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THESIS

PROTOTYPE DISPLAYS FOR THE COMMAND FUNCTION ON BOARD LPD-17

by

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March 1995

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The approach taken to solve the problem has four parts. First, system requirements were captured by interviewing 23 senior officers with command-at-sea experience to isolate design features they require from such a command and control system. Second, a mock-up display was designed based on these requirements; the mock-up was then iteratively tested in the fleet with subject matter experts to ensure it captured the required elements of command and control. Third, a user-interface display was then constructed using a personal computer and Asymetrix application Multimedia Toolbool™; that is, a prototype was made without connecting to the underlying data. Fourth, this prototype was then iteratively reviewed during design by fleet operators to validate that the command and control process could be executed from this workstation. The result of this research is a set of 18 example displays that will be forwarded to NAVSEA and the contractor for consideration during actual system design.

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PROTOTYPE DISPLAYS FOR THE COMMAND FUNCTION ON BOARD LPD-17

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Submitted in partial fulfillment of the requirements for the degree of

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I. INTRODUCTION

This thesis addresses the design of a prototype human-computer interface for a command and control system which will be in place on the next generation amphibious platform: LPD-17. The Naval Sea Systems Command (NAVSEA) is charged with developing this interface, and has already produced a preliminary fiber-optic based network, the Integrated Interior Communication and Control $(IC)^2$ System, which will provide the required data for command and control. This research incorporates data gathered during interviews of Commanding Officers of surface combatants; it evaluates and distills design features they would desire from such a command and control system. A set of engineering design recommendations is proposed for the system's informational interface.

The thesis has four parts. The introduction provides an interpretation of the general problem and NAVSEA's current solution to it. The second part reviews the methods used to extract, isolate, and integrate command and control design recommendations. The third part reviews the analytic interpretation of users' desires; how these desires were translated into system characteristics, and how these characteristics were incorporated into prototype displays. The final part, the discussion, critically evaluates the present method's findings and products, and recommends future courses of action.

A. NATURE OF THE PROBLEM

This section discusses problems associated with current command and control systems. It identifies the problems experienced on surface combatants and discusses why it is important to accommodate these problems during the design of new systems.

Two broad shortfalls account for usability [1] problems with command and control systems used in the surface Navy today:

- There is a lack of understanding about how the user reads, interprets, and uses information, and

- There are few user inputs during the design process.

By extension, these deficiencies are at the root of two common human-computer interface weaknesses:

- User-defined information requirements are not readily available; as a result, interface displays do not adequately depict what the user wants to see.

- Information displayed *in lieu of that which the user wants* is often difficult to comprehend in a timely and efficient manner.

A third related problem deals with the complexities involved with designing a system to support command and control on U.S. Navy ships. The warfare environment in which these ships operate is continually changing, ultimately compressing the battlespace time-line. This change in warfare, in the face of advancing technology, threatens to overwhelm the decision-maker during the process of command and control. Potentially too much information is made available and the user is forced to deal with the serious problems associated with inductive [2] logical processes. The users are forced to select small bits of information from the vast amounts of data available to comprehend the situation and reach a decision. When existing deficiencies are combined with the changing complexities of surface warfare, proper design of the user interface becomes one of the most important aspects to consider during the design and development of the system itself.

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[1] Usability is related to the effectiveness and efficiency of an interface, and to the user's reaction to that interface (Hix, 1993).

[2] Inductive reasoning involves drawing conclusions from specific events. The lexical definition of "inductive" is "...inference of a generalized conclusion from particular instances...." (Websters, 1990, pp. 615) The opposite of inductive reasoning is deductive reasoning — a conclusion reached from observing generalities.

Tactical displays have not improved dramatically until the last few decades. From the days of Nelson's Trafalgar in 1805 when messages were sent by flag signal, to the fleets of World War Two when radar and plexiglass grease boards were first used, much of the information that was passed along was hearsay. The data used for command and control was what someone else said, or saw. In the recent past, and with the advancement of electronic devices, displays now can accurately depict real-time data; but while the typical decision process has not changed, the workload on the user has continued to increase. "Modern computer power has opened the possibility of augmenting, assisting, and supplementing the decision process of commanders by synthesizing for display the information on decision alternatives." (Snyder, 1993, pp. 63) Effective design of command and control interfaces must ensure that computers assist in reducing the workload and help solve problems associated with decision making.

The heart of the problem is straight-forward. Decision aiding interfaces used today often provide the user with *too much data* and *not enough information*. As technology advances and the volume of information available to the decision maker expands, the user needs help to discern the available options from a tactical perspective. As present and future tactical encounters become increasingly complex, decisions and actions are, and will continue to be, time constrained; multiple decisions and required actions must be made in a matter of seconds. Decisions must be made in milliseconds and use all relevant information at the time. The relevant information must be isolated, redundancies and ambiguities must be eliminated, and the system must provide information *when* and *how* the operator or decision maker needs it.

Data and information are different, and this difference must be clarified. In the past, these two terms were used interchangeably, but today's saturated information environment highlights a significant difference in their meaning. The International Standards Organization (ISO) defines *data* as "...a representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by human beings or by automatic means." (American, 1972, pp. 33)

Information is defined as "...the ***meaning*** that is currently assigned to *data*...." (American, 1972, pp. 63) An effective user-interface is one that displays data so that information is effectively and effortlessly imparted to the user.

To fully understand command and control and how it relates to the surface Navy, this section will review the following four areas:

- **The Basics of Command and Control**. The traditional elements of command and control are discussed. Command and control is defined, and a model of how decisions are made is presented.

- **Increasing Complexities of Command and Control**. The reasons for the increase in information flow and the changing complexities in command and control systems are explored.

- **Case Studies: A review of user-interfaces.** Two studies are conducted and user-interfaces are compared. The first study reviews the incident of USS VINCENNES and the shoot down of a commercial airliner. This is an example of how the Navy's most advanced command and control—and weapon system—did not lead its users to the proper decisions. The second study reviews the Integrated Condition Assessment System (ICAS), a computer based analysis and diagnostic tool used to monitor onboard equipment. This system has extensively involved the intended operator in the initial design of the interface.

- **Human Performance in Command and Control**. How human capabilities and limitations come into play during decision making is reviewed.

1. Command and Control

The following reviews command and control to provide the reader with a very basic background in command and control—what command and control is, and what elements are involved with it. Contemporary command and control components are first reviewed to familiarize the reader with what is commonly available in the fleet. Command and control is then defined, followed by a model which displays the basic steps associated with command and control.

a. Contemporary Command and Control Systems of the Surface Navy

In the surface Navy, command and control systems that are predominantly in use are products that were designed and built during the period from the 1960's to the 1980's—a 20 year period during which the application of computer technology began. Today, however, many of these systems are obsolete, in part, due to rapidly advancing technology and the long development cycle these systems required, and in part, due to the slow military procurement process. To understand the problems that exist with current command and control systems, it is important to know the basic components that are available to assist with decision making. Typical command and control systems used by today's surface Navy involve a combination of both computer based and non-computer based components to help the decision-maker. The following components comprise a typical media mix:

- computer monitors or large display screens,
- automatic status boards,
- grease boards,
- hand written pass-down logs, and
- internal and external communications.

Using such a media mix, the user is required to shift his attention between the display devices to retrieve essential pieces of information. For a number of reasons, these systems—systems which should support decision making during the process of command and control—can be designed to better support the user.

b. Command and Control Defined

The Joint Chiefs of Staff define "command" as

> The authority which a commander of the military service lawfully exercises over subordinates by virtue of rank or assignment. **Command** includes the authority and responsibility for planning the employment of, organizing, directing, coordinating, and controlling military forces for the accomplishment of assigned missions. It also includes responsibility for health, welfare, morale and discipline of assigned personnel. (Joint Chiefs of Staff,1972, pp.77)

This definition implies specific action taken by the commander—*organizing* forces for optimal performance, *directing* force actions to accomplish a mission, or *acting* to achieve established goals.

The commander exercises *command* through a process called *command and control*. Command and control is:

> The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. **Command and control functions** are performed through an arrangement of personnel, equipment, communications, facilities and procedures which are employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. (Joint Chiefs of Staff,1972, pp.77)

"...commanders must be given certain specific capabilities that include the ability to communicate to higher and lower command levels, obtain, process, analyze, synthesize, and display information." (Adriole, 1990, pp. 67)

c. A Model of the Command and Control Process

Command is the charge of the commander. Command and control is the process the commander uses to exercise command. Command and control reflects decisions which enable the commander to impose or express his will to, or on, subordinates. A highly simplified approach which diagrammatically represents the command and control process is depicted in Figure 1, on page 7.

To evaluate the situation and determine the appropriate response, the commander must fully comprehend his continually changing environment. The commander must *assess* the situation to determine how to act. In assessing the situation, he must *observe* the information displayed by the supporting system, *process* what he is looking at, and *compare* what (he thinks) exists with what must be done to reach the desired goal. The commander must then *decide* the best course of action, and *act*. Simply stated, the commander must determine:

- What is happening? And,
- What can I, or should I, do about it?

