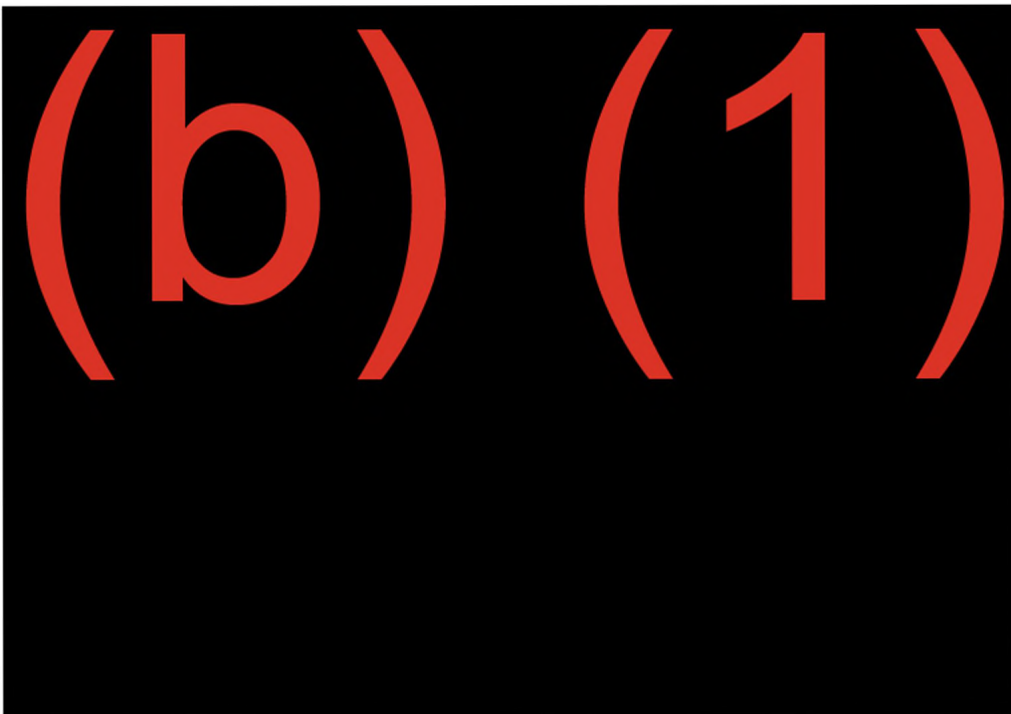
~~(C)~~ Figure IV-3. GROUP 1 COST (U)

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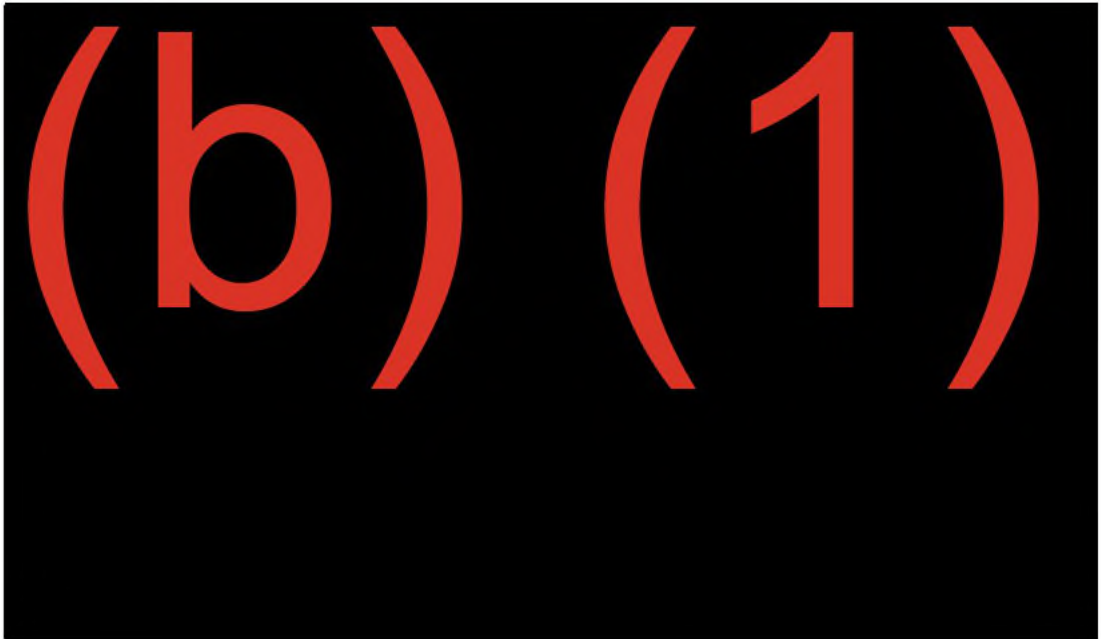
*assumed wrong from pelt?
(ie SES3 = 200K hp, not 4mg's, 50K rad)*

~~(C)~~ Figure IV-4. GROUP 2 COST (U)

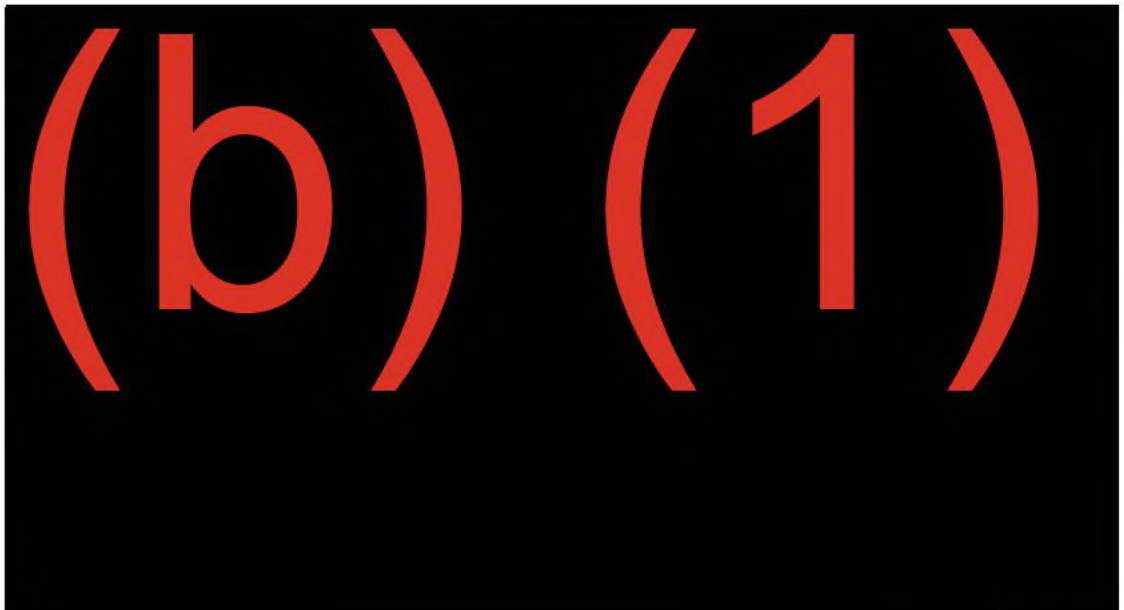


~~(C)~~ Figure IV-5. GROUP 3 COST (U)

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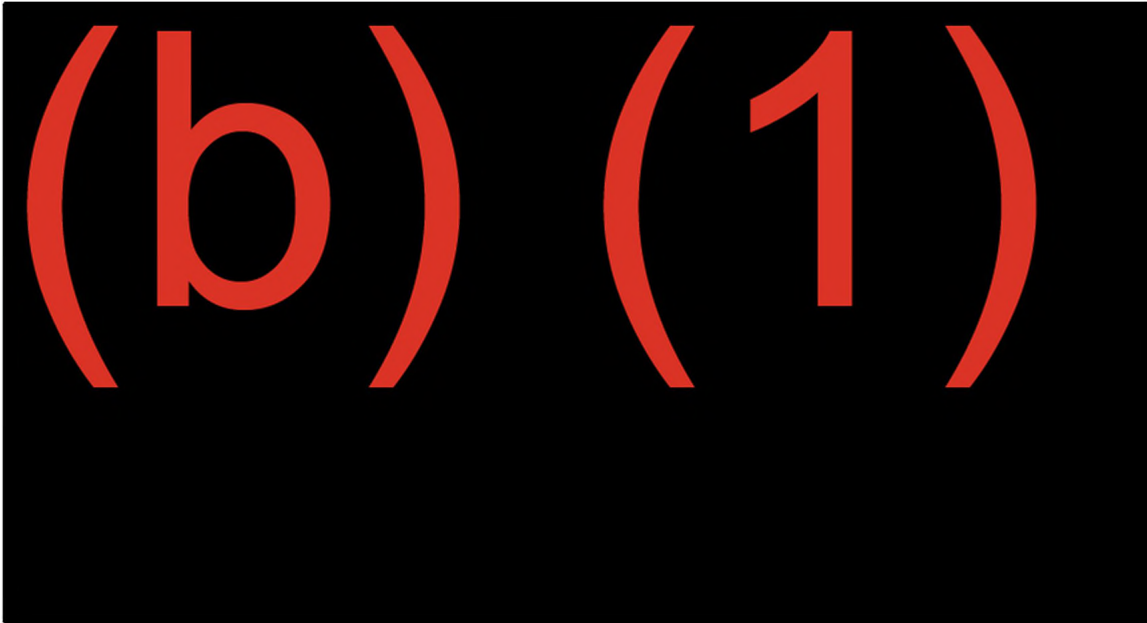


