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DEVELOPMENT OF COST ESTIMATING RELATIONSHIPS FOR MISSILE ENGINEERING MANUFACTURING DEVELOPMENT (EMD) COSTS AND WARSHIP FUEL CONSUMPTION

by

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The purpose of this thesis is to develop estimating relationships for missile Engineering and Manufacturing Development (EMD) costs and warship fuel consumption to aid the Naval Center for Cost Analysis (NCA) in performing independent cost estimates for new weapons programs. Standard factors, which represent the percent that each cost element is typically allocated from the program's total funding, are currently used to predict whether missile EMD costs are "roughly right." For fuel consumption, estimating relationships have only been developed for existing individual ship types. None have been developed which use pooled ship types to estimate fuel consumption of new ship types. Regression analysis was used to develop estimating relationships based on physical and technical characteristics.

The cost estimating relationships (CERs) developed to predict missile EMD costs explained only about 34 percent of the variance. Due to the low explanatory power, no significant physical or technical factors could be determined. Even though the results are not statistically significant, the associated coefficients of variation are lower than the standard factor coefficients of variation.

An estimating relationship with high explanatory power was developed to predict fuel consumption for new warships. Three significant physical and performance factors were determined: steaming hours, age and full load displacement. For new ship types, steaming hours and full load displacement are the significant factors.

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An estimating relationship with high explanatory power was developed to predict fuel consumption for new warships. Three significant physical and performance factors were determined: steaming hours, age and full load displacement. For new ship types, steaming hours and full load displacement are the significant factors.

DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

The purpose of the thesis is to develop estimating relationships for missile Engineering and Manufacturing Development (EMD) costs and warship fuel consumption for the Naval Center for Cost Analysis (NCA). NCA performs independent cost analyses on cost estimates submitted by program managers of major weapons systems, using the methodology most appropriate to the weapons program under study, to ensure they are credible. To refine its current cost estimation methods and techniques, NCA was interested in developing new estimating relationships based on physical and technical characteristics.

The goal of the first section is to develop estimating relationships which predict the total EMD cost, or its element costs, for new missile programs coming on-line based on technical and operational parameters. Currently NCA uses standard factors, which represent the percent that each element is typically allocated from the program's total funding, to judge whether funding for major acquisition programs are "roughly right." A data base containing EMD costs and technical and physical characteristics, such as missile type, launch weight, range and initial operational capability (IOC), was created. A "best fit" regression was performed. The results from the regression were used to address the following questions:

- Are the developed cost estimating relationships (CERs) statistically significant? If so, what are the significant physical or technical factors that affect cost?

- If the result is not significant, is the CER coefficient of variation below that of the standard factors? If so, the developed CER may be a better predictor than the standard factors.

The initial results were poor, so an attempt was made to make the data "cleaner" by deleting dual observations and observations which could not be matched to a particular missile series. The results from the second regression were also poor. The developed CERs explain, at the most, only about 34 percent of the variance. No significant physical or technical factors could be determined due to the low explanatory power. Even though the results are not statistically significant due to the low explanatory power, the associated coefficients of variation are lower than the standard factor coefficients of variation. This means that these developed CERs may be better predictors than the standard factors in use.

The goal of the second section is to develop an estimating relationship to predict fuel consumption for new ships coming on-line. Since fuel costs make up a large part of the Operations and Support (O&S) cost, accurately predicting fuel consumption is vital for the estimatior of that part of the cost estimate. NCA was interested in developing an estimating relationship that used physical and performance factors to estimate fuel consumption. This study of fuel consumption was restricted to seven warship types. After a composite data base was developed, linear regression was performed. The results from the regression were used to address the following questions:

- Are the results significant? If so, what are the significant physical and performance factors that drive fuel consumption of warships?

Based on the results of the analysis, an estimating relationship with a high explanatory power has been developed which predicts fuel consumption of warships. The significant physical and performance factors are steaming hours, age and full load displacement. For new ships, steaming hours and full load displacement are the significant factors. The estimating relationship should be of great help in predicting fuel consumption for inclusion in the O&S cost estimate. It is important that this CER only be used to predict fuel consumption for ships whose characteristics are similar to those in the data base.

I. INTRODUCTION

A. THE PROBLEM

Cost analysts are always looking for ways to more accurately predict future costs. Estimating costs for new programs is extremely difficult. Due to the uncertainty of the factors that impact cost, such as implementing new technology in an existing system or developing an entirely new system, a currently reliable cost estimating tool that does not include these may not perform as well in the future.

One agency responsible for analyzing costs and preparing cost estimates is the Naval Center for Cost Analysis (NCA). The mission of NCA is "...to provide independent cost and financial analyses to support the Secretary of the Navy." [Ref. 1:p. 1] It independently analyzes cost estimates submitted by program managers of major weapons systems to ensure they are credible. Additional tasks include financial analyses of defense contractors and economic analyses of acquisition issues. [Ref. 1:p. 1]

When NCA is tasked with performing an independent cost analysis, it establishes the program baseline and work breakdown structure. These provide the foundation upon which to build the analysis. NCA performs its own independent cost estimate, using the methodology most appropriate to the weapons program under study. The program manager's cost estimate is compared to NCA's estimate. Any differences are reconciled, if possible, and uncertainty and risk/sensitivity analysis is performed. The bottom line of the analysis is to answer the question, "Is the program manager's estimate reasonable?" [Ref. 2:p. 11]

The commodities for which NCA provides independent cost analyses are aircraft, Automated Information Systems (AIS), electronics, missiles, ships, and torpedoes. NCA was interested in developing new Cost Estimating Relationships (CERs) based on physical and technical characteristics in these six areas so that it could refine its current cost estimation methods and techniques. [Ref. 3:p. 1] Two initial areas of study were identified, missile EMD costs and warship fuel consumption.

B. PURPOSE

The purpose of the thesis is to develop estimating relationships for missile Engineering and Manufacturing Development (EMD) costs and warship fuel consumption. Specific physical and technical characteristics will be identified, as appropriate, for inclusion in the models. The goal is to develop reliable estimating tools that can be used by NCA in future independent cost analyses.

1. Missile EMD Costs

In November 1992, a Standard Cost Factors Handbook was published by NCA to provide "rules of thumb" for senior management to use in judging whether acquisition cost estimates were "in the ballpark." These "rules of thumb" were developed for Engineering and Manufacturing Development (EMD) and Procurement costs for six commodities: aircraft, AIS, electronics, missiles, ships, and torpedoes. [Ref. 4:p. iii]

One area, EMD costs for missiles, was identified as a potential area for further study. NCA was interested in determining whether a more reliable cost estimating tool which incorporated technical and physical characteristics could be developed. A data set containing EMD costs and technical and physical characteristics was created. A "best fit" regression was performed on the data. The results from the regression were used to answer the following questions:

- What are the significant physical or technical factors that affect cost?
- Are the results significant? I.e., is the developed CER statistically significant?
- If the results are not significant, is the CER coefficient of variation below that of the standard factors? If so, the developed CER may be a better predictor than the standard factors.

2. Warship Fuel Consumption

Another area of interest was estimating fuel consumption for new ships coming on-line. Since fuel costs make up a large part of the Operations and Support (O&S) cost, accurately predicting fuel consumption is vital for the estimation of that part of the cost estimate. NCA was interested in developing an estimating relationship that used physical and performance factors to estimate fuel consumption. Again, this would provide NCA analysts with another tool to estimate fuel consumption of new ship types or classes. This study of fuel consumption was restricted to seven warship types. After a composite data base was developed, linear regression was performed. The results from the regression were used to answer the following questions:

- What are the significant physical and performance factors that drive fuel consumption of warships?
- Are the results significant?

C. OVERVIEW

The thesis is divided into two sections, missile EMD costs and warship fuel consumption. Missile EMD cost estimating relationships are developed in Chapter II. Warship fuel consumption estimating relationships are developed in Chapter III. Chapter IV contains the Conclusions and Recommendations. Appendix A contains the initial data set of missile EMD costs, while Appendix B contains the cleaner data set. Appendix C contains the warship fuel consumption data. The next four appendices contain statistical information on the excursions run on the base model (Appendix D), Alternative 1 (Appendix E), Alternative 2 (Appendix F), and Alternative 3 (Appendix G). Appendix H contains statistical information on additional excursions which deleted independent variables considered critical to the model.

II. MISSILE EMD COSTS

A. PROBLEM DESCRIPTION

The goal of this chapter is to develop estimating relationships which predict the total EMD cost, or its element costs, for new missile programs coming on-line based on technical and operational parameters. Currently NCA uses standard factors, which are published in its Standard Cost Factors Handbook, to judge whether funding for major acquisition programs are "roughly right." A standard factor is associated with each element of the program, for example, design. These standard factors represent the percent that each element is typically allocated from the program's total funding. The problem is that these factors do not consider technical and operational parameters, so they can never be more than "roughly right." [Ref. 4:p. iii] The need for a more accurate methodology became evident. Development of a cost estimating relationship based on technical and operational characteristics became a high priority. This chapter will concentrate on developing a CER to predict missile EMD costs.

During the selection process, Dr. Daniel Nussbaum, Director of the Missile Division (NCA-4), provided much needed guidance on which technical and operational characteristics to include in the model. The technical and operational characteristics were missile type, launch weight, and range. Initial operational capability was added as a proxy for the level of technology available. These four characteristics shaped the initial model.

The cost data in the handbook was derived from several sources, for example, contractor cost reports. Care was taken to make the data consistent and comparable, but this proved to be a daunting task. Costs from different sources conflicted. For example, one source separately listed costs for the software element, but a second did not. In another case, the difference between the cost elements for dual observations of the same missile was on the order of 400 percent. Despite these problems, it was felt that the data should be explored to see whether usable results could be developed. In a later section, the problems with the data will be more fully discussed and an attempt to derive "cleaner" data will be explored.

B. DESCRIPTION OF DATA

The regression model to be developed depends exclusively on the data obtained. Two sources of data were identified. The Standard Cost Factors Handbook contained missile EMD costs. The U. S. Missile Data Book, 1993 contained the technical and operational characteristics for the missiles under study. The data from the two sources were combined to provide input to the regression model. The missile data is shown in Appendix A. Since the data is cross-sectional, no time-series complications are anticipated. However, use of IOC as an independent variable may induce autocorrelation. This will be checked via the Durbin-Watson statistic. There may be a heteroscedasticity problem since the assumption of constant error variance may be unreasonable.

1. Cost Data

The Standard Cost Factors Handbook contains cost data for each of the five elements of the missile EMD phase, standardized in FY 1989 dollars. The elements are design (DES), hardware (HW), software (SW), support (SUP), and miscellaneous (MISC). These five elements are summed to produce total cost (TOT). Twenty-eight observations are reported. Based on discussions with Dr. Nussbaum, it was decided to delete five observations. Observations were deleted if they were not missiles, if technical and operational characteristics could not be found, or if they were duplicate observations. For example, VIPER was deleted because it was an underwater robotic vehicle system used in mine countermeasures. [Ref. 5:p. 63] The ROLAND missile was deleted because it was not a missile used by U. S. forces. The SLAT was deleted because no technical or operational data could be found. Finally, one set of STINGER and STINGER/POST data was deleted in favor of another more, accurate data set. This left 23 observations in the data set.

2. Technical and Operational Data

The following data was collected from the U. S. Missile Data Book, 1993 for each missile studied:

- missile type
- launch weight
- range
- initial operational capability (IOC).

Based on expert knowledge within NCA's Missile Division, missile type, launch weight, and range were chosen as the variables most likely to have explanatory power. The initial operational capability date was added to act as a proxy for the level of technology available for inclusion into the program. Details on these variables are provided below.

C. DEVELOPMENT OF THE MODEL

The basic objective was to develop a CER to predict missile EMD costs using the data from the Standard Cost Factor Handbook. The dependent variable is EMD cost. However, the available observations [Ref. 4:pp. 37-39] contain not only total EMD costs but individual element costs, such as design, hardware, software, support, and miscellaneous. Therefore, six CERs will be developed, if possible.

In developing a basic model for missile EMD costs, certain *a priori* expectations about the independent variables to be included in the estimation equation shape the model:

EMD Cost = f (missile type, launch weight, range, IOC)

It is assumed that the independent variables will provide explanatory power for each dependent variable.

