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SIMPLE RELATIONSHIPS FOR ESTIMATING PROCUREMENT COST OF U.S. NAVY SHIP CATEGORIES

Pythagoras Cutchis
James H. Henry

March 1982

INSTITUTE FOR DEFENSE ANALYSES
INTERNATIONAL SECURITY ASSESSMENT DIVISION

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A common first step in estimating costs of naval ship categories is to use a linear relationship based on ship displacement. Such estimates represent rough initial approximations. This process can be used, however, with better accuracy to estimate the cost of procurement of aggregations of naval ships and classes. Cost estimating relationships (CERs) are developed in this paper for such applications.

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IDA Independent Research Program

PREFACE

For over a decade IDA has been engaged in comparing U.S. and USSR military RDT&E and acquisition programs in various mission areas and as a whole.

These comparisons are being done in a number of different ways and use a number of different measures. Some measures are appropriate for particular mission areas only (e.g., gross weight, maximum speed, maximum range, etc.), and others are more generally applicable (production, force levels, investment, etc.).

Investment or acquisition cost can be a particularly useful metric, but there is usually great difficulty in acquiring or developing suitable data. The Soviets do not publish aggregate data on military investment suitable for direct international comparisons. This information has to be developed in other ways. One way to estimate costs is to relate known U.S. RDT&E and acquisition costs to weapon system characteristics that are observable or determinable. Then the resulting cost estimating relationship can be applied to cost both U.S. and USSR programs. Fortunately, for broad, general comparisons it is not absolutely necessary that the cost estimates be accurate for each system type--only that overestimates be approximately matched by underestimates--to yield an aggregation that is adequate for trend comparisons.

Another difficulty is the determining of actual unit costs for large systems built over several years for the U.S. military. Such costs are difficult to estimate even after the system is delivered. For shipbuilding the cost is particularly difficult to establish for reasons discussed in this report. And the relevant data are often difficult to acquire.

This paper documents cost data and cost estimating relationships used in our comparison of U.S. and USSR general purpose naval forces.* It is presented primarily as an orderly record of information gleaned about U.S. naval construction costs in the hope that it may be of use to other analysts.

The reader is cautioned that the cost estimating methods that are developed here are not designed to forecast the costs of any particular ship or ship class, although they can be a useful first approximation. They are designed as a part of general comparative studies of military trends.

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*James H. Henry, Norman B. Davis, Margaret M. Mathews, J. Trevor McIntyre, Margaret S. Spencer, "Comparison of U.S. and USSR General Purpose Naval Fleets: Briefing Summary," IDA Paper P-1529, February 1981.

CONTENTS

CONTENTS (Continued)

SUMMARY

A common first step in estimating costs of naval ship categories is to use a linear relationship based on ship displacement. Such estimates represent rough initial approximations. This process can be used, however, with better accuracy to estimate the cost of procurement of aggregations of naval ships and classes. Cost estimating relationships (CERs) are developed in this paper for such applications.

In developing the CERs, the following procedures and limitations were applied:

1. Only costs for ships already delivered were used--not estimates of future procurement costs. All data came from U.S. Navy Sea Systems Command.
2. Costs were converted to constant 1979 dollars.
3. Procurement costs for follow-on ships of each class were averaged and standard deviations were calculated.
4. Costs for ship conversions were excluded.
5. A least-square fit to the data was used to determine the cost-displacement relationship.
6. When ship displacements of a given category (e.g., CVAs) were in a narrow range, the data points were interpreted as a scatter about a single point, and a centroid was located.
7. CERs which intersected the displacement (horizontal) axis were disallowed and the CER was forced to go through the origin (i.e., the estimate was not allowed to become negative for a positive displacement).

8. A constant ratio was assumed for the procurement cost of a nuclear powered ship to that of a non-nuclear powered ship of the same category.

The cost estimating relationships derived are summarized in Table S-1. The full load displacement D is in thousands of long tons and the average follow-on ship cost C is in millions of 1979 dollars. Also listed in Table S-1 is the percent difference between the actual average follow-on ship cost and the CER estimated cost for each class.

The error using the CERs for estimating the total procurement costs of a particular category of ships is less than the error that can occur in estimating the costs of individual classes in the same category because of cancellation effects. For example, the average ship class error for the category of attack submarines was 11.3 percent, whereas the error for costing the entire category of attack submarines was only 0.18 percent. For all the ships in the CER categories of Table S-1, the total procurement error was 1.8 percent. The error for a smaller number of ships is likely to be larger and will depend on the particular characteristics of each class and the number of classes included. In 1979, for example, there were 14 U.S. Navy ships commissioned among six classes. The total error of the estimate of procurement of all 14 ships was 3.2 percent.

TABLE S-1. SHIP COST ESTIMATING RELATIONSHIPS

($1979)

CLASS	LEAD SHIP HULL NO.	TOTAL NO. OF SHIPS COSTED	IOC	LEAD SHIP COST 79$M	AVERAGE FOLLOW-ON SHIP COST 79$M	FULL LOAD DISPLACE-MENT-KLT	ESTIMATE 79$M	% DIFF.	CER
AIRCRAFT AND HELICOPTER CARRIERS									
CV	59	4	1955	-	1,114	79.65	1,219	8.6	
	63	3	1961	-	1,299	80.3	1,229	-5.7	C = 15.3D
	67	1	1968	-	1,286	80.8	1,236	-4.0	
LHA	1	4	1976	-	577.9	39.3	601.4	3.9	
LPH	2	7	1961	-	229.6	18.9	289.21	20.6	
CVN	65	1	1961	-	2,239	91.0	2,017	-11.0	C = 22.2D
	68	2	1975	-	1,878	94.4	2,092	10.2	
ATTACK SUBMARINES									
SSN	578	4	1957	361.9	216.2	2.86	247.4	12.6	
	585	6	1959	358.3	255.9	3.50	270.0	5.2	
	594	13	1961	395.3	387.8	4.45	303.6	-27.7	C = 146 + 35.4D
	637	29	1967	329.8	294.1	4.582	308.3	4.6	
	688	14	1976	603.7	367.2	6.927	391.3	6.3	
SS	580	3	1959	170.6	100.6	2.639	100.6	-	C = 61.3 + 14.9D
DESTROYERS, FRIGATES AND PATROL ESCORTS									
DD	931	18	1954	211.5	135.7	3.950	115.8	-17.2	
FF	1021	10	1957	51.2	52.5	1.914	59.9	12.4	
	1033	4	1959	52.7	49.7	1.750	55.3	10.1	C = 7.2 + 27.5D
	1040	10	1964	121.0	108.2	3.344	99.2	-9.1	
	1052	10	1969	252.5	108.9	4.100	120.0	9.2	
DD	963	30	1975	340.1	221.3	7.924	226.3	2.2	
PG	84	10	1966	-	14.5	.26	14.4	-0.7	
GUIDED MISSILE EQUIPPED CRUISERS, DESTROYERS AND FRIGATES									
CG	16	9	1962	410.6	278.9	8.074	276.0	-1.0	
	26	9	1964	330.8	265.4	8.5	287.2	7.6	
DDG	2	23	1960	257.0	178.2	4.5	132.0	2.1	C = 63.5 + 26.3D
DDG/DLG	37	10	1960	335.5	259.4	5.96	220.3	-17.7	
FFG	1	6	1966	138.1	125.6	3.4	153.0	17.9	
	7	7	1977	452.8	169.5	3.605	158.4	-7.0	
AEGIS CG	47	18	1983	1,014	555*	8.9	555	-	C = 310 + 27.5D
GUIDED MISSILE EQUIPPED, NUCLEAR POWERED CRUISERS									
CGN	9	1	1961	-	1,672	17.1	1,052	-58.9	
	25	1	1962	-	765.7	9.2	625.9	-22.2	
	35	1	1967	-	579.3	8.8	604.3	4.1	C = 130 + 53.9D
	36	2	1974	-	711.3	10.53	697.6	-2.0	
	38	4	1976	-	591.4	11.0	722.9	18.2	
MAJOR AMPHIBIOUS SHIPS									
LPD	1	3	1962	-	210.7	14.651	170.4	-23.6	
	4	9	1965	-	160.8	16.913	196.7	18.3	
LCC	19	2	1970	465.0	256.6	17.0	197.8	-29.7	C = 11.6D
LSD	28	8	1954	-	114.2	12.0	139.6	18.2	
	36	5	1969	-	114.5	14.0	162.9	29.7	

*Estimated

TABLE S-1. (Continued)

($1979)

CLASS	LEAD SHIP HULL NO.	TOTAL NO. OF SHIPS COSTED	IOC	LEAD SHIP COST 79$M	AVERAGE FOLLOW-ON SHIP COST 79$M	FULL LOAD DISPLACE-MENT-KLT	ESTIMATE 79$M	% DIFF.	CER.
CARGO AND SUPPLY SHIPS									
LKA	113	5	1968	-	108.5	18.657	111.1	0.4	
LST	1171	7	1957	-	73.5	7.804	69.6	-11.2	
	1179	20	1969	-	83.1	8.4	71.9	-21.3	
AF	58	2	1955	-	95.2	10.68	80.6	1.4	
AFS	1	7	1963	-	104.4	15.54	101.2	-5.9	
AE	21	5	1951	-	88.0	17.45	106.5	15.5	C = 39.7 + 3.83D
	26	8	1968	-	130.0	19.937	116.0	-14.1	
AO	177	2	1981	-	157.2	27.5	145.0	-9.6	
T-AO	143	6	1953	-	128.3	38.0	185.2	30.6	
AOE	1	4	1963	-	313.4	52.483	240.6	-29.6	
AOR	1	7	1969	-	143.7	41.35	198.0	27.5	
MINE WARFARE SHIPS									
MSB	5	30	1952	-	5.6	.039	8.55	34.5	
MSO	427	36	1952	-	30.9	.87	34.8	11.2	
MSC	121	9	1953	-	32.7	.378	19.3	-69.4	C = 7.32 + 31.6D
MSI	1	2	1958	-	8.3	.24	14.9	44.3	
MCM	82	9	1985	-	50.7*	1.65	59.5	14.8	
DESTROYER AND SUBMARINE TENDERS									
AD	37	2	1967	-	240.0	18.54	260.6	7.9	
	41	1	1980	-	318.4	20.3	273.1	-16.6	C = 129 + 7.10D
AS	33	2	1964	-	265.1	21.0	278.1	4.7	
	36	5	1970	-	278.2	22.646	289.8	4.0	
TUGS AND SALVAGE VESSELS									
YTB	752	80	1959	-	2.0	.35	3.99	39.1	
ATF	166	6	1979	-	16.1	2.00	22.8	29.3	C = 11.4D
ATS	1	3	1971	-	40.8	3.2	36.5	-11.8	
SINGLE UNIT CLASS									
ASR	21	2	1973	-	204.2	4.53	204.2	-	C = 45D
PTF	17	10	1968	-	3.3	.105	3.3	-	C = 31.4D
PHM	1	6	1977	-	78.5*	.238	78.5	-	C = 330D
ACV	**	1	1970	-	4.2	.055	4.2	-	C = 76.6D

*Estimated

**UK-Wellington

INTRODUCTION

A. OBJECTIVE

The objective of this paper is to derive simple cost estimating relationships (CERs) suitable for estimating investment costs for various aggregations of naval vessels including those of foreign navies. These relationships are developed from the actual procurement costs of U.S. ships. More complex relationships (employing as many as nine variables) are available but these require detailed design information as inputs. In general, such input data are not available for foreign ships. We are therefore limited to the attributes derived from visible characteristics. The task of developing CERs is complicated by uncertainties in estimating actual ship procurement costs, variation in commissioning dates, changes in ship and weapons systems technology, approximations for deflation factors, shipyard variations, approximations in aggregating different classes of ships, variations in procurement size, modernization costs, etc. Despite these difficulties, a CER based on linear displacement models is adequate for the purpose intended. The CERs would be of lesser use in estimating the cost of a particular ship of specified design.

B. DATA SOURCE

The primary data source used for ship procurement costs was Navy Sea Systems Command. These costs are translated to constant 1979 dollars by applying the appropriate Navy ship construction deflation factors. Recently commissioned ships or soon-to-be commissioned ships are costed in more detail than older ships to include outlays on a year-by-year basis allowing appropriate deflation factors to be applied for each year of ship construction. For older ships, a single deflation factor was used corresponding to the year in which the ship was authorized. Procurement costs of older ships may therefore be slightly overestimated.

II. METHODOLOGY

A. COST-DISPLACEMENT MODELS

The cost estimating relationship (CER) developed in this paper relates the cost of each category of ship to its full-load displacement. This is a primitive relationship for measuring the actual cost of a particular ship design (although often used to develop an initial estimate). It is satisfactory, however, for developing estimates of aggregations of ship classes. Since the CER yields both high and low estimates, the result, when accumulated over many ship classes, is sufficiently accurate, particularly for comparative purposes.

The greatest difficulty is determining the "true" costs of each ship. To a considerable degree the assignment of costs is somewhat arbitrary particularly when several ships are being built in one shipyard. Many factors affect the actual costs, such as construction time, budget allocations, ordering, scheduling and so on. Some of these factors are discussed in this chapter.

The costs of ship construction, converted to constant 1979 dollars, are tabulated in Appendix B. Recorded here are the costs of most naval ships constructed in the United States since 1952.

The procurement cost for a ship class is the average cost of all ships (i.e. excluding the lead ship) in the class. The average procurement costs of different ship classes in each category, e.g., attack submarines, were related to their full load displacement. Although, when plotted, the human eye can fit the data points fairly well to a straight line, for purposes of reproducibility and increased accuracy, a least squares fit was used. The equation to be determined was

$$C = A + BD \tag{1}$$

where C is the average ship procurement cost, D is full load displacement, and A and B are constants. The fit involved determining the intercept A and the slope B. Negative values of A were disallowed since they imply that a ship of finite displacement could be built for zero cost. the simpler linear equation C = BD, which goes through the origin, was used on such occasions. The following forms of equations were also tested.

$$C = Ae^{bd} \tag{2}$$

$$C = AD^{B} \tag{3}$$

$$C = \frac{D}{A + BD} \tag{4}$$

In almost no cases were any of the above three forms found to yield better fitting solutions than the linear forms.

The least squares solution for the CERs is readily derived and is included in Appendix A.

The percentage error f_i of the average cost C_i of the ith class of ship with respect to the estimated value C_{ei} as given by the CER is defined to be

$$f_i = \frac{100(C_{ei} - C_i)}{C_{ei}} \tag{5}$$

In a few cases, e.g., CGNs, ship displacements were found to lie in a very narrow range. The data points were therefore interpreted to represent a scatter about a single point and a centroid was located by means of the equations

$$\overline{D} = \frac{\sum_{i=1}^{i=n} D_i}{n} \qquad (6)$$

$$\overline{C} = \frac{\sum_{i=1}^{i=n} C_i}{n} \quad . \qquad (7)$$

On occasion the CER is based on a single data point when only a single class is available. For example, the SS 580 class was the only class of diesel powered submarines for which cost data were available. The CER for SSs was therefore assumed to pass through the single data point with a slope which has a ratio equal to the slope of the SSN CER, divided by the ratio of the cost of a nuclear submarine with the displacement of the SS, to the cost of the SS. The validity of this method of determining the SS CER is based on the assumption that the propulsion-related cost of a submarine is proportional to displacement. Thus, let

$$C_n = A_n + (B_n + B_{pn})\, D \qquad (8)$$

$$C_d = A_d + (B_d + B_{pd})\, D \qquad (9)$$

where the subscripts n and d denote nuclear and non-nuclear respectively, and the subscripts pn and pd refer to the propulsion-related cost of the nuclear and non-nuclear respectively. Setting D = 0 in Eqs. (8) and (9) yields

$$\frac{C_n}{C_d} = \frac{A_n}{A_d} = R \qquad (10)$$

where R is a constant.

The ratio of the slopes of Eqs. (8) and (9) is

$$\frac{B_n+B_{pn}}{B_d+B_{pd}} = \frac{C_n-A_n}{C_d-A_d} = \frac{RC_d-RA_d}{C_d-A_d} = R \quad . \tag{11}$$

Therefore the equation of the cost of the diesel submarine is

$$C_d = \frac{A_n}{R} + \frac{\left(B_n+B_{pn}\right)}{R} D \quad . \tag{12}$$

The justification for Eqs. (8) and (9) lies in the assumptions that shaft horsepower for a particular class of ship tends to be approximately proportional to displacement, and that propulsion-related equipment cost in turn is proportional to shaft horsepower. Table 1 shows that for submarines of the same speed capability the ratio of shaft horsepower to displacement is approximately 3.4 over a wide range of submerged displacement, i.e., for the 4,450 tons of the SSN 594 to the 17,500 tons of the SSBN 726. Clearly for surface ships factors other than speed must enter to cause a spread in the values of this ratio. Electric power and ship design characteristics are two obvious factors. It is interesting to note, however, that the FF, DD, CG, and FFG ships have a ratio of approximately 10 (with the exception of the anomalous DD 931), while the DDG class has a ratio of approximately 15. The CGN class has a ratio of approximately 6, while aircraft carriers have approximately the same ratio as submarines, presumably because of their high length/beamwidth ratio. The PG 84 class has a very large ratio of 50 but has a maximum speed of over 40 knots.