~~(C)~~ Figure IV-6. GROUP 4 COST (U)

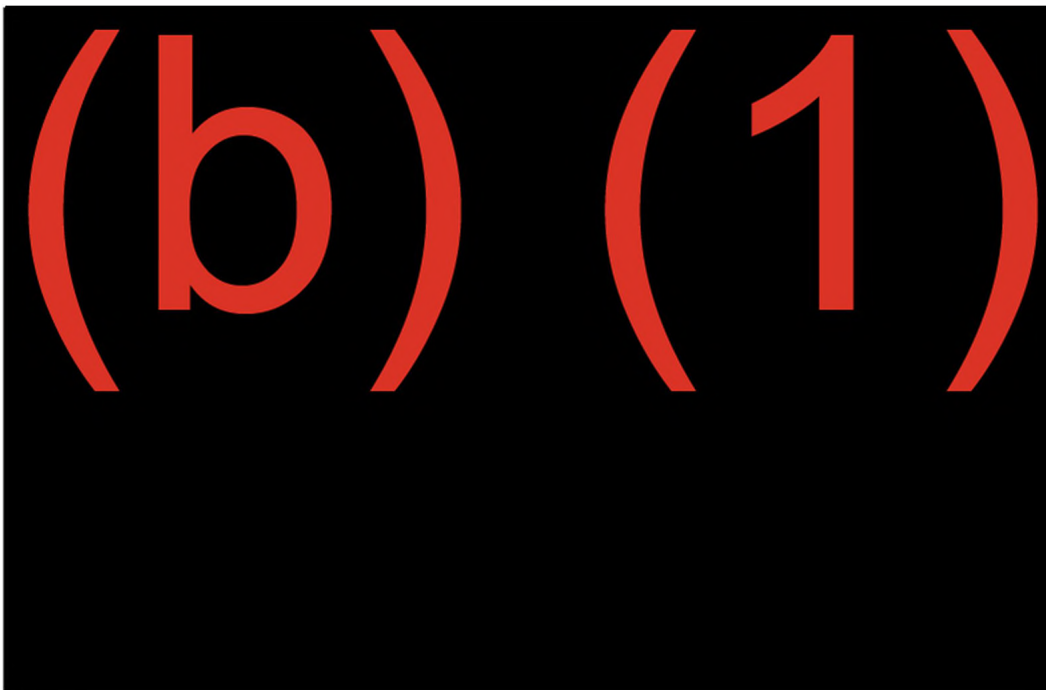


~~(C)~~ Figure IV-7. GROUP 5 COSTS (U)

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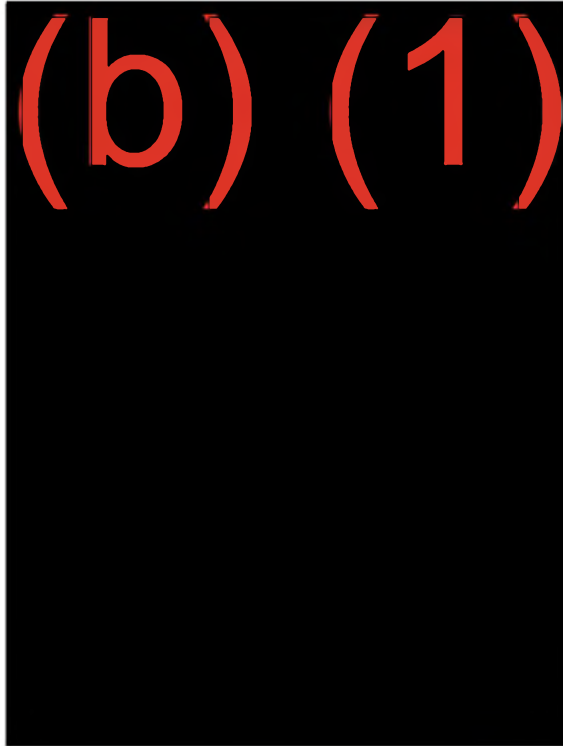


~~(C)~~ Figure IV-8. GROUP 6 COSTS (U)

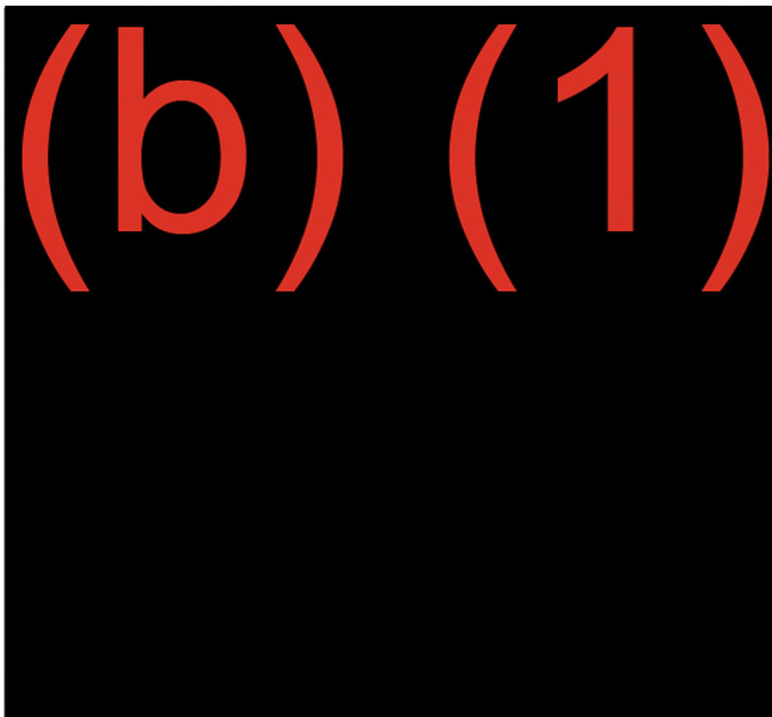


~~(C)~~ Figure IV-9. GROUP 7 COSTS (U)

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~~(C)~~ Figure IV-10. GROUP 8 COSTS (U)



~~(C)~~ Figure IV-11. GROUP 9 COSTS (U)

(U) In general, the ANVCE point design group weights fall within the range of data used to generate the CERs, the major exception being the aircraft carriers. However, several cautionary comments are appropriate. First, the CERs were generated from bid data, not actual cost data; second, the data on the larger dynamic-lift vehicle group weights (appropriate to the ANVCE point designs) were obtained from bid data on vehicles that were never constructed (e.g., 2KSES, SWATH DE, SWATH MCM, DBH); third, the data on most of the dynamic lift vehicles were from bid estimates for R&D vehicles rather than for combatants; and finally, the data base itself is small.

(U) As a part of ANVCE Project cost estimates were obtained for foreign hydrofoils, both those with surface-piercing foils and those with fully submerged foils, and for foreign SESs. The hydrofoil data were obtained from Supramar AG (Reference 14), and the SES data were obtained from Hovermarine (Reference 15). These data, listed in Table IV-2, are plotted in Figure IV-12 along with additional cost data from Reference 16.

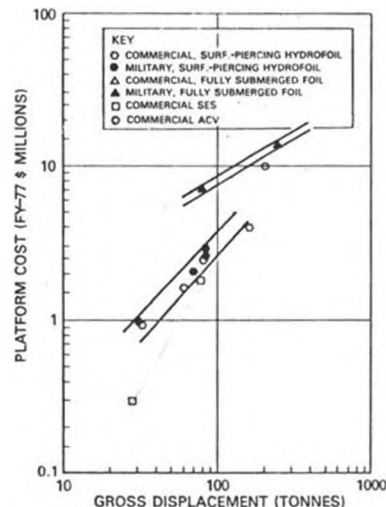
Table IV-2. COST ESTIMATES FOR FOREIGN HYDROFOIL AND SES (U)

VEHICLE	DESCRIPTION	LABOR (HR)	COST (FY 77 \$ THOUSANDS)			MAXIMUM SPEED (KT)	GROSS DISPLACEMENT (TONNES)
			LABOR*	MATERIAL	TOTAL		
HYDROFOILS							
PT 208 MK II	SURFACE PIERCING COMMERCIAL	35 750	429	502	931	36	37.9
PT 50 MK II	" " "	61 300	736	873	1 609	36.5	62.3
PTS 75 MK III	" " "	92 800	1 114	1 352	2 466	38.5	87.2
PAT 20	" " MILITARY	42 650	512	500	1 012	33	31
PAT 70	" " "	68 550	823	1 229	2 052	37	71
NAT 85	" " "	97 800	1 174	1 472	2 645	41.5	85
NAT 90	" " "	100 700	1 208	1 680	2 888	38	85
MT 80	FULLY SUBMERGED	230 000	2 760	4 350	7 119	52	80
MT 250	" " "	485 000	5 820	7 852	13 672	53	250
SES							
HM 2 MK III	COMMERCIAL	11 792	142	159	301		19.7
HM 2 MK IV	" " "	18 592	223	258	481		
HM 5	" " "	64 086	769	1 051	1 820	40	77