1. Dependent Variables

a. Design Costs (DES)

Design costs consist of "the cost of the engineering analysis required to transform a concept into released drawings, engineering data, and final hardware." [Ref.4:p. 89] The variable is measured in millions of FY 1989 dollars.

b. Hardware Costs (HW)

Hardware costs consist of "the vehicle which is the primary means for delivering the destructive effect to the target, including the capability to generate or receive intelligence, to navigate and penetrate to the target area and to detonate the warhead. It includes the propulsion system, payload, airframe, reentry system, guidance and control equipment, and command and launch equipment." [Ref. 4:p. 89] The variable is measured in millions of FY 1989 dollars.

c. Software Costs (SW)

Software costs consist of "the effort required to develop computer software for the weapon system which will provide for operational, data analysis, simulation, and other user requirements." [Ref. 4:p. 89] The variable is measured in millions of FY 1989 dollars.

d. *Support Costs (SUP)*

Support costs include applicable costs for system engineering/program management, system test and evaluation, data deliverables, special tooling and test equipment, and integrated logistics support. [Ref. 4:pp. 89-90] The variable is measured in millions of FY 1989 dollars.

e. *Miscellaneous Costs (MISC)*

Miscellaneous costs consist of all other costs that do not fit into the above categories. [Ref. 4:p. 91] The variable is measured in millions of FY 1989 dollars.

f. *Total Costs (TOT)*

The total cost is the sum of design, hardware, software, support and miscellaneous costs. The variable is measured in millions of FY 1989 dollars.

2. Independent Variables

a. *Missile Type (D1,D2,D3,D4)*

These four dummy variables represent the missile type for each observation. Table I gives the complete codes for each missile type. For example, an air-to-air missile would be represented by D1 equal to one and the other dummy variables (D2, D3, D4) equal to zero.

Table I MISSILE CODES FOR TYPE

Missile Type	D1	D2	D3	D4
Surface-to-Air	0	0	0	0
Air-to-Air	1	0	0	0
Air-to-Surface	0	1	0	0
Surface-to-Surface	0	0	1	0
Surface-to-Surface/ Air-to-Surface	0	0	0	1

b. Launch Weight (LWT)

The launch weight is the missile's total weight at launch, excluding the launcher. [Ref. 6:p. C-7] It is expected that the heavier the launch weight, the higher the cost of the missile. The variable is measured in pounds.

c. Range (RNG)

The range is "the distance at which the missile achieves the selected level of accuracy." [Ref. 6:p. C-10] It is expected that the longer the range, the higher the cost of the missile. The variable is measured in nautical miles.

d. IOC

"The initial operational capability date represents the first attainment of the capability to effectively employ the missile." [Ref. 6:p. C-6] It is used as a proxy for the level of technology available at the time the missile was developed. It is expected that as IOC increases, the cost would increase due to the complexity of designing a missile with increased technology. The variable is a four digit date representing the year that IOC was achieved.

D. REGRESSION WITH INITIAL DATA SET

1. CER Development

Although there were several problems with the initial data set of 23 observations, which will be discussed later, the general feeling was to press ahead and see whether any usable results could be obtained. A statistical program called PACER [Ref. 7] was used to develop the initial set of regressions. PACER had a feature that performed a "Best Fit" regression on the data. The types of regression it performed were linear, power, exponential, semi-log linear (a) (where the natural log of the dependent variable is taken), semi-log linear (b) (where the natural log of the independent variables are taken), quadratic, log linear and stepwise. The results from PACER were checked using MicroTSP [Ref. 8].

Initially the evaluation criteria consisted of an adjusted R^2 greater than 0.90, absolute t-statistics greater than two, and probability of the F-statistic (P(F)) less than or equal to 0.05. Based on the low R^2 values observed in the results, the criteria were changed. The adjusted R^2 criterion was dropped. The t-statistics criterion was changed to the probability of the t-statistic; both probabilities for the F-statistic and t-statistic were changed to be less than or equal to 0.10.

The results were not encouraging. Only a few cost estimating relationships were statistically significant. The largest adjusted R^2 was 0.249. The explanatory power of these regressions is so small as to be useless. The CERs and their statistics are discussed in detail below.

a. *Design Costs*

There were several statistically significant CERs. Table II shows the results. These CERs had t-statistic and F-statistic probabilities less than 0.10. Therefore, the "best" CER was based on the regression that had the highest explanatory power, i.e., adjusted R^2. For DES the best equation was the power fit equation with RNG as the independent variable. However, there really is no best equation since the explanatory power of all the CERs is extremely low.

Table II DESIGN COST REGRESSION RESULTS

Equation Type	t-statistics Constant	D1	LWT	RNG	P(F)	Adj. R^2
Power	2.15*		1.88*		0.0736	0.104
Power	6.26*			2.74*	0.0122	0.229
S-log(a)	14.00	1.76	2.08		0.0625	0.166

* reflects the t-statistic for the natural log of this independent variable

Observations = 23

EQUATIONS:

$$\ln(DES) = \ln(11.2) + 0.299\ln(LWT)$$
$$\ln(DES) = \ln(24.8) + 0.338\ln(RNG)$$
$$\ln(DES) = 4.03 + 1.17D1 + 1.44E\text{-}4LWT$$

b. Hardware Costs

There were no statistically significant CERs. None of the t-statistics or F-statistics had a significance level less than or equal to 0.10.

c. Software Costs

There were no statistically significant CERs. None of the t-statistics or F-statistics had a significance level less than or equal to 0.10.

d. Support Costs

There were several CERs produced in this section. Table III shows the results. These CERs had t-statistic and F-statistic probabilities less than 0.10. Therefore, the "best" CER was based on the regression that had the highest explanatory power, i.e., adjusted R^2. For SUP the best equation was the power fit equation with RNG as the independent variable. However, there really is no best equation since the explanatory power of all the CERs is extremely low.

e. Miscellaneous Costs

There were no statistically significant CERs. None of the t-statistics or F-statistics had a significance level less than or equal to 0.10.

f. Total Costs

There were several CERs produced in this section. Table IV shows the results. These CERs had t-statistic and F-

Table III SUPPORT COST REGRESSION RESULTS

Equation Type	t-statistics Constant	D1	D2	LWT	RNG	P(F)	Adj. R^2
S-log(a)	26.20	1.86				0.0768	0.101
Power	3.94*			1.98*		0.0607	0.117
Power	10.30*				2.73*	0.0124	0.227
S-log(a)	24.10	2.20			1.88	0.0421	0.199
S-log(a)	17.00	2.66	1.72	1.92		0.0462	0.232

* reflects the t-statistic for the natural log of this independent variable

Observations = 23

EQUATIONS:

$$\ln(SUP) = 5.03 + 0.988D1$$
$$\ln(SUP) = \ln(31.5) + 0.245\ln(LWT)$$
$$\ln(SUP) = \ln(63.4) + 0.265\ln(RNG)$$
$$\ln(SUP) = 4.86 + 1.11D1 + 6.79E\text{-}4RNG$$
$$\ln(SUP) = 4.55 + 1.38D1 + 0.649D2 + 1.02E\text{-}4LWT$$

statistic probabilities less than 0.10. Therefore, the "best" CER was based on the regression that had the highest explanatory power, i.e., adjusted R^2. For TOT the best equation was the power fit equation with RNG as the independent variable. However, there really is no best equation since the explanatory power of all the CERs is extremely low.

2. Coefficient of Variation

The coefficient of variation is the standard deviation divided by the mean. The Standard Cost Factors Handbook contains coefficients of variation for all of the standard factors [Ref. 4:p. 33]. The lower the value of the coefficient of variation, the better. A lower coefficient of

Table IV TOTAL COST REGRESSION RESULTS

Equation Type	t-statistics Constant	D1	LWT	RNG	P(F)	Adj. R^2
S-log(a)	28.60	1.80			0.08600	0.0926
Power	4.39*		2.18*		0.04110	0.1450
Power	11.50*			2.88*	0.00890	0.2490
S-log(a)	23.60	2.20	1.87		0.04740	0.1890
S-log(a)	26.50	2.16		1.97	0.04060	0.2010

* reflects the t-statistic for the natural log of this independent variable

Observations = 23

EQUATIONS:

$\ln(TOT) = 5.79 + 1.01D1$
$\ln(TOT) = \ln(54.1) + 0.279\ln(LWT)$
$\ln(TOT) = \ln(125) + 0.290\ln(RNG)$
$\ln(TOT) = 5.54 + 1.18D1 + 1.05E\text{-}4LWT$
$\ln(TOT) = 5.61 + 1.15D1 + 7.43E\text{-}4RNG$

variation means that the predicted value would be closer to the true value. Generally, coefficient of variation values less than or equal to 20 percent are considered good values. Even if the CERs do not have sufficient explanatory power, they may still be useful if they have low coefficient of variation values.

The standard factor and developed coefficient of variation values are shown in Table V. Only three coefficients of variation could be calculated. The coefficients of variation for design, support, and total costs are all less than those of the standard factors. However, the design cost coefficient of variation does not meet the criterion for a good coefficient of variation.

Table V COMPARISON OF COEFFICIENTS OF VARIATION

	DES	HW	SW	SUP	MISC	TOT
Standard Factors	0.450	0.44	1.43	0.240	1.34	n/a
Developed CERs	0.256	n/a	n/a	0.175	n/a	0.161

E. PROBLEMS WITH THE COST DATA

As discussed earlier, there are problems with the cost data being consistent and comparable. The problems are: using multiple sources of data for a single system, using multiple sources of data in general and the attendant problem of different cost accounting methods, not identifying missiles by designations (including the series letter), including dual observations with widely disparate costs for the same missile, and including a missile that combines two types (i.e., the HARPOON is a surface-to-surface and air-to-surface missile).

If all of the cost elements for a missile could not be extracted from a single source, other sources were consulted to find the missing data. The data available in the second source may not be clean. That is, due to different accounting methods, the second source's data may include costs captured by the first source in another element, resulting in "double counting." Or, the second source may not capture all the costs in the element desired, resulting in "undercounting." This highlights the problem of inconsistency. The result is data that is not consistent "within" an observation.

Multiple sources were consulted during the compilation of the data, such as contractor's cost reports, cost estimates, and budget data. Each source has its own methodology for categorizing costs. This created the problem of nonstandard data. The differences in categorization were related to the purpose for which the reports were created. It is basically impossible to break down these "wrapped up" categories into the separate elements under study after the fact. The result is data that cannot be compared by element. However, it is possible that the total costs can be compared.

One of the most serious problems was that the missile for which the cost data was collected was not identified by its missile designator or series letter. This means that technical and operational characteristics cannot be accurately determined and matched to the cost data. In only one of the 23 observations was a missile designator and series letter included. The rest just contained the missile name. There was no way to tell for sure if the EMD cost data was for the first missile in the series or for a later model. There were also several missiles annotated with the acronym FSED (Full Scale Engineering Development). None of the resources researched contained technical and operational characteristics for missiles in this development stage. Therefore, the four observations with this problem were either assigned the same characteristics as the basic missile, or an assumption was made to assign it the most recent model's characteristics. It is evident that the validity of the data is in serious question.

If two reliable sources were found for cost data for a single missile, frequently both would be included as separate observations. In all of the four pairs of missiles with dual observations, the EMD costs for each element and the total varied widely, seriously affecting the validity of the data. For example, the PATRIOT missile had the following values for the cost of design: $904M and $150M. There is a similar discrepancy for the total cost: $2,417M and $1,057M. Obviously one observation is wrong. It is possible that both are wrong. The question is, "Which one(s)?" The correction to this problem is neither evident nor easy, since the data are collected after the fact and require extraction from reports and documents not created or maintained for this purpose.

Finally, the last problem was whether an observation for a missile that was composed of two types should be included. The HARPOON missile is a surface-to-air and air-to-air missile. The methodology used to track missile type used dummy variables. However, there was no way to identify the missile as having both type characteristics, so a separate type was developed for it (D4 equal to one; D1, D2, D3 equal to zero). This does not allow regression to consider the effects of the HARPOON's surface-to-surface characteristics with other surface-to-surface missiles or its air-to-surface characteristics with other air-to-surface missiles. Instead, it puts the HARPOON missile into a separate category, thereby confounding the results, and not accomplishing the goal of using missile type to predict EMD costs.

F. REGRESSION WITH "CLEANER" DATA SET

As discussed in the above section, there are a lot of problems inherent in the data. In this section, an attempt will be made to make the data "cleaner" and then to analyze the new data set to see if any usable results are present. The "clean" terminology does not imply that the data set is now valid. There are inherent problems with the data that simple deletion of observations will not fix.

The original data set used was composed of 23 observations. The following nine observations were deleted to create the cleaner data set: four FSED observations (observations 10, 19, 20, 22), two dual observations (observations 2, 13), and the HARPOON (observations 6, 7) and PHOENIX AIM-56A (observation 15) missiles. The FSED and the PHOENIX missile observations were deleted because no technical data could be found. In the case of the dual observations, the observations with the smaller costs were deleted from the data base. It seems reasonable to assume that observations with larger costs more accurately reflect true costs. Finally, the HARPOON missile observations were deleted due to the dual missile type problem. This left 14 observations in the data base, which are shown in Appendix B.

1. CER Development

Again, the initial evaluation criteria consisted of an adjusted R^2 greater than 0.90, absolute t-statistics greater than two, and probability of the F-statistic (P(F)) less than or equal to 0.05. Based on the low R^2 values observed in the results, the criteria were changed. The adjusted R^2 criterion was dropped. The t-statistic criterion was changed to the probability of the t-statistic; both probabilities for the F-statistic and t-statistic were changed to be less than or equal to 0.10.

