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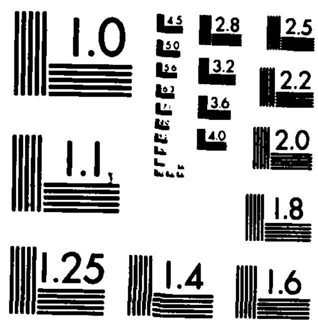

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# CNA's CONCEPTUAL DESIGN AND COST MODELS FOR HIGH-SPEED SURFACE CRAFT

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This paper discusses the need for conceptual design and cost models at the Center for Naval Analyses (CNA) and where the models fit relative to the typical acquisition process. It describes the models and how they are used to arrive at the designs and their costs. The models are evaluated in terms of three parameters--displacement/gross weight, speed, and endcost--against designs entering U.S. Naval service. It also examines how the models are managed and how such activities as staffing, protection of data, and documentation are related to model management. Finally, it looks ahead to how CNA plans to respond to the needs of the U.S. Navy in the future.



## INTRODUCTION

In 1964 a small group of professional staff at the Center for Naval Analyses (CNA) conceived of the idea of conceptually analyzing ships and submarines. The idea was prompted by the general interest in high-speed platforms following the successful development of the Hovercraft in the United Kingdom and by the needs of in-house studies. Shortly thereafter, a study was undertaken that developed a method for conceptually analyzing surface effect ships and, in parallel, a computer program called AIRCUSHV, which could handle both surface effect ships and Hovercraft. Later, in 1971, a conceptual design and cost program was developed and documented for displacement ships. The program included gunboats, frigates, destroyers, cruisers, amphibious warfare ships, auxiliaries, and aircraft carriers. This was then followed in 1973 by a conceptual design and cost program for submarines, and in 1974 by a conceptual design and cost program for hydrofoils.

This paper discusses CNA's need for conceptual cost and design models and where the models fit relative to the typical acquisition process. It describes the models and how they are used to arrive at the designs and their costs. The models are evaluated in terms of three parameters--displacement/gross weight, speed, and endcost--against designs entering U.S. Naval service. It also examines how the models are managed and how such activities as staffing, protection of data, and documentation are related to model management. Finally, it looks ahead to how CNA plans to respond to the needs of the U.S. Navy in the future.

## WHY CNA NEEDS CONCEPTUAL DESIGN AND COST MODELS

CNA is a consolidation of a systems analysis group that supports budget and system procurement actions at the Washington level and an operational analysis group that assists the U.S. Navy in making the best use of these systems. In its studies CNA considers national objectives and policies, psychological attitudes (social, political, and ideological), and available technology. The threat is defined, and the national and military strategies are developed. Tradeoffs among missions, tactics, technology, and available resources are made in which operational and technical capabilities are identified. These can be translated into conceptual designs and into resources in terms of cost and manpower.

The conceptual design and cost synthesis models allow the consideration of a montage of designs that would otherwise not be possible if reliance was to be made on hand calculations or on the provision of parametric design and cost information from sources external to CNA. Although CNA enjoys excellent relationships with other organizations, conflicting work loads usually preclude immediate or timely design and costing assistance for CNA's studies. The models also provide an historical record of design and construction practices--this is implicit in the algorithms in the model and is true of any model.

## WHERE CNA's MODELS FIT IN RELATION TO THE TYPICAL ACQUISITION PROCESS

The acquisition process for major systems such as platforms is complex and comprises many sequential events. Figure 1 illustrates the design phases appropriate to the program phases of a typical acquisition cycle. It also shows the so-called milestones and major design events.

Prior to program initiation, many studies are usually conducted under the sponsorship of the Office of Naval Research or the Deputy Chief of Staff, Research, Development, and Studies (USMC). Milestone 0 represents program initiation, at which time the program has the tacit approval of the Secretary of Defense. Adequate funding is planned and budgeted to carry the program to the next milestone, Requirement Validation.

The first explicit decision by the Secretary of Defense on a major program occurs at Milestone I, the completion of the conceptual design stage. This is the point at which CNA's models are usually no longer used. The milestone represents a validation of the requirement against preliminary evaluation of concepts, costs, schedule, affordability, and readiness objectives. Approval by the Secretary of Defense allows the system to enter the demonstration and validation phase, which develops the system sufficiently to support a Milestone II decision.

The second explicit decision by the Secretary of Defense occurs at Milestone II. Its timing is flexible and depends on the tailored acquisition strategy approved at Milestone I. By the time Milestone II is reached, the payload of the design is frozen. This freeze occurs sometime after the conceptual design is completed during the preliminary design phase.

Although CNA usually develops operating and support costs for conceptual platforms and may also look at conceptual modifications to existing platforms, it is not usually involved in predicting platform costs at the preliminary design stage or beyond. This task belongs to the Navy's Systems Commands, who are also heavily involved in refining the designs and costs throughout the remaining phases of platform development and deployment. The Commands also refine estimates of operating and support costs and, if platform modernization is contemplated, they are responsible for developing the modernization costs.

## THE MODELS

Figure 2 shows the conceptual design and cost models developed by CNA over the last two decades for surface effect ships, Hovercraft, surface ships, submarines, and hydrofoils. Of interest in this paper are the ship, air cushion vehicle, and hydrofoil models. The ship models have been included because they are used to predict the costs of amphibious warfare ships, which can carry both air cushion vehicles and landing craft. CNA has also acquired models, such as CDPLNH, from other sources.