B. DEFLATION FACTORS

In Table 2 and Fig. 1 are shown the Navy ship procurement and Navy aircraft procurement deflation factors from 1952-1983 as given by the office of the DoD comptroller. The Navy air procurement deflation factors are also representative of all other types of military procurement. It is interesting to note

TABLE 1. SHAFT HORSEPOWER-DISPLACEMENT RATIO

CLASS	SHP*	DISPLACEMENT** (KLT)	SPEED* (Knots)	SHP / DISP.
SSN-578	6,600	2.860	25	2.3
SSN-585	15,000	3.500	30 +	4.3
SSN-594	15,000	4.450	30 +	3.4
SSN-637	15,000	4.582	30 +	3.3
SSBN-726	60,000	17.500	--	3.4
DD-931	70,000	3.950	33	17.7
DD-963	80,000	7.964	33	10.0
FF-1040	35,000	3.344	27.5	10.5
FF-1052	35,000	4.100	27	8.5
DDG-37	85,000	5.960	33	14.3
DDG-2	70,000	4.500	30	15.6
FFG-1	35,000	3.400	27.2	10.3
FFG-7	41,000	3.605	29	11.4
CG-16	85,000	8.074	32.7	10.5
CG-26	85,000	8.500	32.5	10.0
CGN-35	60,000	8.800	29	6.8
CGN-36	60,000	10.530	30 +	5.7
CGN-38	60,000	11.000	30 +	5.5
CV-59	260,000	79.650	33	3.3
CV-63	280,000	80.300	30 +	3.5
CVN-65	280,000	91.000	35	3.1
CVN-68	280,000	94.400	30 +	3.0
PG-84	13,000	0.260	40 +	50.0

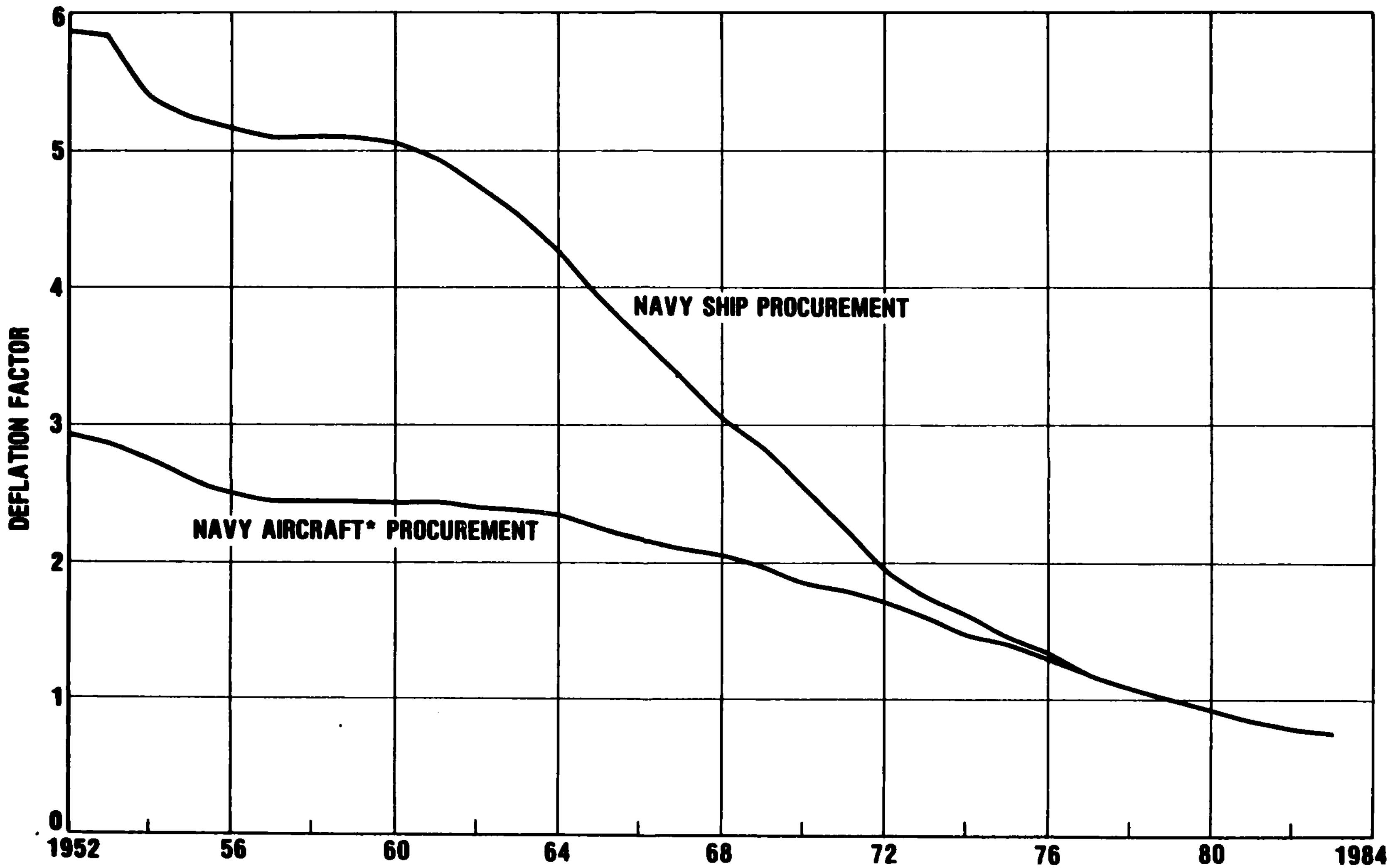
*Jane's Fighting Ships, 1979-1980.

**Submerged displacement for submarines and full load displacement for surface ships.

TABLE 2. NAVY SHIP CONSTRUCTION DEFLATION FACTORS

YEAR	DEFLATION FACTOR* NAVY SHIP PROCUREMENT	NAVY AIRCRAFT PROCUREMENT
1952	5.872	2.929
1953	5.532	2.858
1954	5.397	2.736
1955	5.230	2.604
1956	5.174	2.507
1957	5.087	2.454
1958	5.096	2.432
1959	5.091	2.419
1960	5.066	2.411
1961	4.961	2.411
1962	4.779	2.401
1963	4.545	2.374
1964	4.278	2.323
1965	3.916	2.253
1966	3.619	2.178
1967	3.323	2.104
1968	3.074	2.030
1969	2.854	1.951
1970	2.540	1.853
1971	2.230	1.789
1972	1.944	1.698
1973	1.769	1.591
1974	1.614	1.484
1975	1.472	1.388
1976	1.343	1.300
1977	1.191	1.189
1978	1.092	1.092
1979	1.000	1.000
1980	0.925	0.917
1981	0.857	0.847
1982	0.796	0.788
1983	0.739	0.738

*Source: OASDC, June, 1980



*Also representative of all other types of military procurement

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FIGURE 1. Comparison of deflation factors for Navy ship and aircraft procurement

that for the 1950s the deflation factors for Navy ship procurement are double the Navy aircraft procurement factors, indicating a large loss in ship construction productivity over the past 20 years.

An example of the manner in which "then year" dollars were converted into 79 dollars for each ship, by applying the appropriate deflation factor, is illustrated for the DD-967 in Table 3. The cost of the DD-967 in 79 dollars was almost double the cost in "then year" dollars. The DD-963 is a recently constructed ship; most of the Navy ships costed in this paper are much older and therefore have deflation factors in the range 2-5. The error in the deflation factor is unknown but can be expected to be greater for the older ships.

TABLE 3. ESTIMATED COST OF DD-967

BUDGET YEAR	MILLIONS OF "THEN YEAR" DOLLARS	DEFLATION FACTOR	MILLIONS OF 1979 DOLLARS
1970	4.5	2.540	11.4
1971	78.1	2.230	174.2
1972	1.9	1.944	3.7
1973	0.2	1.769	0.4
1976	11.6	1.343	19.1
1977	16.0	1.191	15.6
1978	5.6	1.092	6.1
	117.9		230.5

C. SHIPYARD COST VARIATIONS

Ships are either constructed in Navy shipyards or commercial shipyards. An extreme example of the variation in shipyard costs is illustrated for the LST 1179 class tank loading ship in Fig. 2. The first three ships of this class were constructed at the Philadelphia Naval Yard, and the subsequent

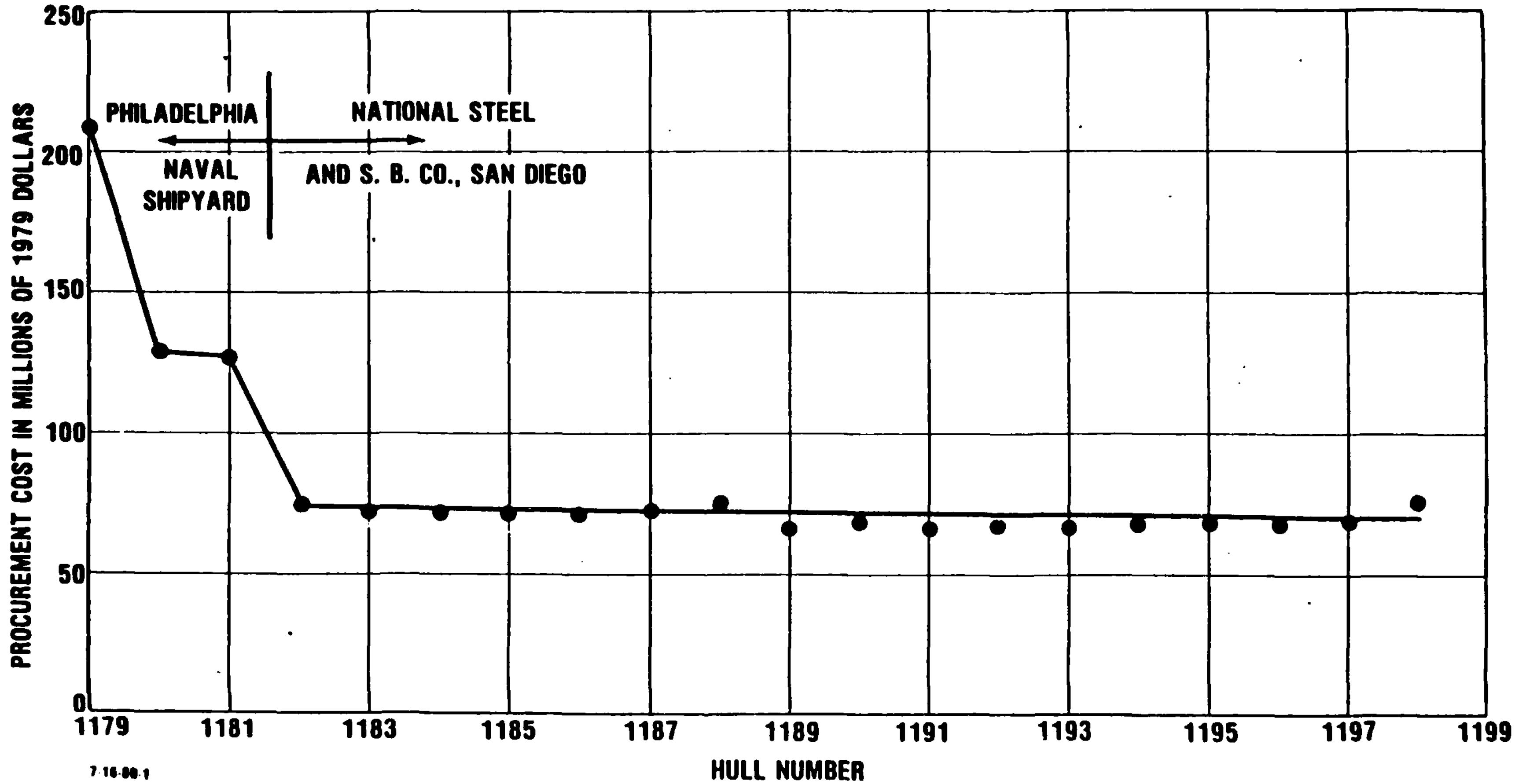


FIGURE 2. Procurement cost of LST 1179 class tank landing ship by hull number and shipyard

ships at the National Steel and Ship Building Co., San Diego. The follow-on ship costs for the two ships (hull numbers 1180 and 1181) constructed at the Philadelphia Navy Yard averaged $128 million in 1979 dollars or approximately 80 percent more than those constructed at the commercial shipyard. Such large variations are the exception rather than the rule, and shipyard cost variations are not therefore believed to play a very significant role in the accuracy of the CERs developed in this paper.

D. LEARNING CURVES

The data indicated that there is essentially no learning curve in most Navy ship construction. This is illustrated in Figs. 2 and 3 for the LST 1179, SSN-688 and the FFG-7 classes. The data for DD-963 class, on the other hand, did reveal a total cost reduction but only for the first dozen ships. This lack of a learning curve greatly simplifies the analysis since a single point, representing the average follow-on ship procurement cost for a given class of ships, suffices to define the CER. The larger the number of ships in a given class, the better is the estimate of the average procurement cost, but that number is not relevant to the definition of the CER.

E. STANDARD DEVIATION OF SHIP PROCUREMENT COSTS

In the CER figures derived for the major surface combatants and submarines, the standard deviation of the ship procurement data for each class of ship is included to illustrate the scatter of the cost data in a single class, and to show the differences in the standard deviation between classes.

The causes for the variation in ship procurement costs are complex. In addition to shipyard variations, there are differences in accounting procedures and differences in particular design characteristics. A breakdown of ship procurement costs into eight coded categories is shown for the lead ship and four follow-on ships of the DD-963, SSN-688, and FFG-7 classes

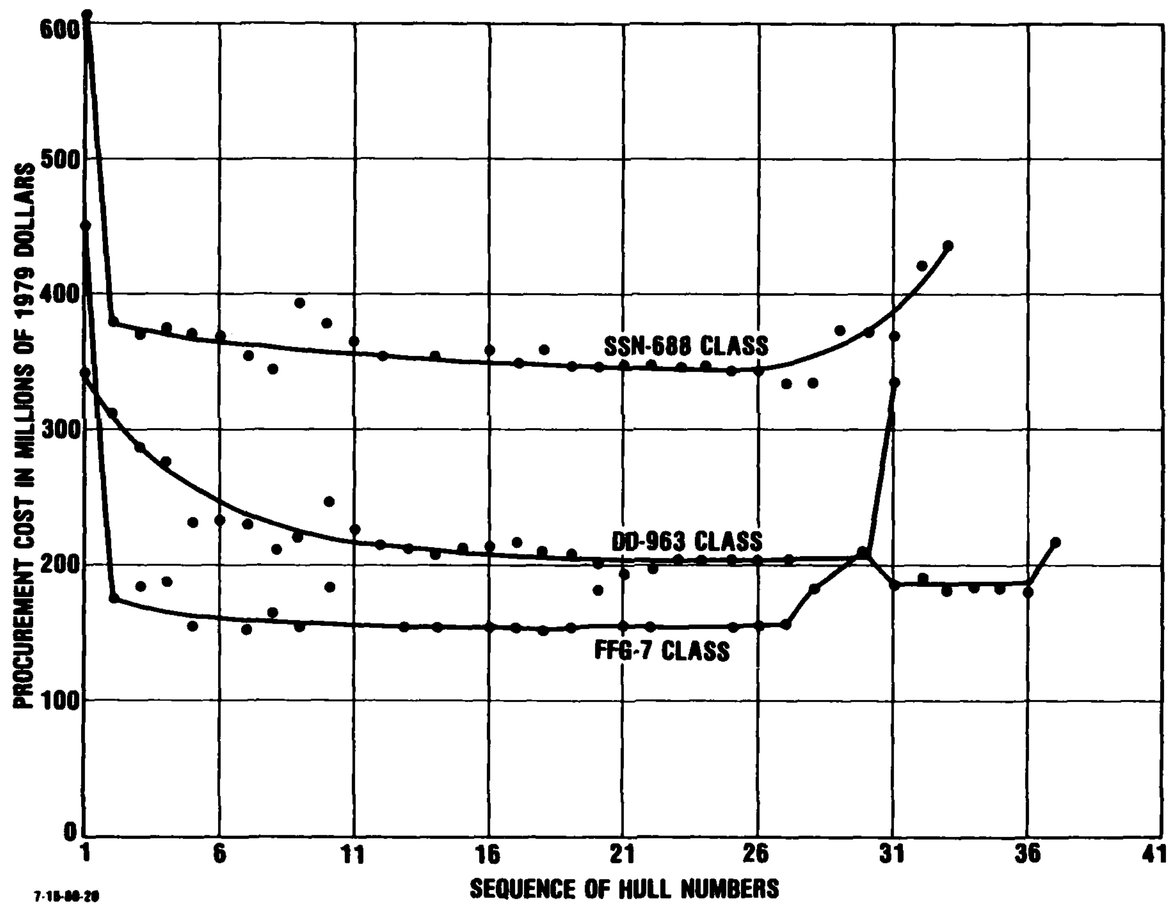


FIGURE 3. Ship procurement cost vs hull number

in Table 4. The DD-963 ships were all constructed in a single shipyard; both the SSN-688 and FFG-7 classes were constructed at more than one shipyard, but there is no indication that this resulted in any significant cost differences. Significant anomalies to be noted are the sharp drop in electronics costs after the DD-964, and in weapons systems costs after the DD-968; a sudden increase in plans and basic construction costs with the SSN-697, accompanied by a sudden decrease in costs of change orders; and a sudden increase in plans costs for the FFG-11, accompanied by a relatively large decrease in basic construction costs.

A more detailed cost breakdown by category is shown in Table 5 for two ships of the FFG-7 class, the FFG-28 and FFG-36. Note that large increases in FFG-36 construction costs, electronics, NAVSEA H/M/E Test/Instrumentation, fire control systems, and gun systems outweighed a large decrease in ordnance systems major components, resulting in an overall increase in total procurement cost of 26 percent. This particular comparison is an extreme case that was chosen to better illustrate the cost differences that may arise in two follow-on ships of the same class.

F. LEAD SHIP COSTS

The data disclosed a large variation in the cost of the lead ship relative to the cost of the average follow-on ship. An average increment in lead ship cost of 52 percent was calculated for 17 classes of surface combatants and submarines, i.e.,

$$\frac{\sum_{i=1}^{i=17} L_i - \sum_{i=1}^{i=17} F_i}{\sum_{i=1}^{i=17}} = 0.52 \tag{13}$$

TABLE 4. COST OF DD-963, SSN-688, AND FFG-7 CLASSES
(In Millions of FY 81 Dollars)

Category	DD-963 Class*					SSN-688 Class†					FFG-7 Class††				
	Hull Number					Hull Number					Hull Number				
	963	964	965	968	974	688	689	690	693	697	7	8	9	10	11
Plans	11	**	**	**	**	139	6	6	8	14	111	7	0	**	4
Basic	282	282	281	225	224	331	228	233	210	247	158	105	124	114	90
Change Orders	9	8	7	11	9	35	26	21	37	12	30	15	20	19	15
Electronics	43	37	6	5	2	63	48	45	38	31	20	16	16	16	13
Propulsion	0	0	0	0	0	77	75	75	87	81	0	15	15	15	13
Hull/M/E	2	1	1	1	1	29	44	41	41	42	83	4	4	4	4
Weapon Systems	45	36	39	32	16	23	11	8	8	11	101	43	42	47	45
Other	4	**	1	**	**	6	4	4	4	4	24	**	**	3	1
Total	397	364	335	274	252	704	442	434	432	443	528	204	221	218	184

*All DD-963 Class ships constructed by Ingalls Shipbuilding Corporation

**Less than 0.5 million

†SSN-688,-689, and -693 constructed by Newport News Shipbuilding Dry Dock Company; SSN-690 and -697 constructed by General Dynamics (Electric Boat)

††FFG-7,-8 and -11 constructed by Bath Iron Works;
FFG-9 by Todd Shipyards Corporation, San Pedro;
FFG-10 by Todd Shipyards Corporation, Seattle.