Systems that are to support command and control must help the user with the first step of the decision process: they must help the user *assess* the situation. Specifically, a command and control system must assist in observing, processing and comparing information—not data—so the operator can make better, faster decisions. It is task that is becoming more difficult as technology advances and surface warfare changes.

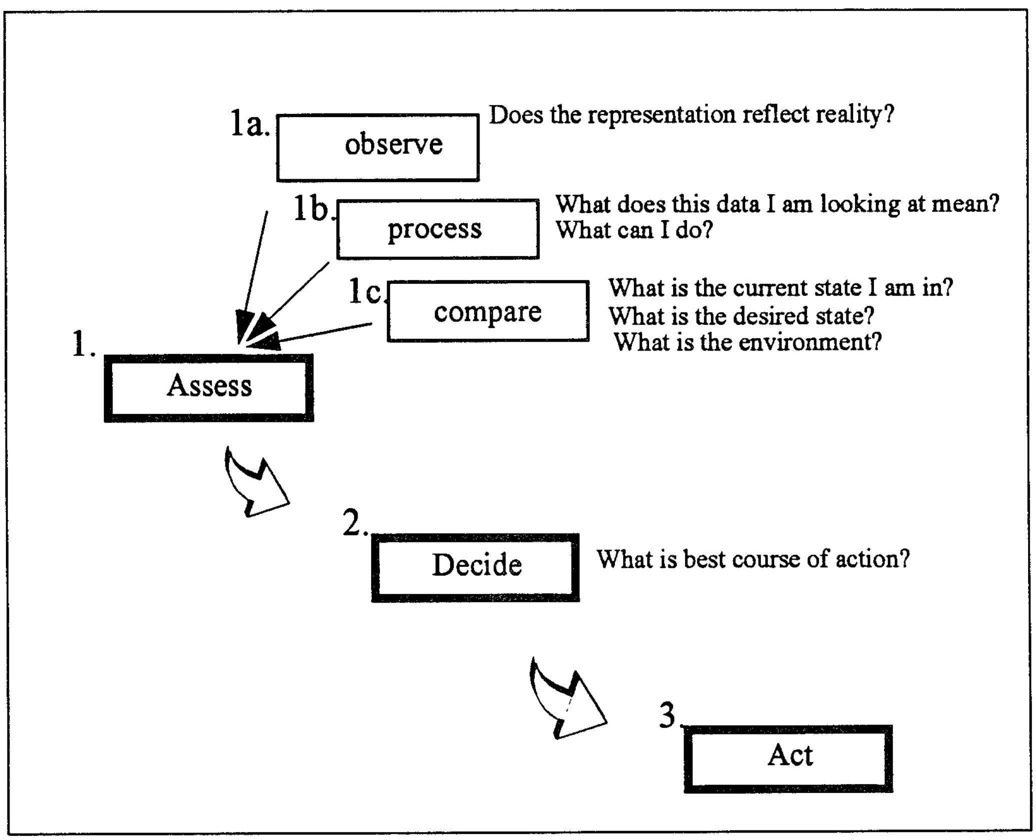

Figure 1: Model of the Basic Steps Followed during Command and Control

2. Increasing Complexity of Command and Control

The compression of traditional battlespace in littoral [3] warfare, coupled with the proliferation of modern anti-ship weapons has created a serious challenge for today's naval tactician. The human ability to recognize, evaluate, and react to the rapid flow of various types of information—tactical, own ship and administrative—with non-integrated shipboard systems has simply become physically and mentally overwhelming. If decision aids are to effectively guide the user to make correct decisions systems designed to assist decision-makers must be designed differently than they have been in the past.

The changing role of the U.S. Navy continues to drive the development and production of new command and control systems. As stated in the Navy and Marine Corps White Paper *...From the Sea,* "The future vision of the Navy will focus on strategic deterrence and defense, forward presence, crisis response, and reconstitution." (U. S. Navy, September 1992, pp. 1) The demise of the Soviet Union and the rapid worldwide expansion of advanced technology to Third World countries have resulted in a rapid shift away from emphasis on open-ocean global warfare to regional or limited conflicts involving Third Word nations in littoral waters.

a. Impact of Littoral Warfare

The littoral environment is characterized by dense commercial air traffic and merchant shipping which presents challenges to command and control systems and their operators. This environment and the projected threat will challenge the detection range, reaction time, defensive performance, and display mechanisms of the system used against the threats. The battlespace in which shipboard systems are to react in will be limited (Ousborne, 1993). "Facing the future, we must prepare to deal with a foe at ranges so close that the incoming weapons are at best only a few seconds away." (Owens, 1993, pp. 90)

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[3] Littoral warfare is the placement of traditionally open-ocean warships in a coastal environment in support of troops on land.

b. Impact of Increased Complexity in Information Systems

In addition to the rapidly changing warfare environment in which the Navy operates, each successive generation of warship has become technologically more complex. Present-day command and control systems, and procedures, must accommodate the explosion of data and the associated complexities of information distribution. In the near future, all voice, video, and data will be transmitted across a common medium—fiber optics. The subsequent integration of this data using common computers and databases will allow for the real-time display of *any* information that is conceivable. *The challenge no longer exists in detecting and recognizing data but in selecting the essential information from this huge amount of data required to make a time critical decision.*

The more technology advances, the more complex command and control becomes. To ensure operators make the best and fastest decisions possible, the following must be accomplished:

- Improve integration and increase the automation of sensors, weapons, and ***display*** systems to shorten reaction time and coordinating responses.

- Enable the Commanding Officer, and subordinate watchstanders, to direct and monitor the overall operation of on board systems in this environment. (Ousborne, 1993)

- Provide seamless command, control and communications to effectively operate in this complex sea-air-land battle.

Accomplishing these tasks will lessen the complexities, and relieve much of the burden associated with decision making.

3. Case Studies: A Review of Two User-Interfaces

As the command and control process continues to become more complex, so does the process of designing command and control systems. The display element of decision aiding equipment—the human-computer interface that the decision maker will use to access data—is becoming one of the most crucial elements of design.

> The tactician of tomorrow is waiting for the designer of today to create a system that will help him understand his environment so that he can fight a better fight and live another day. (Willey, 1988, pp. 292)

Research into the elements of command and control is not a new field, yet the manner in which information is displayed has not adequately focused on the end-user. Computer system interfaces must be designed with the user in mind. System designers must consider the human element. Data must be conditioned and displayed so that it becomes an effective tool for decision makers.

In today's high-tech environment, systems can provide more data than the human can process. The mental act of processing streams of rapidly changing data from multiple sources often induces information overload, a situation where more information is provided than an operator can handle. The same information at sufficient volumes with insufficient time in which to process it can also cause a breakdown in communication between operators. As previously discussed, both advancing technology and the compression of the traditional battlespace have made the flow of information virtually unrestricted. Interfaces designed to support command and control of surface combatants must accommodate and compensate for the possibility of operator information overload. The continually complex and ever changing environment of the surface Navy demands that computer systems must be designed around the conditions in which they will be used. Command and control systems must reflect how human performance is affected by the characteristics of that work environment.

Two case studies follow. The first is a review of the shoot down of Iran Air flight 655—an A-300 Airbus—in the Persian Gulf in July 1988 by USS VINCENNES (CG 49)[4]. This event clearly shows that the AEGIS weapon system interface—in all essence the shipboard command and control system—could have been better designed

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[4] USS VINCENNES is a Ticonderoga Class Cruiser. This ship uses the AEGIS Weapon System, the most advanced computerized shipboard weapon system based around a 3-dimensional radar. Anti-air warfare is the primary mission of this class of ship.

to accommodate the strengths and limitations of its operators. The system was not "user friendly:" the results were tragic. The second study reviews the Integrated Condition Assessment System (ICAS), a real-time computer-based analysis and diagnostic tool used to monitor on board engineering equipment. This system successfully focused on the needs of the intended user by keeping the subject matter experts involved throughout the design process.

a. USS VINCENNES: Was it Only Operator Error?

The accurate display of timely information on U.S. Navy ships greatly affects command decisions. This case exemplifies how the technologically advanced AEGIS Weapon System *may not* have effectively guided its users in making correct decisions. A summary of the incident is provided in Appendix A, on page 55.

(1) Design Weaknesses in VINCENNES' System. The written reports, published after the incident—including the official investigation conducted by Rear Admiral Fogarty—and testimony from a House Armed Services Committee review concluded:

- the downing was "not the result of negligent or culpable conduct...." (Fogarty, 1988, pp. 43)
- the Commanding Officer "...[acted] properly and responsibly in responding to an unknown threat, holding his fire until the last possible minute." (Hill, 1988, pp.108) and
- the AEGIS weapon system performed excellently—as it was designed (Hill, 1988).