The asterisks in figure 2 indicate those models that have not yet been developed. The dotted lines indicate those models for which the existing bid and weight data conversion programs are presently incompatible. All the models will eventually be interrelated. For example, in the CDSHIP model, a Hovercraft is part of the 500-item master payload list. However, the air cushion vehicle model (CDACV) could be used to design a conceptual Hovercraft to be carried by a conceptual amphibious warfare ship. Likewise, the missile (CDMISS), ordnance (CDORDN), and electronics (CDELECT) models could be used to design a small missile and its launcher, a small gun, and a radar to be accommodated in the CDACV payload shopping list.

CDSHIP--is used more frequently than any other of CNA's models. It can conceptually design and cost aircraft carriers, auxiliaries, amphibious warfare ships, frigates, cruisers, destroyers, and battleships. Another version of CDSHIP, called CDSHIPX, can cost a given design but has no conceptual design capability. It is used in assessing the costs of conceptual designs provided to CNA by other organizations and also for model validation discussed later in this paper.

CDWBSCON--is used to convert weight, man-hours, and material cost bid data from the Bureau of Ships Consolidated Index (BSCI) to the CDSHIP classification system. It is also used as an intermediate program for converting data from the Ship Work Breakdown Structure (SWBS) to the CDSHIP classification system. The Ship Work Breakdown Structure was introduced in 1973 and was applicable to all new-design ships including planing hull craft, air cushion vehicles, surface effect ships, hydrofoils, and SWATHs. The SWBS is far more detailed than the BSCI structure, having 342 elements vice 131 elements. SWBSCON converts SWBS elements into BSCI elements. To date, there are only six ship classes in the SWBS format: a single hydrofoil, a surface effect ship, an air cushion vehicle, and three planing hull craft.

CDACV--considers both air cushion vehicles and surface effect ships. It has similar logic to the CDSHIP program but differs in the level of detail for weights, volumes, and costs. The data base for the algorithms is drawn from a sample of 12 types of ships, including some hydrofoils. CDACV can be used to generate conceptual designs for Hovercraft up to 3,000 tons and surface effect ships up to 15,000 tons.

CDHYD--is the hydrofoil conceptual design and cost model, and is a modified CDSHIP. The modifications occur in the powering routines, weights, moments, and volumes as well as cost. CDHYD also has its own payload shopping list and is capable of generating conceptual designs up to 3,000 tons with subcavitating foil systems.

CDPLNH--was developed jointly by the Naval Sea Systems Command and the David Taylor Naval Ship Research and Development Center. A costing subroutine has been added since a paper was published on the model in 1978 [Hadler et al. (1)]. CNA has modified CDPLNH so that the lines of the ship are generated from a series of equations rather than a matrix of data.

## ANALYTIC APPROACH

### Premise

In developing conceptual design and cost models, CNA's professional staff postulated that the purpose of a platform is to transport either an active or passive payload. Active payloads are those payloads carried by aeroplanes, ships, or craft for protection or for attack. Passive payloads are payloads that can be used at some later stage of the war and include fuel, provisions, artillery, tanks, trucks, landing craft and so forth. Furthermore, in order to assess the overall impact of a payload item, the staff postulated that the models should be able to handle the characteristics of payload so that the total impact on platform size and cost could be felt.

## Cost/Work Breakdown Structure

The U.S. Navy has been accumulating weight and cost data for ships and craft since 1954. At the time when CNA began to develop its models, these data were divided into nine major groups (BSCI), two of which--design and engineering services, and construction services--were for costing purposes. These nine single-digit groups were further divided into subgroups, commonly known as three-digit groups. Although this was a logical and useful system to the Navy, it had a major shortcoming in that mission-oriented items and associated hull enclosures and foundations could not be conveniently identified and analyzed together.

Because the old NavSea work breakdown structure (BSCI) did not conveniently lend itself to conceptually adding and removing payload items, decks and foundations, or the bulkheads required to enclose the payload items, CNA's professional staff developed a new system for analyzing ship and craft concepts and concept changes. The new system, shown graphically in figure 3 and defined generically in table 1, describes the ship or craft in such a manner that a complete basic hull platform--including its propulsion and control system, its dynamic or static lift system, and, as appropriate, accommodations for crew--could be determined independently of payload. In this way, the influence of payload specifications on the technical characteristics of the ship or craft could be directly determined. This approach emphasizes the commonality of the ships and craft as vehicles providing transportation for differing payloads.

After the CNA models were developed, the Navy introduced a new work breakdown structure (SWBS) to span the entire life of a ship or craft from early design/cost studies through disposition. SWBS, which is currently in use, is far more detailed than BSCI but poses the same problems in that mission-oriented items and associated hull enclosures and foundations cannot be conveniently identified and analyzed together.