* ASSUMED LABOR + OVERHEAD RATE OF \$12/HR

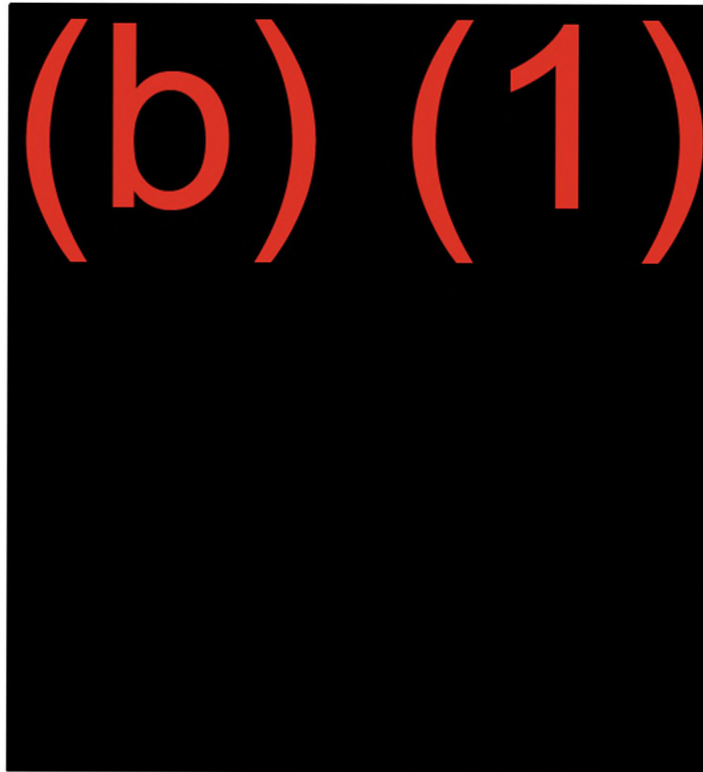
(U) Figure IV-12.

ESTIMATED COSTS
OF FOREIGN HYDROFOILS
AND SES'S



(U) Several features are apparent. First, there appears to be a significant cost difference, about a factor of 2.5, between hydrofoils using the surface-piercing and fully submerged foil systems. The higher cost of the hydrofoil with the fully submerged foil system appears to be mostly a result of the increased propulsion system cost. In comparing the cost differences between two similar-sized craft, the diesel-powered NAT 90 and the gas-turbine-powered MT 80, \$2.7 million is accounted for as increased material costs. Of this \$2.7 million, 63 percent is attributable to costs associated with the propulsion system, 16 percent to costs associated with the fully submerged (vs. surface-piercing) foils, 11 percent to an increased electrical plant system cost, and 9 percent to various other subsystems. What is not clear is how much of these increased costs are associated with the fully submerged foil system versus the increased speed. Hopefully, a diesel-powered, 40-kt hydrofoil with a fully submerged foil system (if technically feasible) would cost significantly less than the 50-kt, gas-turbine-powered MT 80. However, the design and cost information available does not permit a direct assessment of the difference in costs of the two lift approaches.

(U) Another observation is that there appears to be only a 10 percent cost difference between the commercial and military hydrofoil platforms of the same tonnage and speed. However, in comparing these cost data with the ANVCE Project cost estimates, there appears to be a factor-of-two difference between commercial and military vehicles. This comparison is shown in Figure IV-13.



~~(C)~~ Figure IV-13. COMPARISON OF FOREIGN AND ANVCE PROJECT COST ESTIMATES (U)

(U) Even recomputing the estimated costs derived from Supramar AG and Hovermarine at a more realistic U.S. labor rate of \$25/hour, the ANVCE cost estimates will still be about twice as high as the foreign craft costs, even at the same tonnage and speed (compare LCAC and SRN 4). Note also that the cost of the commercial JETFOIL appears to complement the cost estimates for the Supramar's military hydrofoil with fully submerged foils.

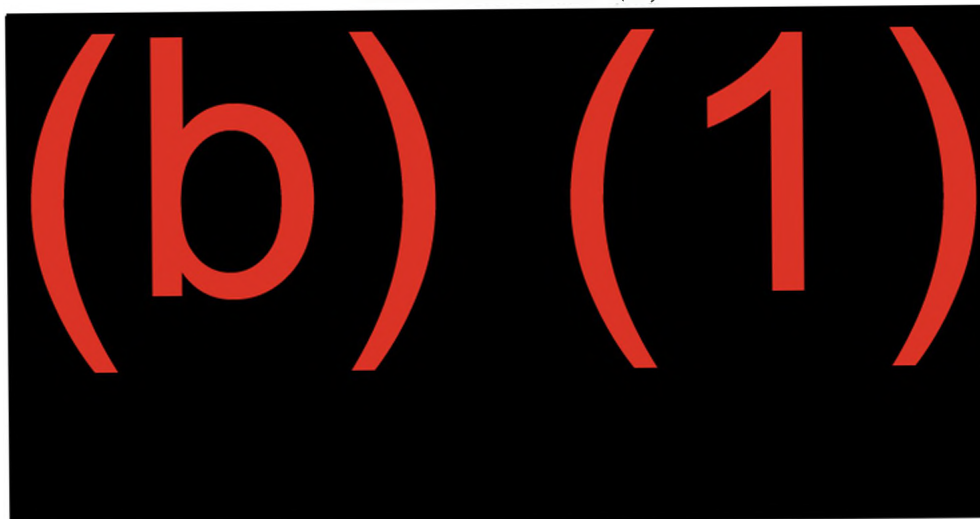
(U) One hypothesis for the factor-of-two difference is that the foreign craft costs are based on long production experience, which effectively has amortized out the major costs associated with engineering services (Group 8) and construction services (Group 9).

(U) A final observation is that the costs of the hydrofoils and SESs (and ACVs) of similar displacements and speeds seem comparable. That is, the "low-speed," subcavitating (≤ 40 kt) hydrofoils and SESs seem to compare favorably on a cost/tonne basis; and the "high-speed," supercavitating (≥ 50 kt) hydrofoils and SESs (and ACVs) seem to compare favorably on a cost/tonne basis. As mentioned previously, the cost spread between the "low-speed" and "high-speed" small-displacement vehicles seems to be about a factor of 2.5. However, this spread may decrease as displacement increases and as costs are increased by factors other than speed, such as increased endurance and mission duration.

1.4 Air Platforms

(U) The first-unit production cost for each air platform being considered in the ANVCE Project was estimated using the methodology previously described. The results, given in Table IV-3, indicate that the airframe cost is the principal first-unit cost. This result reflects the fact that the air vehicles considered in the ANVCE Project are considerably larger, and slower, than most military air vehicles in the data base.

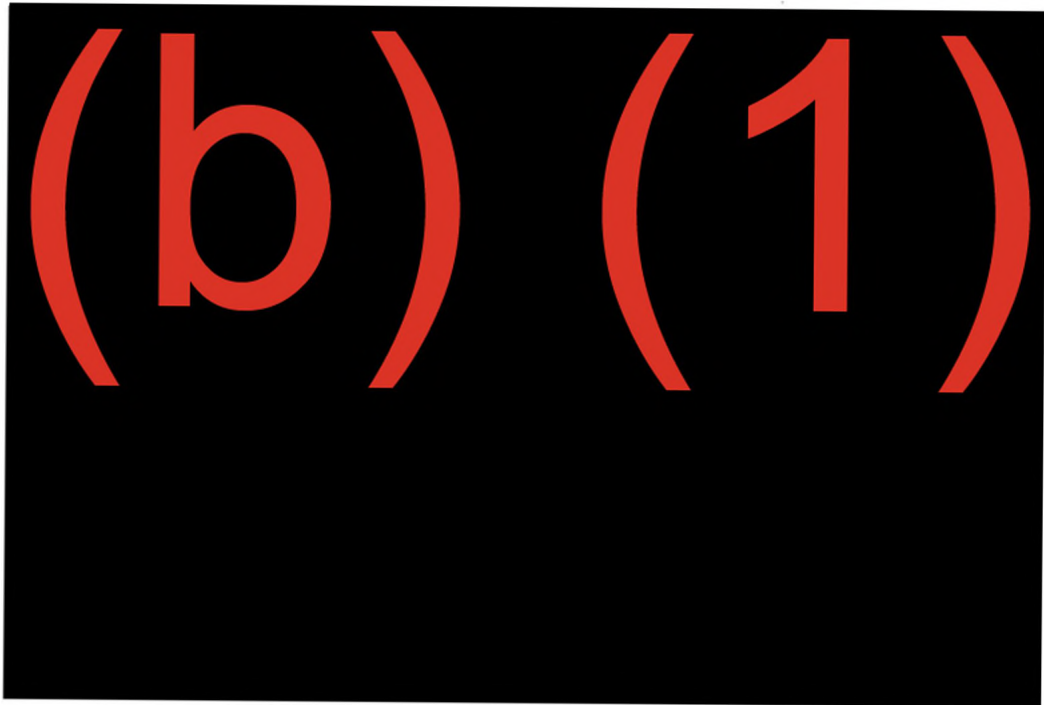
~~(C)~~ Table IV-3. FIRST-UNIT PRODUCTION COST FOR
AIR PLATFORMS (U)



(U) Average platform cost is shown as a function of the size of the buy in Figure IV-14 for each of the air vehicle point design groups. Other than the general trend of unit cost increasing with size, the most notable result is the extremely low costs of the LTA vehicles compared to those of the HTA vehicles.

(U) Since the data base for the LTA CER used to estimate the FAB airframe cost is extremely old,* confidence in the actual FAB cost estimate is low. However, examination of historical data on HTA and LTA vehicles revealed that the qualitative result may not be in error, i.e., LTA vehicles may indeed cost significantly less than HTA vehicles carrying similar payloads. These historical data for U.S. platforms are shown in Figure IV-15.