The results were still not encouraging. Only a few cost estimating relationships were statistically significant. The largest adjusted R^2 was 0.342. The explanatory power of these regressions is so small as to be useless. The CERs and their statistics are listed below.

As discussed previously, use of IOC as an independent variable may induce autocorrelation. This can be checked by the Durbin-Watson statistic. Since IOC did not appear in any of the final CERs, autocorrelation by definition is not a problem.

a. *Design Costs*

There were several CERs produced in this section. Table VI shows the results. These CERs had t-statistic and F-statistic probabilities less than 0.10. Therefore, the "best" CER was based on the regression that had the highest explanatory power, i.e., adjusted R^2. For DES the best equation was the power fit equation with RNG as the independent variable. However, there really is no best equation since the explanatory power of all the CERs is extremely low.

Table VI DESIGN COST REGRESSION RESULTS (CLEANER DATA)

Equation Type	t-statistics Constant	LWT	RNG	P(F)	Adj. R^2
Power	1.16*	1.92*		0.0784	0.172
Power	4.42*		2.63*	0.0219	0.313

* reflects the t-statistic for the natural log of this independent variable

Observations = 14

EQUATIONS:

$$\ln(DES) = \ln(5.87) + 0.419\ln(LWT)$$
$$\ln(DES) = \ln(20.7) + 0.439\ln(RNG)$$

b. Hardware Costs

There were several CERs produced in this section. Table VII shows the results. These CERs had t-statistic and F-statistic probabilities less than 0.10. Therefore, the "best" CER was based on the regression that had the highest explanatory power, i.e., adjusted R^2. For HW the best equation was the power fit equation with RNG as the independent variable. However, there really is no best

equation since the explanatory power of all the CERs is extremely low.

Table VII HARDWARE COST REGRESSION RESULTS (CLEANER DATA)

Equation Type	t-statistics Constant	LWT	RNG	P(F)	Adj. R^2
Power	1.64*	2.17*		0.0511	0.221
Power	5.73*		2.37*	0.0355	0.262

* reflects the t-statistic for the natural log of this independent variable

Observations = 14

EQUATIONS:

$$\ln(HW) = \ln(7.17) + 0.369\ln(LWT)$$
$$\ln(HW) = \ln(26.6) + 0.330\ln(RNG)$$

c. Software Costs

There were no statistically significant CERs. None of the t-statistics or F-statistics had a significance level less than or equal to 0.10.

d. Support Costs

There were several CERs produced in this section. Table VIII shows the results. These CERs had t-statistic and F-statistic probabilities less than 0.10. Therefore, the "best" CER was based on the regression that had the highest explanatory power, i.e., adjusted R^2. For SUP the best equation was the power fit equation with RNG as the independent variable. However, there really is no best

equation since the explanatory power of all the CERs is extremely low.

Table VIII SUPPORT COST REGRESSION RESULTS (CLEANER DATA)

Equation Type	t-statistics Constant	LWT	RNG	P(F)	Adj. R^2
Power	2.4800*	1.91*		0.0801	0.170
Power	7.4000*		2.71*	0.0190	0.327
Semi-log(b)	0.0385		2.03*	0.0650	0.194

* reflects the t-statistic for the natural log of this independent variable

Observations = 14

EQUATIONS:

$$\ln(SUP) = \ln(19.7) + 0.327\ln(LWT)$$
$$\ln(SUP) = \ln(50.9) + 0.350\ln(RNG)$$
$$SUP = 6.17 + 79.3\ln RNG$$

e. Miscellaneous Costs

There were no statistically significant CERs. None of the t-statistics or F-statistics had a significance level less than or equal to 0.10.

f. Total Costs

There were several CERs produced in this section. Table IX shows the results. These CERs had t-statistic and F-statistic probabilities less than 0.10. Therefore, the "best" CER was based on the regression that had the highest explanatory power, i.e., adjusted R^2. For TOT the best equation was the power fit equation with RNG as the independent variable. However, there really is no best

equation since the explanatory power of all the CERs is extremely low.

Table IX TOTAL COST REGRESSION RESULTS (CLEANER DATA)

Equation Type	t-statistics Constant	LWT	RNG	P(F)	Adj. R^2
Power	2.8900*	2.08*		0.0601	0.203
Power	8.5200*		2.79*	0.0164	0.342
S-log(b)	0.0988		1.88*	0.0851	0.162

* reflects the t-statistic for the natural log of this independent variable

Observations = 14

EQUATIONS:

$$\ln(TOT) = \ln(34.5) + 0.361\ln(LWT)$$
$$\ln(TOT) = \ln(105) + 0.370\ln(RNG)$$
$$TOT = 37.2 + 172\ln RNG$$

2. Coefficient of Variation

The standard factor and developed coefficient of variation values are shown in Table X. Only four coefficients of variation could be calculated. The coefficients of variation for design, hardware, support, and total costs are all less that those of the standard factors. However, both design cost and hardware cost coefficients of variation do not meet the criterion for a good coefficient of variation.

Table X COMPARISON OF COEFFICIENTS OF VARIATION (CLEANER DATA)

	DES	HW	SW	SUP	MISC	TOT
Standard Factors	0.450	0.440	1.43	0.24	1.34	n/a
Developed CERs	0.286	0.238	n/a	0.20	n/a	0.18

G. COMPARISON OF RESULTS

One method of comparing the two methods is to use mean absolute percent error. This method was only performed on the cleaner data set. The absolute value of the difference between the predicted value, which is calculated using both the standard factor method and the developed CER, and the true value is divided by the true value for each observation. The average was taken of the 14 values. The results are shown in Table XI.

Table XI MEAN ABSOLUTE PERCENT ERROR COMPARISON

COSTS	STANDARD FACTORS	DEVELOPED CERS
Design	0.448	0.915
Hardware	0.301	0.841
Support	0.216	0.735
Total	-----	0.761

The only costs compared were design, hardware and support costs. These are the only cost elements where both methods could predict costs. In all cases where comparisons can be made, the standard factor method has the lowest mean absolute percent error. The developed CER method predicted values with errors two to three times higher than the standard factors.

For the total cost, the developed CERs predicted values with a mean absolute percent error of 76.1%.

H. SUMMARY

Based on the results of the analysis, it is clear that the data collection process needs to be changed so that the data is as consistent and comparable as possible. Missile designations should clearly identify the missile for which cost data is collected. Duplicate entries should be deleted. Once this has been accomplished, a follow-on study should be completed using the clean data. As it stands now, the data is not suitable for regression analysis.

No significant physical or technical factors could be determined due to the low explanatory power of the independent variables. The highest adjusted R^2 was 24.9% for the initial data set and 34.2% for the "cleaner" data set. Even though the results are not statistically significant due to the low adjusted R^2s, the associated coefficients of variation are lower than the standard factor coefficients of variation. This means that these developed CERs may be better predictors than the standard factors in use.

In the follow-on study, several factors can be added to the model if the initial regressions are not statistically significant. First, other independent variables, like length of the missile or speed, could be added. If EMD costs do not produce reasonable results, then perhaps percent of each cost element might be studied. Finally, heteroscedasticity can be a problem in cross-sectional data. One possibility to consider is that the error variance may vary directly with an independent variable, like launch weight. If this assumption is true, the correction for heteroscedasticity would be relatively easy and should be performed in the follow-on study. It was not performed in this analysis, because of the overwhelming question of data validity.

III. WARSHIP FUEL CONSUMPTION

A. PROBLEM DESCRIPTION

With the ending of the Cold War, the role of the U.S. Navy has been under review to determine what is its mission. The emphasis is changing from global conflicts to regional conflicts. Attendant is the need to examine its force structure. For example, should a new warship type or class be created? Will it emulate existing ship types or be an entirely new design? What is the operational cost of the new warship? Since the 1970s no new warship types have been introduced. The Navy has been satisfied with the current mix and design of its seven warships, each type with the same basic performance and physical characteristics. Estimates of operational costs, such as fuel consumption, have been relatively routine due to the availability of historical data. Because of the aging of the fleet and the changing nature of war, the current mix of ship types will become obsolete. Navy planners are designing a new class of ship that is envisioned as a replacement for either destroyers or cruisers for deployment by 2008. Incorporating new technologies and having the capability for combat in coastal waters will affect the design of its physical and performance characteristics. [Ref. 9:p. 39] Currently, there are no CERs developed to predict the fuel consumption of new warships based on performance and physical characteristics.

The main reason for focusing on fuel consumption is that it makes up a large part of the Operations and Support (O&S) cost of a ship. In a new ship type, it may be one of the hardest elements to predict, since the interaction of the physical and performance characteristics may not be well known with respect to fuel consumption. By examining historical data on seven types of ships that make up the warship category, this chapter will explore the relationship between performance and physical characteristics and fuel consumption.

B. DESCRIPTION OF DATA

The regression model to be developed depends exclusively on the data obtained. Two dependable sources of data were identified: Navy Visibility And Management of Operating and Support Costs (NAVY VAMOSC) and The Naval Institute Guide to the Ships and Aircraft of the U.S. Fleet series. The VAMOSC source contained OPTEMPO and fuel consumption data for the fiscal years 1982 through 1991 for all ships in the seven warship types studied. The Naval Institute Guide series contained physical and performance characteristics for the ships contained in the VAMOSC database. The data from the two sources were combined to provide input to the regression model.

1. OPTEMPO And Fuel Consumption Data

NAVY VAMOSC collects O&S costs from all ships in the active fleet. It does not include information on ships that were inactive, commissioned, or deactivated during the fiscal year. [Ref. 10:p. 1] The information is available in several formats, such as the Individual Ships Report. The data used was in the Individual Ships Report format for the following warships: aircraft carriers (CV), battleships (BB), cruisers (CG), destroyers (DD, DDG), and frigates (FF, FFG). Since the focus was on fuel consumption, the following data fields were extracted for the fiscal years 1982 through 1991:

- ship type
- class number
- hull number
- year
- steaming hours underway
- steaming hours not underway
- barrels of fuel consumed underway
- barrels of fuel consumed not underway
- total barrels of fuel consumed.

2. Physical and Performance Data

The following data was collected from The Naval Institute Guide to the Ships and Aircraft of the U.S. Fleet for each ship in the VAMOSC data base:

- commissioning date (fiscal year)
- full load displacement
- overall length
- beam
- draft
- number of shafts
- horsepower per shaft
- speed.

These independent variables will be discussed in greater detail in a later section.

The independent variables listed above are considered the more important ones. Obviously, others could have been added. However, it was felt that they would not add explanatory power to the model. Similarly, alternate independent variables could have been used. For example, waterline length could have been substituted for overall length. However, these alternate variables were missing some observations. Since incomplete data would adversely affect the analysis and other similar variables with a complete set of observations were available, the alternate variables were not used.

A new independent variable, total shaft horsepower (TSHP), was calculated from this data. Total shaft horsepower was the number of shafts multiplied by the horsepower per shaft. Knowing how much total horsepower the propulsion system provided provides a means for comparing ships that had different numbers of shafts and/or shaft horsepower with a single variable.

The commissioning date was included so that another new variable, age (AGE), could be calculated. AGE represents the level of technology and required maintenance. It was calculated by subtracting the ship's commissioning date from each fiscal year that it operated as provided by the VAMOSC data. Therefore, the ship's age would be a proxy for the level of technology and required maintenance.

3. Constructing the Initial Data Base

The first step in the analysis process was to explore the properties of the data obtained from Navy VAMOSC before performing regression on the combined data base. Each ship type consisted of several classes, which in turn contained many individual ships, resulting in hundreds of observations. A major problem was how to structure the data so that it could be easily analyzed. The simplest method was to construct a separate data base for each ship type. Seven separate data bases, each consisting of one type of ship, were created. Each data base contained the following five OPTEMPO and fuel consumption variables, steaming hours underway, steaming hours not underway, barrels of fuel consumed underway, barrels of fuel consumed not underway, and total barrels of fuel consumed; plus the year for which the observation was collected. Each individual ship in each year counted as one observation. (In this data base, the ship class information was superfluous to the analysis.) The observations were sorted by year, then the average of each type for each year was obtained. The names of these averaged variables are average steaming hours underway (ASHU), average steaming hours not underway (ASHNU), average barrels of fuel consumed underway (ABFCU), average barrels of fuel consumed not underway (ABFCNU), and average total barrels of fuel consumed (ATBFC). Since the number of years over which the OPTEMPO and fuel consumption data were collected varied from eight (for BBs) to ten (for all other ship types), eight to ten data points were collected for each ship type.

4. Exploring Properties of the Data

Before regressing the data, it was necessary to explore its properties. The first question to be answered was, "What proportion of fuel is used underway?" A low proportion would indicate that the relationship between average total barrels of fuel consumed and average barrels of fuel consumed not underway is important. Second, there is obviously a relationship between average barrels of fuel consumed and average steaming hours underway. Through regression, a linear relationship of average barrels of fuel consumed underway to average steaming hours underway could be established. Third, since the data is time series data, it is necessary to check whether autocorrelation was present. The Durbin-Watson test is used to determine if autocorrelation is present. A line graph, plotting average barrels of fuel consumed against year, also provides a useful visual tool in checking for autocorrelation, since autocorrelation patterns can be easily seen. Finally, if autocorrelation was present, a standard data transformation was used to eliminate it. If there was no autocorrelation present, then the data could be pooled. The goal of this section is to pool all ship types that have no autocorrelation so that an analysis could be performed using linear regression.

a. What proportion of fuel is used underway?