The Fogarty report did not find any malfunctions by the AEGIS weapon system; however, it did recognize that specific pieces of equipment were misused by individual operators, resulting in erroneous reports of the aircrafts' descending altitude and IFF. Testimony from human factor specialists however, did find fault with the design of the AEGIS weapon system, "...human error probably contributed to the accident, but not in the way the Fogarty report contends, 'It was human error', he says, 'on the part of the people who designed the system.'" (Hill, 1989, pp. 113)

The Fogarty report did not find fault with the system; however, it is apparent from the result of this incident, the loss of 290 lives, that the AEGIS system—the "cutting-edge" of technology employed by the U.S. Navy—was not thoroughly designed with the user in mind. The report did not say that the AEGIS weapon system was not "user friendly" but the following events did occur:

- operators misidentified the airliner,
- operators incorrectly determined that the airliner was decreasing in altitude,
- operators misread the aircrafts IFF [5],
- operators incorrectly determined that the airliner was outside of the commercial air corridor,
- one operator incorrectly pushed an action button 23 times trying to get the system to perform (Hill, 1988, pp. 204) and,
- those in the chain of command on VINCENNES, including the Commanding Officer, did not use information presented to them at their consoles, information which would have accurately indicated that the aircraft was indeed neither descending in altitude, nor preparing to take an attacking posture.

The report did not state that the AEGIS weapon system failed to display information in a manner that was intuitive to the user. That omission, however, is one of the conclusions which can easily be drawn. Had design issues, like the intuitive display of information, and human factors issues, like mental processing capabilities and limitations, been adequately addressed earlier, the operators may never have been in a situation where so many disjoint errors would have resulted in a mistake of this magnitude.

b. Integrated Condition and Assessment System (ICAS)

The Integrated Condition and Assessment System (ICAS) will provide future generations with the ability to retrieve all required data about a shipboard

[5] Identification Friend or Foe (IFF) is an electronic challenge and reply system that uniquely identifies aircraft. This system is required on all aircraft.

engineering plant from a personal computer monitor. This system is currently being designed by the NAVSEA, Controls and Monitoring Systems Group, and although it is not labeled as such, designers are using a user-centered approach to design the ICAS interface. Intended-users with significant fleet experience have provided the basic requirements around which the system, and intuitive interface, are being designed. These intended-users are the driving force in determining the system characteristics.

This type of design approach will allow designers to initially build and later modify the display in accordance with the desires of the users. It is essential to ensure that these user-defined requirements are tailored from the beginning with consideration into how the intended-user will "see" and "process" these displays. Human factors must be considered during design.

4. Human Factors in Command and Control

Human factors is the study of human behavior based on empirical [6] testing. The goal of human factors in interface design is to make systems usable. Usability is the optimization of human performance by:

- maximizing information transfer,
- reducing errors,
- increasing throughput,
- maximizing user satisfaction.

Design of command and control systems must ensure that the display is intuitive and natural for the end-user. The user should not have to adapt to the interface. When designing command and control systems, human factors must be realized and accommodated. The display of information elements is critical to the success of a command and control system. Design must focus on the desires and limitations of the end user. The former Commander of the Joint Chiefs of Staff, Admiral W.J. Crowe, recognized that improvements were required in the command

[6] Empirical is defined as relying on experience or observation alone.

and control displays of the AEGIS weapon systems. This recommendation came *after* the VINCENNES incident:

> ... I recommend that some additional human engineering be done on the display systems of AEGIS. The objective would be to better equip it for assisting with rapid decisions in a situation such as VINCENNES confronted.... It seemed to our inexperienced eyes that the Commanding Officer should have some way of separating crucial information from other data. Moreover, the vital data should be displayed in some fashion on the LSD [7] so the Commanding Officer and his main assistants will not have to shift their attention back and forth between displays. (Crowe, 1988, pp. 8)

a. Human Performance: Capability and Limitations

Human performance must be recognized and considered, it must have a direct impact on the design of a decision-aiding system. As exemplified at the VINCENNES hearings

> ...the ship's sophisticated AEGIS radar and computerized battle management system worked properly, but that some of the men monitoring the screens and digital displays may have distorted the information they were receiving.... (Moore, 1988, pp. A1)

For example, human short term memory is an intermediate stage of memory between sensory storage and long term memory that can last up to approximately 18 seconds and is limited to seven plus or minus two items. Moreover, to increase the processing ability, people "chunk" data; that is, data is organized into recognizable groups. By grouping information in this way, the human processing capability increases dramatically. Recognizing these strengths and limitations, and tailoring a system to limit the processing weaknesses and exploit the strengths should be a focal point of design for a user interface.

b. Human Factors as a Force Multiplier

If not recognized, human memory and processing can become a force attentuator; thereby limiting capabilities and preventing the users from obtaining the

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[7] Large Screen Displays (LSD's) are 42" x 42" wall mounted displays used on AEGIS cruisers and destroyers for command and control.

desired goal. By recognizing these limitations and designing human-computer interfaces with them in mind, human mental ability can become a *force multiplier.*

By emphasizing the importance of human factors, complex systems can be designed to be "user friendly." Interface displays are the keystone of command and control systems and the decision making process on board surface Navy combatants. Correct design of interfaces will strengthen and assist the ability to effectively apply assets in order to achieve military objectives.

B. PROPOSED SOLUTION

This sub-section introduces a proposal to fix the deficiencies that exist in today's command and control systems. The Total Ship Integrated Interior Communication and Control (IC)^2 program is a NAVSEA initiative to solve the problem of information explosion on board U.S. Navy ships. This system will be reviewed, followed by a discussion of the Command Function—the display element of (IC)^2. (IC)^2 will differ from existing command and control systems by providing:

- seamless command, control, and communications because all shipboard components will be connected to a real-time fiber-optic network,
- information available to the Commanding Officer and his subordinate watchstanders will provide the ability to monitor and direct on board systems, and,
- interface displays will consider the human element, human-computer displays will be intuitive yet provide comprehensible information.

1. NAVSEA's Integrated Interior Communication and Control (IC)^2 System

NAVSEA has designed and successfully demonstrated the abilities of a new information transfer system. The next generation amphibious ship—LPD-17—will have a complete fiber optic network system that will connect all shipboard equipment and sensors. The Integrated Interior Communication and Control (IC)^2 System, will integrate the entire ship as a warfighting unit. The flow of data will be unrestricted. By effectively harnessing the data that exists on this network, the command and control display element, called the Command Function, will be a critical element in the overall system.

Implementation of $(IC)^2$ will replace the way current interior communication collect, process, distribute and display orders. Through the use of $(IC)^2$, information will be available to assist decision making. The challenge is to correctly and methodically determine *what* to display and *how* to display it to support the user.

a. Description of $(IC)^2$

$(IC)^2$ is the means by which future ships will exercise command and control. $(IC)^2$ permits individual ship systems to improve their connectivity and versatility by using newly available technology to improve conventional interior communication designs. This information management approach will screen, fuse and integrate all shipwide data into real-time information to aid in the command and control of the ship. $(IC)^2$ will allow surface ship fighters to evolve from the traditional use of compartmented information into the integration of the ship as a total entity. LPD-17 will operate for the first half of the 21st century [8].

$(IC)^2$ equipment will pass all data, information, voice, video and orders between on board users. The components consist of:

- a shipboard data network,
- a video distribution system,
- a voice distribution system,
- the information transfer cable plant, and
- ***the Command Function.***

The first four components are specific hardware that will facilitate the collection, processing, and transfer of data. They are not addressed in this research. The Command Function is what users will use to access $(IC)^2$, and is discussed next.

[8] LPD-17 has an initial operational capability (IOC) of 2002.

b. Introduction to the Command Function

The Command Function is the display element of $(IC)^2$. The Command Function will enable operators to exercise command and control from a workstation using real-time information that traditionally was unavailable, or at best, late. This display will provide fused summary data of shipboard functions to facilitate command and control. This workstation which uses a 25 inch color graphics monitor will enable its to monitor systems and provide guidance to others.

C. THESIS SCOPE

This thesis provides prototype displays for the Command Function—the display element of $(IC)^2$ system. The design recommendations and displays will be forwarded to NAVSEA for consideration during interface design and development.

The shortfalls that exist in current command and control systems are by-products of a flawed design process. Systems in use today often lack a crucial design element, input and feedback from the intended-user to determine the required system functionality. Systems are often not designed around what the user actually wants; consequently, the systems are not "user friendly."

The term "user friendly" in engineering parlance means "usable." Usability relates to the effectiveness and efficiency of the interface, and to the users reaction to the interface. To ensure usability designers must accomplish these tasks:

- Determine what the intended-user requires from a new system.
- Establish a foundation of ideas based on the inputs of operational experts and the desires of intended users. Base the mock-up and initial prototype on these requirements.
- Document these findings in such a manner that system characteristics can be outlined and so that other designers can further modify and build onto the system.

The next chapter reviews the method used to design the Command Function.