TABLE 5. COMPARISON OF COMPONENT COSTS OF FFG-28 AND FFG-36

Code	Description	FFG-23 Cost*	FFG-36 Cost*
111	Construction Plans	0	6.7
211	Construction	54.0	75.4
212	Cost Amendment	1.5	0.8
223	Miscellaneous Basic Items	0	0.2
291	Escalation Earned	1.1	3.0
311	Construction Changes (HMR)	7.4	8.9
312	Construction Changes (FMR)	4.7	5.1
321	Deferred Work Items	0	2.0
418	NAVSEA-Electronics Production	2.9	6.5
419	NAVELEX-Electronics Production	3.6	5.0
428	SONAR-Electronics Production	3.6	8.8
429	NAVSEA-Electronics Testing	0	0.1
439	NAVELEX-Electronics Testing	0.1	0.1
449	Sonar-Electronics Testing	0.4	0.4
462	SONAR-Electronics Repair Parts	0	0.1
521	NAVSEA H/M/E Propulsion Machinery	11.1	10.8
525	NAVSEA H/M/E Equipment	0.9	1.9
529	Small Boats Procurement	0.1	0.1
541	NAVSEA H/M/E Test/Instrumentation	2.1	11.8
543	NAVSEA H/M/E Engineering Services	0.1	0.1
561	SUPSHIPS Material/Services	0.7	0.6
814	Planned Maintenance Subsystems	0.1	0
824	NAVSEC In-House Engineering Services	0	0.1
825	Other In-House Engineering Services	0	0.5
827	Commissioning Ceremony	0.1	0.1
901	Fire Control Systems	0	11.9
902	Search Radars	0	1.7
904	Gun Systems	0	6.9
911	Ordnance Systems Major Components	37.0	13.9
931	NAVAIR Systems Major Components	0.1	1.5
951	Basic Construction Growth	2.1	0
952	GFM Growth	2.9	7.7
953	Escalation Reserves	20.0	18.6
		156.6	211.3

*In Millions of 1979 Dollars

where L_i is the lead ship procurement cost of the ith class and F_i is the average follow-on ship cost of the ith class. The 17 classes of ships included in Eq. (13) are indicated in Table 6 which summarizes, for each class of ship, the lead ship hull number and cost, IOC, number of ships of each class costed, average follow-on ship cost, full load displacement, estimated cost in 79 dollars, the CER and percent error with respect to the CER cost estimate. Only the cases of the AEGIS CG, which has an expected IOC of 1983, and the LCC, which had only one follow-on ship, were omitted.

TABLE 6. SHIP COST ESTIMATING RELATIONSHIPS
($1979)

CLASS	LEAD SHIP HULL NO.	TOTAL NO. OF SHIPS COSTED	IOC	LEAD SHIP COST 79$M	AVERAGE FOLLOW-ON SHIP COST 79$M	FULL LOAD DISPLACE-MENT-KLT	ESTIMATE 79$M	% DIFF.	CER
AIRCRAFT AND HELICOPTER CARRIERS									
CV	59	4	1955	-	1,114	79.65	1,219	8.6	
	63	3	1961	-	1,299	80.3	1,229	-5.7	C = 15.3D
	67	1	1968	-	1,286	80.8	1,236	-4.0	
LHA	1	4	1976	-	577.9	39.3	601.4	3.9	
LPH	2	7	1961	-	229.6	18.9	289.21	20.6	
CVN	65	1	1961	-	2,239	91.0	2,017	-11.0	C = 22.2D
	68	2	1975	-	1,878	94.4	2,092	10.2	
ATTACK SUBMARINES									
SSN	578	4	1957	361.9	216.2	2.86	247.4	12.6	
	585	6	1959	358.3	255.9	3.50	270.0	5.2	
	594	13	1961	395.3	387.8	4.45	303.6	-27.7	C = 146 + 35.4D
	637	29	1967	329.8	294.1	4.582	308.3	4.6	
	688	14	1976	603.7	367.2	6.927	391.3	6.3	
SS	580	3	1959	170.6	100.6	2.639	100.6	-	C = 61.3 + 14.9D
DESTROYERS, FRIGATES AND PATROL ESCORTS									
DD	931	18	1954	211.5	135.7	3.950	115.8	-17.2	
FF	1021	10	1957	51.2	52.5	1.914	59.9	12.4	
	1033	4	1959	52.7	49.7	1.750	55.3	10.1	C = 7.2 + 27.5D
	1040	10	1964	121.0	108.2	3.344	99.2	-9.1	
	1052	10	1969	252.5	108.9	4.100	120.0	9.2	
DD	963	30	1975	340.1	221.3	7.924	226.3	2.2	
PG	84	10	1966	-	14.5	.26	14.4	-0.7	
GUIDED MISSILE EQUIPPED CRUISERS, DESTROYERS AND FRIGATES									
CG	16	9	1962	410.6	278.9	8.074	276.0	-1.0	
	26	9	1964	330.8	265.4	8.5	287.2	7.6	
DDG	2	23	1960	257.0	178.2	4.5	182.0	2.1	C = 63.5 + 26.3D
DDG/DLG	37	10	1960	335.5	259.4	5.96	220.3	-17.7	
FFG	1	6	1966	138.1	125.6	3.4	153.0	17.9	
	7	7	1977	452.8	169.5	3.605	158.4	-7.0	
AEGIS CG	47	18	1983	1,014	555*	8.9	555	-	C = 310 + 27.5D
GUIDED MISSILE EQUIPPED, NUCLEAR POWERED CRUISERS									
CGN	9	1	1961	-	1,672	17.1	1,052	-58.9	
	25	1	1962	-	765.7	9.2	625.9	-22.2	
	35	1	1967	-	579.3	8.8	604.3	4.1	C = 130 + 53.9D
	36	2	1974	-	711.3	10.53	697.6	-2.0	
	38	4	1976	-	591.4	11.0	722.9	18.2	
MAJOR AMPHIBIOUS SHIPS									
LPD	1	3	1962	-	210.7	14.651	170.4	-23.6	
	4	9	1965	-	160.8	16.913	196.7	18.3	
LCC	19	2	1970	465.0	256.6	17.0	197.8	-29.7	C = 11.6D
LSD	28	8	1954	-	114.2	12.0	139.6	18.2	
	36	5	1969	-	114.5	14.0	162.9	29.7	

*Estimated

TABLE 6. SHIP COST ESTIMATING RELATIONSHIPS (Continued) ($1979)

CLASS	LEAD SHIP HULL NO.	TOTAL NO. OF SHIPS COSTED	IOC	LEAD SHIP COST 79$M	AVERAGE FOLLOW-ON SHIP COST 79$M	FULL LOAD DISPLACE-MENT-KLT	ESTIMATE 79$M	% DIFF.	CER.
CARGO AND SUPPLY SHIPS									
LKA	113	5	1968	-	108.5	18.657	111.1	0.4	
LST	1171	7	1957	-	73.5	7.804	69.6	-11.2	
	1179	20	1969	-	83.1	8.4	71.9	-21.3	
AF	58	2	1955	-	95.2	10.68	80.6	1.4	
AFS	1	7	1963	-	104.4	15.54	101.2	-5.9	
AE	21	5	1951	-	88.0	17.45	106.5	15.5	C = 39.7 + 3.83D
	26	8	1968	-	130.0	19.937	116.0	-14.1	
AO	177	2	1981	-	157.2	27.5	145.0	-9.6	
T-AO	143	6	1953	-	128.3	38.0	185.2	30.6	
AOE	1	4	1963	-	313.4	52.483	240.6	-29.6	
AOR	1	7	1969	-	143.7	41.35	198.0	27.5	
MINE WARFARE SHIPS									
MSB	5	30	1952	-	5.6	.039	8.55	34.5	
MSO	427	36	1952	-	30.9	.87	34.8	11.2	
MSC	121	9	1953	-	32.7	.378	19.3	-69.4	C = 7.32 + 31.6D
MSI	1	2	1958	-	8.3	.24	14.9	44.3	
MCM	82	9	1985	-	50.7*	1.65	59.5	14.8	
DESTROYER AND SUBMARINE TENDERS									
AD	37	2	1967	-	240.0	18.54	260.6	7.9	
	41	1	1980	-	318.4	20.3	273.1	-16.6	C = 129 + 7.10D
AS	33	2	1964	-	265.1	21.0	278.1	4.7	
	36	5	1970	-	278.2	22.646	289.8	4.0	
TUGS AND SALVAGE VESSELS									
YTB	752	80	1959	-	2.0	.35	3.99	39.1	
ATF	166	6	1979	-	16.1	2.00	22.8	29.3	C = 11.4D
ATS	1	3	1971	-	40.8	3.2	36.5	-11.8	
SINGLE UNIT CLASS									
ASR	21	2	1973	-	204.2	4.53	204.2	-	C = 45D
PTF	17	10	1968	-	3.3	.105	3.3	-	C = 31.4D
PHM	1	6	1977	-	78.5*	.238	78.5	-	C = 330D
ACV	**	1	1970	-	4.2	.055	4.2	-	C = 76.6D

*Estimated
**UK-Wellington

G. COST DATA

Only costs for ships already delivered were used in the determination of the CERs, i.e., ships already commissioned or expected to be commissioned by 1981. Because the data available extended back to a ship authorization year of 1952, some of the ships used in CERs have been retired from service. Data on such ships is no less useful and appropriate in determining CERs than data on ships in the active fleet. Indeed, restricting the data to ships in the active fleet would lead to a poorer determination of the CERs because of the loss of a substantial amount of valid data.

H. CONVERSION COSTS

Only original procurement cost data were used in the data base used for the CERs, i.e., conversion costs incurred were not included (for a few ships only conversion costs data were available). The principal conversion costs encountered were incurred by the DLG-37, CG-16, and DD-931 classes. In Table 7 are listed the average follow-on ship procurement and conversion costs, and the number of follow-on ships converted for these three classes of ships.

TABLE 7. FOLLOW-ON SHIP CONVERSION COSTS (MILLIONS OF 79 DOLLARS)

Class	Average Procurement Cost	Average Conversion Cost	Number of Follow-on Ships Converted
DLG-37	259.4	100.1	9
CG-16	278.9	83.0	8
DD-931	135.7	64.5	5

The average follow-on ship conversion cost, as a fraction of the average follow-on ship procurement cost, is approximately given by

$$\frac{100.1 \times 9 + 83 \times 8 + 64.5 \times 5}{259.4 \times 9 + 278.9 \times 8 + 135.7 \times 5} = 0.36 .$$

III. AGGREGATION OF SHIP CLASSES

A. SELECTION OF CER GROUPS

The 63 classes of U.S. Navy general purpose ships costed in this paper encompass virtually the entire tactical fleet for the post 1952 period with the exception of Coast Guard, Naval Reserve, survey, research, and intelligence gathering ships. The classes costed are grouped by order of magnitude intervals in cost and displacement in Table 8. While these classes range in both cost and displacement over more than three orders of magnitude, 40 or 60 percent fall in the cost interval $100 to $1,000 millions and displacement interval 1 to 100 KLT. It is obvious from Table 8 that it is not possible to find a single CER that would serve to estimate the cost of all classes without incurring totally unacceptable errors. However, by judiciously aggregating the classes according to ship characteristics and functions, it is shown below that surprisingly good linear fits to the data can be obtained for each category defined. In this paper the ship classes were aggregated into the following 14 CER categories.

1. Aircraft and helicopter carriers (CV, LHA*, LPH*)
2. Nuclear powered aircraft carriers (CVN)
3. Nuclear Powered Submarines (SSN)
4. Diesel powered submarines (SS)
5. Destroyers, frigates and patrol escorts (DD, FF, PG*)

*Included here at the suggestion of Dr. Paul J. Berenson, Special Assistant for Assessment, OUSDR&E.

TABLE 8. GROUPING OF U.S. NAVY GENERAL PURPOSE SHIPS BY COST AND DISPLACEMENT

Average Cost Interval in 79 $ Millions	DISPLACEMENT INTERVAL IN THOUSANDS OF LONG TONS			
	10^{-2}-10^{-1}	10^{-1}-1	1-10	10-100
1000-10,000				CV 59 CV 63 CV 67 CVN 65 CVN 68
100-1000			FF-1040 FF-1052 DD-931 DD-963 FFG-1 FFG-7 DDG-2 DDG-37 ASR-21 CG-16 CG-26 CGN-25 CGN-35 AEGIS CG SSN-578 SSN-585 SSN-594 SSN-637 SSN-688 SS-580	AFS-1 AE-26 LSD-28 LSD-36 LPD-1 LPD-4 LHA-1 LPH-2 LCC-19 LKA-113 CGN-35 CGN-36 AD-37 AD-41 AS-33 AS-36 AD-177 ADE-1 AOR-1 T-AO-143
10-100	PHM-1	MSO-496 MSO-121 PG-84 PHM-1	LST-1171 LST-1179 FF-1021 FF-1033 MCM-82 ATS-1 ATF-166	AE-21 AF-58
1-10	MSB-25 ACV	MSI-1 PTF YTB-752		

6. Guided Missile Equipped Cruisers, Destroyers, and Frigates (CG, DDG, DLG, FFG)
7. AEGIS CG
8. Guided Missile Equipped, Nuclear Powered Cruisers (CGN)
9. Major Amphibious Ships (LPD, LCC, LSD)
10. Cargo and Supply Ships (LKA, LST, AF, AFS, AE, AO, T-AO, AOE, AOR)
11. Mine Warfare Ships (MSB, MSO, MSI, MCM)
12. Destroyer and Submarine Tenders (AD, AS)
13. Tugs and Salvage Vessels (YTB, ATF, ATS)
14. Single Unit Classes (ASR, PTF, PHM, ACV)

B. ACCURACY OF CERs

A measure of the accuracy of the CER for each category is the average absolute error or the average of the ship class absolute error values (the percent difference column in Table 6). In Table 9 are listed 11 values $|\overline{f_i}|$ for the CER categories in which a percent difference could be calculated. If the heterogeneous group of major amphibious ships, and the relatively much less costly mine warfare ships and tugs and salvage vessels are excluded, the average of the average ship class absolute percentage errors for the remaining 8 CER categories, each of whose average follow-on ship cost exceeds 20 million (79$), is only 10.5 percent.

Another measure of the accuracy of the CER category is based on the costs of procuring all the ships in that group. This CER group error f_g is given by

$$f_g = \frac{100 \sum_{i=1}^{i=m} n_i \, (C_{ei} - C_i)}{\sum_{i=1}^{i=m} n_i \, C_{ei}} \qquad (14)$$

TABLE 9. AVERAGE ABSOLUTE ERROR BY CER CATEGORY

CER Group	m-no. of Ship Classes	Total No. of Ships Costed	Average Group Follow-on Ship Cost (79$M)	$\lvert \bar{f}_i \rvert$-Average Ship Class Absolute Error (%)	CER Group Cost $\sum_{i=1}^{i=m} n_i(C_{ei}-C_i)$	CER Group Error f_g(%)
Aircraft and helicopter carriers	5	19	901.3	8.6	14,229	4.72
Nuclear powered aircraft carriers	2	3	2,058.5	10.6	6,201	3.32
Attack submarines	5	73	304.1	11.3	21,530	-0.18
Destroyers, frigates, and patrol escorts	7	92	98.7	8.7	11,339	-0.81
Guided missile equipped cruisers, destroyers, and frigates	6	64	212.8	8.9	12,208	-0.38
Guided missiles equipped, nuclear powered cruisers	4	8	661.9	11.6	5,519	6.99
Major amphibious ships	5	27	171.4	23.9	4,411	13.35
Cargo and supply ships	11	73	129.6	15.2	8,446	-0.22
Mine warfare ships	4	77	19.4	39.9	1,713	7.09
Destroyer and submarine tenders	4	10	275.4	8.3	2,800	2.83
Tugs and salvage vessels	3	89	19.8	26.7	566	26.91
		535				

where m is the number of ship classes in the category and n_i is the number of follow-on ships in the ith class (second column in Table 6, except subtract 1 in each case for which a lead ship cost is indicated). Note in Table 9 that the CER category error, f_g, as a result of cancellation effects induced by the presence of both positive and negative ship class errors, is substantially smaller than the average ship class absolute error for all categories save one, tugs and salvage vessels, where the error increased a negligible amount from 26.7 to 26.9 percent. Fortunately, the CER categories with the highest costs (except for the aircraft and helicopter carrier category) are associated with the lowest values of f_g. The value of f_g for three of the categories was calculated to be less than 1 percent.

Finally, the total error f_T for costing all of the ships in all of the CER categories is given by

$$f_T = \frac{100 \sum_{j=1}^{j=p} \sum_{i=1}^{i=m_j} n_{ij} \left(C_{eij} - C_{ij}\right)}{\sum_{j=1}^{j=p} \sum_{i=1}^{i=m_j} n_{ij} \, C_{eij}} \qquad (15)$$

where m_j is the number of ship classes in the jth CER category and p is the number of CER categories. For all the CER categories of Table 9, p = 11 and f_T = 1.8 percent. Even if the four negative values of f_g were all made positive, by reversing the signs of the individual errors in those classes, f_T would increase to only 2.7.

The small values calculated for f_g and f_T above are obviously dependent on the number and class distribution of U.S. Navy ships. The f_g values for a foreign fleet of similar ships with different distributions would undoubtedly differ. However, cancellation effects will almost surely also occur for the foreign fleet, and therefore accuracies comparable to those for the U.S. fleet could be expected.

The relative procurement cost total error for a foreign fleet of size comparable to the U.S. fleet would be maximized if the values of f_T for the two countries were of opposite sign, or $2\ |f_T| \cong 4$ percent, and would be minimum, or close to zero, if they were of the same sign. The errors involved in using the CER cost estimates to estimate the procurement cost for a large number of ships can therefore be expected to be small compared to the errors inherent in the crudity of the Americanization assumption, in which foreign ships of the same class and displacement are assumed to have the same structure, weapons, sensors, etc. as their U.S. counterparts.