The proportion of average barrels of fuel consumed underway by ship type, averaged on a yearly basis, is 85.8%. The proportions ranged from a low of 82.3% for guided missile destroyers (DDG) to a high of 90.4% for frigates (FF). This means that, on the average, 14.2% of the average total barrels of fuel consumed is consumed while not underway.

b. Evaluate relationship between barrels of fuel consumed underway and steaming hours underway.

Each ship type was examined separately to determine the relationship between the dependent variable, average barrels of fuel consumed underway (ABFCU), and the independent variable, average steaming hours underway (ASHU). Four steps were taken to examine the data in each ship type data base.

First, ABFCU was plotted against time and analyzed. Second, the ABFCU was plotted against ASHU and analyzed. Third, the results from regressing ASHU on ABFCU were analyzed. Fourth, the Durbin-Watson test was performed to check for autocorrelation. If autoregression was present, then a fifth step, data transformation, would be necessary.

Both the first and second steps plotted the averaged variables. The first graph plotted ABFCU (dependent variable) against the year (independent variable). Since the data is clearly times series data, serial correlation patterns would be obvious. The second graph plotted ABFCU (dependent variable) against ASHU (independent variable). This graph was a visual representation of how linear the relationship was.

The third step used the following regression equation:

$$ABFCU = \beta_0 + \beta_1 ASHU$$

The results of the regression for all ship types are shown in Table XII. It is clear that the OPTEMPO proxy, ASHU, explains between 71.3% and 94.4% of the variation.

In the last step, the Durbin-Watson statistic is used to evaluate if there is autocorrelation present in each of the seven type data bases. Based on the number of observations (eight for the BB ship type and ten for all others) and one regressor (ASHU), the decision rules for the Durbin-Watson statistic ($\alpha = 1\%$) result in <u>not rejecting</u> the

Table XII PRELIMINARY REGRESSION RESULTS

	β_0	β_1	P(F)	Adj. R^2	D-W Stat	Auto Corr*
BB	49,900 (1.78)	40.30 (4.29)	0.005	0.713	1.980	No
CG	8,810 (1.04)	24.80 (7.98)	0.000	0.875	1.730	No
CV	-76,500 (-1.88)	145.00 (11.9)	0.000	0.940	1.430	No
DD	- 3,270 (-0.528)	27.30 (11.8)	0.000	0.939	1.690	No
DDG	2,080 (0.437)	24.10 (12.4)	0.000	0.944	2.380	No
FF	- 1,530 (-0.314)	16.60 (8.95)	0.000	0.898	0.334	Yes
FFG	10,300 (2.35)	9.03 (5.59)	0.001	0.771	1.460	No

t-statistics in parentheses
* α = 1%

Observations = 10, except 8 for BB.

null hypothesis of no autoregression for all ship types except FFs.

c. Data Transformation

The results of the regression for the FF type definitely reject the null hypothesis of no autoregression. One way to correct for autoregression is to apply an autoregressive process of order one, AR(1), to the data. This method is used to obtain an estimate of the first-order serial-correlation coefficient (ρ), $\hat{\rho}$. Using $\hat{\rho}$, the data can be transformed using the following transformation equations [Ref. 11:p. 619]:

$$ABFCU_t^* = \sqrt{1-\beta^2}ABFCU_t$$
$$ASHU_t^* = \sqrt{1-\beta^2}ASHU_t\ , \quad for\ t = 1$$

$$ABFCU_t^* = ABFCU_t - \beta ABFCU_{t-1}$$
$$ASHU_t^* = ASHU_t - \beta ASHU_{t-1}\ , \quad for\ t = 2, \ldots, T$$

After transforming the data, the last step was to run a linear regression on the transformed data and evaluate the Durbin-Watson statistic.

The Durbin-Watson statistic is used to determine if autocorrelation is present. An autoregressive process of order one, AR(1), is used to correct for first-order correlation. First-order correlation is "when errors in one time period are correlated directly with errors in the ensuing time period." [Ref. 12:p. 137] There are several procedures used to correct serial correlation, such as the Cochrane-Orcutt or Hildreth-Lu procedures. They all use different methodologies to obtain an estimate for $\hat{\rho}$. Estimating $\hat{\rho}$ is important because it measures the correlation coefficient between errors in one time period and the next. If $\hat{\rho}$ were known then it is easy to remove autocorrelation from the data. [Ref. 12:p. 140].

Using the AR(1) feature available on MicroTSP, a $\hat{\rho}$ equal to 0.862 was obtained. The methodology used by MicroTSP is explained in the following passages.

> The AR(1) specification provides a method to obtain efficient estimates when the disturbance displays first order serial correlation, that is,

$$u_t = e_t + \rho u_{t-1}$$

> ...When the AR(1) error specification is invoked MicroTSP transforms the linear model,
>
> $$Y_t = \alpha + \beta X_t$$
>
> into the nonlinear model,
>
> $$Y_t = \rho Y_{t-1} + (1-\rho)\alpha + \beta(X_t - \rho X_{t-1})$$
>
> The coefficients, β and ρ, are then estimated by applying a Marquardt nonlinear least squares algorithm to the transformed equation. The transformed equation is linearized around initial starting values for the coefficients...New values for the coefficients are calculated by applying least squares to the linearized equation. This process is repeated until the coefficients converge or the maximum number of iterations is reached. The nonlinear least squares procedure is asymptotically equivalent to maximum likelihood but estimates may differ substantially in small samples...LS decides upon convergence by examining the change in the estimated value of ρ. Normally, when the magnitude of change reaches .005 [sic] or less, LS stops iterating.... [Ref. 13:pp. 14-8 - 14-9]

The data was transformed using $\hat{\rho}$ in the above equations. Linear regression was performed on the result. The results of the regression are shown in Table XIII. The new Durbin-Watson statistic was used to evaluate whether autocorrelation was still present in the FF data. Based on ten observations and one regressor (ASHU), the decision rules for the Durbin-Watson statistic (α = 1%) result in <u>not rejecting</u> the null hypothesis of no autoregression for the FFs.

It is clear from the results of the analysis performed in this section that the time series and cross-

Table XIII REGRESSION RESULTS AFTER FF DATA TRANSFORMATION

	β_0	β_1	P(F)	Adj. R^2	D-W Stat	Auto Corr*
FF	-737 (-1.64)	16.8 (24.3)	0.000	0.985	1.58	No

t-statistics in parentheses Observations = 10
* α = 1%

section data from the seven warship types should be pooled. Six of the seven types could be pooled immediately. The seventh type, FF, had to be transformed before it could also be pooled.

5. Constructing the Regression Data Base

After correcting for autocorrelation present in the OPTEMPO data, a new data base was constructed, this time using the technical and performance data in addition to the OPTEMPO and fuel consumption data (including the transformed FF data). Again, seven data bases based on ship type were created. Each ship type consisted of several classes, each of which had its own technical and performance characteristics. By knowing to which class the individual ships in each type belonged, it was easy to assign the correct characteristics.

Each individual ship type was an observation. Each observation consisted of the following data:

- fiscal year for which the data was collected
- steaming hours underway
- age

- full load displacement
- overall length
- beam
- draft
- total shaft horsepower
- speed.

The observations in each ship type data base were sorted by year and averages were taken of the yearly data. The result was eight (for BBs) or ten (for all other ship types) yearly averaged observations per ship type. These sixty-eight averaged observations comprised the regression data base. This data is contained in Appendix C.

C. DEVELOPMENT OF THE MODEL

In developing a basic model for fuel consumption, certain *a priori* expectations are held about the independent variables included in the estimation equation:

$$ABFCU = f\,(ASHU, AGE, DISPFL, LENOA, BEAM, DRAFT, TSHP, SPEED)$$

Although there are several other independent variables representing the physical and performance factors, these seven variables were the most likely to be available for new ships and were directly related to fuel consumption.

1. Average Steaming Hours Underway (ASHU)

Average steaming hours underway is a measure of the OPTEMPO of the ship. It is the average number of hours steamed underway for each year a ship of a particular ship type was operated. It is reasonable to expect that the OPTEMPO of the ship would affect the fuel consumption. For instance, the higher the average number of hours steamed underway, the higher the average number of barrels of fuel consumed. The variable is measured in hours.

2. Age

Age is a proxy for the level of technology and maintenance level of the ship. It is reasonable to expect that the newer the ship, the more new technology in ship propulsion and naval engineering could be incorporated into the design. It is also the case that the newer the ship the more likely it has not gone through its maintenance cycle. Both of the reasons would be expected to affect the fuel consumption. For example, the older the ship, the less fuel efficient it would be. The variable is measured in years.

3. Full Load Displacement (DISPFL)

Full load displacement is the displacement of a fully loaded ship ready to steam into service and perform its mission. [Ref. 14:p. 13] It is expected that the displacement of the ship would affect the fuel consumption. For example, the heavier the ship, the more fuel would be needed to sail the ship. The variable is measured in tons.

4. **Overall Length (LENOA)**

The overall length of a ship is measured at the longest part of the ship. [Ref. 14:p. 13] It is expected that the length of the ship would affect the fuel consumption. For example, the longer the ship, the larger the ship. It is expected that larger ships would consume more fuel since they have larger masses to push forward in the water. The variable is measured in meters.

5. **Beam**

The beam is measured at the most extreme width of the ship's hull. [Ref. 14:p. 13] It is expected that the wider the beam, the more fuel would be consumed. The width of the ship would act as a braking force in the water, requiring more power (which requires more fuel) to push it forward. The variable is measured in meters.

6. **Draft**

The draft of the ship is the maximum draft of the ship at full load and includes fixed projections under the keel. [Ref. 14:p. 13] It is expected that the depth of the ship's draft would affect the fuel consumption. For example, the deeper the draft, the more mass under the waterline. The draft would act as a braking force in the water, requiring more power (which requires more fuel) to push it forward. The variable is measured in meters.

7. **Total Shaft Horsepower (TSHP)**

Total shaft horsepower is a derived variable obtained by multiplying the number of shafts for a ship by its shaft horsepower. This value is the total horsepower supplied by the propulsion plant. It is expected that the size of the power plant would affect the fuel consumption. For example, a larger power plant would be expected to consume more fuel. The variable is measured in horsepower.

8. **Speed**

The speed is the maximum speed that a ship class is capable of operating at. [Ref. 15:p. 14] It is expected that the ship's speed would affect the fuel consumption. For example, the faster the speed, the less fuel efficient the ship. The variable is measured in knots.

The specified form of the basic model follows:

$$ABFCU = \beta_0 + \beta_1 ASHU + \beta_2 AGE + \beta_3 DISPFL + \beta_4 LENOA + \beta_5 BEAM + \beta_6 DRAFT + \beta_7 TSHP + \beta_8 SPEED$$

The criteria for identifying the best model is the one with high t-statistics, adjusted R^2, and F-statistics, respectively, with as few independent variables as possible. For the purposes of this chapter, the benchmarks for the criteria are absolute t-statistics greater than or equal to two, adjusted R^2 values greater than or equal to 0.90 and the probability of the F-statistic less than 0.000.

Three independent variables are considered to be crucial to the model: ASHU, AGE, and DISPFL. The basic model includes eight independent variables. However, four (DISPFL, LENOA, BEAM, DRAFT) may be correlated and create potential multicollinearity in the model. The presence of multicollinearity will make it difficult (if not impossible) to interpret the regression coefficients. The presence of multicollinearity may be reduced and, perhaps, eliminated by deleting one or more of the four independent variables. This will be discussed in the alternative specifications section.

Whenever time-series data is used, autocorrelation may be a problem. The data set used in this analysis was constructed to eliminate the presence of autocorrelation, as discussed in a prior section. In interpreting the results of the following regressions, the methodology of data construction must be kept in mind. For this data set, the Durbin-Watson statistic will be meaningless, since this final data set consists of pooled time-series and cross-section observations. The Durbin-Watson statistic is useful only on true first order autocorrelated data. Because of this deliberate construction and because the time series are short (at most ten observations) and there were only seven ship types, autocorrelation is ignored.

Typically, *a priori* expectations about the sign of the coefficients are held. These were discussed in the above section. The expected sign hypotheses are listed in Table XIV.