II. METHOD

This thesis develops functional specifications, including the required functionality and associated system characteristics, and develops prototype displays for the Command Function of LPD-17. The method used to design those prototypes is discussed below. The process adopted closely follows a set of contemporary commercial design guidelines (Mayhew, 1992) comprised of five notional phases. These phases are:

(1) a definition of the system's purpose,

(2) the development of the functional specifications,

(3) the actual system design,

(4) system development, and

(5) test and implementation.

The present discussion addresses the second phase of these design guidelines, the development of the functional specifications. Functional specifications are determined by first identifying what the system needs to do from a user's perspective, then secondly, isolating the system characteristics needed to meet those requirements. A task analysis was used to systematically isolate and define the performance requirements imposed on the system by the operator. This chapter describes two sets of procedures employed for the task analysis of LPD-17's Command Function.

The first set concerns the five design phases and their associated steps, including a review of NAVSEA's work on the $(IC)^2$ program. It then focuses on the methods used to extend NAVSEA's effort in designing the interface for $(IC)^2$. The second set discusses the task analysis procedure itself and how it was performed.

A. DESIGN PHASES

Mayhews' (1992) approach to interface design was selected because it is simple, concise, and provides clear-cut guidance. Moreover, the approach is commonly referenced in both commercial and military documents concerning human-computer interfaces. Table 1, on the following page, depicts the five phases which comprise this approach a nd their completion status with respect to accomplishment by NAVSEA, and the areas which will be addressed by this research. The shaded portions highlights the two specific areas—the *task analysis* in Phase 2, and *the mock-up and prototype* in Phase 3—presently addressed. The table shows that despite the accomplishments to date on "Scoping the System," the next phase, "Developing Functional Specifications," must be addressed. The main step in that work is to conduct a task analysis.

B. TASK ANALYSIS

The task analysis' approach adopted identifies the systems' functional requirements by observing and interviewing its intended end-users. In short, it solicits inputs from subject matter experts to specify product requirements. This approach studies the user's actions, work-flow patterns and demands, and evaluates human information processing limitations, user capabilities, and task characteristics. The results become the basis for the conceptual design of a high-level mock-up which, in turn, is iteratively critiqued by the intended-user. The task analysis therefore, is a critical step in the design process. If it is incorrectly done, the resultant system may not meet user expectations and operator performance could suffer.

Phase	Phase Name and Required Actions	Action Item Status	
		Status[a]	Remarks
I	**SCOPE** Define the purpose of the system. Conduct user profiles.	[N] [N]	The scope of the system has been defined by the military requirements. The user profiles are highlighted by specific job requirements—in this case it is that of an officer who would command a ship of the class LPD-17.
II	**FUNCTIONAL SPECIFICATION** Conduct a *task analysis.* Discuss training and documentation.	[T] [ ]	This is where interviews of subject matter experts begin. The intended end-user determines the demanded system functionality. System designers ***then*** determine the associated system characteristics to meet these demands.
III	**DESIGN** Construct an interface *mock-up.*[b] Establish a style guide. Prototype a *user-interface.* Establish a prototype test plan. Test the user interface.	[T] [ ] [T] [ ] [ ]	Actual design begins with a high-level conceptual design called a mock-up. This is based on data gathered during the task analysis. The mock-up is the basis for the prototype. The prototype is a representation of the system's core functionality. The mock-up, and later the prototype, are iteratively critiqued by subject matter experts and intended-users. **FOLLOW-ON RESEARCH TO BE CONDUCTED BY NAVSEA & CONTRACTORS**
IV	**DEVELOP** Establish training and documentation. Develop a user-interface test plan.	[ ] [ ]	**FOLLOW-ON RESEARCH TO BE CONDUCTED BY NAVSEA & CONTRACTORS**
V	**TEST & IMPLEMENTATION** Test the user interface. Evaluate the user interface.	[ ] [ ]	**FOLLOW-ON RESEARCH TO BE CONDUCTED BY NAVSEA & CONTRACTORS**

a. [N] denotes items completed by NAVSEA.
[T] denotes areas addressed by this thesis.
[ ] denotes items that remain to be completed.

b. A mock-up is made from paper-and-pencil. It is a disposable tool which forms the basis for the prototype display.

Table 1: The Phases and Status of Interface Design for LPD-17's Command Function

The field situations in which command and control systems operate are extremely complex, change very rapidly, involve diverse operator job requirements, and are typically characterized by extraordinarily high-levels of information exchange. Users' information requirements often tend to be stated in ambiguous, imprecise, and in a context-dependent manner. These user information requirements were systematically identified by interviewing a sample of officers who have had command-at-sea experience. Contents from the interviews were then subjected to a content analysis which produce a set of discrete information requirements. The following introduces the sampling method used and the task analysis' tools employed to express the required functional specifications. These specifications were then used to develop the prototype displays for the Command Function. The task analysis is described first, followed by a review of the method used to produce the mock-up and prototype displays.

1. Sample of Subject Matter Experts

Structured interviews were conducted with fifteen senior officers—members of the Surface Warfare Officers College Command, the Senior Officer Ship Material Readiness Course, and the Naval War College—who had command-at-sea experience on a broad range of different ships. The communities that were represented included, CRUDES, Amphib, Minesweeps, Combat Logistic Force, and Carriers. [9] These field grade officers, Commanders and Captains, were chosen because they were subject matter experts with a record of consistent proven performance at sea, and were recognized as leaders in the surface community. The interviews were designed to tap what they considered to be the critical information requirements needed to meet command and control requirements for their respective ships. The interviews with senior officers were followed by interviews with 23 junior officers, Lieutenants, who had experienced duty at sea and who were prospective users of the Command

[9] Surface ships are divided into groups, CRUisers and DEStroyers are called CRUDES, amphibious capable ships are called Amphibs; Combat Logistic Force ships are used for supply.

Function. The goal of these interviews was to determine what users thought was required from a system designed to fully support shipboard command and control.

Extensive written comments were recorded during all interviews, and later evaluated to discern patterns of responses which highlighted what these officers thought they needed to effectively execute command and control at sea. Moreover, the comments were examined to reveal desired design features absent from existing systems. The information needed to exercise command and control and the desired new design features were incorporated into the mock-up and prototype displays.

2. Task Analysis' Tools

An analytic method called Quality Function Deployment (QFD) was used for the task analysis. QFD is a methodology aimed at satisfying the consumer by *translating their demands into design goals.* It is based upon a simple premise: by building a system around the desires of intended-users, operator performance improves. QFD, a design method is commonly used throughout industry, is briefly reviewed below before its application to the present research is described.

a. Introduction to QFD

QFD is a way to establish quality in a product's design, manufacturing, and service; quality becomes a focal point in the initial stages of design and remains an important design goal throughout the products life-cycle. This approach bases product design *on the demands of the user.* It is a methodical plan for producing quality by reviewing the product at each stage of its design and development. The QFD method of design was adopted for two reasons: it uses interviews and anecdotal narrative data which are relatively easy to collect; and it produces detailed documentation as the method is applied. This documentation ensures that user-provided data is readily available for the primary design phase *and* subsequent design changes. The system's final design becomes directly linked to documented user requirements.

b. QFd Tools Used In The Task Analysis

Eight tools were used in the task analysis: the first four to determine user demands, and the second four to determine the concomitant system requirements. Table 2, on the following page reviews the eight tools. This table lists the goals, procedures, and the results of the application of each QFD tool. Operator demands were first identified using the following steps:

- Intended users were interviewed to determine their demands.
- User comments were translated into engineering design language.
- The data was organized into logical categories.
- Specific characteristics needed to achieve the specific user-demands were identified.

After this data was collected and organized, a conceptual model—the first mock-up interface—was made for review.

The following section discusses the manner in which these design characteristics were incorporated first into the mock-up, and then into the prototype.

Area	Tool Name	Goal	Procedure	Results
FUNCTIONALITY	CUSTOMER DEMAND LIST	Determine what the users' want	• Interview the intended user • Document the users' demands—in their own words • List the demand • Verify the list of requirements with the intended user	• A list of demands that are recorded in the users' own words
	AFFINITY DIAGRAM	Organize the data collected during interviews.	• List the each demand on an index card • Separate the card based on logical grouping	• A grouping of the demands into logical categories
	TREE DIAGRAM	Determine *how* the demands will be accomplished—what subordinate tasks are required	• Identify one statement that clearly and simply states the core issue • Generate all possible tasks required to support this statement • Evaluate these ideas, determine if they are within the project scope • Place these tasks in a tree structure, the root being the initial statement	• Three levels of demands are produced The lowest level, the third level, determine the required system characteristics, and the identification of missing items
	DEMANDED QUALITY CHART	List all demands and supporting task as determined by the user	• List highest-level demand, to the right list the associated lower level demands • Continue until all have been listed	• An organized chart with the demands of the user, beginning at the highest level, and ending with a level of detail that can be used to determine required characteristics.
CHARACTERISTICS	QUALITY EXTRACTION TABLE	Translate demands into required high-level characteristics	• List the lowest level (third level) demands • Determine the required characteristics to meet these demands	• Translation of demands into high level characteristics
	AFFINITY DIAGRAM	Organize the data	• List the each demand on an index card • Separate the card based on logical grouping	• Grouping of characteristics
	TREE DIAGRAM	Find supporting tasks	• Identify one statement that clearly and simply states the core issue • Generate all possible tasks required to support this statement • Evaluate these ideas, determine if they are within the project scope • Place these tasks in a tree structure, the root being the initial statement	• High and low level characteristics
	QUALITY CHARACTERISTICS CHART	List the required characteristics	• List highest level characteristic to the right list the associated lower level characteristic • Continue until all characteristics have been listed	• Organized chart of required characteristics to meet the user demands

Table 2: The Tools of QFD: Goals, Procedures, and Results

C. MOCK-UP AND PROTOTYPE

User requirements identified by the task analysis were incorporated in the mock-up and prototype. Data from the task analysis and preliminary design decisions already made by NAVSEA were merged and depicted in a paper-and-pencil mock-up, which was the point of departure for an iterative series of design sessions. This process ultimately optimize user-acceptance by incorporating user-defined functional requirements. Given the absence of specific design guidelines for the initial interface design, the process used to translate user-requirements into the mock-up was intuitive. It was based on familiarity with the subject matter, familiarity with the criterion environment, and a review of pertinent human factors and computer literature.