## Data Base

The data base includes all types of Navy combatant, amphibious, and auxiliary displacement ships and high-performance craft. It represents a total of more than 50 classes of ships and craft, ranging in displacements from 10 to 100,000 tons, lengths from 30 feet to 1,040 feet, installed power from 500 to 300,000 shaft horsepower, and craft speeds in excess of 60 knots. Powerplant options include diesel, gas turbine, steam, and nuclear. Propulsors include air drives, water-jets,

**TABLE 1 - CODESHIP Classification System for Ships, Hydrofoils, and Air Cushion Vehicles/Surface Effect Ships**

| Group No. | Type | Element |
|---|---|---|
| 1.0 | Hull | 1.1 Primary Structure<br>1.2 Secondary Structure<br>1.3 Foils<br>1.4 Pods<br>1.5 Struts<br>1.6 Flexible Skirts and Seals |
| 2.0 | Power | 2.1 Boiler/Reactor System<br>2.2 Engine System (Main Propulsion)<br>2.3 Transmission System (Main Propulsion)<br>2.4 Electric Power System<br>2.5 Propeller System (Main Propulsion)<br>2.6 Fuel (Main Propulsion)<br>2.7 Auxiliary Engine System<br>2.8 Auxiliary Transmission<br>2.9 Auxiliary Propeller System |
| 3.0 | Ship Control | 3.1 Pilot House<br>3.2 Navigation and Communication System<br>3.3 Mooring and Rigging System<br>3.4 Steering and Trim System<br>3.5 Ballast |
| 4.0 | Accommodations | 4.1 Personnel<br>4.2 Personal Effects<br>4.3 Personnel Stores<br>4.4 Personnel Enclosures<br>4.5 Personnel Furnishings<br>4.6 Heat, Ventilation, and Plumbing<br>4.7 Lighting<br>4.8 Personnel Safety |
| 5.0 | Ship Safety | 5.1 Ballistic Protection<br>5.2 Torpedo Protection<br>5.3 Blast Protection<br>5.4 Fire Protection<br>5.5 Degaussing System |
| 6.0 | Payload | 6.1 Electronics<br>6.2 Weapons<br>6.3 Cargo<br>6.4 Miscellaneous<br>6.5 Special |

semisubmerged propellers, and conventional marine screws, with the options of subcavitating, supercavitating, and ventilating propellers.

Documentation acquired for these ships and craft includes ship and craft specifications; final, contract, or quarterly weight reports; booklets of general plans; contractor bid and return data; a list of government-furnished material for ordnance and electronics; weapon equipment lists; and miscellaneous books on electronics, ordnance, and weapon systems characteristics.

## Design and Cost Development

Overview. The models are structured to accept various mission-related input data such as electronics, ordnance, and cargo payload, as well as limiting ship or craft performance characteristics such as endurance, range and speed, hull and powerplant sizing characteristics, and habitability standards. Based on these data, the models apply a set of engineering or empirical relationships that reflect current design and construction practices. The models then synthesize ships or craft that not only are capable of accommodating all the mission functions, but also have the required naval architectural, propulsion, and aerodynamic/hydrodynamic characteristics. The models then accept a technical description of a given design and compute labor hours and material costs associated with that design. Current overhead and profit margins are then applied to arrive at the basic construction cost.

Non-shipbuilder peculiar costs are then estimated as a percentage of basic ship cost or are applied as direct input. These include the cost of construction plans, specification changes, systems engineering, test instrumentation, and stock spares plus projections for contract escalation. These program costs are then applied to arrive at the total endcost of the ship.

How a design is developed (figure 4). Based on the mission requirements and required payload, an initial weight is estimated. This weight is then used to calculate the crude dimensions of a hull to fulfill the mission. Different subroutines are used to determine the dimensions of the platforms. For air cushion vehicles and surface effect ships, these are calculated on the basis of cushion pressure and desired initial length/beam ratio for the maximum speed. For the hydrofoil, the CDSHIP geometry routine is used to initially size the hull, and then another subroutine is used to estimate the geometry of the foil system given taper ratios, aspect ratios, leading and trailing edge sweeps, and foil loading. In addition, a first-cut estimate is made of the strut and pod dimensions.

Drag and the propulsion power required to meet mission needs is calculated based on the crude dimensions calculated above. The procedures for calculating drag differ according to the type of platform being considered. For the hydrofoil, a cavitation routine is entered as a subprogram to the foilborne drag calculation routine to ensure that the foil planform and section operate in cavitation-free conditions. This is done by the judicious selection of foil camber, thickness/chord ratio, taper ratio, and sweep to meet the design conditions. Then the displacement routine of CDSHIP is used for hullborne operation, while a separate routine is used for foilborne operation.

The foilborne routine estimates the foil system drag components including friction and form, classical induced drag, surface drag, wave drag, and aerodynamic drag. To calculate the hump drag, the hull is assumed to be unloaded as a function of a proportion of the square of the take-off speed. More specifically, the foils and flaps are assumed to be set in their take-off positions so that their lift is directly proportional to speed. Likewise, for air cushion vehicles and surface effect ships, the cushion lift can be assumed to increase from nil to where lift is equal to the gross weight of the craft (1-g) at take-off speed or it can be assumed to be at the 1-g level at zero forward speed. In calculating drag for air cushion vehicles and surface effect ships, momentum drag, wave drag, and aerodynamic drag components are estimated for the entire craft and form drag components are estimated for the skirts and side hulls.

After the drag of the craft is calculated, the shaft horsepower required is developed based on the estimated system propulsive characteristics of the propulsors. Choices include air drives, water-jets, semisubmerged propellers, or conventional marine screws with subcavitating, supercavitating, or ventilated propellers. For air cushion vehicles and surface effect ships, the power to provide hovering capability is also estimated. Once the specific fuel consumption characteristics of the propulsion engines—and lift engines for the air cushion vehicles—is known, the fuel weight needed to meet the mission requirements can then be calculated.