Table XIV REGRESSION HYPOTHESIS OF COEFFICIENT SIGNS

Explanatory Variable	Expected Sign
ASHU	+
AGE	+
DISPFL	+
LENOA	+
BEAM	+
DRAFT	+
TSHP	+
SPEED	+

D. RESULTS OF THE BASIC MODEL

By regressing the average barrels of fuel consumed underway on the explanatory variables, the following base-case empirical model is obtained. The t-statistics are in parentheses.

$$ABFCU = \underset{(-5.61)}{-2{,}380{,}000} + \underset{(5.39)}{46.8ASHU} \underset{(-4.28)}{-5{,}490AGE} + \underset{(1.68)}{32.3DISPFL}$$

$$\underset{(-6.46)}{-16{,}600LENOA} + \underset{(3.37)}{148{,}000BEAM} + \underset{(3.02)}{111{,}000DRAFT}$$

$$\underset{(-3.86)}{-3.48TSHP} + \underset{(3.92)}{63{,}700SPEED}$$

Observations = 68   *Adj.* R^2 = 0.938   *P(F-stat)* = 0.000

From the results, it is clear that this model closely fits the data. Except for the t-statistic for DISPFL, all the other statistics meet or exceed the decision criteria for a good model. The interpretation of the model is, holding all other independent variables equal, for each additional unit of the independent variable, ABFCU is increased or decreased by the amount of the coefficient. The expected and estimated sign hypotheses of the coefficients are listed in Table XV.

Table XV REGRESSION RESULTS (BASE CASE)

Explanatory Variable	Expected Sign	Basic Estimated Sign
ASHU	+	+
AGE	+	-
DISPFL	+	+
LENOA	+	-
BEAM	+	+
DRAFT	+	+
TSHP	+	-
SPEED	+	+

Although certain expectations of the coefficients' signs were theorized, it is clear that for three of the independent variables (AGE, LENOA, TSHP) the estimated signs are the opposite. One approach to explain this is that the model results come from sample data. In this sample, the older ships may be more fuel efficient. This differs from the *a priori* expectations. Several different methods, such as using a new calculated variable, ABFCU divided by ASHU, as the dependent variable, were used to try to see whether the sign of AGE would change. However, it remained negative. Originally, the coefficient for LENOA was expected to be positive. However, as LENOA becomes larger, it could make the ship more streamlined, thereby reducing fuel consumption. Finally, larger propulsion plants, signified by a larger TSHP, may be correlated with a larger ship. Larger ships have more mass to push through the water and therefore may consume more fuel. With this explanation a negative coefficient for TSHP would be expected.

E. ALTERNATIVE SPECIFICATIONS

Although the results of the basic model are very good, there is some question about whether all eight independent variables are necessary, specifically TSHP and SPEED. Accordingly, three alternative cases will be examined. The first alternative model deletes SPEED as an independent variable. The second alternative model deletes TSHP. The third alternative model deletes both TSHP and SPEED. The results are shown in Appendices D through G.

Within the base case and the three alternative models, it is important to check whether multicollinearity exists between DISPFL, LENOA, BEAM, and DRAFT. In each of these four models the following combinations of the independent variables were deleted from the model:

- LENOA
- BEAM
- DRAFT
- BEAM, DRAFT
- LENOA, DRAFT
- LENOA, BEAM
- LENOA, BEAM, DRAFT.

Although it is believed that DISPFL and AGE should remain in the model, the regression results obtained by deleting them in addition to TSHP and SPEED were also examined. Although the results for these additional excursions will not be discussed, the results are shown in Appendix H.

1. Basic Model

Based on the assumption that DISPFL must remain in the model, only one excursion meets the criteria:

$$ABFCU = \underset{(-4.56)}{-2{,}030{,}000} + \underset{(4.06)}{34.8}ASHU \underset{(-3.09)}{-4{,}040}AGE + \underset{(5.31)}{78.4}DISPFL$$
$$\underset{(-5.12)}{-11{,}400}LENOA + \underset{(4.63)}{165{,}000}DRAFT \underset{(-4.64)}{-4.35}TSHP$$
$$\underset{(4.84)}{+80{,}900}SPEED$$

Observations = 68   *Adj.* R^2 = 0.927   *P(F-stat)* = 0.000

2. Alternative 1: Delete SPEED

Based on the assumption that DISPFL must remain in the model, no excursions meet the criteria.

3. Alternative 2: Delete TSHP

Based on the assumption that DISPFL must remain in the model, no excursions meet the criteria.

4. Alternative 3: Delete SPEED, TSHP

Based on the assumption that DISPFL must remain in the model, two excursions meet the criteria. The first is:

$$ABFCU = \underset{(-4.05)}{-937,000} + \underset{(6.54)}{46.8ASHU} \underset{(-6.74)}{-6,760AGE} \underset{(-3.83)}{-32.5DISPFL}$$

$$\underset{(-4.77)}{-11,900LENOA} + \underset{(4.60)}{194,000BEAM}$$

Observations = 68 *Adj*. R^2 = 0.925 *P(F-stat)* = 0.000

The second excursion is:

$$ABFCU = \underset{(0.335)}{5,960} + \underset{(4.14)}{25.0ASHU} - \underset{(-4.66)}{2,990AGE} + \underset{(16.2)}{4.68DISPFL}$$

Observations = 68 *Adj*. R^2 = 0.900 *P(F-stat)* = 0.000

As discussed in the basic model section, the signs of the coefficients of the independent variables are not consistent with the *a priori* expectations. Table XVI lists the expected and estimated sign hypotheses of the coefficients. In fact, upon reviewing the results of all the excursions, all independent variables, except ASHU, change signs. This could be due to collinearity between independent variables.

Although certain expectations of the coefficient signs were theorized, it is clear that the estimated signs are different. For the excursions in the basic model, three independent variables (AGE, LENOA, TSHP) are the opposite of the expected sign. As discussed previously, in this sample the older ships may be more fuel efficient. As LENOA becomes larger, it could make the ship more streamlined, thereby reducing fuel consumption. For TSHP, larger propulsion plants, signified by a larger TSHP, may be correlated with a larger ship. Larger ships have more mass to push through the

Table XVI REGRESSION RESULTS (EXCURSIONS)

Explanatory Variable	Exp. Sign	B Est. Sign	B-E Est. Sign	A-3(1st) Est. Sign	A-3(2nd) Est. Sign
ASHU	+	+	+	+	+
AGE	+	-	-	-	-
DISPFL	+	+	+	-	+
LENOA	+	-	-	-	
BEAM	+	+		+	
DRAFT	+	+	+		
TSHP	+	-	-		
SPEED	+	+	+		

ABBREVIATIONS:
A: Alternative Specifications.
B: Basic Model.
E: Excursions.
Exp.: Expected.
Est.: Estimated.

water and therefore may consume more fuel. Both explanations seem reasonable.

For the first Alternative 3 excursion, AGE, DISPFL and LENOA have negative coefficients. Again the same reasoning as above can be applied to AGE and TSHP. As discussed in a prior section, there may be some collinearity between DISPFL, LENOA, BEAM, and DRAFT. By deleting DRAFT, a possible relationship between the other three may be described more fully. The signs imply that an increase in DISPFL will decrease average fuel consumption, holding LENOA, BEAM, and the other variables constant. This does not make sense.

For the second Alternative 3 excursion, only AGE has a negative coefficient. Again the same reasoning as above can be applied to AGE. These results match the expected signs of the variables much better than the previous excursions. The estimated equation also contains the fewest independent variables. Based on these two results, this equation is chosen as the best model.

F. HETEROSCEDASTICITY

1. Definition

Heteroscedasticity violates one of the assumptions for a normal linear regression model, resulting in the model being incorrectly specified. The parameter estimates will be unbiased and consistent, but not efficient. Heteroscedasticity is non-constant variance of the error term. [Ref. 12:pp. 127-128] For example, the variance of the error terms associated with larger ships may be larger than the variance of the error terms associated with smaller ships. Since the data are pooled time-series, cross-section observations, we expect that pure heteroscedasticity may be difficult to remove. There are several tests to check for heteroscedasticity. One is the Goldfeld-Quandt test.

The Goldfeld-Quandt test procedure estimates two regression lines, one using data thought to come from the data with low variance errors and the other from data with high variance errors. The residual sum of squares is calculated for each regression, i.e., ESS_{Hi} and ESS_{Lo}. The new test statistic, ESS_{Hi}/ESS_{Lo}, is distributed as an F-statistic. The number of degrees of freedom in the general linear case is:

$$N-d-2k$$

where N is the number of observations, d is the number of middle observations deleted, and k is the number of independent variables (including the constant term). The null hypothesis is that there is homoscedasticity. The alternative hypothesis is that the variance (σ^2_i) varies by some function of an independent variable (X) for each observation (i):

$$\sigma^2_i = f(X_i)$$

The null hypothesis can not be rejected if the residual variances of the two lines are approximately equal. It is rejected when the calculated statistic is greater than the critical value of the F distribution. [Ref. 12:p. 133]

2. Correction

Using the Goldfeld-Quandt test, the best model from the previous section was tested for heteroscedasticity. The initial assumption was that the independent variable DISPFL was associated with the error variance. Two regressions were performed, one on the 27 largest observations and one on the smallest 27 observations. The result is an F-statistic of 173, clearly rejecting the null hypothesis of homoscedasticity at any level of significance. This result makes intuitive sense. The next step tried to correct the heteroscedasticity.

As previously discussed, there may be some relationship between the error variances and one of the independent variables. It is reasonable to conclude that DISPFL could be that variable. If this is true, then there is an easy transformation to correct the heteroscedasticity present in the data. [Ref. 12:p. 130] One way to determine the form of the function is to create a scatter plot, plotting the residuals of the best equation versus DISPFL. Depending on the shape of the scatter plot, it may be possible to recognize the function that describes it.

No pattern was recognizable in the scatter plot of the residuals and DISPFL, so an assumption was made to use the following transformation:

$$Var(e_i) = C*DISPFL_i^2, \quad \text{where } C = \text{a nonzero constant}$$

The process is straightforward. Once the independent variable is identified, in this case DISPFL, all the terms in the original regression equation are divided by it. The Goldfeld-Quandt test is used again to test whether the transformation corrected the heteroscedasticity. The same test statistic described previously is used to decide whether or not to reject the null hypothesis. If the assumption of the transformation form is correct, the null hypotheses will not be rejected. Since the homoscedasticity assumption would no longer be violated, the resulting parameter estimates will be efficient. [Ref. 12:pp. 130-131]

The results of this transformation showed that the null hypothesis was rejected. Heteroscedasticity could not be corrected by the square of DISPFL. This same methodology was performed on the other two independent variables in the equation, ASHU and AGE. The results were the same: heteroscedasticity in the original equation, heteroscedasticity after the transformation.

Another way to deal with heteroscedasticity is to use a heteroscedasticity consistent covariance matrix with the least squares regression instead of the one normally used to calculate standard errors and t-statistics. The one used by MicroTSP is the White covariance matrix [Ref. 13:p. 14-6]:

$$\left(\frac{n}{n-k}\right)(X'X)^{-1}(e_t^2 x_t x_t')(X'X)^{-1},$$

where n = number of observations
k = number of regressors
e_t = least squares residual

This method corrects the heteroscedasticity problem so that the results may be interpreted correctly. The White test does not require specification of the final form, so it is easier to perform than the Goldfeld-Quandt test. However, it is not as intuitive.

3. Results of the Corrected Model

Although the results from the previous section were very good, the estimated parameters are not efficient. A transformation equation could not be determined from the scatter plots, so its methodology could not be used. The heteroscedasticity consistent covariance method was identified as another way to correct heteroscedasticity. The results of this method produced the following regression equation:

$$\underset{}{ABFCU} = \underset{(0.446)}{5{,}960} + \underset{(4.85)}{24.9ASHU} - \underset{(-3.82)}{2{,}990AGE} + \underset{(12.5)}{4.68DISPFL}$$

Observations = 68   *Adj.* R^2 = 0.900   *P(F-stat)* = 0.000

Except for the t-statistics, the results are the same as in the previous section for the best fit model. The result is an efficient estimator.

G. ALTERNATIVE DATA STRUCTURES

The regression data set was constructed to eliminate autocorrelation. First, it was necessary to check for autocorrelation in each of the seven warship type data sets by regressing ASHU onto ABFCU and examining the Durbin-Watson statistic. All of the ship types had no autocorrelation except for the FFs. An autoregressive transformation of order one was performed on the FF data set. The Durbin-Watson statistic of the transformed FF data showed that this procedure had eliminated the autocorrelation. Confident that the constructed sample did not contain autocorrelation, the analysis proceeded to its conclusion. Even though there exist different ways to pool time-series and cross-section data, this current procedure seemed to be the most straightforward for the purpose of this thesis.

There are several other ways to pool time-series and cross-section data. One method involves covariance analysis.

Dummy variable are added to the model to compensate for omitted variables which may be related to changing cross-section and time-series intercepts. A second method is the error-components pooling procedure. It improves efficiency by accounting for cross-section and time-series disturbances. A final method is the time-series autocorrelation model. It assumes that the error term is correlated over time and cross-section units. [Ref. 12:p. 224]

H. SUMMARY

Based on the results of the analysis, it is clear that a statistically significant CER has been developed which predicts fuel consumption of warships based on physical and performance data. It is reasonable to expect that the CER will remain valid for ships whose characteristics are similar to those in the data base.