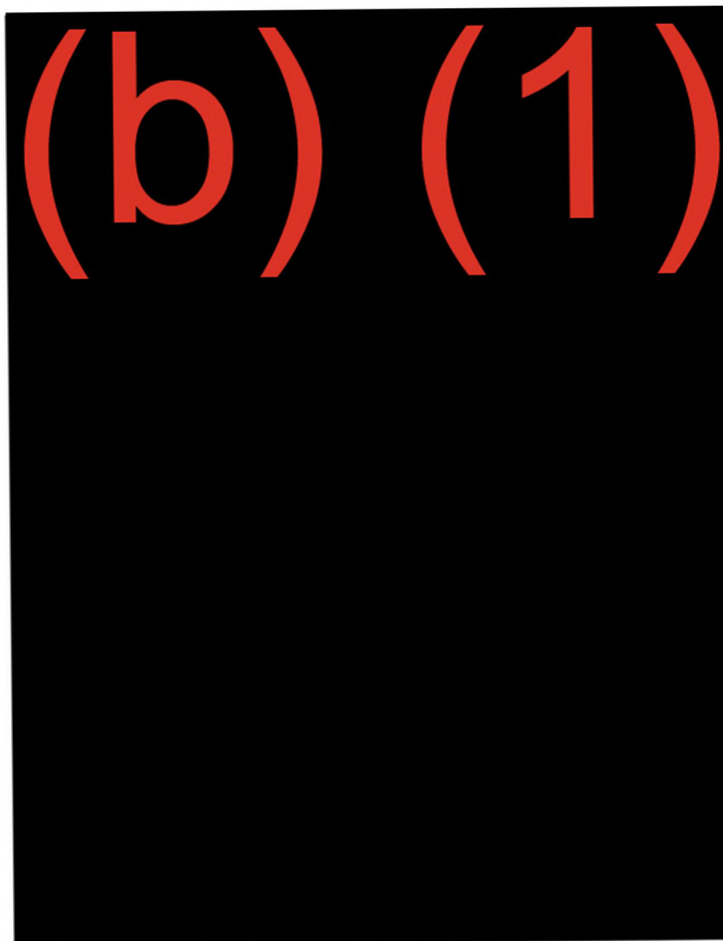
(U) In the 1930s, the cost of a rigid air-ship was several orders of magnitude more than that of an airplane.[†] However, as technical developments permitted, airplanes grew in size, speed, and cost, with the cost increasing at a much greater rate than a price index would indicate. This trend of increasing airplane costs with time is shown in Figure IV-15; in addition, the broad band representing costs for "100-kt" airplanes is included to indicate a trend in which performance



~~(C)~~ Figure IV-14. AIR PLATFORM COST AS A FUNCTION OF BUY SIZE (U)

* The most recent airship actually constructed and in the data base is the HINDENBERG.

† It is not known whether the much larger payload of the rigid airship was considered by the decision-makers in the 1930s or whether their decision was based on cost.



(C) Figure IV-15. HISTORICAL TREND OF HTA AND LTA PLATFORM COSTS (U)

levels are not significantly increasing.* The performance limits of recent LTA vehicle designs are about the same as those of the AKRON and MACON, and their estimated costs seem to correspond with a price index growth rather than with the price index plus improved performance growth experienced with airplanes.

(U) In Figure IV-15, the ANVCE point design cost estimates are plotted in then-year dollars, assuming an annual price index growth of 10 percent.

(U) A further indication that the ANVCE cost estimate for FAB of \$63 million may not be too low came from an examination of two published reports that give CERs for LTA vehicles. Coughlin (Reference 17) provided a cost estimating procedure based on airframe weight, power-plant horsepower, and lifting-gas cost; when the CER was applied to FAB, the resulting cost estimate was less than \$10 million. In a University of Houston study for the National Aeronautics and Space Administration (NASA) (Reference 8), the CER was assumed to be a conservative \$5.00/ft³ in FY-75 dollars, which translates to a FAB cost of about \$58 million in FY-77 dollars.

* The use of commercial airplane data for the 1970s does not interfere with the general trend. The approximate factor-of-two difference between military and commercial airplanes of a similar nature would not alter the general trend.

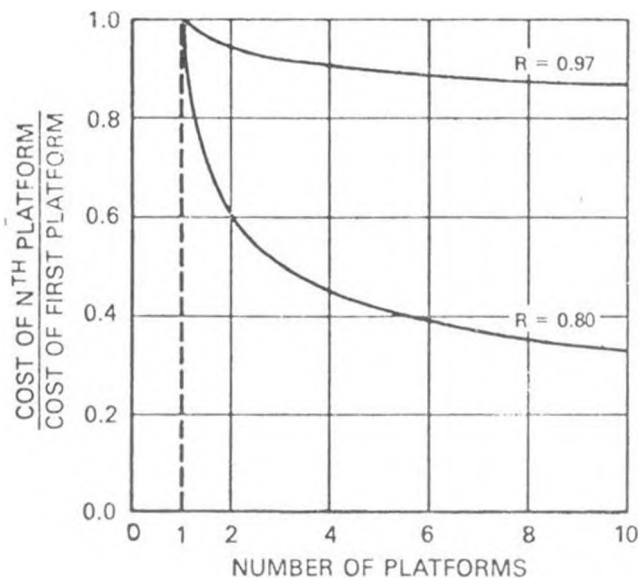
2. VEHICLE COSTS

2.1 Introduction

(U) Vehicle costs consist of platform costs (Section 1 of this chapter) plus combat suite costs, including the costs of the basic equipment, related expendables (e.g., ordnance), and subvehicles (Appendix B). Thus, the results discussed include (a) the average cost of the individual vehicles as a function of the size of the buy, which reflects the impact of the learning rate, and (b) the breakdown of average costs by platform costs and combat suite costs (including ordnance and subvehicles).

(U) However, caution must be used in the interpretation of these results. As stated in Chapter I, it was assumed that one air vehicle (but no surface vehicles) would be purchased out of the R&D appropriation. This assumption, while appropriate for the LCC analysis (Section 3 of this chapter), tends to add confusion to the discussion in this section with respect to the cost of the first vehicle. Is the cost of the "first" air vehicle the cost of the first R&D vehicle or the first operational vehicle? Given the high learning rate for air platforms ($R = 0.80$), the difference is quite significant. As shown in Figure IV-16, the second air platform is only 60 percent of the cost of the first air platform.

(U) However, the intent here is to show the comparative costs of air and surface vehicles without regard to the number of vehicles procured for R&D purposes. Therefore, for the purpose of this presentation, the cost of the air and surface vehicles will be presented as they are, without distinguishing whether the vehicle is an R&D or operational vehicle.



(U) Figure IV-16. PLATFORM COST AS A FUNCTION OF BUY SIZE

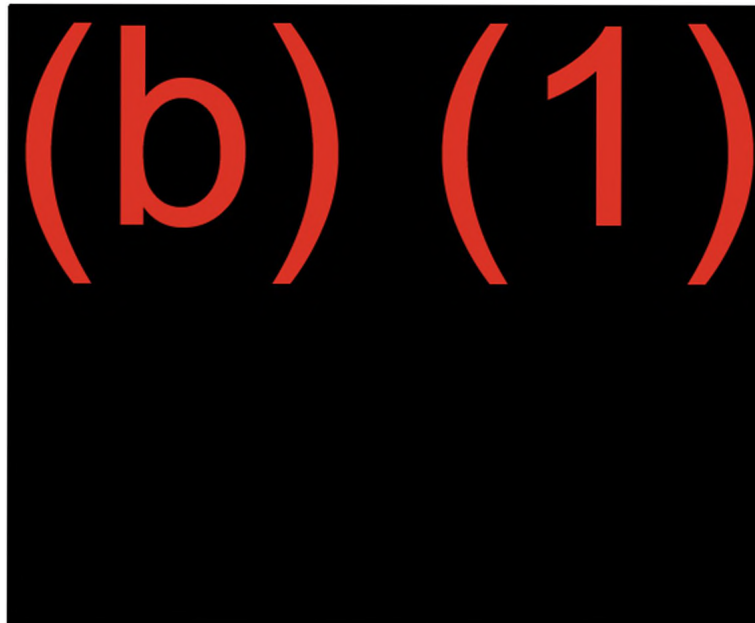
2.2 Cost Summary

(U) The estimated cost of the first and second vehicles (surface and air) constructed are summarized in Table IV-4. The difference between the costs of the first and second vehicles primarily results from the change in platform costs. For surface vehicles, the cost of the combat suite for the follow vehicle is generally 10 percent lower than that for the lead vehicle. After the first follow vehicle, no further learning-rate reductions occur. For air vehicles, the cost of the combat suite is the same for the second vehicle (and all other vehicles) as that for the first vehicle, i.e., no learning was assumed for the air combat suite.