The next step is to calculate the component weights so that a new platform weight is arrived at. If the weight is not equal to its displacement or lift, which it is not at this point, the program returns to the geometry routine and iterations continue until the weight falls within the required accuracy limits for the diplacement. For hydrofoils, foil system buoyancy is also taken into account.

When the displacement accuracy is satisfactory, the vertical moments for each generic CDSHIP component are calculated. They are summed, along with the vertical moment data for the payload, to calculate the location of the center of gravity of the platform. Then the locations of the center-of-buoyancy and metacenter are estimated, as well as the metacentric height.

Next, the required volume for each component is calculated and the component volumes are summed, including the volume for payload. The available volume is then calculated. If the volume available is not adequate, the calculations are repeated, starting with the dimensions.

When the available volume is within the required volume tolerance, the transverse stability of the platform is checked. Again, the calculations are repeated, beginning with the geometry subroutines, if the stability is not adequate. In the case of hydrofoils, a longitudinal stability criterion, foilborne, must be met before an adequate design is generated for costing purposes.

How the endcost is calculated. Once a design has been developed, the models then compute an estimate of the Shipbuilding Conversion Navy (SCN) procurement cost. Three discrete estimates of a conceptual ship or craft are made: the cost of the lead ship of a multi-ship class, the cost of the first follow ship, and the cumulative average cost of all subsequent follow ships. In general, all costs are computed using the same synthesis logic, but they vary the applicable applied cost factors to discriminate between prototype cost and the cost of subsequent follow ships. Cost coefficients, which are usually set to unity, are incorporated into the algorithms to adjust for changes in productivity and manufacturing technology.

The models compute the following cost data elements (figure 5):

- Labor hours and material costs to construct the basic ship (groups 1 through 5)
- Labor hours and material costs for integration and engineering, including working drawings, technical manuals, lofting, and models (groups 1 through 5)
- Ship-assembly support services, including non-engineering services such as staging, launching, material handling, and temporary utilities (groups 1 through 5)
- Acquisition cost of specified payload items
- Labor hours and material cost for installing payload items, including any required foundations and enclosures.

The summation of all computed labor hours is converted to appropriate labor costs by applying labor, overhead, and profit rates for CDSHIP groups 1 through 5, integration and engineering, and ship-assembly support services. Labor, overhead, and profit rates are provided to CNA by the appropriate Systems Command, but are held in close confidence.

Certain other costs are incurred during platform procurement. They are commonly referred to as equipment and program inputs or endcost increments. They include costs for government-furnished material, electronics, hull machinery, and weapon systems, if not included in the basic construction cost or payload cost. These costs also include the cost of appropriate training, engineering services, and on-board repair parts.

Program inputs include the cost of plans, change orders, outfitting and post-delivery, miscellaneous costs, and the cost of reserves.

The Algorithms

Engineering and empirical relationships are used for conceptual design, whereas parametric (empirical and statistical) relationships are used for developing costs. Because engineering formulae rely on physical and scientific principles, they are preferred over parametrically-derived formulae, which are limited by the extent and context of their source data. Engineering formulae can also provide a guide for the development of parametric relationships such as those involving costs. Table 2 shows how an engineering relationship is derived to estimate the weight of a transmission shaft and how a cost factor is used to obtain the cost of manufacturing the shaft. If shaft horsepower is known, shaft torque can be obtained. Shaft torque is then used to determine the polar moment of inertia from which shaft diameter (hollow or solid) is obtained. The weight of the shaft is then estimated from the shaft's diameter, length, and material.

To obtain the cost of the transmission shaft, a cost factor based on shaft weight is used, as shown in table 2. The cost factor is derived using empirical or statistical methods. Table 2 indicates those variables that should be considered in an empirical or statistical analysis. Obviously, the dominant cost drivers are material, shaft speed, power, and length. (Length might be a discrete function of the type of platform, powerplant, and propulsor.)

Engineering judgment should be used when dealing with parametric relationships. If, for example, a linear regression shows that the cost of a transmission shaft doubles when the horsepower or shaft speed doubles, the relationship is suspect because, as table 2 indicates, if either shaft horsepower or shaft speed is doubled, the cost of the shaft increases by about 59 percent, assuming a constant cost factor. Similarly, if in a multiple linear regression, cost is determined as a function of shaft horsepower, shear stress, and shaft speed--and if all three impact the cost of the shaft differently--the relationship would also be questionable because, assuming a constant cost factor, the cost of the shaft is proportional to shaft horsepower, shear stress, and shaft speed to the exponent of two thirds. That is,

$$\text{Cost} \propto \left[\frac{SHP}{SN}\right]^{2/3}$$

TABLE 2 - Algorithms for Computing the Weight and Cost of a Transmi ·ion Shaft

Assumptions:

- A single hollow shaft is to be designed.
- The length, horsepower, and shear stress of the shaft are known.
- The inside diameter of the shaft equals one-half the outside diameter.

$$SHP = \frac{2\pi NT}{33,000}$$

where:

N = revolutions per minute
T = torque
SHP = shaft horsepower

Therefore,

$$T = \frac{33,000SHP}{2\pi N}$$

Now,

$$\frac{T}{J} = \frac{s}{r} = \frac{C\theta}{\ell}$$

where:

J = polar moment of inertia
s = shear stress
ℓ = length of shaft
r = radius of shaft
C = modulus of rigidity
θ = angle of twist

Therefore, knowing the maximum allowable stress, we can solve for the outside diameter of the shaft:

$$\frac{T}{J} = K\frac{s}{r}$$

$$\frac{T}{\frac{\pi}{32}(D^4-d^4)} = \frac{Ks}{\frac{D}{2}}$$

TABLE 2 (Cont'd)

where:

K = safety factor
D = outside diameter
d = inside diameter

$$\frac{T}{Ks} = \frac{\pi}{32} \times 2 \left[\frac{(D^4 - 0.0625D^4)}{D}\right]$$

$$\frac{T}{Ks} = \frac{\pi}{16}\left(\frac{0.9375D^4}{D}\right)$$

$$\frac{T}{Ks} = \frac{\pi}{16}(0.9375D^3)$$

$$D = \sqrt[3]{\frac{5.43249T}{Ks}}$$

The weight of the shaft, $W_s$, is calculated as:

$$W_s = \rho_m \left[\pi\frac{(D^2 - d^2)}{4}\right] \ell$$

$$W_s = \rho_m \left[\pi\frac{(0.75D^2)}{4}\right] \ell$$

$$W_s = 0.58905\rho_m D^2 \ell$$

$$W_s = 0.58905\rho_m \left(\frac{5.43249T}{Ks}\right)^{2/3} \ell$$

$$W_s = 0.58905\rho_m \left(\frac{(28,532,076SHP)}{KsN}\right)^{2/3} \ell$$

where $\rho_m$ is the density of the material. If we know the cost per ton of shafting for a given material, then the shaft cost simply becomes:

$$C_{SHAFT} = C_F \times W_s$$

where $C_F$ is the cost factor and is equal to the units divided by the weight of the shaft. The sensitivity of the cost of the shaft ($C_{SHAFT}$) to shaft horsepower (SHP) or shaft speed (N) can be examined by assuming:

TABLE 2 (Cont'd)

- The cost factor $(C_F)$ is constant.
- The horsepower or shaft speed is increased by a factor of 2.

Thus,

$$C_{SHAFT} = 0.58905\rho_m \left[2\left(\frac{28,532,076SHP}{KsN}\right)\right]^{2/3} \ell$$

$$C_{SHAFT} = \left[2.0\right]^{2/3} W_s$$

$$C_{SHAFT} = 1.58740 W_s \quad .$$

## THE "QUALITY" OF THE RESULTS

### The Conceptual Design

CNA's conceptual designs are usually somewhat larger in terms of gross weight and displacement, overall dimensions, and power compared to the platforms that ultimately enter service. This, however, is not necessarily deleterious when the overall utility of the platform is assessed over its service life. Generally, a platform designed to severe constraints will be more difficult and more expensive to maintain, less reliable, and possibly more vulnerable and less survivable in war. Furthermore, its usefulness may be severely impaired because inadequate margins in weight and stability prevent it from being significantly modified during its service life to meet changing threats.

Although a design can be made to minimize cost at the expense of performance, no optimal design can be claimed to be produced at the conceptual level. To produce an optimal design would require detailed point designs together with experimental verification. Even more important, though, is that the parameters be specified in which the optimum is to be sought.

### The Endcost

The accuracy of the endcost of a conceptual design depends on the type of costing approach used, the data available, and the point in the design phase at which the estimate is made. As a platform becomes better defined, costing methodology changes and the quality of the cost estimate improves. Figure 6 shows this relationship for typical high-speed platforms. At the end of the concept design phase, the quality of the estimate is either "Class D" or "Class E." A "Class E" estimate is usually obtained from a computer model using cost-estimating relationships based on gross parameters. A "Class D" estimate is usually based on technical feasibility studies or extrapolated from higher-quality (greater than "Class D") estimates of similar items.

As figure 6 shows, the payload of a platform is not frozen until some time after preliminary design has begun. Therefore, the design characteristics on which CNA makes its cost predictions are subject to change. At the time CNA does a conceptual design, the design represents the wisdom of those involved in generating the logic and algorithms of the models and their personal interpretations of what is an acceptable design for the proposed mission or missions. Furthermore, the design itself might not be constrained by gross weight/displacement, performance, or cost.

To ensure technical and costing validity, CNA checks its models from time to time against technical and cost parameters of current designs. Major technical parameters include performance, geometry, weight, and volume; major cost parameters include ship-labor man-hours, material costs, and payload costs. The first two cost items are obtained from contract design estimates or return costs. The last cost item--payload costs--is obtained from either the ship program manager or the payload item program manager. Figure 7 compares calculated parameters with actual parameters across the spectrum of CNA's models. Three major parameters are considered: displacement/gross weight, speed, and endcost. Displacement and speed were selected because they are usually the primary cost drivers. The comparison is expressed as a percentage difference between the calculated parameter from the CNA models and the actual parameter from current designs. It is interesting to note that although the models were developed 10 or more years ago, their algorithms still give acceptable results. While this is not surprising for the design sections of the models, it is perhaps surprising for the costing sections in view of changing design and manufacturing standards and government regulations.