The data studied in the ship fuel consumption problem was comprised of times-series and cross-sectional data. Care was taken to remove serial correlation and heteroscedasticity. The basic model and three alternative specifications were analyzed. The results produced several statistically significant estimating relationships. Since they were virtually indistinguishable in all other respects, the one with fewest independent variables is the one recommended for use. It is:

$$ABFCU = 5{,}960 + 24.9ASHU - 2{,}990AGE + 4.68DISPFL$$

It is a good CER because it is statistically significant. The low t-statistic for the constant is not a problem since predicting near the origin is outside the range of the data. The equation also includes the variables considered crucial to the explanatory power of the model.

Note that the age for a new ship is zero. This means that AGE will drop out of the equation. Therefore, for new ships, the estimating equation is:

$$\underset{(-2.62)}{ABFCU = -46{,}000} + \underset{(4.23)}{31.4ASHU} + \underset{(12.4)}{3.69DISPFL}$$

This CER is also statistically significant. Its adjusted R^2 is 0.869.

IV. CONCLUSIONS AND RECOMMENDATIONS

The two objectives of this thesis were to develop estimating relationships for both missile EMD costs and warship fuel consumption. The results of each analysis were summarized in their respective chapters.

For missile EMD costs, no firm conclusions can be drawn from the results. Due to the data not being consistent nor comparable, no statistically significant results were obtained. Therefore, no significant physical or technical factors could be identified. However, the coefficients of variation obtained were much better than the standard factors' coefficients of variation. This means that the developed CERs may be a better predictor than the standard factors currently in use. As long as the NCA analyst realizes their limitations, the CERs obtained may be helpful in independent cost analysis.

The recommendation for the missile EMD costs is to do a follow-on study of this area after the data has been sanitized. In the meantime, the developed CERs may be useful since their coefficients of variation are smaller that the standard factors in use now.

For warship fuel consumption, three CERs met the criteria. The one with the fewest independent variables was chosen as the best CER. The variables from the best CER were regressed again, this time using a heteroscedasticity consistent covariance matrix to remove the effects of heteroscedasticity. The result was statistically significant and should be of great help in predicting fuel consumption for inclusion in the O&S cost estimate. The physical and performance characteristics identified are steaming hours, age and full load displacement. Since the age of a new ship is zero, it will drop out of the equation. A new CER, reflecting the absence of AGE, was developed and corrected for heteroscedasticity. It was also significant. It is important that this CER only be used to predict fuel consumption for ships whose characteristics are similar to those in the data base. Otherwise, it may not predict fuel consumption with the accuracy expected.

The recommendations for the fuel consumption section is to expand the analysis to other ship categories. It appears that this methodology produces good results and can be applied to other ship categories.

APPENDIX A

#	Name	Missile	D1	D2	D3	D4	LWT (lbs)	RNG (nmi)
1	ALCM	AGM-86B	0	1	0	0	3144	1550
2	ALCM.Boeing	AGM-86B	0	1	0	0	3144	1550
3	AMRAAM	AIM-120A	1	0	0	0	345	40
4	ATACMS	MGM-140A	0	0	1	0	3748	62
5	HARM	AGM-88A	0	1	0	0	807	10
6	Harpoon	RGM-84A	0	0	0	1	1500	75
7	Harpoon	RGM-84A	0	0	0	1	1500	75
8	Hellfire	AGM-114A	0	1	0	0	99	4
9	MAVERICK	AGM-65A\B	0	1	0	0	475	14
10	Maverick.FSED	AGM-65E\F	0	1	0	0	646	14
11	MLRS	M-26	0	0	1	0	680	18
12	Patriot	MIM-104A	0	0	0	0	2200	37
13	Patriot	MIM-104A	0	0	0	0	2200	37
14	Pershing.II	MGM-31A	0	0	1	0	16400	1200
15	PHOENIX.AIM-56A	AIM-54C	1	0	0	0	985	73
16	Phoenix	AIM-54C	1	0	0	0	985	73
17	SM-I	RIM-66A (MR)	0	0	0	0	1380	25
18	SM-II	RIM-66C (MR)	0	0	0	0	1556	40
19	SM-II.FSED	RIM-67B (ER)	0	0	0	0	3180	69
20	SM-I.FSED	RIM-67A (ER)	0	0	0	0	3000	40
21	SRAM	AGM-69A	0	1	0	0	2240	120
22	Stinger.FSED	FIM-92B (RPM)	0	0	0	0	35	2.4
23	Sting.POST*	FIM-92B	0	0	0	0	35	2.4

* POST = Passive Optical Seeker Technique

#	Name	IOC (year)	DES	HW	SW	SUP	MISC
			(All costs in FY89 $M)				
1	ALCM	1982	393.6	171.5	0.0	531.7	15.1
2	ALCM.Boeing	1982	89.7	104.9	4.1	179.4	24.7
3	AMRAAM	1991	518.5	199.8	0.0	279.4	1.3
4	ATACMS	1990	72.0	55.5	0.0	64.0	0.8
5	HARM	1983	63.2	113.4	0.0	130.5	0.0
6	Harpoon	1977	101.4	218.4	7.1	147.5	0.6
7	Harpoon	1977	124.1	1.5	0.0	191.8	0.0
8	Hellfire	1984	133.0	75.4	0.0	128.1	9.5
9	MAVERICK	1973	56.0	47.0	0.0	141.1	0.8
10	Maverick.FSED	1985	53.6	40.9	0.5	120.9	0.8
11	MLRS	1983	46.4	19.8	0.0	94.5	36.3
12	Patriot	1982	904.5	539.7	0.0	913.4	59.8
13	Patriot	1982	150.1	324.2	119.9	454.5	7.8
14	Pershing.II	1983	490.5	196.2	0.0	390.4	14.8
15	PHOENIX.AIM-56A	1984	197.8	151.7	15.0	383.2	0.0
16	Phoenix	1984	79.5	258.8	0.0	638.6	0.2
17	SM-I	1968	18.4	38.1	0.0	75.2	0.0
18	SM-II	1983	35.6	60.1	0.0	72.4	0.0
19	SM-II.FSED	1981	34.2	57.8	0.0	71.3	0.0
20	SM-I.FSED	1968	17.8	37.6	0.0	76.3	0.0
21	SRAM	1972	260.3	234.2	0.0	709.4	0.0
22	Stinger.FSED	*	33.4	31.5	0.0	82.4	7.0
23	Sting.POST	1982	10.9	11.7	0.0	34.4	0.0

* missing data

#	Name	TOT FY89 $M
1	ALCM	1111.9
2	ALCM.Boeing	402.8
3	AMRAAM	999.0
4	ATACMS	192.3
5	HARM	307.1
6	Harpoon	475.0
7	Harpoon	317.4
8	Hellfire	346.0
9	MAVERICK	244.9
10	Maverick.FSED	216.7
11	MLRS	197.0
12	Patriot	2417.4
13	Patriot	1056.5
14	Pershing.II	1091.9
15	PHOENIX.AIM-56A	747.7
16	Phoenix	977.1
17	SM-I	131.7
18	SM-II	168.1
19	SM-II.FSED	163.3
20	SM-I.FSED	131.7
21	SRAM	1203.9
22	Stinger.FSED	154.3
23	Sting.POST	57.0

APPENDIX B

#	Name	Missile	D1	D2	D3	LWT (lbs)	RNG (nmi)	IOC
1	ALCM	AGM-86B	0	1	0	3144	1550	1982
2	AMRAAM	AIM-120A	1	0	0	345	40	1991
3	ATACMS	MGM-140A	0	0	1	3748	62	1990
4	HARM	AGM-88A	0	1	0	807	10	1983
5	Hellfire	AGM-114A	0	1	0	99	4	1984
6	MAVERICK	AGM-65A\B	0	1	0	475	14	1973
7	MLRS	M-26	0	0	1	680	18	1983
8	Patriot	MIM-104A	0	0	0	2200	37	1982
9	Pershing.II	MGM-31A	0	0	1	16400	1200	1983
10	Phoenix	AIM-54C	1	0	0	985	73	1984
11	SM-I	RIM-66A (MR)	0	0	0	1380	25	1968
12	SM-II	RIM-66C (MR)	0	0	0	1556	40	1983
13	SRAM	AGM-69A	0	1	0	2240	120	1972
14	Sting.POST*	FIM-92B	0	0	0	35	2.4	1982

* POST = Passive Optical Seeker Technique

#	Name	DES	HW	SW	SUP	MISC	TOT
		(All costs in FY89 $M)					
1	ALCM	393.6	171.5	0.0	531.7	15.1	1111.9
2	AMRAAM	518.5	199.8	0.0	279.4	1.3	999.0
3	ATACMS	72.0	55.5	0.0	64.0	0.8	192.3
4	HARM	63.2	113.4	0.0	130.5	0.0	307.1
5	Hellfire	133.0	75.4	0.0	128.1	9.5	346.0
6	MAVERICK	56.0	47.0	0.0	141.1	0.8	244.9
7	MLRS	46.4	19.8	0.0	94.5	36.3	197.0
8	Patriot	904.5	539.7	0.0	913.4	59.8	2417.4
9	Pershing.II	490.5	196.2	0.0	390.4	14.8	1091.9
10	Phoenix	79.5	258.8	0.0	638.6	0.2	977.1
11	SM-I	18.4	38.1	0.0	75.2	0.0	131.7
12	SM-II	35.6	60.1	0.0	72.4	0.0	168.1
13	SRAM	260.3	234.2	0.0	709.4	0.0	1203.9
14	Sting.POST	10.9	11.7	0.0	34.4	0.0	57.0

APPENDIX C

* transformed data

TYPE	YEAR	ABFC-U	ABFC-NU	ASH-U	ASH-NU	AGE
BB	1984	219882	16179	4652	770	41.0
BB	1985	104865	36662	1818	3120	42.0
BB	1986	220523	35656	3074	2184	43.0
BB	1987	141369	20213	2080	1122	43.7
BB	1988	192231	30309	3203	1866	44.7
BB	1989	116785	27670	2061	1489	45.7
BB	1990	136767	29475	2215	1647	46.5
BB	1991	180948	25764	3614	1634	47.0
CV	1982	529645	73032	3823	1683	24.1
CV	1983	352358	55380	2961	1614	25.1
CV	1984	533413	60036	4324	1873	24.9
CV	1985	351369	50691	2853	1988	27.3
CV	1986	353235	75465	3034	1878	28.4
CV	1987	384966	70235	3154	1954	29.4
CV	1988	303771	55438	2655	1585	30.7
CV	1989	330547	63244	2785	1763	31.7
CV	1990	348755	58177	3036	1723	32.0
CV	1991	502614	51938	4083	1385	33.0
CG	1982	78238	13525	2714	1398	17.3
CG	1983	60508	10486	2242	1144	18.3
CG	1984	82246	16174	3098	1678	18.4
CG	1985	84981	14351	3120	1465	18.5
CG	1986	77582	18291	2638	2017	18.6
CG	1987	71384	14497	2545	1603	18.0
CG	1988	71260	14009	2518	1514	16.9
CG	1989	77114	12747	2658	1522	16.7
CG	1990	77758	13015	2768	1737	15.9
CG	1991	82614	12245	2934	1455	16.1
DD	1982	69083	14185	2714	2243	10.0
DD	1983	74314	9839	2832	1651	4.7
DD	1984	80391	10205	3025	1739	5.5
DD	1985	71548	9368	2747	1511	6.5
DD	1986	62984	10973	2347	1967	7.5
DD	1987	66807	11739	2595	1982	8.7
DD	1988	76905	10348	2876	1796	9.4
DD	1989	59860	8142	2313	1529	10.5
DD	1990	67954	9342	2655	1629	11.6
DD	1991	68340	8712	2704	1507	12.5
DDG	1982	56040	12560	2237	1519	19.6
DDG	1983	65914	13344	2593	1593	19.0
DDG	1984	69921	13563	2765	1566	20.0
DDG	1985	61659	12328	2521	1553	21.0

TYPE	YEAR	ABFC-U	ABFC-NU	ASH-U	ASH-NU	AGE
DDG	1986	56257	1527[illegible]	2220	1842	22.0
DDG	1987	57234	13195	2329	1512	23.0
DDG	1988	60177	12921	2370	1507	24.0
DDG	1989	52693	11799	2091	1416	25.0
DDG	1990	61528	14298	2566	1679	26.3
DDG	1991	65754	10386	2643	1219	23.7
FFG	1982	34376	4919	2437	1778	5.8
FFG	1983	33783	3882	2599	1670	5.1
FFG	1984	39902	4397	3192	1754	4.4
FFG	1985	34161	3805	2745	1765	4.7
FFG	1986	31732	3691	2369	1781	5.0
FFG	1987	35204	3868	2617	1792	5.8
FFG	1988	35446	2767	2847	1367	4.5
FFG	1989	32354	3363	2654	1521	5.2
FFG	1990	32413	3342	2562	1746	5.9
FFG	1991	38343	2873	3051	1536	6.9
FF*	1982	24383	7628	1435	1301	11.9
FF*	1983	7413	6937	511	1310	12.9
FF*	1984	3157	7280	241	1335	13.9
FF*	1985	847	6936	65	1270	14.9
FF*	1986	7367	7452	377	1311	15.9
FF*	1987	5596	7645	401	1338	16.9
FF*	1988	-320	6653	56	1219	17.6
FF*	1989	-6	5818	32	1117	17.9
FF*	1990	13414	6602	906	1197	18.9
FF*	1991	12466	7244	840	1318	19.5