The estimated procurement cost error for a small number of ship classes is very likely to be larger than f_T and will depend on the classes and number of ships in each class. In 1979, for example, there were 14 U.S. Navy ships commissioned which were distributed among six classes as indicated in Table 10. The error for these 14 ships is only 3.2 percent, only slightly larger than f_T because of the dominating accurate error of 2.2 percent for the 7 ships in the DD-963 class. On the other hand, there was little in the way of cancellation effects because all of the class errors were positive with the exception of the single ship in the FFG-7 class. Clearly the annual procurement error will fluctuate from year to year as the composition of the ships procured changes.

TABLE 10. SHIPS COMMISSIONED IN 1979

Class	No. of Ships $-n_i$	C_{ei}	n_iC_{ei}	C_i	n_iC_i
DD-963	7	226.3	1584.1	221.3	1549.1
SSN-688	1	391.3	391.3	366.6	366.6
AS-36	2	289.8	579.6	278.2	556.4
ATF-166	2	22.8	45.6	16.1	32.2
LHA-1	1	601.4	601.4	577.9	579.9
FFG-7	1	158.4	158.4	169.5	169.5
			3360.4		3253.7

IV. U.S. NAVY GENERAL PURPOSE SHIP CERs

A. AIRCRAFT AND HELICOPTER CARRIERS

As indicated in Table 6 and Figure 4, all three CV carrier classes (CV 59, 63, and 67) have essentially the same full load displacement of approximately 80 KLT. By combining these points with the LHA and LPH amphibious ships, which are helicopter carriers, the zero intercept solution is

$$C = 15.3\ D \quad . \tag{16}$$

Eq. (16) is found to provide better than 10 percent accuracy for all ships in this CER category with the exception of the LPH, whose cost lies 20.6 percent below the value as estimated by Eq. (16). Lead ships were not distinguished from follow-on ships in this CER group because their costs were negligibly larger, or even smaller than their follow-on ship costs, e.g., the lead ship cost of the CV-59 was 1,109 79 $ millions, whereas the follow-on ships CV-60 and CV-62 cost 1,189 and 1,178 79 $ millions, respectively.

There are only two classes of nuclear powered aircraft carriers (CVN 65 and 68). The linear relationship

$$C = 22.2\ D \tag{17}$$

which also goes through the origin, insures that the ratio of CVN to CV cost, 22.2/15.3 = 1.47, is independent of displacement, in accordance with the rule discussed in Section IIA.

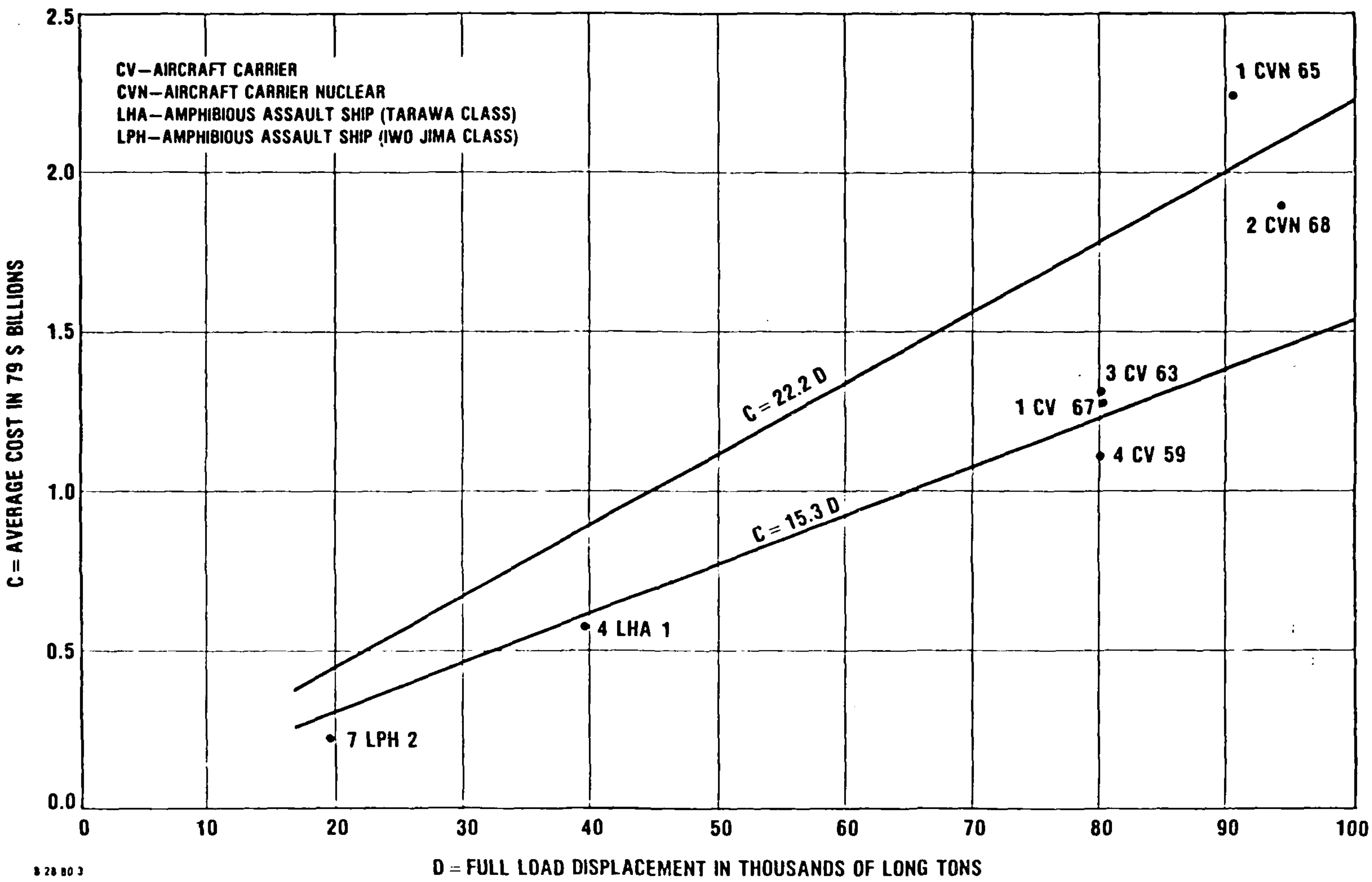


FIGURE 4. CER for aircraft and helicopter carriers

The accuracy of the CVN CER is approximately 10 percent. The size of this error is largely attributable to the fact that the CVN-65 is a single class ship, whereas the CVN-68 is a two ship class, the lead ship CVN-68 costing 2,148 79 $ millions, and the CVN-69 costing only 1,608 79 $ millions. The CVN-70 also belongs to the CVN-68 class but was not included because its IOC is expected to be 1982*. A single follow-on ship was judged to be inadequate for obtaining a CER, and hence the CVN-68 and CVN-69 costs were averaged and used, along with the single CVN-65 cost, as shown in Fig. 4.

The average ship class absolute error was 8.6 percent, and the CER category error was 4.7 percent (Table 9).

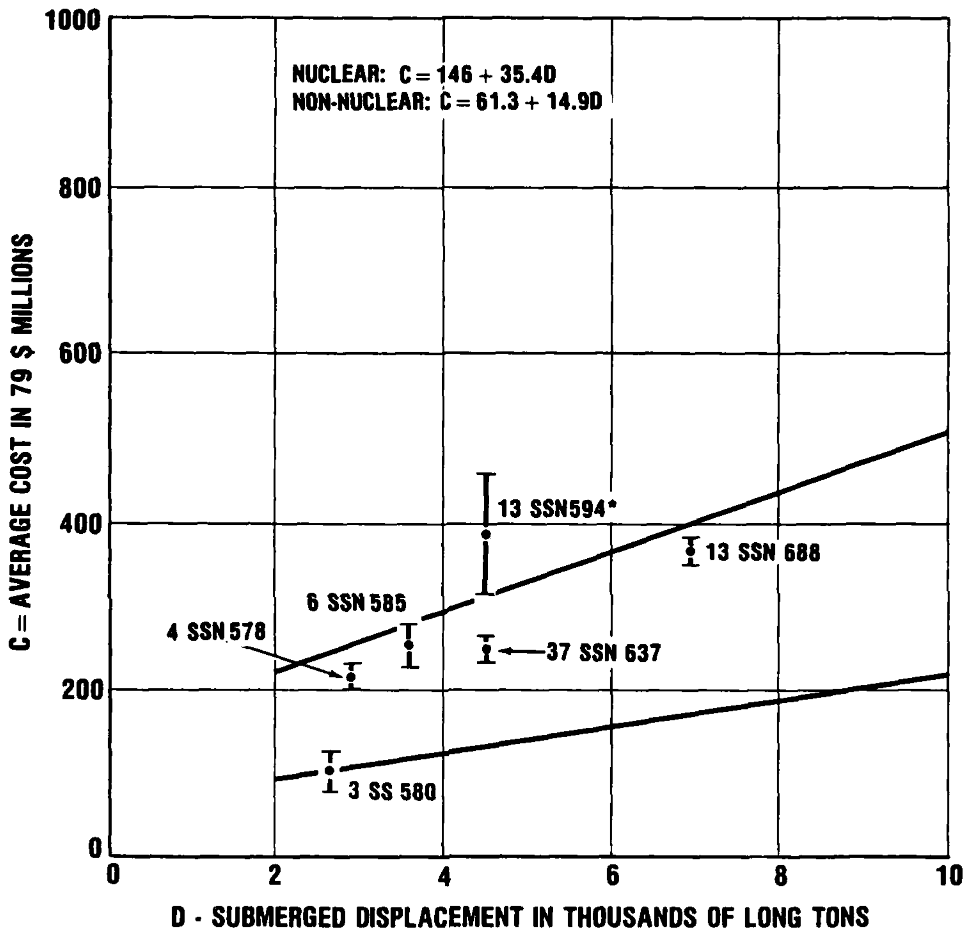
B. ATTACK SUBMARINES

The U. S. Navy has built five classes of nuclear powered attack submarines; the SSN-578, 585, 594, 637, and 688. The intercept solution

$$C = 146 + 35.4\ D \qquad (18)$$

was selected over the no intercept solution for this CER category because it yielded smaller errors. The large 27.7 percent error for the SSN-594 class (see Table 6) is partially explainable by safety modifications made subsequent to the loss of the Thresher (SSN-593) and construction problems encountered (see footnote of Fig. 5). If the SSN-594 class had been excluded, the average ship class absolute error for the nuclear powered attack submarine CER would have been reduced from 11.3 (Table 9) to only a few percent, as is obvious from an inspection of Fig. 5. Note also in Fig. 5 that the lower end of the large standard deviation

*The current estimated cost of the CVN-70 is 1957 79 $ millions; Eq. (25) yields 2097 79 $ millions, corresponding to an error of 6.7 percent. Since the current cost estimate is probably on the low side, the CER estimate could well prove to be more accurate.



*Later submarines of the SSN-594 were delayed because of submarine safety program modifications, increased quality control of submarine construction, and specific problems of shipyards.

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FIGURE 5. CER for attack submarines

interval falls on the CER line, proving that some submarines of the SSN-594 class were built for a cost predicted by the CER. It would have been somewhat difficult to justify excluding the SSN-594 class from the derivation of the CER, since the Soviet Navy is quite likely to have encountered similar problems along the way in its submarine construction programs. In any case, the nuclear powered attack submarines, which represent the largest total procurement investment of any of the CER categories at 21,530 79 $ billions, had the smallest CER category error of 0.2 percent (Table 9).

Cost data were available on only one class of diesel powered submarine, the lead ship SS-580 and the two follow-on ships SS-581 and SS-582. These were the last diesel powered submarines constructed in the U.S. However, this is an important CER category because the Soviet Union has constructed many diesel powered submarines and is continuing to construct them at the present time. A nuclear powered submarine with the 2.639 KLT displacement of the SS-580, according to Eq. (18), would cost 239.4 $ 79 millions. The cost ratio of a nuclear to a diesel powered submarine is therefore 239.4/100.6 = 2.38. The slope of the CER for the diesel submarine, according to Eq. (12), is therefore given by 35.4/2.38 = 14.9, and the intercept by 146/2.38 = 61.3. Hence the CER for diesel submarines is

$$C = 61.3 + 14.9 D \quad . \qquad (19)$$

Since the SS CER is obtained from only a single data point, there is unfortunately no way to measure its accuracy.

Ship procurement costs were also determined and a CER derived for strategic submarines (SSBNs) which have the characteristics listed in Table 11.

TABLE 11. SSBN COST ESTIMATING RELATIONSHIP

Lead Ship Hull Number	Total of Ships Costed	IOC	Lead Ship Cost 79 $ M	Average Follow-on Ship Cost 79 $ M	Submerged Displacement KLT	Estimate 79 $ m	% Diff.
598	5	1958	918.3	514.0	6.688	441.4	-16.4
608	5	1961	755.5	478.4	7.888	506.3	5.5
616	31	1963	769.0	468.7	8.220	524.3	10.6
726	7	1980	1,976.4	1,037.2	17.500	1,026.2	- 1.0
			4,419.2	2,498.3			

The best CER solution for SSBN submarines was found to be given by

$$C = 79.7 + 54.1\ D \quad . \tag{20}$$

As shown in Fig. 6, the fit is good with an average ship class absolute error of 8.4 percent, and a CER category error f_g of 5.6 percent. The derivation of Eq. (20) would not have been possible without the estimated costs of the large Trident submarine (SSN-726) follow-on ships which will not begin entering the fleet until 1981.

It is interesting to note that the average lead ship cost of the strategic submarines is 77 percent higher than the average follow-on ship cost, whereas the average lead ship cost of the attack submarines is only 35 percent higher.

C. DESTROYERS, FRIGATES, AND PATROL ESCORTS

The ship classes for the FF/DD/PG CER category consist of the FF-1021, 1033, 1040, and 1052, the DD-931 and DD-963, and the PG-84. The best least mean squares fit to the data is given by

$$C = 7.2 + 27.5\ D \quad . \tag{21}$$

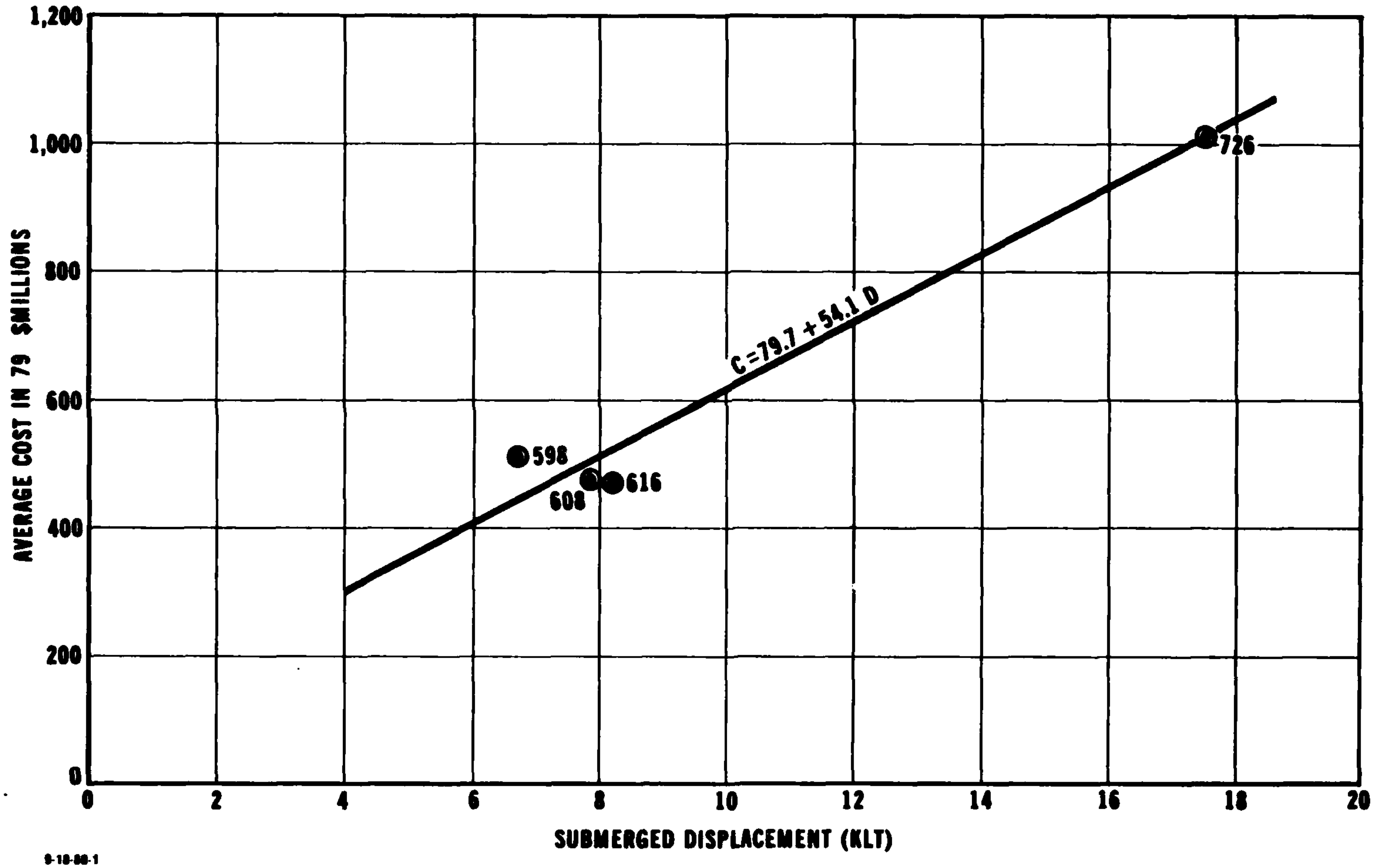

FIGURE 6. CER for ballistic missile submarines

As indicated by Table 6 and Fig. 7 the DD 931 is the most poorly estimated class in this group with an error of 17.2 percent. However, the average ship class absolute error is only 8.7 percent and the CER category error less than 1 percent (Table 9).