Almost all cost data for CNA conceptual designs are based on bid estimates that generally assume program stability. The range shown in figure 7 for endcost is based upon return costs or anticipated return costs. These return costs represent the dynamics of the program. Specifically, they may include charges associated with delays, retraining as a result of layoffs caused by delays, the effects of production starts and stops over and above the control of the builder, and, finally, those costs incurred as a result of subcontractors, vendors, and suppliers deciding to drop out of the business midway through the program. To put this into perspective, figure 8 shows that the 47 major programs [Shutt and Acker (2)] included in Selected Acquisition Reports (SARs) of December 31, 1980, reflected a total cost growth of 129 percent over previous estimates made at the time of the "intent to deploy" decision (Milestone II of figure 1). According to Frank C. Carlucci, former Deputy Secretary of Defense, the most common causes for these changes were financial. Decreased budget levels and competition among programs forced tough decisions to terminate programs, delay planned production, or stretch the planned buy.

## MODEL MANAGEMENT

As models become more expensive to develop, they are less likely to be sponsored or approved. Clearly, the point has been reached at which the development of any new model comes under close scrutiny by management. The development of CNA's conceptual design and cost models was a major undertaking, requiring about 40 man-years. An additional 12 man-years have been devoted to improving and documenting the models. These figures compare very well with those of models developed by other organizations. For example, a much less complex cost model developed outside CNA took a total of about 24 man-years to develop over a 2-year period.

Modelling is divided into three major functions: model development to meet new needs, model operation, and model maintenance. Model development primarily involves the evolution of new models or the expansion of existing models. Model operation generally refers to the running of the models to support specific studies or to answer questions posed by the Naval community via CNA's scientific analysts program. This program selects highly qualified individuals to support Navy Program Offices on an ad hoc basis. Model maintenance includes the review and updating of existing methodologies, the refinement of data bases or data-base additions, the development of new algorithms to extend the capability of existing models or to replace existing algorithms, and the modification or restructuring of programs for more efficient running.

## Staffing

A study director is responsible for the development, operation, and maintenance of CNA's models. He is supported by additional professional staff and by technical and support staff. Professional staff focus on the engineering and cost aspects of model development and maintenance, while the technical staff are concerned with programming and model operation. Support staff are generally concerned with data management and collection. Areas of expertise of individual staff members include naval architecture, marine engineering, hydrodynamics, aerodynamics, structures, propulsion, cost estimation, computer programming, and data management.

Past experience at CNA has shown, in general, that staff members assigned to the conceptual design and cost models have not been able to devote much more than 50 percent of their time to developing and maintaining the models. Although the technical and support staff are full-time, they are dedicated only to operating and maintaining the models. Demands for use of the models are cyclic. Models to be used in support of specific studies are updated, if necessary, before they are used. While this is being done, model development and model maintenance activities for models not being used for the studies are halted.

## Protection of Data

To keep its models current, CNA must have access to relevant data. But like other organizations, CNA has experienced data famine from time to time. This is not a disease, but a sometimes annoying fact of life, which requires tact and perseverance to overcome. The problem is twofold: access is needed to both technical and cost data. Although, for the most part, CNA develops its own analytical methods for its conceptual designs, in some cases it must use methods from proprietary sources. Furthermore, the cost data CNA uses is almost always proprietary, business-sensitive.

Fortunately, as a result of new procedures for protecting proprietary and business-sensitive data, CNA has had much easier access to the types of data it needs. To guard against unauthorized access to this data and to keep from compromising its sources, CNA has developed strict in-house procedures for handling such data. Not only is the data not releasable under the Freedom of Information Act, but also any proposed release of documentation containing such data must be approved first by the originating office of the Command supplying the data and then by the contracts directorate, by the acquisition manager, by the appropriate director of congressional and public affairs, and by the office of general counsel.

Documentation

Documentation is probably the most disliked aspect of developing computer programs and probably the most neglected, often because the resources required are substantial. However, the development of new software packages has eased the burden somewhat since the same computer on which the program is developed can be used as a word processor. This is now a fact at CNA.

To simplify the documentation of its models, CNA produces three types of documents: users manuals, working papers, and memoranda.

A users manual is available only on the terminals. It briefly describes the input to a program, its format, and any operating instructions necessary to get the program to run. For example, CNA has limits on the processing time for interactive jobs, and if a range of designs is being addressed, it is necessary to run in the batch mode.

A working paper has a limited internal distribution and is used to document the methodology used in a program. Generally, a working paper is written for each main program and each subroutine. The working paper describes the input to the main program or subroutine, the calculation procedure, and the output. In addition, a working paper is used to document the payload shopping list.

A memorandum provides an overview to a program by describing the data base, program logic, and structure; by summarizing the content of related working papers; and by presenting comparisons of calculated and actual characteristics of the platform being considered. Like a working paper, a memorandum is intended for limited distribution and contains no proprietary or business-sensitive information.

Review and editing procedures at CNA vary according to the type of document. For example, a working paper is not usually edited unless the author intends to upgrade it to a more formal document. A memorandum, however, is edited and technically reviewed to ensure that it is clearly written and analytically sound.