TYPE	AGE	DISP-FL	LEN-OA	BEAM	DRAFT	SHFT NO.	SHP
BB	41.0	57350	270.70	33.00	11.60	4	212000
BB	42.0	57350	270.65	33.00	11.60	4	212000
BB	43.0	57350	270.65	33.00	11.60	4	212000
BB	43.7	57350	270.63	33.00	11.60	4	212000
BB	44.7	57350	270.63	33.00	11.60	4	212000
BB	45.7	57350	270.63	33.00	11.60	4	212000
BB	46.5	57350	270.63	33.00	11.60	4	212000
BB	47.0	57350	270.60	33.00	11.60	4	212000
CV	24.1	78847	315.46	39.63	11.14	4	262667
CV	25.1	78940	315.86	39.63	11.14	4	264889
CV	24.9	80658	317.09	39.98	11.20	4	271500
CV	27.3	78620	315.26	39.64	11.13	4	263000
CV	28.4	78847	315.46	39.63	11.14	4	262667
CV	29.4	78847	315.46	39.63	11.14	4	262667
CV	30.7	78793	315.67	39.63	11.14	4	262667
CV	31.7	78793	315.67	39.63	11.14	4	262667
CV	32.0	80279	316.61	40.03	11.19	4	267429
CV	33.0	80279	316.61	40.03	11.19	4	267429
CG	17.3	8182	164.65	16.75	8.25	2	85000
CG	18.3	8182	164.65	16.75	8.25	2	85000
CG	18.4	8256	165.08	16.75	8.32	2	84737
CG	18.5	8322	165.48	16.75	8.39	2	84500
CG	18.6	8374	165.83	16.75	8.45	2	84286
CG	18.0	8466	166.44	16.75	8.55	2	83913
CG	16.9	8580	167.19	16.75	8.67	2	83462
CG	16.7	8651	167.62	16.75	8.74	2	83200
CG	15.9	8738	168.19	16.75	8.83	2	82857
CG	16.1	8768	168.40	16.75	8.87	2	82727
DD	10.0	6834	158.41	15.86	8.17	2	76977
DD	4.7	8040	171.70	16.80	8.80	2	80000
DD	5.5	8040	171.70	16.80	8.80	2	80000
DD	6.5	8040	171.70	16.80	8.80	2	80000
DD	7.5	8040	171.70	16.80	8.80	2	80000
DD	8.7	8040	171.70	16.80	8.80	2	80000
DD	9.4	8040	171.70	16.80	8.80	2	80000
DD	10.5	8040	171.70	16.80	8.80	2	80000
DD	11.6	8040	171.70	16.80	8.80	2	80000
DD	12.5	8040	171.70	16.80	8.80	2	80000
DDG	19.6	5353	140.69	14.82	7.98	2	74474
DDG	19.0	5697	143.59	15.03	8.31	2	75135
DDG	20.0	5697	143.59	15.03	8.31	2	75135
DDG	21.0	5697	143.59	15.03	8.31	2	75135
DDG	22.0	5697	143.59	15.03	8.31	2	75135
DDG	23.0	5697	143.59	15.03	8.31	2	75135
DDG	24.0	5697	143.59	15.03	8.31	2	75135
DDG	25.0	5697	143.59	15.03	8.31	2	75135
DDG	26.3	5607	143.12	15.00	8.25	2	75208
DDG	23.7	6445	149.63	15.42	8.59	2	76667

TYPE	AGE	DISP-FL	LEN-OA	BEAM	DRAFT	SHFT NO.	SHP
FFG	5.8	3658	132.86	13.64	6.89	1	38421
FFG	5.1	3645	133.48	13.65	6.84	1	38846
FFG	4.4	3702	134.66	13.67	6.79	1	39219
FFG	4.7	3754	135.30	13.67	6.78	1	39306
FFG	5.0	3813	135.87	13.67	6.78	1	39318
FFG	5.8	3837	136.04	13.67	6.79	1	39286
FFG	4.5	3908	137.68	13.69	6.72	1	39853
FFG	5.2	3907	137.93	13.70	6.70	1	40000
FFG	5.9	3912	137.98	13.70	6.70	1	40000
FFG	6.9	3912	137.93	13.70	6.70	1	40000
FF*	11.9	4048	131.73	14.07	7.48	1	34455
FF*	12.9	4040	131.64	14.06	7.48	1	34434
FF*	13.9	4040	131.64	14.06	7.48	1	34434
FF*	14.9	4040	131.64	14.06	7.48	1	34434
FF*	15.9	4040	131.64	14.06	7.48	1	34434
FF*	16.9	4058	131.80	14.08	7.48	1	34400
FF*	17.6	4082	132.03	14.10	7.49	1	34375
FF*	17.9	4180	132.97	14.20	7.52	1	34250
FF*	18.9	4171	132.85	14.19	7.52	1	34167
FF*	19.5	4260	134.00	14.30	7.55	1	35000

TYPE	TSHP	SPEED
BB	848000	33.0
BB	848000	33.0
BB	848000	33.0
BB	848000	33.0
BB	848000	33.0
BB	848000	33.0
BB	848000	33.0
BB	848000	33.0
CV	1050667	31.7
CV	1059556	31.8
CV	1086000	31.8
CV	1052000	31.5
CV	1050667	31.7
CV	1050667	31.7
CV	1050667	32.1
CV	1050667	32.1
CV	1069714	32.4
CV	1069714	32.4
CG	170000	33.0
CG	170000	33.0
CG	169474	32.8
CG	169000	32.7
CG	168571	32.6
CG	167826	32.3
CG	166923	32.1
CG	166400	31.9
CG	165714	31.7
CG	165455	31.6
DD	153953	32.5
DD	160000	32.5
DD	160000	32.5
DD	160000	32.5
DD	160000	32.5
DD	160000	32.5
DD	160000	32.5
DD	160000	32.5
DD	160000	32.5
DD	160000	32.5
DDG	148947	31.9
DDG	150270	31.7
DDG	150270	31.7
DDG	150270	31.7
DDG	150270	31.7
DDG	150270	31.7
DDG	150270	31.7
DDG	150270	31.7
DDG	150417	31.8
DDG	153333	31.5
FFG	38421	28.4

TYPE	TSHP	SPEED
FFG	38846	28.5
FFG	39219	28.7
FFG	39306	28.7
FFG	39318	28.7
FFG	39286	28.7
FFG	39853	28.9
FFG	40000	29.0
FFG	40000	29.0
FFG	40000	29.0
FF*	34455	26.9
FF*	34434	26.9
FF*	34434	26.9
FF*	34434	26.9
FF*	34434	26.9
FF*	34400	26.9
FF*	34375	26.9
FF*	34250	26.9
FF*	34167	26.8
FF*	35000	27.0

APPENDIX D

Statistics for the Base Case and Excursions

t-statistics								
C*	ASHU	AGE	DISPFL	LENOA	BEAM	DRAFT	TSHP	SPEED
Base Case								
-5.61	5.39	-4.28	1.68	-6.46	3.37	3.02	-3.86	3.92
Excursions								
-0.76	2.47	-1.17	0.88		-0.48	0.41	-0.84	0.77
-4.56	4.06	-3.09	5.31	-5.12		4.63	-4.64	4.84
-4.46	4.77	-3.78	-1.83	-5.38	4.91		-2.29	2.35
-1.16	2.24	-1.62	2.26	-1.91			-1.21	1.73
-0.65	2.50	-1.23	1.28		-0.27		-0.89	0.71
-0.62	2.69	-1.23	1.37			-0.08	-0.74	0.69
-0.70	3.11	-1.24	1.52				-0.87	0.69

Adj. R^2	F-stat	P(F)
Base Case		
0.938	127.0	0.000
Excursions		
0.896	83.1	0.000
0.927	123.0	0.000
0.929	129.0	0.000
0.903	105.0	0.000
0.897	98.3	0.000
0.897	98.2	0.000
0.899	120.0	0.000

* Constant

APPENDIX E

Statistics for Alternative 1 and Excursions
DELETE: SPEED

t-statistics

C*	ASHU	AGE	DISPFL	LENOA	BEAM	DRAFT	TSHP
Alternative 1							
-3.73	5.18	-4.35	-3.07	-4.70	4.35	-0.14	-0.47
Excursions							
-0.24	2.89	-1.69	0.46		0.32	-0.27	-0.33
0.34	3.29	-2.77	2.01	-1.60		1.20	-0.32
-3.77	5.52	-4.67	-3.77	-4.75	4.60		-0.62
1.00	3.10	-2.48	1.73	-1.05			0.36
-0.19	3.17	-1.94	1.85		0.18		-0.53
-0.00	2.93	-2.29	1.42			-0.02	-0.33
-0.16	3.35	-2.34	2.30				-0.61

Adj. R^2	F-stat	P(F)
Alternative 1		
0.923	116.0	0.000
Excursions		
0.896	97.5	0.000
0.900	102.0	0.000
0.924	137.0	0.000
0.900	121.0	0.000
0.898	119.0	0.000
0.898	119.0	0.000
0.899	151.0	0.000

* Constant

APPENDIX F

Statistics for Alternative 2 and Excursions
DELETE: TSHP

t-statistics

C*	ASHU	AGE	DISPFL	LENOA	BEAM	DRAFT	SPEED
Alternative 2							
-3.95	4.40	-4.91	-3.04	-4.78	4.21	-0.43	-0.80
Excursions							
-0.06	2.50	-2.03	0.28		0.27	-0.49	0.00
-0.03	2.42	-3.44	3.59	-2.02		1.16	1.23
-4.11	4.42	-6.49	-3.31	-4.82	4.41		0.81
-0.06	2.23	-4.18	3.59	-1.72			1.29
0.38	2.50	-3.75	0.95		-0.18		0.00
0.24	2.59	-3.01	7.45			-0.45	0.17
0.34	3.06	-3.82	15.30				-0.28

Adj. R^2	F-stat	P(F)
Alternative 2		
0.924	116.0	0.000
Excursions		
0.896	97.3	0.000
0.903	104.0	0.000
0.925	138.0	0.000
0.902	124.0	0.000
0.897	118.0	0.000
0.898	119.0	0.000
0.899	150.0	0.000

* Constant

APPENDIX G

Statistics for Alternative 3 and Excursions
DELETE: TSHP, SPEED

t-statistics

C*	ASHU	AGE	DISPFL	LENOA	BEAM	DRAFT
Alternative 3						
-3.89	6.51	-4.93	-3.44	-4.72	4.37	-0.43
Excursions						
-0.06	3.94	-2.13	0.35		0.32	-0.49
1.19	4.37	-3.20	3.69	-1.61		1.22
-4.05	6.54	-6.74	-3.83	-4.77	4.60	
1.21	4.19	-4.57	4.77	-1.16		
0.38	3.95	-4.22	1.80		-0.34	
0.58	4.02	-3.08	11.60			-0.51
0.33	4.14	-4.66	16.20			

Adj. R^2	F-stat	P(F)
Alternative 3		
0.924	137.0	0.000
Excursions		
0.898	119.0	0.000
0.902	124.0	0.000
0.925	166.0	0.000
0.901	153.0	0.000
0.899	150.0	0.000
0.899	150.0	0.000
0.900	203.0	0.000

* Constant

APPENDIX H

Statistics for Alternative 4 and Excursions
DELETE: DISPFL

t-statistics

C*	ASHU	AGE	LENOA	BEAM	DRAFT	TSHP	SPEED
Alternative 4							
-5.42	5.56	-4.82	-6.25	6.36	3.14	-4.77	4.85
Excursions							
-0.22	2.66	-1.57		1.14	-1.00	-0.04	-0.17
2.09	2.32	-2.74	-0.70		-0.11	2.71	-0.73
-4.23	4.34	-3.43	-5.19	5.17		-3.62	4.10
2.27	2.47	-3.80	-0.93			2.96	-0.97
0.11	3.06	-2.47		0.83		0.21	-1.50
2.10	2.43	-3.85			-0.62	7.28	-0.77
-0.70	3.11	-1.24				-0.87	0.69

Adj. R^2	F-stat	P(F)
Alternative 4		
0.936	141.0	0.000
Excursions		
0.896	97.2	0.000
0.895	95.8	0.000
0.927	142.0	0.000
0.896	117.0	0.000
0.896	116.0	0.000
0.896	116.0	0.000
0.897	146.0	0.000