D. GUIDED MISSILE EQUIPPED CRUISERS, DESTROYERS, AND FRIGATES

The FFG/DDG/CG CER category consists of the FFG-1 and FFG-7, the DDG-2, and the CG-16, 26, and 37 classes. The data points for this group are plotted in Fig. 8. The best CER least square fit for these 6 classes is

$$C = 63.5 + 26.3\,D \quad . \tag{22}$$

Although two of the six classes in this CER category had a relatively large error of 17 percent, the average ship class absolute error was only 8.9 percent, and cancellation efforts led to a CER category error of only 0.4 percent (Table 9).

A comparison of the CER for FFGs and DDGs, Eq. (22), with the CER for FFs and DDs, Eq. (21), shows that they have essentially the same slope. An interesting and unexpected conclusion to be drawn from this observation is that an FFG or DDG can be expected to cost approximately 50 millions of 79 dollars more than an FF or DD of the same full load displacement, an amount that is essentially independent of the magnitude of that displacement.

E. AEGIS CG

The AEGIS CG-47 is treated here as a separate class of ship because of its unique complexity and high cost (for a non-nuclear powered cruiser). It is expected to have an IOC of 1983 and therefore its cost estimate is not based on historical data. The slope of the CER for AEGIS class cruisers is here somewhat arbitrarily assigned the same slope as the CER for the DD/FF/PG category, so that

$$C = 310 + 27.5\,D \tag{23}$$

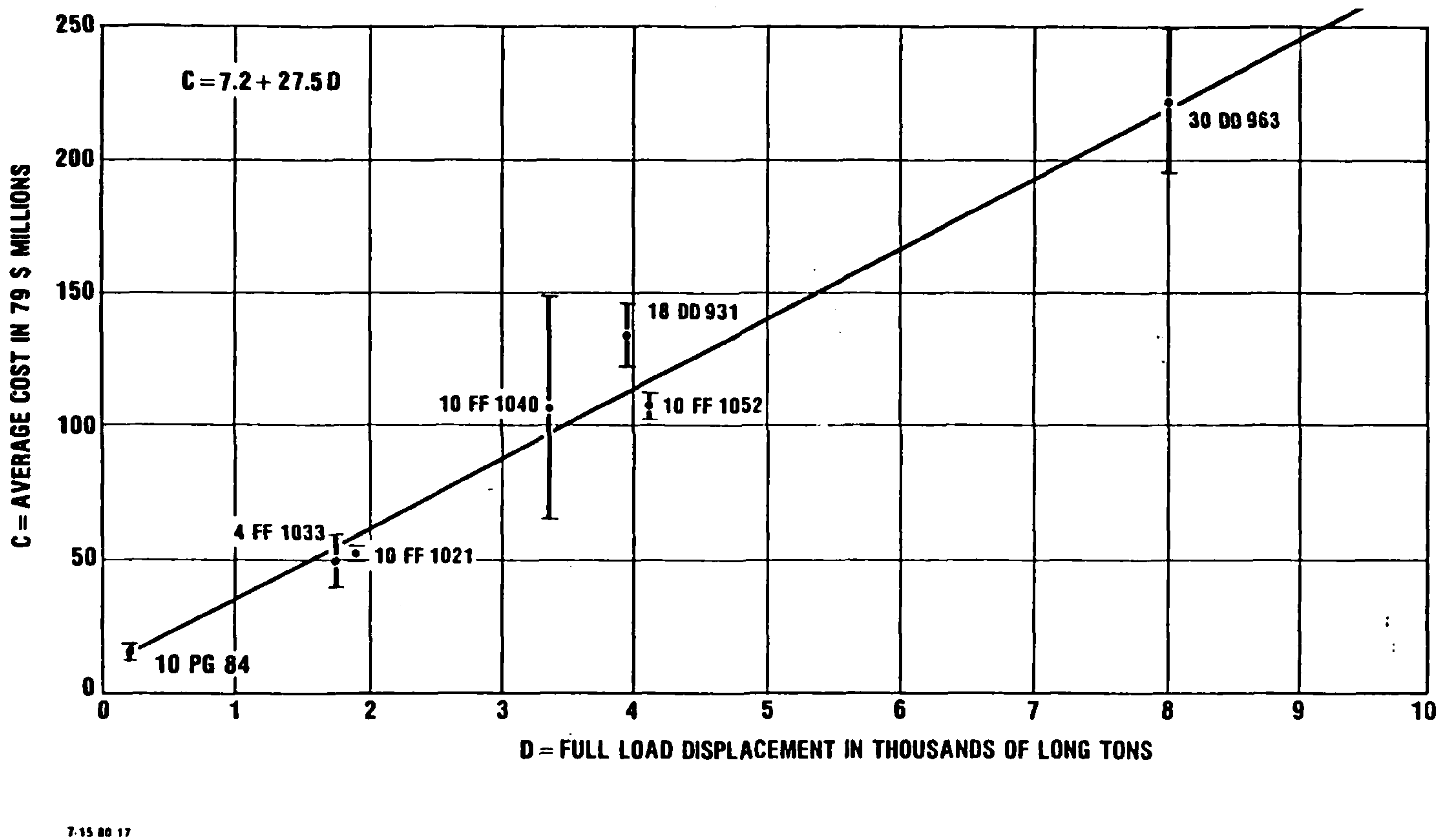

FIGURE 7. CER for FF/DD/PG

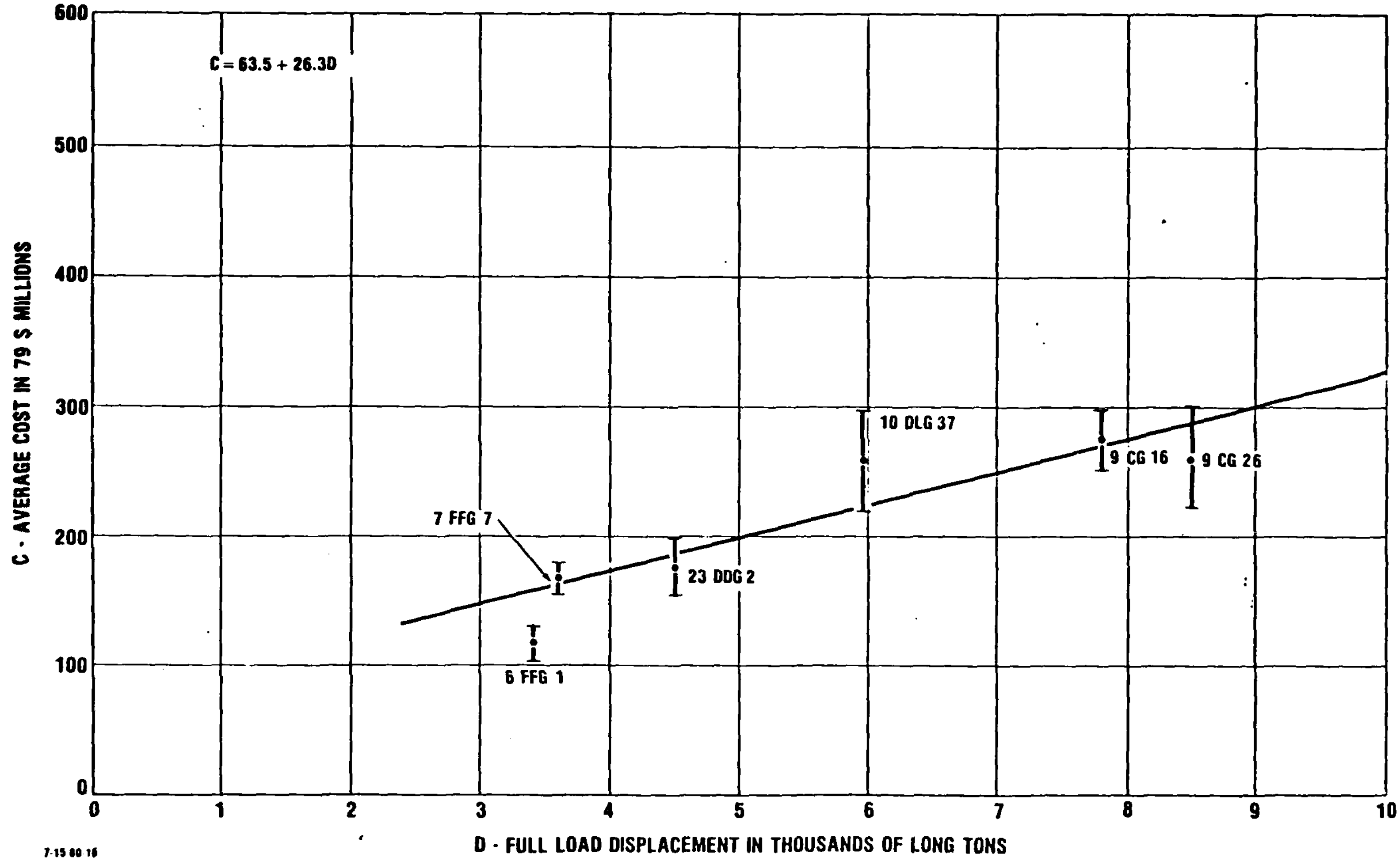

FIGURE 8. CER for FFG/DDG/DLG/CG

F. GUIDED MISSILE EQUIPPED, NUCLEAR POWERED CRUISERS

The CGN-9 (Long Beach) was excluded from the CGN CER because it was the world's first nuclear-powered surface warship and the first warship to have a guided missile main battery. It also went through several design modifications and was really a basic lead ship for the CGN classes that were to follow.

With the CGN-9 excluded, the remaining four classes of CGNs (25, 35, 36, and 38) are found to occupy a narrow full load displacement band between 8.8 and 11.0 KLT (Table 6). Because of the small number of ships in each class, all ships were included in deriving the CGN CER by the method described in Section II A, i.e., a cost-displacement centroid was determined by means of Eqs. (6) and (7). The centroid has the coordinates $\overline{C}$ = 662 millions of 79 dollars and $\overline{D}$ = 9.88 KLT. From Eq. (22) the cost of a CG of 9.8 FLT displacement is equal to 323 millions of 79 dollars. The ratio R of the cost of a CGN to a CG is therefore

$$R = \frac{662}{323} = 2.05 \quad . \qquad (24)$$

The slope of the CGN CER is therefore 2.05 x 26.3 = 53.9 and the intercept 2.05 x 63.5 = 130, leading to a CER for the CGN class of

$$C = 130 + 53.9\ D \qquad (25)$$

Eq. (25) and the CGN data points are shown in Fig. 9, along with the AEGIS CG, FFG/DDG/CG, and DD/FF/PG CERs.

The CGN CER leads to errors of approximately 20 percent for two classes and 3 percent for the other two classes (Table 6). The average ship class absolute error is 11.3 percent and the CER category error 7 percent (Table 9).

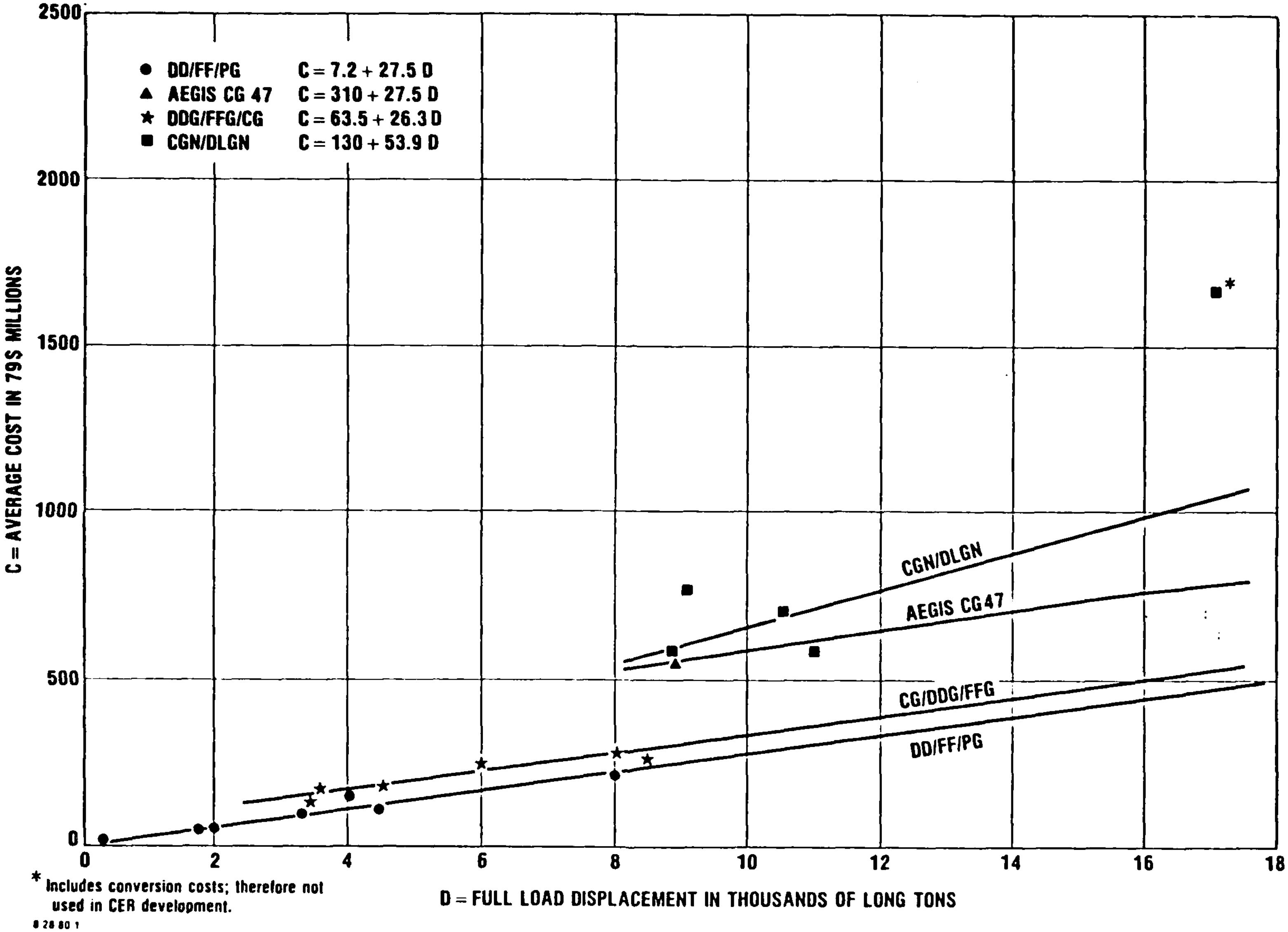

FIGURE 9. CER for cruisers, destroyers, frigates and patrol escorts

G. MAJOR AMPHIBIOUS SHIPS

The CER category selected for the major amphibious ships are the LPD, LCC, and LSD classes. The data points for these ships (Table 6) are plotted in Fig. 10. The following zero intercept solution yielded the better fit for this heterogenous category,

$$C = 11.6\ D\ . \tag{26}$$

The errors for each of the five classes of amphibious ships were rather large, ranging between 18 and 30 percent (Table 6) with an average ship class absolute error of 24 percent (Table 9). Cancellation effects contributed to a much smaller CER category error of 13.4 percent (Table 9), but by either accuracy measure this CER is at least a factor of two less accurate than any of the other major ship CER groups discussed above. In view of the major design differences in the types of ships aggregated, this is not a very surprising result.

H. CARGO AND SUPPLY SHIPS

While the cost of construction of a cargo or supply ship can be expected to be proportional to lightweight tonnage, this more appropriate parameter was not available for Soviet ships, and hence had to be discarded. The use of full load displacement, however, is an acceptable variable because the ratio ρ of lightweight to full load displacement tends to be somewhat close to a constant for cargo and supply ships. Thus, if

$$C = A + B_{\ell}\ D_{\ell} \tag{27}$$

is the CER based on lightweight displacement D_{ℓ} with a slope B_{ℓ},

$$C = A + (B_{\ell}\bar{\rho})\ D \tag{28}$$

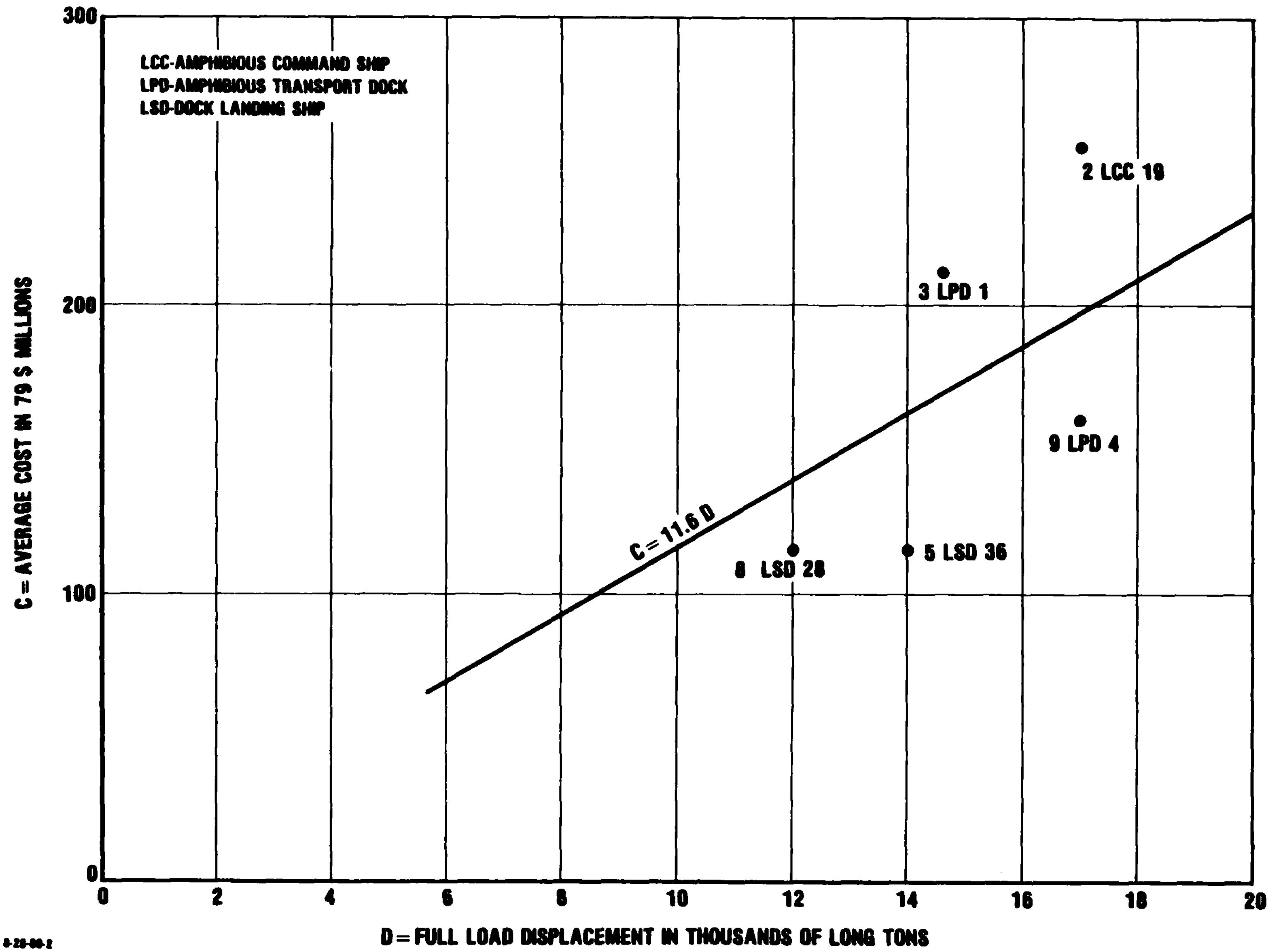

FIGURE 10. CER for major amphibious ships

should be approximately the same CER in terms of full lead displacement D where

$$\rho = \frac{D_\ell}{D} \qquad (29)$$

or the ratio of lightweight to full load displacement. The values of ρ are listed for six classes of cargo and supply ships in Table 12. The values of ρ fall in the range 0.3 - 0.6 with an average of $\bar{\rho}$ = 0.44. Note that oilers have substantially smaller values of ρ than LSTs or ammunition ships.