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

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

~~(C)~~ Table IV-4. COSTS OF FIRST AND SECOND VEHICLES (U)

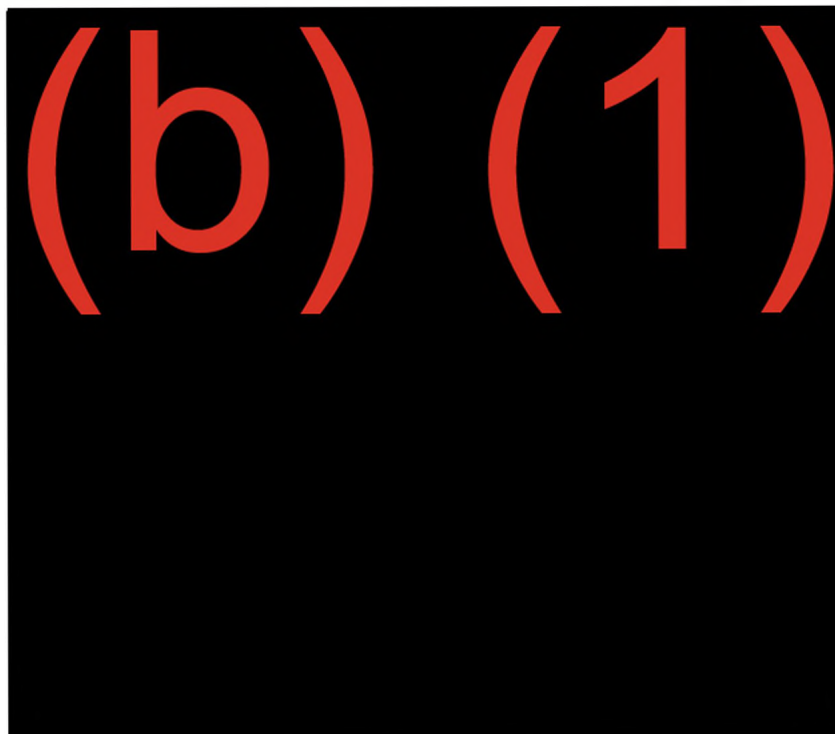


(U) The average vehicle cost as a function of the size of the buy is shown in Figures IV-17 through IV-19. For buys of "tens" of vehicles, learning no longer has any significant impact on surface vehicles. However, for similar buys the average air vehicle cost is still decreasing at a significant rate because the learning rate associated with the air platforms is higher and the combat suite cost portion of the total cost is relatively low.

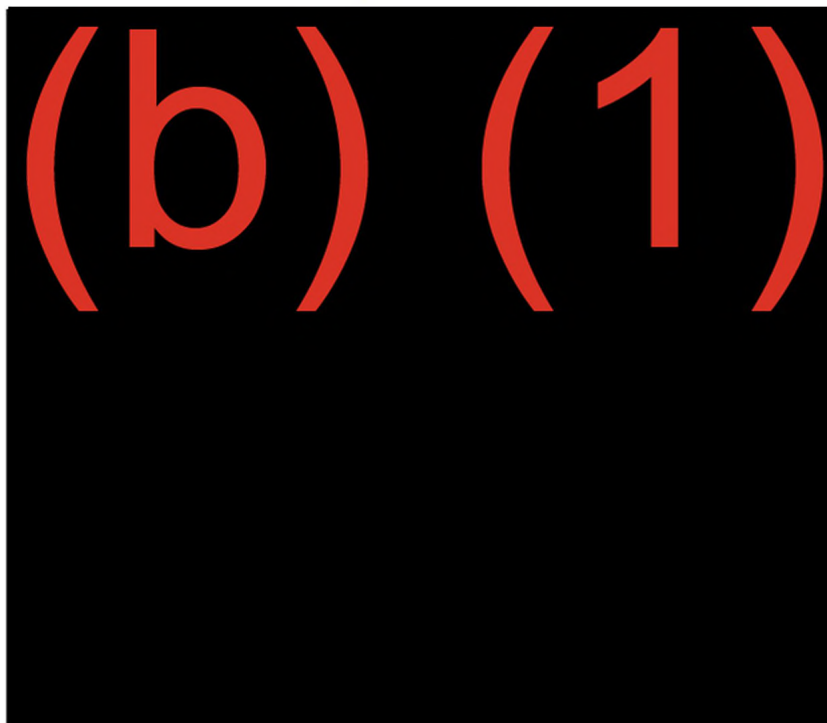
~~(C)~~ (b) (1)



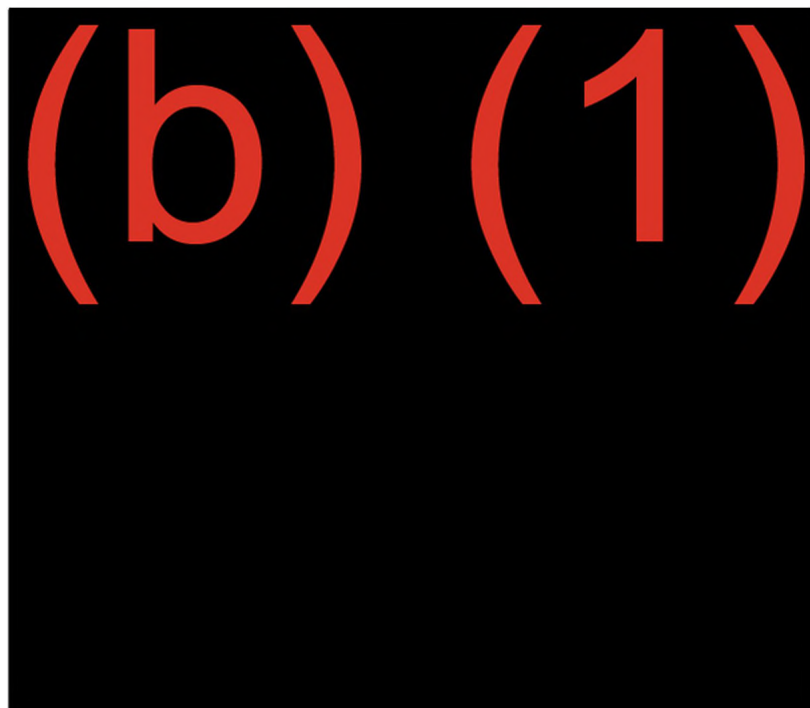
(U) Therefore, the best way of comparing the two vehicle classes is on the basis of buys of equal cost. For \$5 billion, about three times as many air loiter aircraft could be purchased as surface vehicles of the 3000-tonne class. For \$10 billion, the ratio is three to four, and the ratio continues to increase as the amount spent increases. This increase results from the high platform learning rate and the relatively low combat suite cost (which has no learning rate).



~~(C)~~ Figure IV-17. SURFACE VEHICLE COST/QUANTITY RELATIONSHIP (U)



~~(C)~~ Figure IV-18. AIR VEHICLE COST/QUANTITY RELATIONSHIP (U)



~~(C)~~ Figure IV-19. AIRCRAFT CARRIER VEHICLE COST/QUANTITY RELATIONSHIP (U)

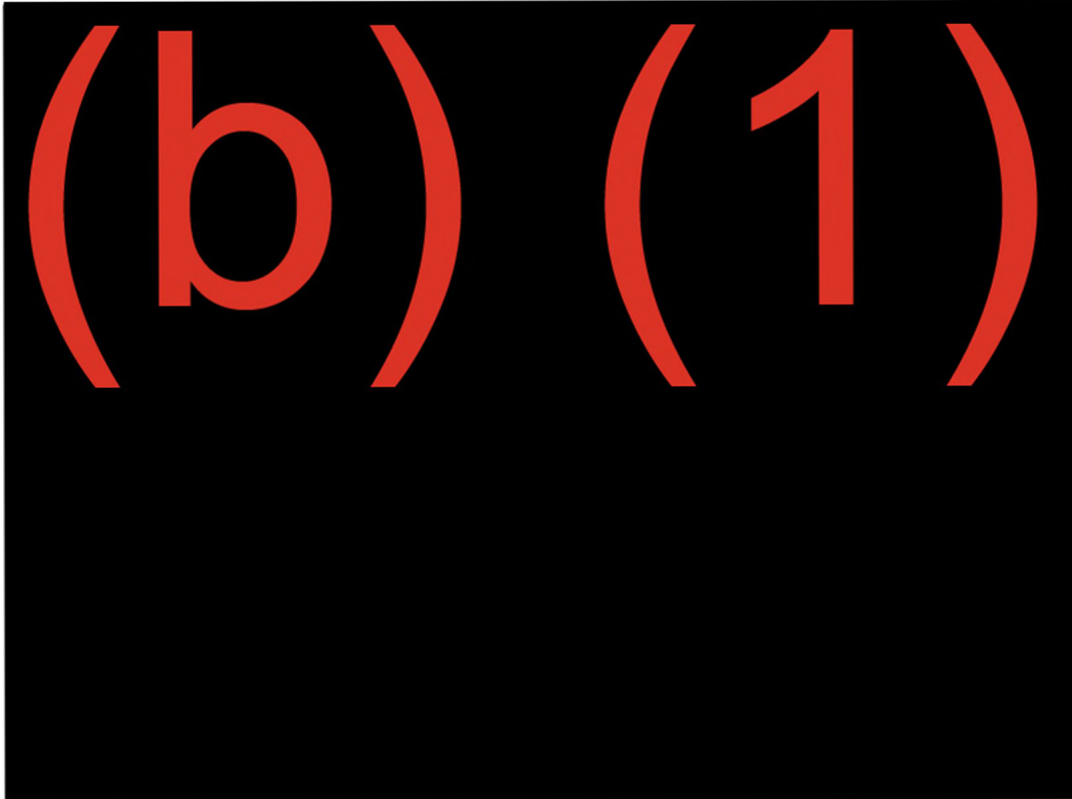
3. LIFE-CYCLE COSTS

(U) Life-cycle costs, based on an operating period of 15 years, were computed for each of the point designs considered in the ANVCE Project. The methodology and assumptions for computing the LCCs were addressed in Chapter III. Computations for "buys" of 3, 25, and 100 vehicles are given in Appendix C. Table IV-5 summarizes the estimated LCC for a buy of 25 vehicles according to the four major LCC categories—R&D, investment, O&S, and residual value.