1. Design Tools

The prototype displays were developed with Asymetrix™ object-oriented application Multimedia Toolbook™. The design was conducted using an Intel 486 processor, Window NT™ operating system, and a 21" NEC™ MultiSync 6FGp high-resolution color monitor. The prototype screens were printed on a Shinko CHC-S446i printer.

D. SUMMARY

Mayhews' (1992) approach to system design was adopted to develop the Command Function. Quality Function Deployment (QFD), a variant of task analysis methodology, was used to identify user's functional requirements and by extension, the associated system characteristics. Officers with command-at-sea experience were interviewed and their desires and opinions concerning command and control display requirements were solicited. These narratives were analyzed to extract common themes which formed the basis for a mock-up of the Command Function. The next chapter describes the results of applying this methodology.

III. RESULTS

The application of the user-centered design method previously discussed yielded products: a set of user-defined system requirements and system characteristics, and the interface display characteristics derived from those requirements. The first part of the present chapter discusses the results obtained from the task analysis. It presents the functional specifications essential for the Command Function; that is, the desired functionality of the system as stipulated by a representative sample of users, and the system characteristics. The second part reviews the actual interface; that is, prototype display screens. Two screens are provided to exemplify how the user-defined requirements were incorporated in the design of this interface. The remaining screens can be reviewed in Appendix B. The chapter concludes with a summary of these results.

A. TASK ANALYSIS

The results of the task analysis are displayed in Tables 3 and 4. These tables depict summary data collected from interviews, and subsequently translated into specific engineering system characteristics. These data collectively comprise the basis for the Command Function design characteristics.

Table 3, on the next page, lists the task requirements and resulting design characteristics the system must meet from an operator's perspective while performing the job: that is, in exercising command and control. Table 4, on page 29, lists the design requirements and associated system characteristics of the equipment designed to support command and control. Both tables reflect the data collected from the previous steps used in the task analysis.

Job Function	Supporting Task	System Characteristics
PROVIDE C^2 TOOLS	Display current tools available	• Display all data from status boards • Display data in real-time • Integrate data from phone-talkers • Show equipment status, call signs, and battle group responsibilities
	Use video	• Allow selection of any video camera
	Track organic units	• Track own ships units display - bearing / range, loadout - limiting factors, destination
	Display surveillance picture	• Integrate radar displays
	Show restrictive events	• Model current situation's events • Display limiting events - show percent of completion • Prevent errors during these events
	Compare data	• Provide list of available options • Provide traditional checklists
ASSIST USER IN PROCESSING DATA	Avoid task overload	• Recognize memory capacity • Provide all required data • Use recognition instead of recall • Use pictures / graphics instead of text
	Assure fidelity	• Display data as it is expected • Display data realistically
	Ensure interpretability	• Use pictures and graphics • Ensure logical representation • Use familiar icons and layouts
	Rank information	• Prioritize alarms • Update displays based on importance
ASSIST USER IN MONITORING AND CONTROLLING EQUIPMENT	Show equipment status	• Display on / off / stand-by status • Use color to amplify status • Use pictures of equipment • Display equipment in expected locations • Display information as it is organized in text
	Allow trend analysis	• Provide access to databases • Correlate trends • Use graphs to display information
	Show configuration changes	• Display what changed and when • Tell the user why something changed • Allow the user to select time limits of query
	Allow varied selection of equipment	• Allow queries of equipment by - department, division, system, and status

Table 3: Job-related Requirements and Associated System Characteristics of the Command Function

Design Function	Supporting Task	System Characteristics
ENSURE RELIABILITY	Use both routine everyday events	• Use inport and at sea • Use to conduct everyday routine events and real-time operations • Use to train personnel
	Use for emergent and special events	• Use for emergencies • Prioritize information
	Provide all the required tools in one place	• Display schedules • Display training requirements and status • Integrate video • Access personnel records and reference publications
	Optimize system performance	• Minimize system crashes • Prevent errors • Respond in adequate time
ENSURE EASE-OF-USE	Make system rapidly configurable	• Allow user to select desired display information
	Access the information as it is expected	• Display elements logically • Use pictures and graphics instead of text • Do not require extensive learning • Use traditional / expected colors • Use traditional / expected layouts
	Prevent the user from getting lost	• Make the display intuitive • Ensure navigation pathways are logical
SUSTAIN COMMAND RELATIONSHIPS	Tailor the system like relationships on board	• Pass orders down only one level • Pass information up only one level • Screen certain data before entry on the network
	Limit access based on rank or position	• Limit access to data based on position • Require users to log in • Provide information security
USE IN PLANNING	Use for C^2 planning	• Display outcomes from potential changes

Table 4: Design-related Requirements and Associated System Characteristics of the Command Function

B. MOCK-UP AND PROTOTYPE

The mock-up and prototype were produced using the system requirements defined in the task analysis. These requirements were displayed in Tables 3 and 4. Recall that a paper-and-pencil design, a mock-up, was the basis for the prototype. The discussion now focuses specifically on the prototype itself. The prototype which evolved as a result of evaluating the mock-up.

The prototype for the Command Function interface was designed in two parts, the background, and the specific screens. When observed by the user, the screen and the background appear as a single entity. Figure 2, below, shows the layering effect from an operators point-of-view. By designing the interface in two parts, screens with specific information can be layered on top of permanent data elements.

The purpose and associated elements of both the background and specific screens are listed on page 32. First however, NAVSEA's design specifications for the Command Function are reviewed.

1. Operator Interface Design Specifications

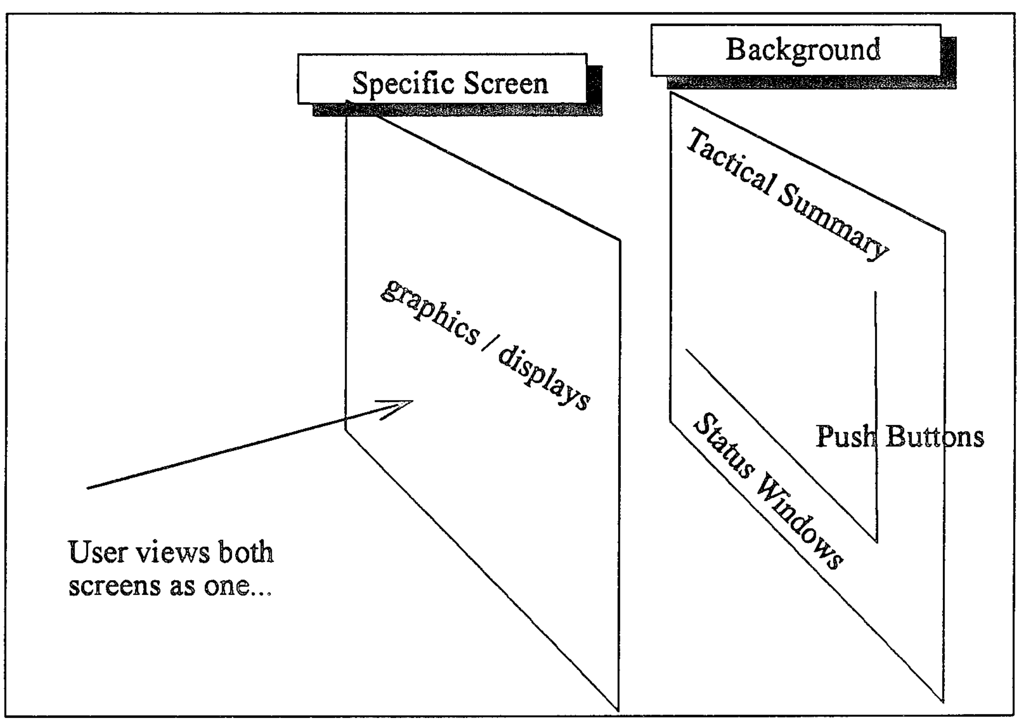

Figure 2: Command Function Interface Design

The basic operator interface design features of the Command Function have been stipulated by NAVSEA (1994). These features include the use of a 21 inch or 25 inch high-resolution color graphics monitor with a touchscreen—in place of a traditional keyboard—for operator interaction. These two features, along with the user-defined functional requirements, are the basis for the prototype.