## FUTURE DEVELOPMENT

It is CNA's objective to be responsive to the ever-changing needs of the Navy. In the mid-1960s great import was placed on the evaluation of new platform concepts such as the Hovercraft, the surface effect ships, the hydrofoil, and the SWATH. Today, none of these concepts has seen widespread military use in the West. There is evidence to suggest that the benefits offered by these high-performance ships and craft are generally less important today than they were in the past and that the cost of acquiring these benefits is too high. It may be a number of decades before the capabilities of these ships and craft can be matched with new weapon systems to make their potential worthwhile. Nevertheless, there are roles that small numbers of Hovercraft, hydrofoils, surface effect ships, and SWATHs can fulfill in the immediate future.

Today--and for some time into the future--the emphasis is and will be on developing more sophisticated payloads (weapon systems, electronics, and sensors). This, in turn, increases the complexity of the platforms that carry them and escalates platform costs so that large acquisition programs for ships and high-speed surface craft will be less likely in the future. It might even be that the United States and its allies will have to rely on each other for help in building certain types of platforms.

How do these ever-changing trends affect model development at CNA? CNA models will have to be able to handle the assessment of ship and craft construction outside the U.S. Still another requirement would be for the models to be able to incorporate scientifically sound techniques for estimating program risk and for determining how large a contingency fund should be set aside for dealing with unanticipated difficulties. These techniques would consider each element of the work breakdown structure, assign a risk to each element, and use mathematical methods to combine the data. Finally, in the area of cost, subroutines for operating and support costs need to be incorporated into the models, and, because of the increased life of ships, the models need to be able to estimate ship modernization costs.

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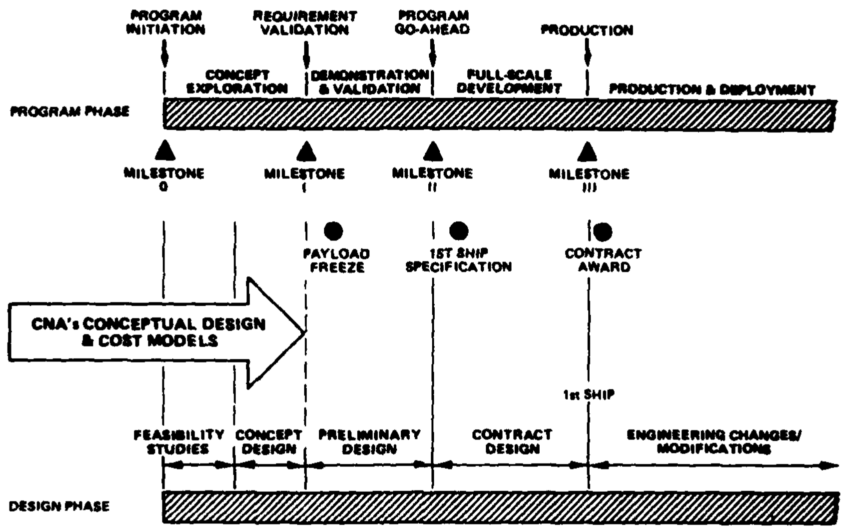