* Constant

Statistics for Alternative 5 and Excursions
DELETE: DISPFL, SPEED

t-statistics

C*	ASHU	AGE	LENOA	BEAM	DRAFT	TSHP
Alternative 5						
-2.06	4.61	-3.37	-3.37	3.60	2.01	-1.48
Excursions						
-0.44	2.99	-1.64		1.38	-1.81	-0.11
1.99	2.65	-2.77	-0.74		-0.64	3.01
-1.08	4.05	-2.65	-3.26	2.99		-0.75
2.06	2.58	-5.93	-1.81			4.35
-1.14	2.64	-2.56		1.31		-0.22
2.11	2.76	-3.84			-1.77	11.30
1.58	2.36	-5.84				15.40

Adj. R^2	F-stat	P(F)
Alternative 5		
0.912	117.0	0.000
Excursions		
0.898	118.0	0.000
0.895	116.0	0.000
0.908	133.0	0.000
0.896	146.0	0.000
0.894	142.0	0.000
0.896	146.0	0.000
0.893	187.0	0.000

* Constant

Statistics for Alternative 6 and Excursions
DELETE: DISPFL, TSHP

t-statistics

C*	ASHU	AGE	LENOA	BEAM	DRAFT	SPEED
Alternative 6						
-2.54	3.11	-4.39	-3.47	4.68	1.23	1.68
Excursions						
-0.45	2.86	-2.48		7.45	-1.03	-0.20
0.60	3.05	-0.95	6.44		-1.06	-1.40
-2.32	2.85	-5.20	-3.42	4.66		0.06
0.80	3.84	-2.26	13.90			-3.15
-0.18	3.58	-3.64		15.10		-1.52
1.66	6.21	-3.11			9.67	-6.39
1.62	5.96	5.47				-2.34

Adj. R^2	F-stat	P(F)
Alternative 6		
0.913	118.0	0.000
Excursions		
0.898	119.0	0.000
0.884	103.0	0.000
0.912	141.0	0.000
0.884	128.0	0.000
0.898	148.0	0.000
0.809	72.0	0.000
0.533	26.5	0.000

* Constant

Statistics for Alternative 7 and Excursions
DELETE: DISPFL, TSHP, SPEED

t-statistics

C*	ASHU	AGE	LENOA	BEAM	DRAFT
Alternative 7					
-2.20	5.13	-4.00	-3.00	4.60	1.55
Excursions					
-1.10	3.96	-2.50		11.60	-1.84
-0.83	2.91	-0.56	10.30		-2.99
-1.58	4.85	-5.67	-3.19	5.47	
-13.10	2.20	-3.60	13.40		
-11.00	3.49	-4.86		15.70	
-7.98	2.53	-2.46			6.38
-4.35	5.83	4.79			

Adj. R^2	F-stat	P(F)
Alternative 7		
0.911	137.0	0.000
Excursions		
0.899	150.0	0.000
0.882	126.0	0.000
0.909	168.0	0.000
0.867	147.0	0.000
0.896	192.0	0.000
0.690	50.8	0.000
0.501	34.7	0.000

* Constant

Statistics for Alternative 8 and Excursions
DELETE: AGE

t-statistics

C*	ASHU	DISPFL	LENOA	BEAM	DRAFT	TSHP	SPEED
Alternative 8							
-5.07	5.01	2.56	-4.47	1.81	2.34	-4.52	3.99
Excursions							
-2.08	2.92	1.36		-0.59	0.54	-1.84	1.43
-4.67	4.62	5.09	-4.07		3.68	-4.95	4.63
-4.44	4.60	1.01	-3.73	3.32		-5.44	3.47
-2.83	3.03	4.18	-1.59			-4.00	2.56
-2.22	2.99	2.49		-0.24		-3.63	1.64
-2.08	3.24	3.91			0.00	-2.83	2.04
-2.33	3.71	4.64				-3.70	2.08

Adj. R^2	F-stat	P(F)
Alternative 8		
0.920	111.0	0.000
Excursions		
0.895	96.1	0.000
0.917	124.0	0.000
0.914	120.0	0.000
0.900	122.0	0.000
0.896	117.0	0.000
0.896	117.0	0.000
0.898	148.0	0.000

* Constant

Statistics for Alternative 9 and Excursions
DELETE: AGE, SPEED

			t-statistics			
C*	ASHU	DISPFL	LENOA	BEAM	DRAFT	TSHP
Alternative 9						
-2.81	4.88	-1.63	-2.33	2.77	-1.42	-2.03
Excursions						
-1.52	4.27	0.07		1.54	-0.95	-1.29
-0.67	3.86	2.01	0.52		-0.11	-1.52
-2.60	5.68	-0.83	-2.07	2.36		-4.19
-1.17	5.70	5.53	0.62			-3.66
-1.55	6.33	2.49		1.26		-3.67
-0.71	5.65	3.31			0.34	-1.98
-3.44	6.29	5.82				-3.91

Adj. R^2	F-stat	P(F)
Alternative 9		
0.900	102.0	0.000
Excursions		
0.893	113.0	0.000
0.890	109.0	0.000
0.899	120.0	0.000
0.891	138.0	0.000
0.893	141.0	0.000
0.891	138 0	0.000
0.892	186.0	0.000

* Constant

Statistics for Alternative 10 and Excursions
DELETE: AGE, TSHP

t-statistics

C*	ASHU	DISPFL	LENOA	BEAM	DRAFT	SPEED
Alternative 10						
-2.02	3.88	-2.24	-1.75	2.50	-3.57	-0.69
Excursions						
-1.00	3.40	-1.39		2.16	-3.09	-0.58
0.80	2.91	1.35	1.23		-2.45	-0.07
1.07	3.53	0.35	0.43	-0.11		-1.49
1.86	5.27	1.08	0.67			-2.05
1.12	4.80	0.05		0.53		-1.68
0.95	3.02	7.56			-2.22	0.50
1.90	5.26	17.14				-2.38

Adj. R^2	F-stat	P(F)
Alternative 10		
0.894	95.6	0.000
Excursions		
0.891	110.0	0.000
0.885	105.0	0.000
0.874	94.3	0.000
0.876	120.0	0.000
0.876	119.0	0.000
0.885	129.0	0.000
0.877	161.0	0.000

* Constant

Statistics for Alternative 11 and Excursions
DELETE: AGE, TSHP, SPEED

t-statistics

C*	ASHU	DISPFL	LENOA	BEAM	DRAFT
Alternative 11					
-2.04	4.66	-2.14	-1.72	2.42	-3.88
Excursions					
-1.07	4.49	-1.29		2.16	-3.54
1.05	3.85	1.81	1.34		-3.27
1.57	3.46	2.22	0.85	-1.37	
0.75	4.75	3.83	-1.33		
1.37	5.03	2.80		-1.73	
2.42	5.41	11.23			-3.29
-2.88	4.67	16.40			

Adj. R^2	F-stat	P(F)
Alternative 11		
0.895	116.0	0.000
Excursions		
0.892	139.0	0.000
0.887	133.0	0.000
0.872	115.0	0.000
0.870	151.0	0.000
0.873	154.0	0.000
0.886	174.0	0.000
0.869	223.0	0.000

* Constant

Statistics for Alternative 12 and Excursions
DELETE: AGE, DISPFL

			t-statistics			
C*	ASHU	LENOA	BEAM	DRAFT	TSHP	SPEED
Alternative 12						
-4.19	5.22	-3.81	4.65	-0.11	-4.33	3.41
Excursions						
-1.57	3.45		3.66	-2.13	-1.87	0.44
1.11	2.90	2.63		-2.47	0.86	-0.76
-4.82	7.50	-4.51	5.50		-5.36	3.44
1.39	5.30	2.39			-0.07	-4.22
-1.55	5.74		3.73		-2.54	-1.62
3.09	3.17			-2.20	6.77	-0.59
3.27	5.46				16.10	-3.73

Adj. R^2	F-stat	P(F)
Alternative 12		
0.913	118.0	0.000
Excursions		
0.894	133.0	0.000
0.883	103.0	0.000
0.914	143.0	0.000
0.874	117.0	0.000
0.888	133.0	0.000
0.873	116.0	0.000
0.865	144.0	0.000

* Constant

Statistics for Alternative 13 and Excursions
DELETE: AGE, DISPFL, SPEED

t-statistics

C*	ASHU	LENOA	BEAM	DRAFT	TSHP
Alternative 13					
-2.32	4.65	-1.65	3.04	-0.26	-2.47
Excursions					
-1.62	5.61		3.72	-2.69	-1.84
0.83	3.54	2.60		-4.99	1.25
-5.54	6.83	-3.19	6.16		-4.82
-1.91	3.15	1.49			0.46
-5.59	5.72		5.23		-3.92
3.73	4.26			-4.41	10.40
-2.56	3.68				14.30

Adj. R^2	F-stat	P(F)
Alternative 13		
0.898	119.0	0.000
Excursions		
0.895	144.0	0.000
0.884	129.0	0.000
0.899	150.0	0.000
0.841	119.0	0.000
0.885	172.0	0.000
0.874	156.0	0.000
0.838	174.0	0.000

* Constant

Statistics for Alternative 14 and Excursions
DELETE: AGE, DISPFL, TSHP

t-statistics					
C*	ASHU	LENOA	BEAM	DRAFT	SPEED
Alternative 14					
0.10	3.08	0.22	1.74	-2.72	0.09
Excursions					
0.04	3.16		7.89	-2.74	0.21
0.78	3.08	7.52		-2.32	-1.18
1.42	5.47	0.25	1.03		-2.69
1.81	5.37	17.00			-4.29
1.43	5.64		17.20		-3.32
2.55	7.28			11.80	-6.01
-0.53	4.10				0.19

Adj. R^2	F-stat	P(F)
Alternative 14		
0.888	107.0	0.000
Excursions		
0.889	136.0	0.000
0.884	129.0	0.000
0.876	120.0	0.000
0.876	159.0	0.000
0.878	162.0	0.000
0.783	81.7	0.000
0.333	17.2	0.000

* Constant

Statistics for Alternative 15 and Excursions
DELETE: AGE, DISPFL, TSHP, SPEED

		t-statistics		
C*	ASHU	LENOA	BEAM	DRAFT
Alternative 15				
-0.37	4.03	0.29	2.12	-3.95
Excursions				
0.48	5.20		11.60	-4.46
-0.62	3.34	11.00		-4.84
-2.46	4.62	-1.84	3.34	
-11.90	3.15	14.60		
-10.50	4.24		15.70	
-8.66	3.74			8.15
-2.27	5.90			

Adj. R^2	F-stat	P(F)
Alternative 15		
0.889	136.0	0.000
Excursions		
0.891	183.0	0.000
0.883	170.0	0.000
0.864	143.0	0.000
0.843	181.0	0.000
0.859	205.0	0.000
0.666	67.8	0.000
0.335	34.8	0.000

* Constant

LIST OF REFERENCES

1. Coleman, R. L., "Naval Center for Cost Analysis," Naval Center for Cost Analysis point paper, 7 October 1992.

2. Naval Center for Cost Analysis, "Naval Center for Cost Analysis Brief," Naval Center for Cost Analysis briefing slides, 10 November 1992.

3. Naval Center for Cost Analysis, Memorandum NCA-103/92 to Lieutenant Sandra Kawaguchi and NCA-4, Subject: Candidate Thesis Topic, 16 November 1992.

4. Naval Center for Cost Analysis, *Standard Cost Factors Handbook*, 4 November 1992.

5. Blake, B., *Jane's Underwater Warfare Systems 1989-90*, 1st ed., Jane's Information Group, 1989.

6. Nicholas, T., and Rossi, R., *U.S. Missile Data Book 1993*, 17th ed., Data Search Associates, October 1992.

7. Metagraphics Software Corporation, *Parametric Cost Estimating Relationship (PACER) Module*, 1991.

8. Lilien, D. M., *MicroTSP Student Version 7.0*, Quantitative Micro Software, 1990.

9. Holzer, R., "New Warship on the Horizon," *Navy Times*, v. 45, 16 August 1993.

10. *Navy Visibility and Management of Operating Support Costs (NAVY VAMOSC) Individual Ships Report, Active Fleet Ships, Fiscal Year 1991, Volume 1, Report Description*, Naval Center for Cost Analysis, June 1992.

11. Kmenta, J., *Elements of Econometrics*, 2d ed., Macmillan Publishing Company, 1986.

12. Pindyck, R. S., and Rubinfeld, D. L., *Econometric Models & Economic Forecasts*, 3d ed., McGraw-Hill, Inc., 1991.

13. Hall, R. E., Johnston, J., and Lilien, D. M., *MicroTSP User's Manual, Version 7.0*, Quantitative Micro Software, 1990.

14. Polmar, N., *The Naval Institute Guide to the Ships and Aircraft of the U.S. Fleet*, 15th ed., Naval Institute

Press, 1993.

15. Polmar, N., *The Ships and Aircraft of the U.S. Fleet*, 12th ed., Naval Institute Press, 1981.

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