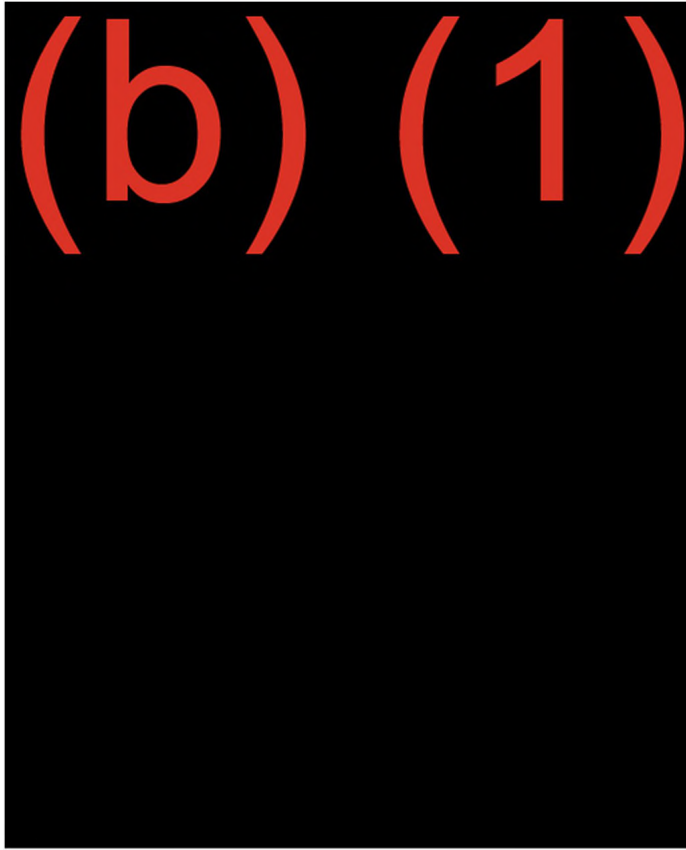
(U) The most immediate observation is that the LCC results correlate almost directly with the platform and vehicle cost results presented in Sections 1 and 2 of this Chapter. That is, there were no cases in which the higher vehicle costs were offset by reduced R&D or O&S costs. This correlation partially results from the fact that three of the O&S CERs (operations, maintenance, and major support) use the vehicle weight and costs as inputs and the principal R&D CER uses platform and combat suite costs as inputs. This observation held true even for the SES CV and SES CVN where the only design difference was the propulsion system. Both of these carriers had the same estimated annual O&S cost—about \$55 million/year. However, the energy cost of \$3.2 million/year for the SES CVN is lower than the energy cost of \$4.6 million/year for the SES CV.

~~(C)~~ Table IV-5. SUMMARY OF LCC'S FOR A BUY OF 25 VEHICLES (U)

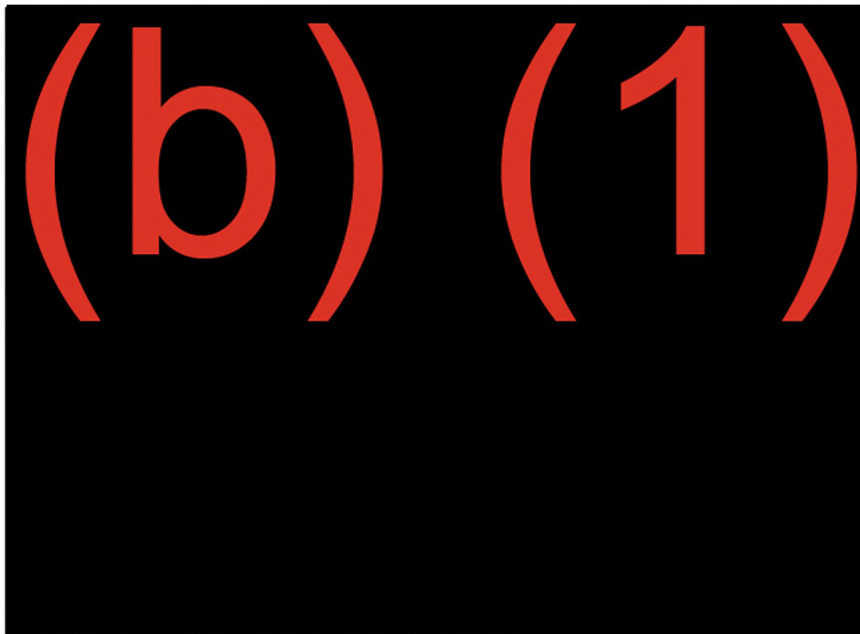
(U) LCC as a function of the size of the buy is shown in Figures IV-20 through IV-22. There are only a few cases in which the size of the buy affects the relative cost ranking of the vehicles. Where these exceptions occur (indicated by the crossovers on the figures), the buy size is relatively small and the crossover is indicative of a relatively high R&D cost (relative to vehicle cost) associated with several of the vehicles considered.



~~(C)~~ Figure IV-20. LCC AS A FUNCTION OF QUANTITY FOR SURFACE COMBATANTS (U)

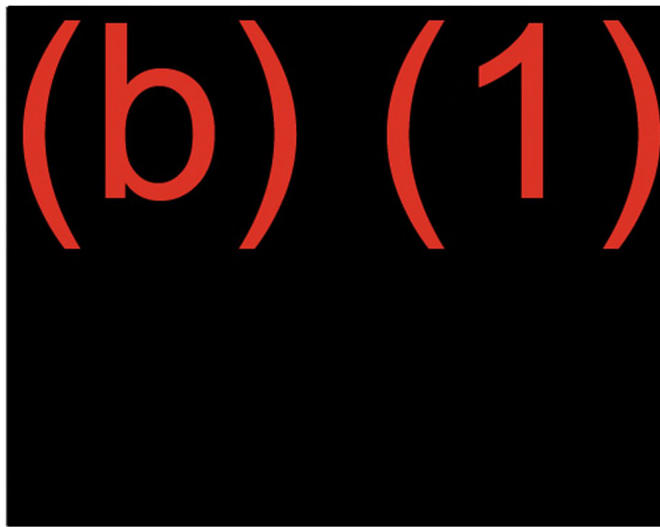


~~(C)~~ Figure IV-21. LCC AS A FUNCTION OF QUANTITY FOR AIR COMBATANTS (U)

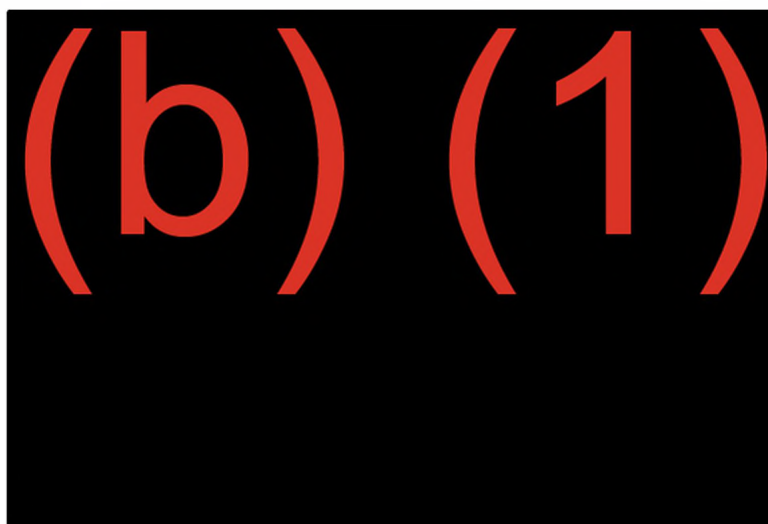


~~(C)~~ Figure IV-22. LCC AS A FUNCTION OF QUANTITY FOR AIRCRAFT CARRIERS (U)

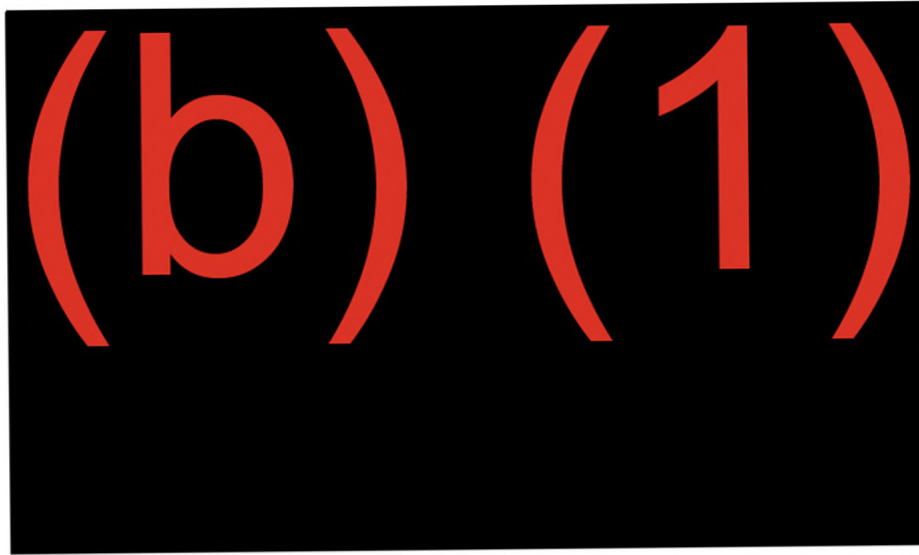
(U) The breakdown of LCC according to the major contributors of R&D, investment, and O&S costs is indicated in Figures IV-23 and IV-24 for the A/L and ACV 3, respectively as typical examples of the air vehicle and surface vehicle groups. These data are plotted as a percentage of total LCC in Figures IV-25 and IV-26. These plots show the relative impact on total system cost of each component as a function of the size of the buy and indicate the differences in distribution between air and surface vehicles. For buys of "tens," the major observation is that for air vehicles, nonrecurring costs are a much larger fraction of the total LCC than they are in the case of surface vehicles. For example, for a buy of 20-30 vehicles, the fraction of LCC attributable to nonrecurring costs is 80 percent for the A/L and 60 percent for the ACV 3.