**Figure 1 Relationship of CNA's models to the typical acquisition process**

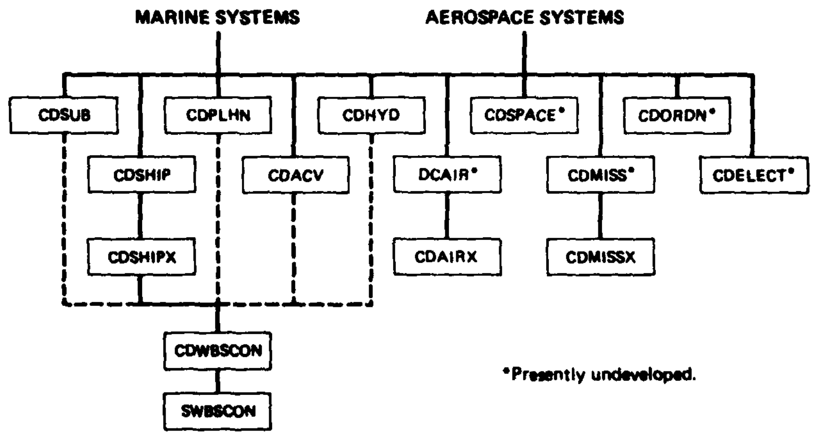


**Figure 2 CNA's conceptual design and cost models**

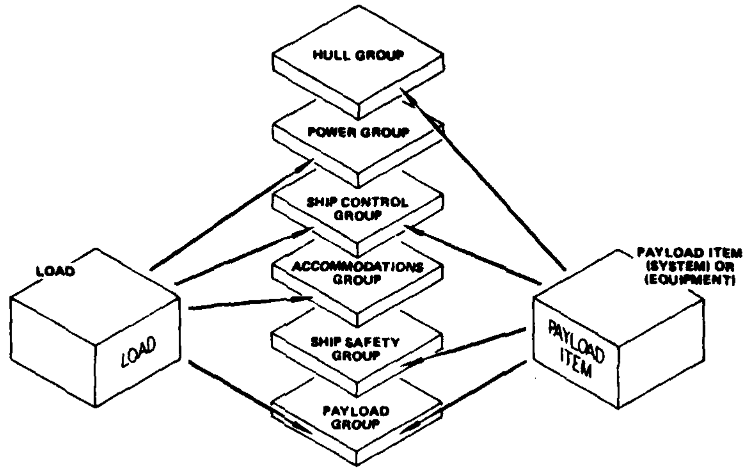


**Figure 3 Cost and weight classification system for CNA models**

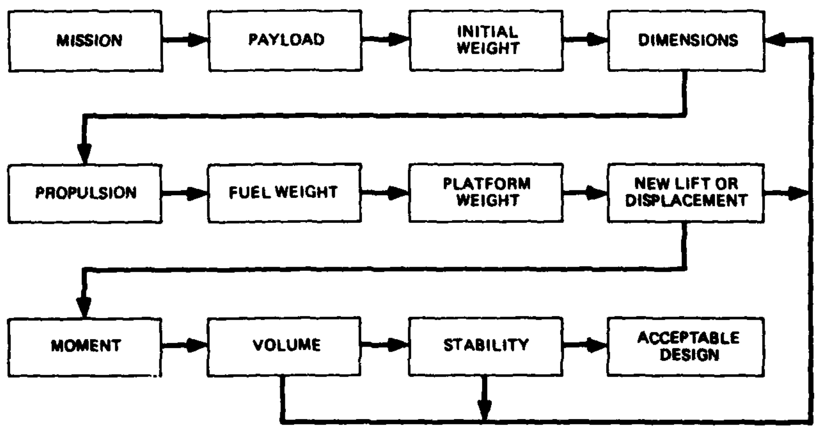


**Figure 4 How a design is developed**

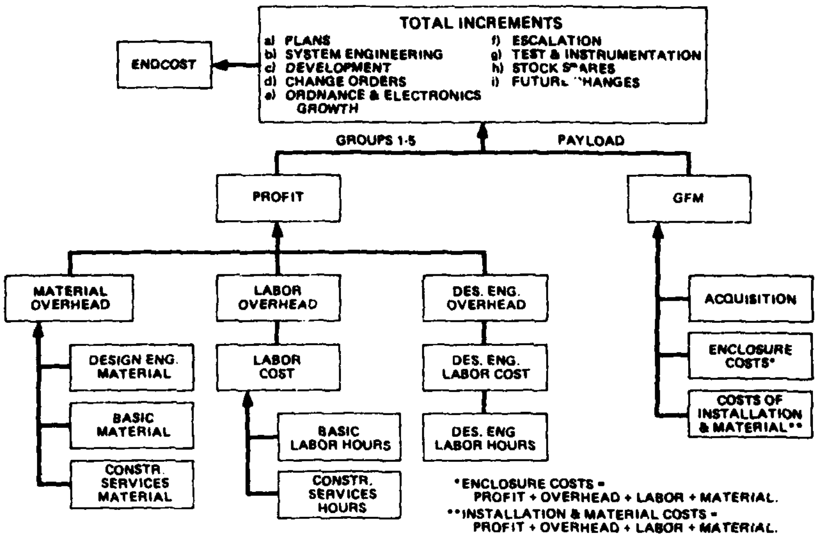


**Figure 5 How the endcost is calculated**

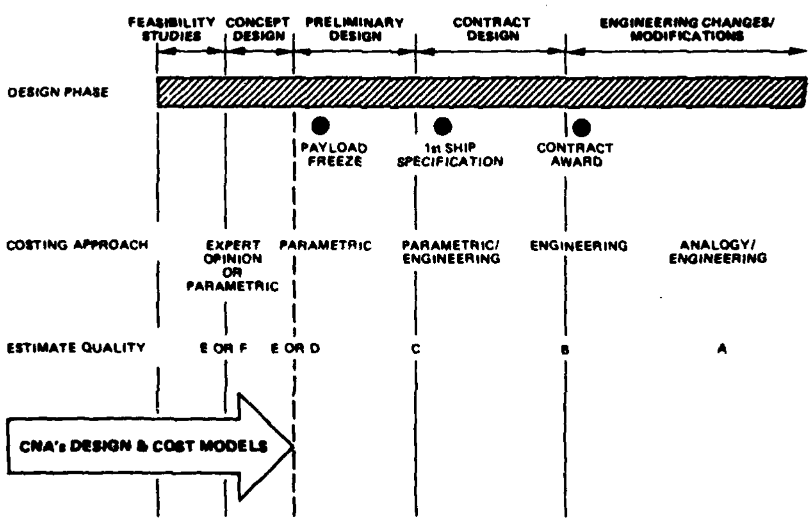


**Figure 6 Relationship of costing approach and quality of estimate to design phase**

| PARAMETER | DIFFERENCE* |
|---|---|
| DISPLACEMENT OR GROSS WEIGHT | −5 TO +10% |
| SPEED | −10 TO +5% |
| ENDCOST | −20 TO +10% |

*Expressed as percentage difference between the calculated parameter from CNA's models and the actual parameter from current designs

**Figure 7 Comparison of three calculated and actual parameters across spectrum of CNA's models**

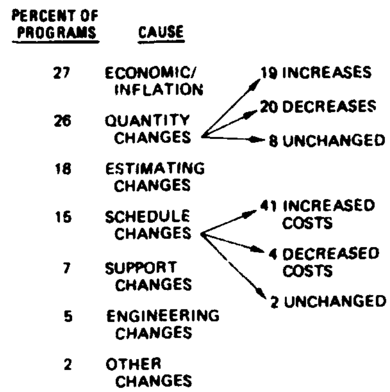


**Figure 8 Reasons for 129-percent cost growth of 47 SAR programs**

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