TABLE 12. RATIO OF LIGHTWEIGHT TO FULL LOAD DISPLACEMENT

Class	D_ℓ(LKT)	D(LKT)	ρ
LST-1171	4.164	7.10	0.586
LST-1156	2.59	5.80	0.447
AF-58	7.95	15.54	0.512
AE-21	7.47	17.45	0.428
AO-143	11.60	38.00	0.305
AOE-1	19.20	52.483	0.366

The best linear fit to the 11 classes of cargo and supply ships listed in Table 6 and plotted in Fig. 11 is given by

$$C = 35.4 + 3.94\ D \ . \qquad (30)$$

The average ship class absolute error for all 11 classes of ships in Fig. 11 is 15.2 (Table 9). However, if the largest oilers AO-143, AOE-1*, and AOR-1 are excluded, the average ship class absolute error for the 8 classes of ships below 30 LKT

*Construction of the AOE-5 was cancelled in 1969 because of high cost, the availability of new-construction ammunition ships, and the success of the AOR-1 class (Jane's Fighting Ships, 1979-1980).

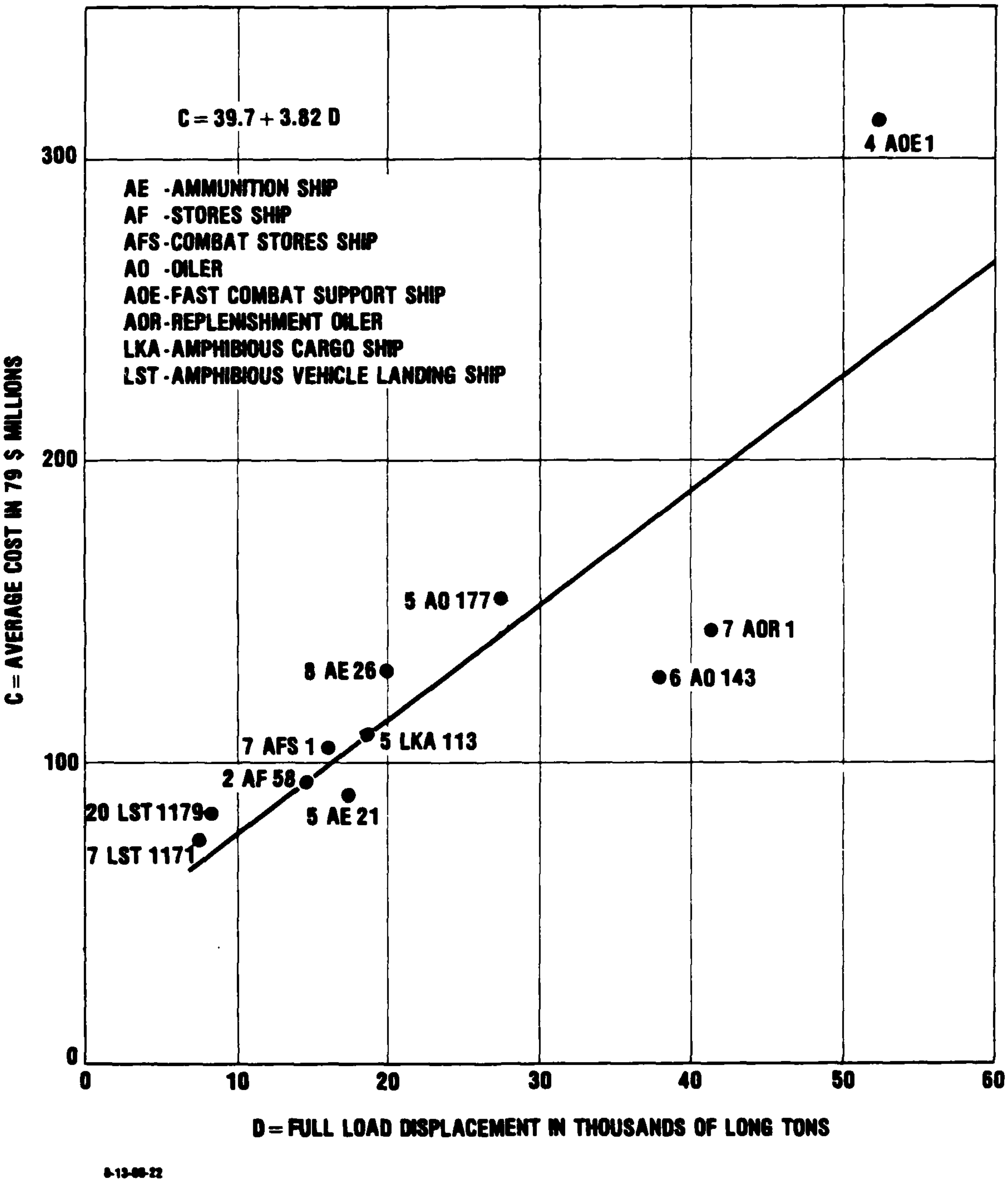

FIGURE 11. CER for cargo and supply ships

full load displacement is reduced to 8.0 percent. The CER category error f_g is a remarkably low 0.2 percent.

I. MINE WARFARE SHIPS

The data of four mine warfare ships, the MSB, MSC, MSO, and MSI, were used to obtain the CER for this category of ships which are defined in Fig. 12. The MCM 82 class was omitted because of its expected future IOC of 1985. The best fit was the intercept solution

$$C = 7.32 + 31.6 D \quad . \tag{31}$$

The mine warfare category is quite heterogeneous. The MSBs, for example, are wooden hull minisweepers which were originally intended to be carried to the theater of operations by large assault ships.

The average ship class absolute error for the mine warfare ships was 40 percent, the largest such value of any of the CER categories. However, the group CER was only 7.1 percent (Table 9). The accuracy of the CER for ships above 0.4 KLT is typified by the MSO which has an error of 11.2 percent. The heaviest mine warfare ship, the MCM, although not used in the derivation of the CER, lends additional credence to this CER, since its estimated cost is only 15 percent below the cost predicted by the CER. Inasmuch as such estimates are generally lower than actual costs, the two estimates appear in excellent agreement.

The category of mine warfare ships is one in which there is a very large procurement imbalance between the U.S. and the Soviet Union. The latter has today (1980) 325 mine warfare ships totaling 13.7 KLT, or an average of 0.42 KLT per ship. The average U.S. mine warfare ship displacement for the 77 ships costed in Table 6 is only 0.11 KLT. It is therefore fortunate that the mine warfare ship CER is more accurate for displacements above 0.4 KLT.

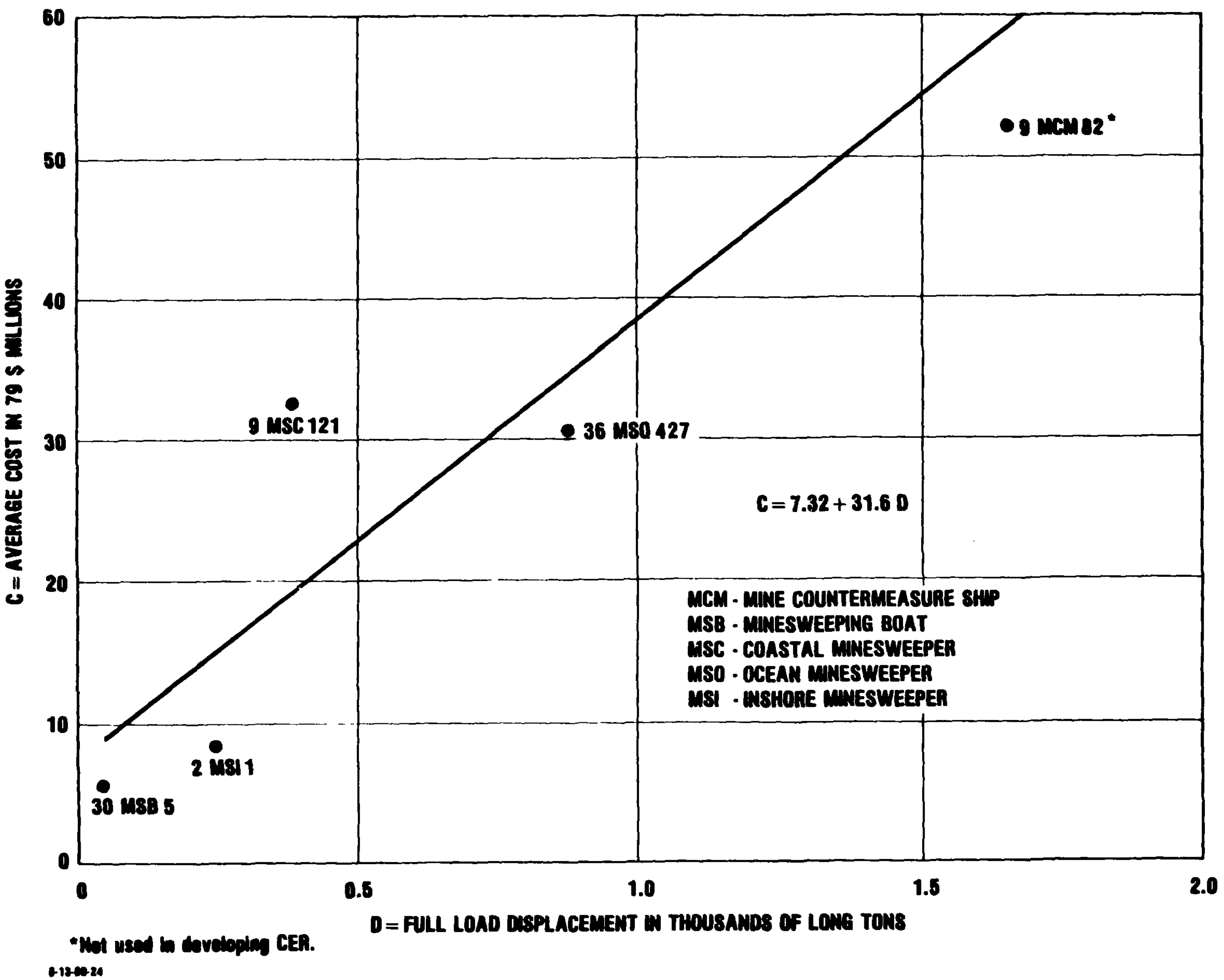

FIGURE 12. CER for mine warfare ships

J. DESTROYERS AND SUBMARINE TENDERS

There are tw[illegible] and AD-41) and two classes [illegible] in this CER category. [illegible] displacement interval [illegible] percent solution [illegible]

[illegible]

[illegible] category [illegible]

Because of the sm[illegible] large differences in ship design characteristics, [illegible] surprising that a large average ship class [illegible] CER category error of [illegible] percent (Table 9) was calculated for these ships. However, the CER category cost was far smaller than for any other group (Table 9), and hence the impact on the total error f_T was not very significant.

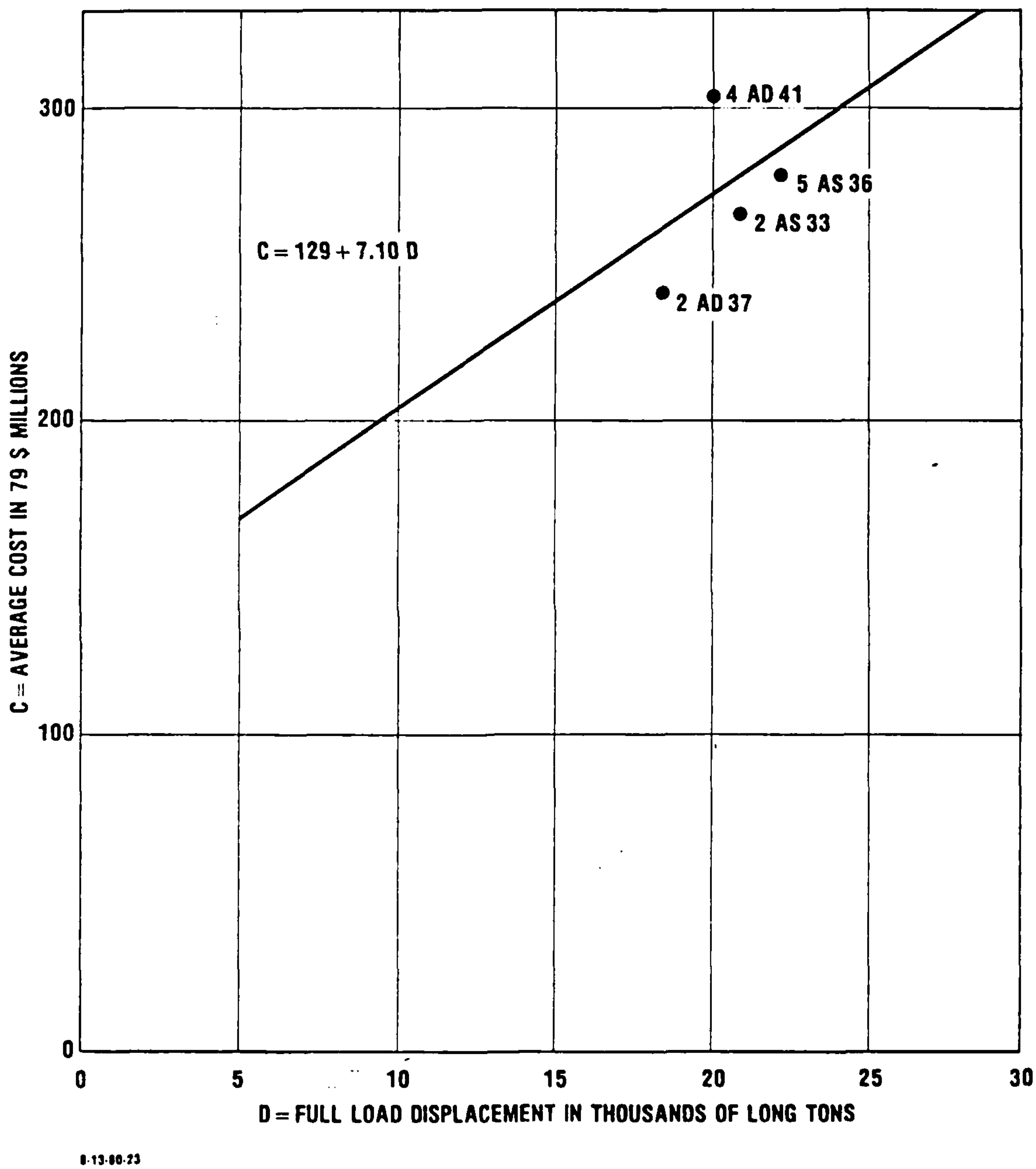

FIGURE 13. CER for destroyer and submarine tenders

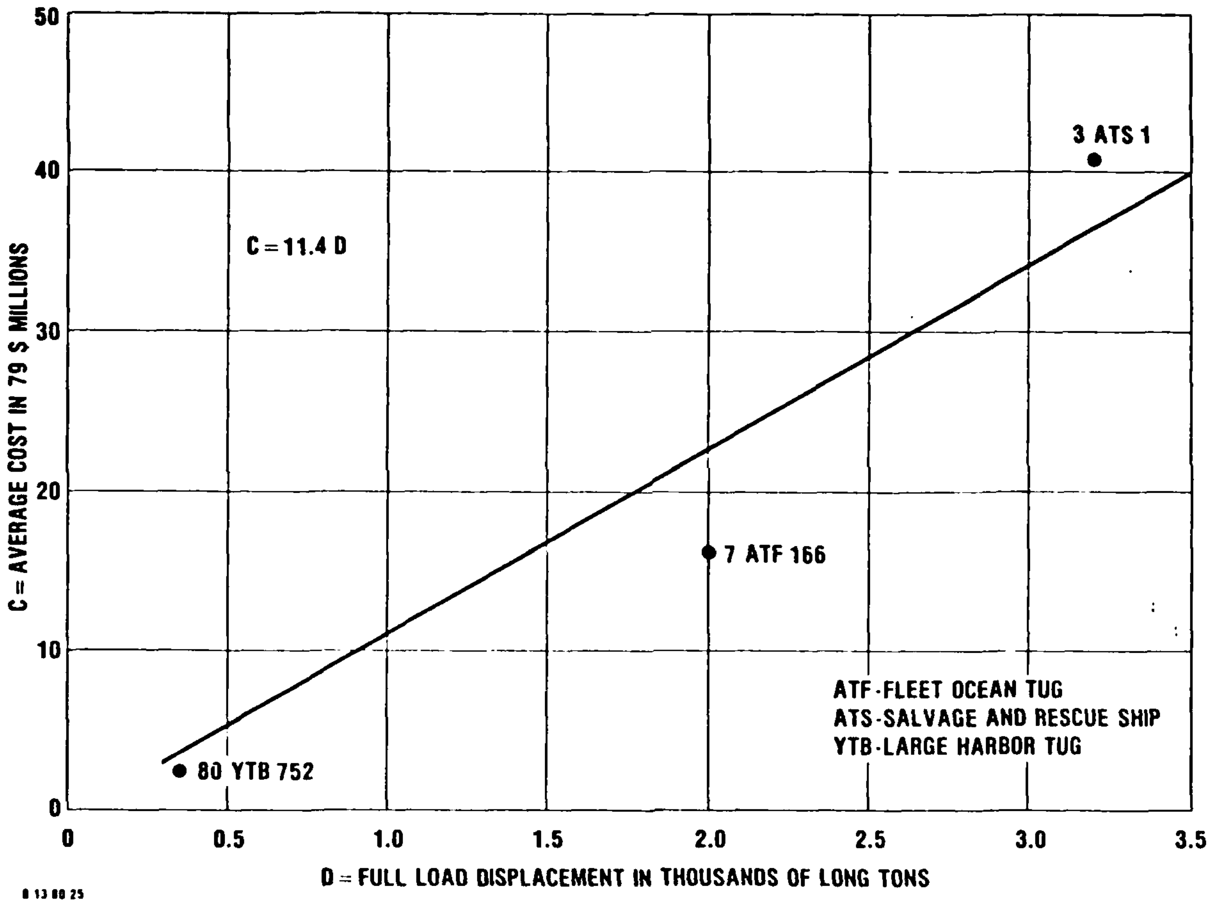

FIGURE 14. CER for tugs and salvage vessels

L. SINGLE UNIT CLASSES

The U.S. has two submarine rescue ships, the ASR-21 and ASR-22 which, unlike other Navy ships, have catamaran hulls. The zero intercept solution for this class is

$$C = 45\ D \quad . \tag{34}$$

The data on the PTF fast patrol craft did not fit into any of the CER categories discussed above and hence was treated as a single unit class. The zero intercept solution is

$$C = 31.4\ D \quad . \tag{35}$$

The PHM is a patrol hydrofoil ship which is unique in design and uniquely costly. The zero intercept solution is

$$C = 330\ D \tag{36}$$

which, on a tonnage basis, makes the hydrofoil ship an order of magnitude more expensive than the ships of the PTF class. Because of its high cost, production of the PHM will cease with the production of six ships instead of the 30 ships originally planned*.