2. Backgrounds

The background was designed to display data required by all subsequent screens. These data elements provide amplifying information to assist the user in evaluating their environment. The background is divided into three parts to provide distinct separation of information elements. This separation divides information logically—as the user expects it—and reduces the possibility of operator sensory overload. The three groups are:

- tactical summary,
- status windows, and
- push buttons.

The specific location of these elements on the background can be reviewed on Figure 2, on the previous page. Although it is desirable to allow the user to configure the display as they see fit, these locations serve as the default. The main reason these groupings and locations were selected is that configuration reflects *how* and *where* the user traditionally *expects* to find this information. Table 5, on page 32, lists the three parts of the background and describes their purpose and specific components.

There are two backgrounds used for the Command Function, one used with the departmental screens, and the other with the special evolution screens. The only difference between the two is the choice of push buttons: the main background allows navigations to the individual departments, the special evolution background allows navigations to special evolution screens. Table 6, on the next page, lists the navigation options of each background

Item	Purpose	Components
TACTICAL SUMMARY	Inform user of tactical situation	• Condition of readiness • Material condition • EMCON posture and amplification • HERO posture and amplification • Warning / Weapon status - AAW - ASUW - ASW • Flight deck status. • Well deck status • Ballast / de-ballast status and level at sill • Time: - local - zulu
STATUS WINDOWS	Inform user of ships parameters	• Ships course and speed • Rudder angle indicator • Latitude and Longitude read-out • Selectable display: - PIM information - Wind display, or - Weather display • Equipment on-line display: - Engineering equipment, or - Combat System Equipment. • Restricted Maneuvering Label
PUSH BUTTONS	Navigate to other screens	• Equipment • Personnel • New Messages • Video • Forward • Backward • Administration • Aviation • Combat Systems • Deck • Embarked Forces • Engineering • Navigation • Operations • Supply • Special Evolutions

Table 5: Parts of the Background

From this background...	The user can navigate to...
Main Default	Any department screen Special Evolutions Screen (and background)
Special Evolution	Any special evolution screen Main Default Screen (and background)

Table 6: Navigating through the Command Function Screens

3. Screen

The individual screens display specific information as the user navigates through each screen. This specific information is layered on top of the main or special evolution background. The screens themselves are divided into two groups: ship departments and special evolutions.

The purpose of, and the display elements of the department screens are listed below, and on page 34. Due to the extraordinary amount of data present, the table has been divided into two parts, Table 7a and Table 7b. The purpose and display elements of the special evolution screens are listed in Table 8, on page 35.

Screen Name	Screen Purpose	DIsplay Elements On Screen
ADMIN	Provide typical administrative data.	• Gateway to SNAP III • Provide at a minimum access - personnel and training records - past evaluations - instructions, references and reports - ticklers and the plan-of-the-day
AIR	Provide data about embarked air element	• Tactical display[a] - default range set at 40 NM • Aircraft summary display - A/C# / Brg / Rng / Fuel / Serial # or load / destination • Aircraft flight plan - integration of Air Tasking Order (ATO) • Weather information (ceiling, visibility, density / pressure altitude, wind, dew point) • Flight deck status • Video selection - flight deck or well deck • Ships tactical communication plan • Push button to show boat schedule
CS	Allow for monitoring and controlling of Combat System equipment	• Graphic display of equipment: - on-line, in stand-by, out of commission (OOC) • Text field with above information. • Ammunition status - type and location, allowances: on board & training. • Video selection * Status window of background will automatically show the Engineering equipment display
DECK	Provide status of deck related equipment	• Tactical display - default range set at 15 NM - emphasis on own ships' boats • Graphic display of stern gate and well deck status - well deck depth / percent ballast • Field with Sea state information, hangar door status, life boat status, and anchor status • Video selection - well deck and vehicle stowage.

Table 7a: Department Screens and Associated Display Elements

a. The tactical display is the integration of the ships position, a digital navigation chart, and the radar surveillance picture. Range and chart will be selectable, ships positioning on the display will be moveable.

Screen Name	Screen Purpose	Display Elements On Screen
EMB FORCES	Provide embarked Marine commanders information required for command and control of their troops	◦ Tactical Maps - integrated with tactical display - allow overlays on land areas - use for planning ◦ Landing Serial Table - wave number / serial / craft / unit / beach / load - allow for amplification on demand ◦ Graphic of percent of MOGAS on board ◦ Communication Field - circuit status and location ◦ Go / No Go button to direct troop movement ◦ Push button to display LFORM - landing force operational reserve material - ordnance / equipment / rations / fuel ◦ Summary field - personnel on board, sea state, equipment
ENG	Allow for monitoring and controlling of Engineering equipment	◦ Graphic display of ship with equipment status: - equipment on-line, stand-by, OOC ◦ Field with equipment information in text ◦ Fuel / water / aviation fuel graphs ◦ Push button to navigate to Damage control. * Status window of background will automatically show the Combat Systems equipment display
NAV	Provide information normally collected at the navigation table	◦ Tactical display - default range set at 10 NM - provide specific navigation details on chart ◦ Call sign field ◦ Field with fix information * Status window of background will automatically show the Engineering equipment display
OPS	Provide tactical information	◦ Tactical display - default range set at 50 NM ◦ Call sign field. ◦ Push button to display battle group information: - responsibilities - ships in company ◦ Push button for message retrieval - allow query to database for received msg - access files of stored msgs - review new msgs ◦ Push button to display schedules - integrate plan-of-the-day and schedule-of-events. ◦ Push button to access communication information
SUPPLY	Provide status of Supply Department	◦ Hotel service status ◦ Budgets ◦ Supplies on board ◦ Parts status

Table 7b: Department Screens And Associated Display Elements (continued)

Screen Name	Screen Purpose	Display Elements On Screen
A/C LAUNCH	Provide all required information for the launch and recovery of aircraft	• Tactical display - default range set at 15 NM • Graphic display of flight deck, required winds for specific deck spots • Field with launch / recovery cycles • Pitch and roll indicators • Video of flight deck * Status window of background will automatically show the Combat Systems equipment display.
ANCHORING	To anchor	• See Sperry interface already designed
BOAT OPS	Provide all required information for the launch and recovery of boats	• Tactical Display - default range set at 15 NM • Sea State indicator • Field with launch / recovery cycles • Wind display • Field with stern gate status • Video selection
FIRE / FLOOD	Damage Control	• See CAE Link Damage Control Interface
MAN OVER BOARD	Provide quick and easy entry of position of man overboard, and to provide all required information for recovery	• Tactical display - default range set at 2NM - ship will be positioned in middle of screen • Push button for entry of position - green button for stbd - red button for port • Field displaying checklist for M.O.B. • Field with information about OSCAR - brg & rng - time in water - water temp and stay time • Field with course to steer to pick up man • Field displaying ships' boat status * Status window of background will automatically show the Engineering equipment display. * Status window of background will automatically show the Wind display.
REPORTS	Display reports which have been labor-intensive	• 8 o'clock report information • 12 o'clock report information
SEA DETAIL	Provide all require information for safe navigation while at sea detail.	• Navigation Display - like tactical display but ships heading defaults to true north • Field with navigation courses / speed distance remaining • Field with communication circuits • Field with anchor status
UNREP	Provide information required for planning and conducting an underway replenishment	• Tactical display - to include own ships position, and unrep location • Field with unrep ship data: CO / rig placement etc. • Field displaying material for unrep / conrep • Status bar and time-to-go displays
SHIP DEFENSE	To quickly and effortlessly transition the ship into the most defensive posture available	• Tactical display - default range set at 10NM - ships position in middle of screen • Push button activation of ships defensive systems - SLQ-32 / CIWS / RAM • Push button to set General Quarters • Graphic summary of ships defensive systems • Field with equipment on-line * Status window of background will automatically show Combat Systems equipment display * Status window of background will automatically show graphic of wind display

Table 8: Special Evolution Screens And Associated Display Elements

4. Example Display Screens

Two screens of the Command Function, Figures 3 and 4, are included to provide the user with examples of how user-demands have been integrated with human factors to display *what* is desired—by the intended-user—in a logical and clear manner. The remaining screens are provided in Appendix B, on page 59.

The first screen, Figure 3 on the next page, is the Main Default Screen. This screen will be used during normal operations. The screen is designed to provide the user with the elements normally required to exercise "routine" command and control. These elements are:

- a tactical display combining a digital chart, ships position, and radar surveillance
- selection of ship specific check-lists' to guide the user through routine operations
- a field displaying contact information. This pop-up field will correlate the text from the summary field with the actual contact location shown on the tactical display.