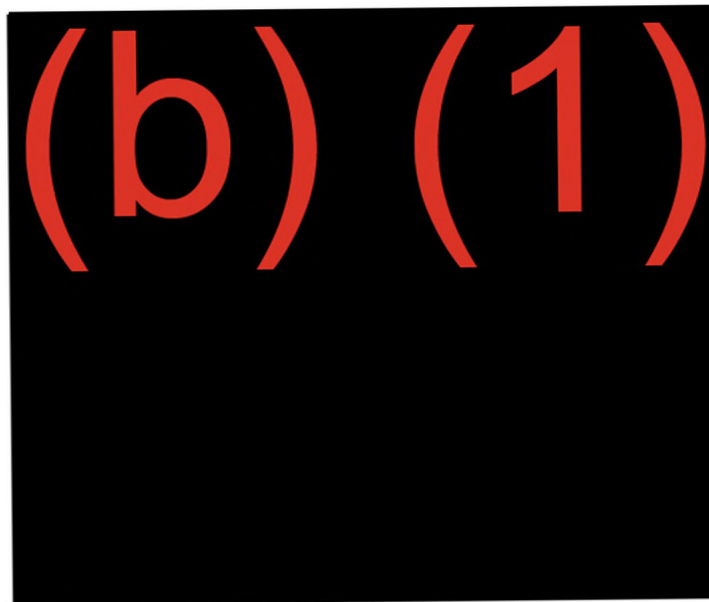
~~(C)~~ Figure IV-23. LCC BREAKDOWN AS A FUNCTION OF QUANTITY FOR AIR LOITER AIRCRAFT (U)



~~(C)~~ Figure IV-24. LCC BREAKDOWN AS A FUNCTION OF QUANTITY FOR ACV 3 (U)



~~(C)~~ Figure IV-25. LCC DISTRIBUTION FOR AIR LOITER AIRCRAFT (U)



~~(C)~~ Figure IV-26. LCC DISTRIBUTION FOR ACV 3 (U)

(U) For the surface combatants as a whole, and within each design group, the R&D plus investment costs are quite close, the total spread being approximately 20 percent. The differences among the LCCs are principally related to the O&S costs, and the principal differences in the O&S costs result from the energy costs.

(U) For the air combatants, however, the major difference among the LCCs results from the R&D plus investment costs, which are dependent on the size of each of the point designs. It is also worth noting that the energy costs are a much less significant factor for the air combatants than for the surface combatants.

4. SELECTED ASSESSMENTS

(U) The previous sections in this chapter presented the direct results of computing the platform, vehicle, and LCCs for the ANVCE point designs. This section discusses a few of the observations made in the ANVCE Project with respect to the cost of these advanced naval vehicles, particularly the cost of speed, the potential for cost reduction, and the cost of lightweight, nuclear propulsion (LWNP).

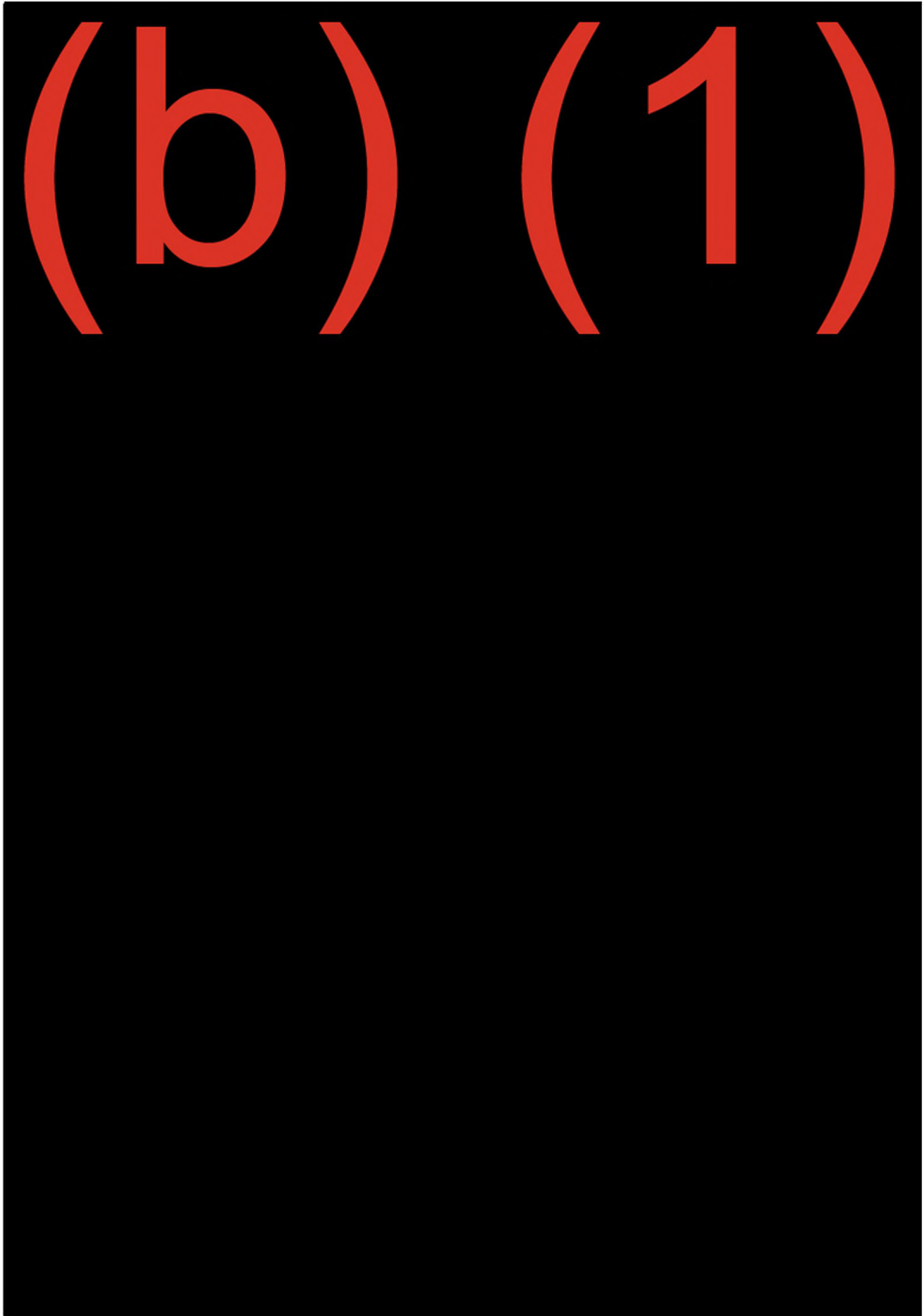
4.1 Cost of Speed

(U) Higher speed has an impact on the cost of ANVs in the cost of lighter-weight structures, the cost of the dynamic-lift systems (for cushion and foil vehicles), the cost of the higher installed power, and the cost of increased fuel consumption. The first three items affect the cost of the platform; the energy cost and the platform cost affect the LCC.

(U) Figure IV-27 presents the platform cost and LCC as a function of design speed for the surface combatants. The implication is that the major cost increase occurs as the design speed is increased above 30 kt. The envelope of the ANVCE cost estimates shows the cost curve, which appears to flatten out with increasing design speed; however, for each concept (ACV, hydrofoil, etc.), a cost-speed relationship would show a rapidly increasing cost as speed is increased.

(U) Note also on Figure IV-27 the inclusion of a high-L/B SES design. This design is a 3600-tonne, 50-kt vehicle postulated as a lower speed and lower cost alternative to the SES 3 (Volume 2). As shown, the platform cost and LCC were indeed lower; the platform cost is lower primarily because of the reduced propulsion cost and the LCC is lower primarily because of the lower platform cost and lower energy cost.

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~~(C)~~ Figure IV-27. COST AS A FUNCTION OF DESIGN SPEED FOR SURFACE COMBATANTS (U)

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4.2 Cost Reduction Options

(U) As stated in Section 1 of this chapter, the major contributors to surface platform costs were hull structure (Group 1), propulsion (Group 2), and auxiliary systems (Group 5). Two analyses were performed to determine the potential for reducing Group 1 costs; the first dealt with the issue of hull fabrication in a shipyard vs. an aerospace plant, the second dealt with aluminum vs. steel hulls.

(U) One thesis about the cost of advanced surface vehicles is that the costs could be significantly reduced if the hull were fabricated in a shipyard, aerospace plant costs supposedly being higher because of the construction methods and standards required in the aerospace industry. To examine this thesis, the 50-kt SES was costed using two different Group 1 coefficients. The first Group 1 coefficient ($KN = 5.59$) was derived from hydrofoil and SES cost data from aerospace companies (Appendix A) and was used for the SES 3; the second Group 1 coefficient ($KN = 2.19$) was derived from data on planing boat fabrication costs in small boat-yards (Appendix A).