The average estimated cost of the PHM may prove to be still higher than the estimated value of 78.5 millions of 79 dollars, which was based on the five follow-on ships that are expected to be commissioned in 1981 and 1982. The first follow-on ship cost was estimated at 117.9 million; successive ship costs decreased monotonically to the last ship at 58.1 million, or one-half of the first. This implies a substantial learning curve of a magnitude not found in any other class of Navy ship for which delivered ship cost data were available.

*Jane's Fighting Ships, 1979-80.

The Soviet Navy has operational air-cushion vehicles (ACV); the U.S. Navy does not. Resort was therefore made to the single British Wellington class ACV which began testing in 1970. This vehicle has a displacement of 0.055 KLT and cost 700,000 pounds*. The fact that this vehicle was constructed in a foreign shipyard poses an additional problem in attempting to derive a CER that would approximate that for a U.S. shipyard. U.K. wages and salaries have been significantly below those in the U.S. and hence it is necessary to derive a productivity factor P that should be applied to convert an actual U.K. shipyard cost to a projected U.S. shipyard cost.

In Table 13 the costs of six British ships are costed in 79 millions of dollars by multiplying the cost in pounds* by the U.S./U.K. exchange rate prevailing in the year the ship was laid down, and then multiplying by the deflation factor (Table 2) for that year. The cost of a comparable U.S. ship was estimated in two ways: (1) by inserting the ship displacement in the appropriate CER (Table 6), and (2) by scaling to the average cost of the U.S. ship closest in displacement to the U.K. ship. The productivity factors obtained with the first method yielded an average P value of 1.43, while the second method yielded 1.64. An average P value of 1.5 was adopted to cost the Willington, so that, in millions of 79 U.S. dollars,

$$C = 0.7 \times 1.5 \times 2.4 \times 2.54 = 6.4 \qquad (37)$$

where 2.4 is the 1970 U.S./U.K exchange rate and 2.54 is the U.S. 1970 deflation factor.

The Wellington was a test vehicle, and therefore it is necessary to deflate the value of 6.4 by the ratio of average lead ship cost to average follow-on ship cost or 1.52, as given

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*Jane's Fighting Ships, 1979-80.

TABLE 13. U.K. SHIP COSTS

Class	Name of Ship	D(KLT)	Cost in Pounds (M)	Laid Down	Exchange Rate($/Pound)	U.K.Ship Cost in 79 $ M	CER Cost in 79 $ M	Cost, Based on Cost/Ton Of Closest U.S. Ship	P-CER Based Productivity Factor	P-Closest U.S. Ship Based Productivity Factor
DDG	Birmingham	4.1	30.9	1972	2.6	156	171	162	1.10	1.04
SSBN	Revenge	8.4	38.6	1965	2.8	423	534	479	1.26	1.13
SSN	Superb	4.5	41.3	1972	2.6	209	305	392	1.46	1.88
MCM	Ledbury	0.725	12.0	1977	1.8	26	30.2	25.8	1.16	0.99
MSI	Wilton	0.450	2.3	1970	2.4	14	21.5	38.9	1.54	2.78
PTF	Sandpiper	0.194	1.4	1977	1.8	3.0	6.1	6.1	2.03	2.03

by Eq. (13). Thus the slope of the ACV follow-on ship cost is estimated to be 6.4/1.52 ÷ 0.055 = 76.6, leading to a zero intercept CER of

$$C = 76.6\ D \quad . \tag{38}$$

Because of the uncertainties in the many conversion factors required to obtain this CER based on only a single vehicle, there is the potential here of a large error which only future U.S. data can remove.

M. COMPARISON OF CATEGORY CERs

In Fig. 15 all of the category CERs are shown on 3 x 3 cycle log-log scale. The zero intercept CERs on such paper still appear as straight lines and have a 45° slope. The CERs with an intercept, however, appear as curved lines. Extrapolations of these CERs beyond the approximate limits shown on the individual curves would be ill-advised.

N. DISTRIBUTION OF SHIP CLASS COST ESTIMATE ACCURACIES

In Table 14 is tabulated the distribution of absolute errors for all the ship classes in Table 6 for which errors could be estimated.

TABLE 14. DISTRIBUTION OF SHIP CLASS COST ESTIMATE ACCURACIES

Accuracy (%)	No. of Ships	Fraction (%)
< 5	13	23
< 10	24	42
< 15	34	60
< 20	42	74
< 25	46	81
< 30	52	91
< 35	54	95
< 40	55	97
< 45	56	98
< 70	57	100

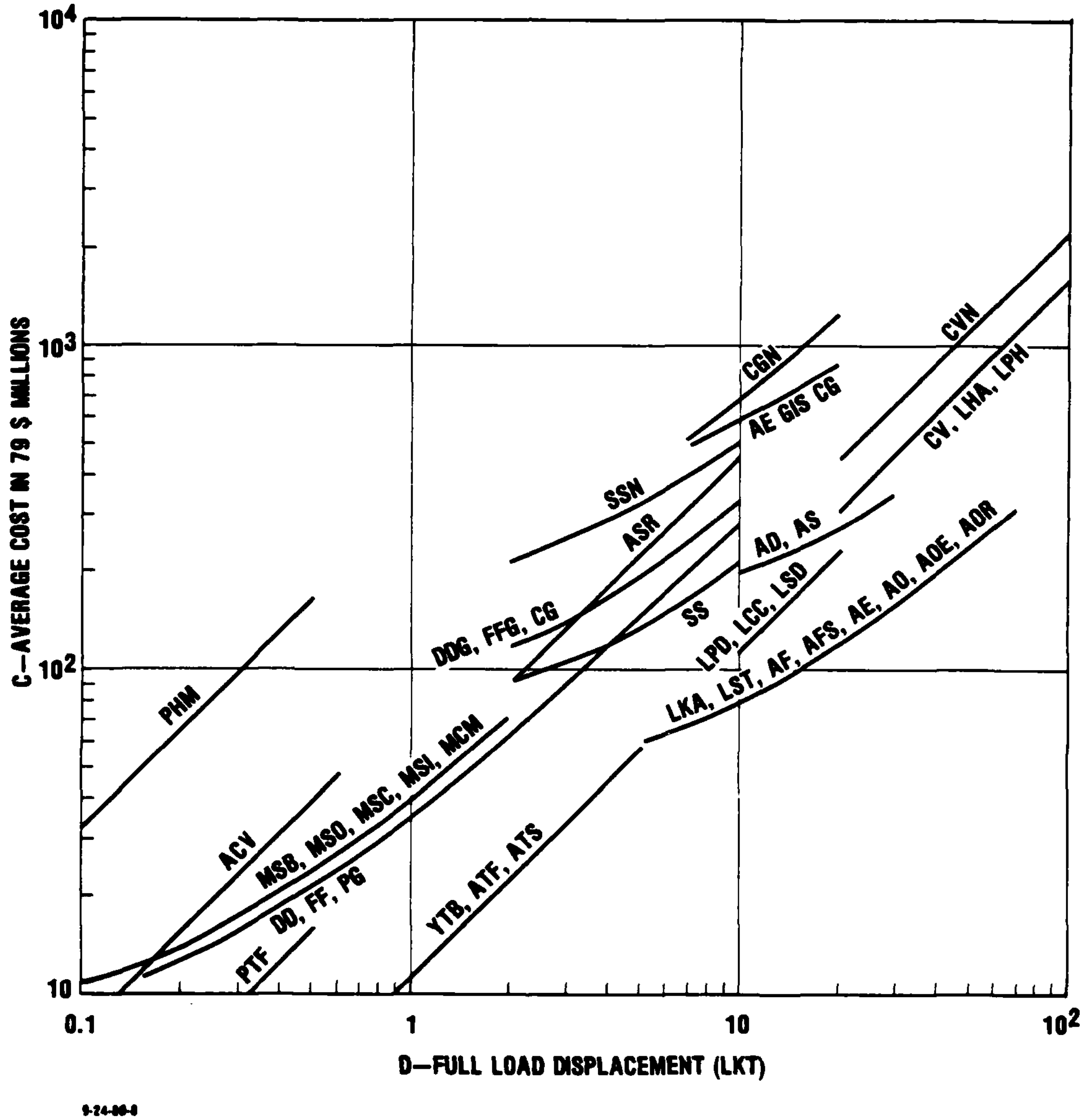

FIGURE 15. CERs for all groups

Of the total of 57 ship classes, 46 or 81 percent were estimated by the linear cost-displacement CERs to within an accuracy of 25 percent. More importantly, all but one (SSN-594) of the attack submarines and all of the major surface combatants (carriers, cruisers, destroyers, and frigates) were estimated to an accuracy of better than 25 percent. For the purposes of this paper, however, the accuracy of most interest relates to the error in estimating the aggregated cost of many ships in a number of ship classes. The error, as discussed in Section III B, depends on the ship classes and the number of ships in each class, but is likely to be less than 10 percent because of cancellation effects.

APPENDIX A

DERIVATION OF LEAST SQUARE FORMULAS

If C_i, D_i, and E_i are the cost, displacement, and error for the ith ship of a class of n ships, for the CER going through the origin

$$\sum_{i=1}^{i=n} E_i^2 = \sum_{i=1}^{i=n} (BD_i - C_i)^2 \quad . \qquad \text{(A-1)}$$

Differentiating Eq. (A-1) with respect to B,

$$\frac{d\left(\sum_{i=1}^{i=n} E_i^2\right)}{dB} = 2 \sum_{i=1}^{i=n} D_i (BD_i - C_i) \quad . \qquad \text{(A-2)}$$

Setting Eq. (A-2) equal to zero and solving for B yields

$$B = \frac{\sum_{i=1}^{i=n} C_i \; D_i}{\sum_{i=1}^{i=n} D_i^2} \quad . \qquad \text{(A-3)}$$

For the intercept case,

$$\sum_{i=1}^{i=n} E_i^2 = \sum_{i=1}^{i=n} (A + BD_i - C_i)^2 \quad . \qquad \text{(A-4)}$$

Taking the partial derivatives of Eq. (A-4) with respect to B and A and and equating to zero,

$$\frac{\partial\left(\sum_{i=1}^{i=n} E_i^2\right)}{\partial B} = 2\sum_{i=1}^{i=n} D_i\ (A + BD_i - C_i) = 0 \qquad \text{(A-5)}$$

$$\frac{\partial\left(\sum_{i=1}^{i=n} E_i^2\right)}{\partial A} = 2\sum_{i=1}^{i=n} (A + BD_i - C_i) = 0 \qquad \text{(A-6)}$$

The slope in B is therefore given by

$$B = \frac{\sum_{i=1}^{i=n} (C_i - A)\ D_i}{\sum D_i^{\ 2}} \qquad \text{(A-7)}$$

and the intercept A by

$$A = \frac{\sum_{i=1}^{i=n} (C_i - BD_i)}{n} \qquad \text{(A-8)}$$

The solution* to the linear simultaneous equations (A-7) and (A-8) is given by

$$A = \frac{\left(\sum_{i=1}^{i=n} C_i\right)\left(\sum_{i=1}^{i=n} D_i^2\right) - \left(\sum_{i=1}^{i=n} D_i\right)\left(\sum_{i=1}^{i=n} D_i C_i\right)}{n\left(\sum_{i=1}^{i=n} D_i\right)^2 - \left(\sum_{i=1}^{i=n} D_i\right)^2} \qquad \text{(A-9)}$$

---

*Also derived from a general solution fitting a polynomial to data represented by a set of points in the "Handbook of Probability and Statistics with Tables" by R. C. Burington and D. C. May, Handbook Publishers, Inc.

$$B = \frac{n \sum_{i=1}^{i=n} C_i D_i - \left(\sum_{i=1}^{i=n} C_i \right) \left(\sum_{i=1}^{i=n} D_i \right)}{n \sum_{i=1}^{i=n} D_i^2 - \left(\sum_{i=1}^{i=n} D_i \right)^2} . \qquad \text{(A-10)}$$

APPENDIX B

INDIVIDUAL SHIP PROCUREMENT COST

INDIVIDUAL SHIP PROCUREMENT COST*

HULL NO.	NAME	COST (Millions of 1979 Dollars)
CV-59	FORRESTAL	1,109
CV-60	SARATOGA	1,189
CV-61	RANGER	975
CV-62	INDEPENDENCE	1,178
CV-63	KITTY HAWK	1,371
CV-64	CONSTELLATION	1,346
CV-66	AMERICA	1,180
CV-67	JOHN F. KENNEDY	1,286
LHA-2	SAIPAN	532
LHA-3	BELLEAU WOOD	590
LHA-4	NASSAU	580
LHA-5	PEILIEU	610
LPH-2	IWO JIMA	252
LPH-3	OKINAWA	246
LPH-7	GUADALCANAL	244
LPH-9	GUAM	250
LPH-10	TRIPOLI	190
LPH-11	NEW ORLEANS	249
LPH-12	INCHON	175
CVN-65	ENTERPRISE	2,239
CVN-68	NIMITZ	2,148
CVN-69	DWIGHT D. EISENHOWER	1,608
SSN-578	SKATE	362
SSN-579	SWORDFISH	209
SSN-583	SARGO	220
SSN-584	SEADRAGON	217

*Table includes only those ships for which U.S. Navy historical cost data were available.