The central focus of this Main Default Screen is on safety-of-transit, navigation and planning. Operations which require more in-depth information and/or guidance can be accessed at the touch of a push button.

The second screen used for an example, Figure 4 on page 39, is the special evolution screen Sea Detail. This screen would be selected by the operator when the ship is conducting or planning precise navigation. The information elements of this screen include:

- a tactical display with additional in-depth detail normally found on navigation charts
- a pictorial display of the anchor status; the ready status of each anchor
- a field displaying the course-to-steer, required speed, distance remaining in this navigation leg, and time-to-turn to the next course. Additional course information—the future courses and speeds—is also available at the touch of a button
- communications information, including circuits that are on-line

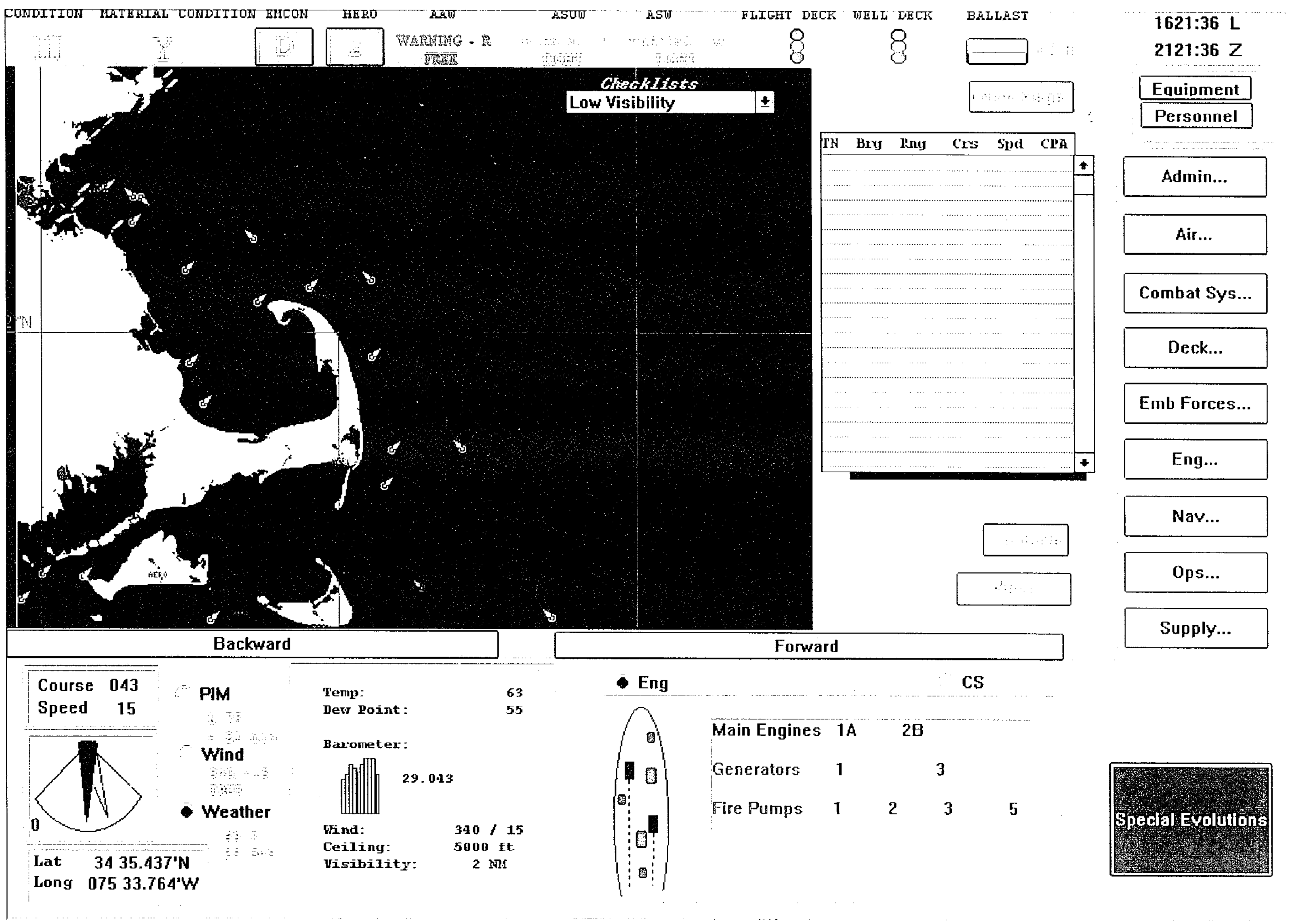

Figure 3: Main Default Screen

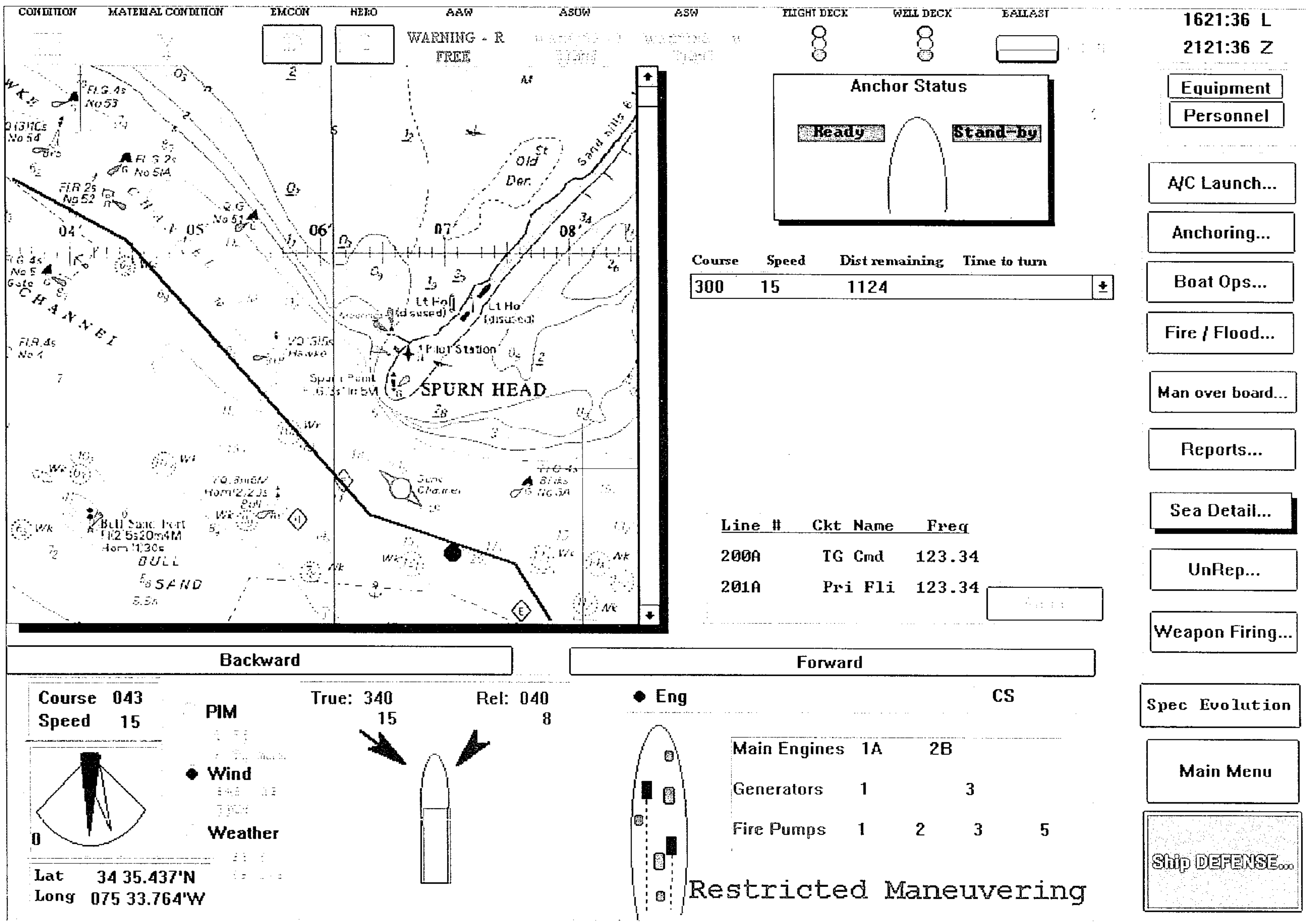

Figure 4: Sea Detail Screen

C. SUMMARY

The results are a set of design recommendations and the associated prototype for the command and control interface—the Command Function—on LPD-17. User demands have been evaluated and basic functional requirements associated with a surface ship command and control systems have been determined. Using these basic functional requirements, system characteristics of the Command Function were determined. These characteristics were tailored to meet the user-defined requirements, and were the basis for the mock-up and prototype displays.