(U) The cost estimates using the two approaches are given in Table IV-6. As indicated, the difference in the Group 1 costs is approximately \$18 million, which leads to an estimated 16 percent lower cost for Groups 1 through 7 when constructed in a shipyard instead of an aerospace company. The Δ costs, enclosed in parentheses, may be artifices of the CERs, i.e., the Group 8, Group 9, profit, and NAVSEA factors are determined by the Group 1-7 cost and *not* by the type of platform or where (how) it is constructed. Nonetheless, whether the potential cost saving is \$18 million or \$80 million, further exploration of the construction alternatives appears warranted. (Note that the high-performance craft of other nations are built in shipyards, and as indicated in Section 1 of this chapter, they appear to be less expensive per tonne than U.S.-built, high-performance platforms.)

(U) The second factor examined was whether the use of a steel or aluminum structure would have a significant impact on cost. To resolve this issue an analysis was performed using the SWA 4, an aluminum-hulled design of 3408 tonnes. The steel version developed had a full-load displacement of 3925 tonnes with the same payload and range as the aluminum version. This comparison is shown in Table IV-7. In this case, the potential cost reduction is about \$9 million, or approximately 10 percent. Therefore, it appears that in designing SWATH (small-water-plane-area, twin-hull)-type platforms the use of aluminum rather than steel hulls should be considered.

~~(C)~~ Table IV-6. COMPARISON OF LEAD-SHIP PLATFORM COST
FOR 50-kt SES CONSTRUCTED IN A SHIPYARD
VS. AN AEROSPACE COMPANY (U)

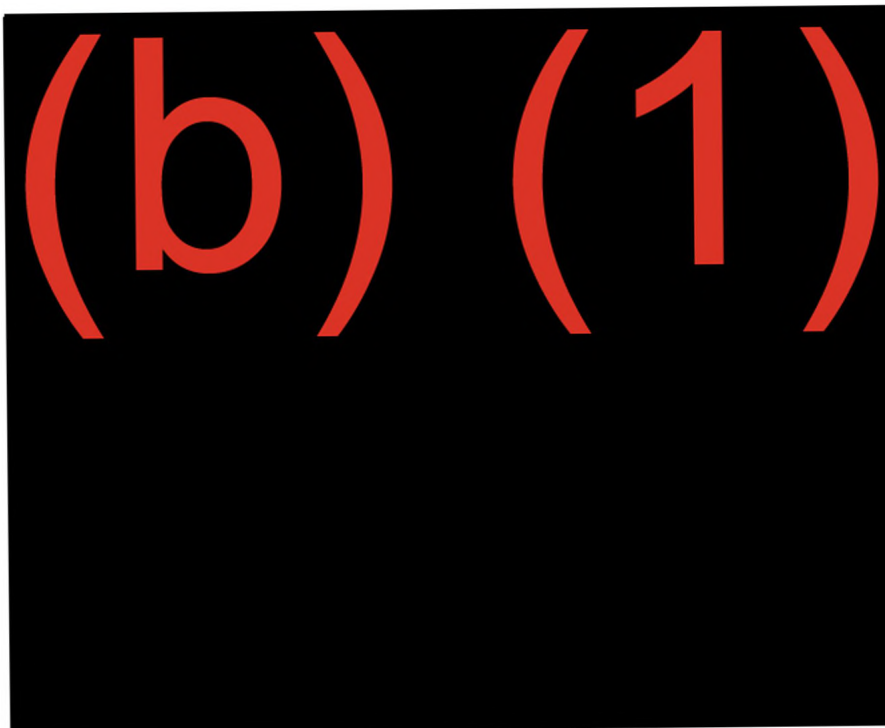


Table IV-7. COMPARISON OF LEAD-SHIP PLATFORM COST FOR
SWA 4 CONSTRUCTED OF ALUMINUM VS. STEEL (U)

COST FACTORS	HULL FABRICATION COSTS (FY-77 \$ MILLIONS)		Δ COST (FY-77 \$ MILLIONS)	Δ WEIGHT (TONNES)
	ALUMINUM	STEEL		
GROUP 1	15.9	11.2	4.7	513.5
GROUP 2	33.0	33.0	—	
GROUP 3	5.9	5.9	—	
GROUP 4	4.4	4.4	—	
GROUP 5	15.8	15.8	—	41.9
GROUP 6	8.5	4.7	3.8	
GROUP 7	1.9	1.9	—	
SUM (1-7)	85.4	76.9	8.5	471.6
GROUP 8	130.3	116.0	(14.3)	
GROUP 9	22.5	20.6	(1.9)	
CONSTRUCTION COST	238.2	213.5	(14.7)	
PROFIT	35.7	32.0	(3.8)	
CONSTRUCTION PRICE	273.9	245.5	(28.4)	
NAVSEA FACTORS	91.8	82.4	(9.4)	
TOTAL	365.7	327.9	(37.8)	

4.3 Cost of Lightweight, Nuclear Propulsion

(U) The feasibility of applying LWNP to an ANV* is addressed from a technical standpoint in Volume 2. This section discusses the question of whether the increased investment cost of nuclear-powered platforms is offset by reduced operating costs.

(U) The results of the ANVCE cost estimates indicate that there are no net savings with nuclear-powered vehicles. In the case of the A/L(N), the platform size was significantly larger than that required for conventional aircraft, increasing the cost. In fact, for a vehicle the size of the A/L(N), the energy cost (predicted on an annual basis) is greater than the annual cost of JP-5 fuel for the A/L.

(U) In comparing the SES CV and the SES CVN, the energy cost of the SES CVN was approximately 30 percent less than that of the SES CV; however, the total annual O&S costs were within 1 percent of each other. In fact, the LCC of the SES CVN was greater than that of the SES CV by approximately 7 percent for an assumed buy of 25 vehicles.

* It has been assumed throughout this study that LWNP is technically feasible, although issues related to its feasibility were not examined in detail. Only its application to ANVs was fully examined in this study.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

(U) This chapter highlights some of the findings and conclusions reached with respect to estimating the acquisition and LCCs of the ANVCE point designs and provides some general recommendations for future cost analysis efforts.

1. FINDINGS AND CONCLUSIONS

(U) Confidence in the estimates of platform acquisition and life-cycle O&S costs of *any* vehicle is dependent upon the quality of the CERs and whether they appropriately reflect the essential features of the candidate designs. In some areas, a CER could not be developed because of the confusion and misinformation regarding the cost data bases available. Experience gained in the ANVCE Project indicates that the *true* costs (either acquisition or life cycle) of vehicles to the government are generally not known either inside the U.S. Navy or in industry.

(U) Among the surface vehicles, the platform CERs were based on the SWBS groups and for Groups 1 through 7 attempted to relate the cost group and the essential features of each subsystem. More than 50 percent of the total platform acquisition cost, however, is in Groups 8 and 9 and the various NAVSEA planning factors, which are dependent on the Group 1-7 costs. Thus, the unique features of each platform had a less direct effect on total cost than was expected.

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

(U) Platform acquisition cost and energy costs are the two principal elements of LCC which reflect the platform-unique differences. Where platform and combat suite costs are nearly the same, the major LCC differences are in energy costs. Most of the major CERs used for estimating O&S costs do not depend primarily on platform-unique features, but rather, are based on the cost of the platform as an input. For example, the maintenance cost is a function of vehicle cost, manning, and vehicle weight. Thus, potential hydrofoil LCC savings through use of titanium foils (with reduced maintenance) as opposed to steel foils are not reflected in the LCC model; in fact, the estimated maintenance costs with titanium foils are higher because of the increased platform cost of a hydrofoil designed with titanium foils.

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

(U) The cost/speed curves for the dynamic-lift concepts are generally flatter than for the displacement hulls; however, the dynamic-lift concepts have higher platform costs at speeds below the crossover point. This difference reflects the additional cost imposed by the lift system.

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

- For speeds up to 30 kt, a displacement-type ship offers the lowest cost alternative.
- For higher speeds, dynamic-lift vehicles provide the lower-cost design solution but at a higher cost than for the displacement ship with a speed of 0-30 kt.
- Although the absolute platform cost increases with increased design speed, the relative rate of increased cost diminishes with increased speed as the dynamic-lift vehicles are introduced.
- There is a significant cost threshold to overcome when exceeding the 30 kt limit of the displacement ship.

(U) Among the air vehicles, the platform CER for HTA craft was based on a parametric relationship involving AMPR weight, speed, and thrust. While this approach may be valid when applied to configurations similar to those in the cost data base (e.g., AVP), it is certainly questionable to apply the same relationship to radically different configurations such as the WIG(O) and S/L(L). For rigid LTA vehicles, the data base is 46 years old.

(U) LTA vehicles appear to offer potential for significantly lower cost as maritime patrol options where minimum response time or very high speed is not required. This observation is probably a result of the relative technology standstill associated with the LTA concept, compared with other HTA, long-endurance vehicle alternatives.

2. RECOMMENDATIONS

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

- Common cost reporting schemes should be integrated into U.S. Navy construction contracts to record actual costs in each functional area (weight groups, designs, services).
- The ANVCE LCC model should be developed further so that the effects of vehicle functional parameters and design and manufacturing choices on platform and operating costs can be better reflected.
- Further investigation into the costs of LTA vehicles should be preceded by the development of a data base on engineering cost estimates for today's labor rates, labor productivity, and material costs.

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