HULL NO.	NAME	COST (Millions of 1979 Dollars)
SSN-585	SKIPJACK	358
SSN-588	SCAMP	253
SSN-589	SCORPION	290
SSN-590	SCULPIN	234
SSN-591	SHARK	273
SSN-592	SNOOK	230
SSN-594	PERMIT	395
SSN-595	PLUNGER	331
SSN-596	BARB	333
SSN-603	POLLACK	416
SSN-604	HADDO	332
SSN-605	JACK	515
SSN-606	TINOSA	484
SSN-607	DACE	290
SSN-612	GUARDFISH	384
SSN-613	FLASHER	386
SSN-614	GREENLING	362
SSN-615	GATO	350
SSN-621	HADDOCK	471
SSN-637	STURGEON	330
SSN-638	WHALE	338
SSN-639	TAUTOG	389
SSN-646	GRAYLING	419
SSN-647	POGY	429
SSN-648	ASPRO	323
SSN-649	SUNFISH	282
SSN-651	QUEENFISH	281
SSN-652	PUFFER	324
SSN-653	RAY	279
SSN-662	GURNARD	333
SSN-663	HAMMERHEAD	235
SSN-664	SEA DEVIL	247
SSN-665	GUITARRO	419
SSN-666	HAWKBILL	330
SSN-667	BERGALL	271
SSN-668	SPADEFISH	220
SSN-669	SEAHORSE	212
SSN-670	FINBACK	220
SSN-672	PINTADO	347
SSN-673	FLYING FISH	253
SSN-674	TREPANG	214
SSN-675	BLUEFISH	214
SSN-676	BILLFISH	210
SSN-677	DRUM	345
SSN-683	PARCHE	261
SSN-684	CAVALLA	279
SSN-686	L. MENDEL RIVERS	286
SSN-687	RICHARD B. RUSSELL	274

HULL NO.	NAME	COST (Millions of 1979 Dollars)
SSN-688	LOS ANGELES	604
SSN-689	BATON ROUGE	379
SSN-690	PHILADELPHIA	372
SSN-691	MEMPHIS	376
SSN-692	OMAHA	373
SSN-693	CINCINNATI	371
SSN-694	GROTON	356
SSN-695	BIRMINGHAM	345
SSN-696	NEW YORK CITY	392
SSN-697	INDIANAPOLIS	379
SSN-698	BREMERTON	363
SSN-699	JACKSONVILLE	354
SSN-701	LA JOLLA	355
SSN-702	PHOENIX	358
SS-580	BARBEL	170.6
SS-581	BLUEBACK	107.5
SS-582	BONEFISH	93.6
DD-931	FOREST SHERMAN	211.5
DD-932	JOHN PAUL JONES	146.0
DD-933	BARRY	155.0
DD-936	DECATUR	162.8
DD-937	DAVIS	147.7
DD-938	JONAS INGRAM	139.5
DD-940	MANLEY	139.6
DD-941	DUPONT	126.0
DD-942	BIGELOW	126.0
DD-943	BLANDY	133.9
DD-944	MULLINNIX	133.3
DD-945	HULL	128.7
DD-946	EDSON	123.6
DD-947	SOMERS	123.6
DD-948	MORTON	130.3
DD-949	PARSONS	130.8
DD-950	RICHARD S. EDWARDS	130.3
DD-951	TURNER JOY	130.3
FF-1021	COURTNEY	51.2
FF-1022	LESTER	50.7
FF-1023	EVANS	50.7
FF-1024	BRIDGET	49.2
FF-1025	BAUER	53.3
FF-1026	HOOPER	53.3
FF-1027	JOHN WILLIS	52.3
FF-1028	VAN VOORHIS	52.3
FF-1029	HARTLEY	52.3
FF-1030	JOSEPH TAUSSIG	52.3

HULL NO.	NAME	COST (Millions of 1979 Dollars)
FF-1033	CLAUDE JONES	52.7
FF-1034	JOHN PERRY	39.8
FF-1035	CHARLES BERRY	54.9
FF-1036	MC MORRIS	54.5
FF-1040	GARCIA	121.0
FF-1041	BRADLEY	107.1
FF-1043	EDWARD McDONNELL	104.7
FF-1044	BRUMBY	92.3
FF-1045	DAVIDSON	99.4
FF-1047	VOGE	207.0
FF-1048	SAMPLE	91.3
FF-1049	KOELSCH	101.2
FF-1050	ALBERT DAVID	89.4
FF-1051	O'CALLAHAN	81.3
FF-1052	KNOX	252.5
FF-1053	ROARK	112.6
FF-1054	GRAY	113.4
FF-1055	HEPBURN	113.8
FF-1056	CONNOLE	105.3
FF-1057	RATHBURNE	104.9
FF-1058	MEYERKORD	110.9
FF-1059	W. S. SIMS	101.9
FF-1060	LANG	110.0
FF-1061	PATTERSON	107.0
DD-963	SPRUANCE	340.1
DD-964	PAUL F. FOSTER	312.2
DD-965	KINKAID	286.5
DD-966	HEWITT	278.9
DD-967	ELLIOTT	230.5
DD-968	ARTHUR W. RADFORD	233.3
DD-969	PETERSON	231.4
DD-970	CARON	210.8
DD-971	DAVID R. RAY	222.3
DD-972	OLDENDORF	247.4
DD-973	JOHN YOUNG	228.5
DD-974	COMTE DE GRASSE	217.2
DD-975	O'BRIEN	212.2
DD-976	MERRILL	208.9
DD-977	BRISCOE	213.4
DD-978	STUMP	213.2
DD-979	CONOLLY	217.5
DD-980	MOOSBRUGGER	209.9
DD-981	JOHN HANCOCK	210.2
DD-982	NICHOLSON	201.3
DD-983	JOHN RODGERS	194.5
DD-984	LEFTWICH	199.0

(continued)

HULL NO.	NAME	COST (Millions of 1979 Dollars)
DD-985	CUSHING	206.5
DD-986	HARRY W. HILL	204.7
DD-987	O'BANNON	204.0
DD-988	THORN	203.9
DD-989	DEYO	204.1
DD-990	INGERSOLL	205.2
DD-991	FIFE	203.7
DD-992	FLETCHER	206.1
PG-92	TACOMA	16.6
PG-93	WELCH	12.3
PG-94	CHEHALIS	14.5
PG-95	DEFIANCE	12.7
PG-96	BENICIA	17.0
PG-97	SURPRISE	12.7
PG-98	GRAND RAPIDS	15.6
PG-99	BEACON	12.7
PG-100	DOUGLAS	17.4
PG-101	GREEN BAY	13.0
CG-16	LEAHY	410.6
CG-17	HARRY E. YARNELL	264.7
CG-18	WORDEN	266.7
CG-19	DALE	316.5
CG-20	RICHMOND K. TURNER	280.0
CG-21	GRIDLEY	266.7
CG-22	ENGLAND	285.5
CG-23	HALSEY	284.5
CG-24	REEVES	266.2
CG-26	BELKNAP	330.8
CG-27	JOSEPHUS DANIELS	254.9
CG-28	WAINWRIGHT	241.1
CG-29	JOUETT	332.2
CG-30	HORNE	294.0
CG-31	STERETT	268.6
CG-32	WILLIAM H. STANDLEY	238.0
CG-33	FOX	266.7
CG-34	BIDDLE	227.5
DDG-2	CHARLES F. ADAMS	257.0
DDG-3	JOHN KING	196.0
DDG-4	LAWRENCE	205.1
DDG-5	CLAUDE V. RICKETTS	205.1
DDG-6	BARNEY	205.1
DDG-7	HENRY B. WILSON	196.0
DDG-8	LYNDE McCORMICK	198.0
DDG-9	TOWERS	209.7
DDG-10	SAMPSON	188.2

(continued)

HULL NO.	NAME	COST (Millions of 1979 Dollars)
DDG-11	SELLERS	176.5
DDG-12	ROBISON	170.9
DDG-13	HOEL	172.4
DDG-14	BUCHANAN	180.5
DDG-15	BERKELEY	201.2
DDG-16	JOSEPH STRAUSS	169.2
DDG-17	CONYNGHAM	169.7
DDG-18	SEMMES	166.6
DDG-19	TATTNALL	167.1
DDG-20	GOLDSBOROUGH	161.2
DDG-21	COCHRANE	144.0
DDG-22	BENJAMIN STODDERT	144.5
DDG-23	RICHARD E. BYRD	143.8
DDG-24	WADDELL	149.3
DDG-37*	FARRAGUT	335.5
DDG-38	LUCE	222.8
DDG-39	MACDONOUGH	225.9
DDG-40	COONTZ	328.3
DDG-41	KING	291.6
DDG-42	MAHAN	298.8
DDG-43	DAHLGREN	260.6
DDG-44	WILLIAM V. PRATT	258.6
DDG-45	DEWEY	224.5
DDG-46	PREBLE	223.5
FFG-1	BROOKE	138.1
FFG-2	RAMSEY	130.5
FFG-3	SCHOFIELD	128.6
FFG-4	TALBOT	137.6
FFG-5	RICHARD L. PAGE	114.9
FFG-6	JULIUS A. FURER	116.2
FFG-7	OLIVER HAZARD PERRY	452.8
FFG-8	McINERNEY	177.0
FFG-9	WADSWORTH	185.7
FFG-10	DUNCAN	189.4
FFG-11	CLARK	158.2
FFG-13	SAMUEL ELIOT MORISON	153.8
FFG-14	SIDES	168.4
FFG-15	ESTOCIN	153.9
CGN-9	LONG BEACH	1,672
CGN-25	BAINBRIDGE	765.7

*Or DLG-6, etc.

HULL NO.	NAME	COST (Millions of 1979 Dollars)
CGN-35	TRUXTUN	579.3
CGN-36	CALIFORNIA	768.3
CGN-37	SOUTH CAROLINA	654.3
CGN-38	VIRGINIA	683.1
CGN-39	TEXAS	566.3
CGN-40	MISSISSIPPI	538.6
CGN-41	ARKANSAS	577.7
LPD-1	RALEIGH	232.1
LPD-2	VANCOUVER	199.6
LPD-3	LaSALLE	221.8
LPD-7	CLEVELAND	170.9
LPD-8	DUBUQUE	157.7
LPD-9	DENVER	191.8
LPD-10	JUNEAU	187.7
LPD-11	CORONADO	157.4
LPD-12	SHREVEPORT	145.5
LPD-13	NASHVILLE	142.9
LPD-14	TRENTON	148.4
LPD-15	PONCE	144.9
LCC-19	BLUE RIDGE	465.0
LCC-20	MOUNT WHITNEY	256.6
LSD-28	THOMASTON	163.8
LSD-29	PLYMOUTH ROCK	114.5
LSD-30	FORT SNELLING	114.5
LSD-31	POINT DEFIANCE	114.5
LSD-32	SPIEGEL GROVE	107.4
LSD-33	ALAMO	104.7
LSD-34	HERMITAGE	98.3
LSD-35	MONTICELLO	96.2
LSD-36	ANCHORAGE	118.3
LSD-37	PORTLAND	119.8
LSD-38	PENSACOLA	114.0
LSD-39	MOUNT VERNON	115.8
LSD-40	FORT FISHER	104.7
LKA-113	CHARLESTON	128.8
LKA-114	DURHAM	108.1
LKA-115	MOBILE	101.4
LKA-116	ST. LOUIS	101.8
LKA-117	EL PASO	102.4

HULL NO.	NAME	COST (Millions of 1979 Dollars)
LST-1171	DE SOTO COUNTY	59.9
LST-1173	SUFFOLK COUNTY	121.3
LST-1174	GRANT COUNTY	57.5
LST-1175	YORK COUNTY	61.7
LST-1176	GRAHAM COUNTY	76.4
LST-1177	LORAIN COUNTY	69.0
LST-1178	WOOD COUNTY	68.5
LST-1179	NEWPORT	207.9
LST-1180	MANITOWOC	129.2
LST-1181	SUMTER	127.4
LST-1182	FRESNO	74.2
LST-1183	PEORIA	72.0
LST-1184	FREDERICK	70.9
LST-1185	SCHENECTADY	70.9
LST-1186	CAYUGA	71.3
LST-1187	TUSCALOOSA	73.1
LST-1188	SAGINAW	75.4
LST-1189	SAN BERNARDINO	65.8
LST-1190	BOULDER	68.1
LST-1191	RACINE	65.8
LST-1192	SPARTANBURG COUNTY	66.8
LST-1193	FAIRFAX COUNTY	66.5
LST-1194	LA MOURE COUNTY	66.8
LST-1195	BARBOUR COUNTY	67.5
LST-1196	HARLAN COUNTY	67.8
LST-1197	BARNSTABLE COUNTY	68.5
LST-1198	BRISTOL COUNTY	75.4
AF-58	RIGEL	95.2
AF-59	VEGA	95.4
AFS-1	MARS	120.1
AFS-2	SYLVANIA	103.2
AFS-3	NIAGARA FALLS	102.7
AFS-4	WHITE PLAINS	104.6
AFS-5	CONCORD	102.2
AFS-6	SAN DIEGO	99.2
AFS-7	SAN JOSE	98.7
AE-21	SURIBACHI	103.1
AE-22	MAUNA KEA	76.6
AE-23	NITRO	88.0
AE-24	PYRO	85.4
AE-25	HALEAKALA	87.0
AE-26	KILAUEA	139.4
AE-27	BUTTE	141.0

(continued)

HULL NO.	NAME	COST (Millions of 1979 Dollars)	
AE-28	SANTA BARBARA	132.0	
AE-29	MOUNT HOOD	134.0	
AE-32	FLINT	125.3	
AE-33	SHASTA	125.3	
AE-34	MOUNT BAKER	122.7	
AE-35	KISKA	119.9	
AO-177	CIMARRON	177.5	
AO-178	MONONGAHELA	138.0	
T-AO-143	NEOSHO	156.2	
T-AO-144	MISSISSINEWA	122.7	
T-AO-145	HASSAYAMPA	122.7	
T-AO-146	KAWISHIWI	122.7	
T-AO-147	TRUCKEE	122.7	
T-AO-148	PONCHATOULA	122.7	
AOE-1	SACRAMENTO	338.3	
AOE-2	CAMDEN	286.9	
AOE-3	SEATTLE	324.2	
AOE-4	DETROIT	304.4	
AOR-1	WICHITA	164.9	
AOR-2	MILWAUKEE	155.5	
AOR-3	KANSAS CITY	131.4	
AOR-4	SAVANNAH	129.6	
AOR-5	WABASH	137.2	
AOR-6	KALAMAZOO	145.5	
AOR-7	ROANOKE	141.9	
MSB-25	(No Names for MSBs)	18.2	
MSB-26		5.3	
MSB-27		5.7	
MSB-28		10.6	
MSB-29		8.8	
MSB-30-34		4.7	(for each of 5 ships)
MSB-35-39		4.8	"
MSB-40-44		4.7	"
MSB-45-49		4.9	"
MSB-50-54		4.7	"
MSO-455	IMPLICIT	41.1	
MSO-456-457	INFLICT (456)	33.5	(for each of 2 ships)
MSO-463-467	PLUCK (464)	33.5	(for each of 5 ships)
MSO-458	LUCID	52.3	
MSO-459-462	NIMBLE, NOTABLE, OBSERVER, PINNACLE	31.7	(for each of 4 ships)
MSO-468-474	RIVAL, SAGACITY, SALUTE, SKILL, VALOR, VIGOR, VITAL	31.7	(for each of 7 ships)
MSO-488	CONQUEST	35.4	(continued)

HULL NO.	NAME	COST (Millions of 1979 Dollars)
MSO-489-492	GALLANT, LEADER, PERSISTANT, PLEDGE (492)	25.4 (for each of 4 ships)
MSO-493-496	STALWART, STURDY, SWERVE, VENTURE	27.1 (for each of 4 ships)
MSO-508	ACME	33.5
MSO-509-511	ADROIT, ADVANCE, AFFRAY	26.4 (for each of 3 ships)
MSO-519	ABILITY	39.8
MSO-520-521	ALACRITY, ASSURANCE	24.1 (for each of 2 ships)
MSC-121	BLUEBIRD	22.7
MSC-122	COMORANT	16.9
MSC-190	FALCON	27.1
MSC-191	FRIGATE BIRD	46.4
MSC-195	LIMPKIN	37.1
MSC-198	PEACOCK	26.8
MSC-200	REDWING	14.8
MSC-201	SHRIKE	44.9
MSC-205	VIREO	56.9
MSI-1	COVE	9.5
MSI-1	CAPE	7.1
AD-37	SAMUEL GOMPERS	262.2
AD-38	PUGET SOUND	217.7
AD-41	YELLOWSTONE	318.4
AS-33	SIMON LAKE	301.5
AS-34	CANOPUS	228.7
AS-36	L. Y. SPEAR	269.4
AS-37	DIXON	202.0
AS-39	EMORY S. LAND	333.2
AS-41	McKEE	305.5
YTB-752-753	EDENSHAW	3.798 (for each of 2 ships)
YTB-756-759	PONTIAC, OSHKOSH, PADUCA, BOGALUSA	2.996 (for each of 4 ships)
YTB-760	NATICK	2.837
YTB-761	OTTUMWA	2.674
YTB-762	TUSCUMBIA	2.649
YTB-763	MUSKEGON	2.910
YTB-764	MISHAKAWA	2.915
YTB-767	APALACHIOLA	2.954
YTB-768	ARCATA	2.995
YTB-769	CHESANING	2.590
YTB-770	DAHLONEGA	2.595
YTB-771	KEOKUK	2.591
YTB-772		2.463

(continued)

HULL NO.	NAME	COST (Millions of 1979 Dollars)
YTB-773		2.445
YTB-774	NASHUA	2.576
YTB-775	WAUWATOOSA	2.593
YTB-776	WEEHAWKEN	2.717
YTB-777	NOGALES	3.016
YTB-778	APOPKA	2.623
YTB-779	MANHATTAN	2.678
YTB-780	SAUGUS	2.456
YTB-781	NIANTIC	2.507
YTB-782-783	MANISTEE, REDWING	2.491 (for each of 2 ships)
YTB-784	KALISPELL	2.330
YTB-785	WINNEMUCCA	2.326
YTB-786	TONKAWA	2.330
YTB-787-788	KITTANING, WAPATO	2.350 (for each of 2 ships)
YTB-789	TOMAHAWK	2.326
YTB-790	MENOMINEE	2.236
YTB-791	MARINETTE	2.244
YTB-792	ANTIGO	2.233
YTB-793	PIQUA	2.240
YTB-794	MANDAN	2.716
YTB-795	KETCHIKAN	2.625
YTB-796	SACO	2.616
YTB-797-798	TAMAQUA, OPELIKA	2.612 (for each of 2 ships
YTB-799	NATCHITOCHES	2.426
YTB-800	EUFAULA	2.423
YTB-801	PALATKA	2.392
YTB-802	CHERAW	2.389
YTB-803-808	NANTICOKE, AHOSKIE, OCALA, TUSKEGEE, MASSAPEQUA, WENATCHEE	2.440 (for each of 6 ships)
YTB-809-810	AGAWAN, ANOKA	2.563 (for each of 2 ships)
YTB-811-815	HOUMA, ACCONAC, POUGHKEEPSIE, WAXAHATCHIE, NEVDESHA	2.114 (for each of 5 ships)
YTB-816-827	CAMPTI, HAYANNIS, MECOSTA, IUKA, WANAMASSA, TONTOGANY, PAWHUSKA, CANONCHE, SANTAQUIN, WATHENA, WASHTUCNA, CHETEK	2.124 (for each of 12 ships)
YTB-828-836	CATAHECASSA, METACOM, PUSHMATHA, DEKANAWIDA, PETALESHARO, SHABONEE, NEWGAGON, SKENANDOA, POKAGON	2.123 (for each of 9 ships)
ATF-166	POWHATAN	19.1
ATF-167	NARRAGANSETT	19.7
ATF-168	CATAWBA	17.7
ATF-169	NAVAHO	18.1
ATF-170	MOHAWK	22.1
ATF-171	SIOUX	17.4

*One ship cost was missing and not included.

HULL NO.	NAME	COST (Millions of 1979 Dollars)
ATS-1	EDENTON	52.5
ATS-2	BEAUFORT	35.0
ATS-3	BRUNSWICK	34.9
ASR-21	PIGEON	219.0
ASR-22	ORTOLAN	189.4
PTF-17	(No names for PTFs)	4.98
PTF-18		2.99
PTF-19-22		3.32 (each of 4 ships)
PTF-23-26		2.99 (each of 4 ships)
PHM-2	HERCULES	52.3
PHM-3	TAURUS	117.9
PHM-4	AQUILA	89.1
PHM-5	ARIES	75.1
PHM-6	GEMINI	58.1

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