IV. DISCUSSION

The prototype display screens for LPD-17's Command Function, produced by the method adopted in this study, were presented and briefly discussed in the previous chapter. These displays are the tangible products of this design effort; but as noted here the selection and use of the design method itself departed from conventional practice. This chapter addresses the salient aspects of the design method adopted herein and uses the prototype display screens as a basis from which to discuss its general concepts and principles. The first section places the prototype screens in context; that is, they really reflect only a first generation design effort. The second section contrasts the current method with others commonly used today.

A. PROTOTYPE DISPLAY SCREENS

The two screens presented in the previous chapter reflect a careful accounting of user-demands and an incorporation of accepted design principles. These screens, however, are first generation displays and their design will require additional iterations during the remaining design phase itself, and later, during developmental and operational test and evaluation of the integrated system. The displays were designed based on inputs of the intended-users and shaped by technical literature from the fields of computer science and human factors. Again, these products reflect activity at the very beginning of the design phase. By presenting this first generation prototype to the intended-operator at this early design stage, the interface will be subjected to modifications based both on user-requirements and relevant technical literature. Accordingly, time is not wasted at a later and more costly, stage of development. This rudimentary interface is simply a point-of-departure for subsequent design enhancements.

The screens themselves reflect straight-forward design objectives. The arrangements of informational elements were designed to enable operators to access the information they need to efficiently and effectively exercise command and control on LPD-17. This stage of design took an iterative approach. *Operational experts repeatedly evaluated the design to ensure the interfaces provided what they wanted, and displayed this information in a manner they clearly understood.*

B. DESIGN METHOD

The interface between the operator and shipboard command and control systems is frequently cited as the weak link in the overall design of the integrated systems. To date, no particular school of design guidance has been accepted in either the rapidly advancing commercial sector, or the slow and methodical acquisition procedures of the Department of Defense. Computer system interfaces need to be designed around user-requirements to ensure acceptance, they must be "usable."

Selecting an interface design method must ultimately produce a "usable" system. User-centered methods provide the required iteratations during design and development to collect, represent, and analyze data obtained from the intended users. This process increases the likelihood that the resulting interface will display what the intended user actually wants, and consequently operator performance should improve as users come to rely on the system.

The design methods employed to produce today's computer interfaces for the surface Navy often do little to ensure cognitive compatibility, which is the extent that an interface accomplishes a task in the manner the user expects to accomplish that task. The resulting interfaces are, in general, not considered "user friendly". In fact, end-users often wonder whether designers solicited opinions from fleet users during the design or if the interface was designed in a "box;" that is, in isolation. To provide a basis for comparison, the common method used today in interface design is contrasted with the method used in the present research—a method committed to user-centered design.

1. Methods Used Today

Approaches employed to design interfaces today typically do not use procedures needed by designers to ensure that the systems' broad design objectives meet a fleet operator's requirements. There is insufficient design guidance and few design tools available to interface developers for them to consistently make fleet-relevant decisions during the design process. In military procurement programs, which are typically constrained by inflexible schedules and an intolerance to cost over-runs, designers tend to make decisions from a narrow technical *engineering* perspective which may not reflect a boarder operational *fleet* perspective. Many interfaces used in the surface Navy reflect this narrow *engineering* design perspective.

The practice of relying on a contractor—typically cost and time constrained ***and*** removed from the fleet—to determine both system functionality and subsequently system design, is common. This practice of simultaneously relying on contractors, while not ensuring they solicit *current* fleet input, has an accepted practice in the face of increasingly complex systems, and increasingly complex informational requirements, both of which in turn are imposed by increasingly complex mission requirements. It is the operator, and by extension the mission, that is adversely impacted. Fleet personnel will readily adapt to design short-falls, but often, it is at the expense of mission capabilities. Generally operators are unaware of design alternatives, they use the tools that are available "....they generally accept the result because when you give them an application, the way it looks is the way it is." (Nielsen, 1994, pp. 378) Clearly, it is incumbent on the designers to provide the fleet with carefully considered designs which are fleet validated.

a. Reliance on Contractors in Determining System Functionality

Relying on the commercial sector as the dominant source of design input is a poor way to determine system requirements. Although the commercial sector, or more specifically contractors, is often staffed with retired or ex-military personnel, these same people may not reflect today's fleet operators. More specifically, the methods currently used by contractors are often personnel dependent. Employees' memories, the breadth of their individual experiences, and the extent to which they can associate with their fleet counterparts become the foundation on which design solutions to contemporary problems are based (Nielsen, 1994). This method of design limits the range of possible solutions. Moreover, an experience dependent approach may possibly perpetuate design errors unrecognized in predecessor systems.

Given the rapidity with which technology is advancing, design ideas, and both developmental and operational test and evaluation, must be based on today's fleet. *An iterative approach must be used to solicit inputs from both master-level operators—users of predecessor systems—and journeyman-level operators—intended-users of the new system.* For the Command Function, the master is typically a Captain or Commander with command experience, and the journeyman is today's Lieutenant.

These groups have generational differences. Generational differences are perhaps best exemplified by the users' "trust" in a new computer system. Differences in "trust" may simply reflect newer generations having greater access to, and consequently more use of, like systems. This variation in perspective can result in subtle differences in the system design features desired by the operator. The functional requirements of both groups must be met. Meeting those requirements entails a clear emphasis on what is euphemistically called "user-centered" design.

2. User-Centered Design

The design process reflected in this research is a method based on user-centered design. It is not essential that one particular method is chosen over another, as long the method that is chosen focuses on the user and accommodates their preferences and requirements. In this regard, the present effort used Mayhew's (1992) guidance, and by following its prescribed steps used the associated guidelines for an iterative approach to design.

The focal point of user-centered design is obviously the user. For this approach to be successful, designers must understand the user. If they understand both demographic characteristics and fundamental job requirements, they then are positioned to actively solicit meaningful input for design. Fleet input, including initial ideas and subsequent evaluation, becomes the predominant criterion on which design decisions are based. User-determined requirements are solicited from both subject matter experts and the intended-operators. These anecdotal accounts of operators' desires are then balanced with basic design principles. Transforming the users' desires into system characteristics, and balancing these ideas with established design principles ensures usability. Models are used to represent system functionality and are iteratively evaluated by the user to assure fleet relevance. Two procedural elements of design, the sample of users which affect the design process, and the set of design principles used to produce the initial prototype are critical to the overall process.

a. Sample of Users

An important design element is gathering and interpreting fleet input. In the present case, inputs from subject matter experts located at the Naval Education and Training Center at Newport, Rhode Island were solicited. The Command Function itself is a tool used to support the command and control process. Naval organizations in Newport presented a broad range of diverse experience on command and control. As previously reported, extensive interviews were conducted with members of the Surface Warfare Officers College Command Staff, the Senior Officer Ship Material Readiness Course, and the Naval War College. Junior Officers, the eventual intended-users of the Command Function, were found throughout the waterfront and on afloat units. Another excellent and concentrated source of junior officers was found at the Naval Postgraduate School (NPS) in Monterey. This School provided readily accessible volunteers with diverse backgrounds. Subject matter experts from these sources provided inputs to the design which reflect not only diverse technical backgrounds, but inter-generational aspects as well.

b. Basic Design Principles

The basic principles used for the design of the Command Function interface are listed in Table 9, on page 50. These principles are a summary of ideas collected from the technical engineering literature encompassing interface design and from the common desires of fleet personnel.

c. Future Research

LPD-17's Command Function interface is by no means complete. The prototype displays produced by this research are an initial step in the design phase. Further design is needed before the development phase begins and NPS can provide this work. NPS can provide subject matter experts with recent fleet experience and the technical design expertise needed to integrate this fleet experience with engineering principles to achieve the desired user-centered results. Student officers at NPS have a selfish interest to ensure that quality products are provided to the fleet, as they will soon return to sea. The six recommendations which follow provide additional avenues for further research at NPS.

- **Examine the information elements displayed on each screen.** Continue to solicit fleet input to determine missing elements and to critique current displays. Verify that the colors, shapes, and layouts used to simulate the traditional environment are accurate. Modify and update the displays during this iterative process.

- **Evaluated the prototype display in a realistic shipboard environment.** Allow intended-users to "play" with the prototype display in a shipboard environment. Real-time data is not required, operators will be evaluating the display screens.

- **Conduct additional analysis of the data collected during the functional specifications.** Review the data collected and weigh the user-determined functionality against the system characteristics. Use a method like QFD to determine the importance of each user-demand. Compare the results of the analysis with the prototype displays.

- **Review the system display characteristics to determine which items a user might need to tailor.** Review the situations this interface will be used in, and identify the particular elements an operator might need to change.

- **Conduct Laboratory Experiments**. Determine optimum displays to provide rapid recognition and maximum information transfer. Review how the use of color, shapes and information layout affects the users' perception of the displayed information.

- **Determine required element refresh rate**. Determine the minimum graphic refresh rate for each specific display element.

Principle	Meaning	Way to accomplish
ENSURE DESIGN IS USER-CENTERED	"Make the job easier and better for the user, as determined by the user."	∘ Know the user ∘ Involve subject matter experts, intended-users, and human factors experts during design ∘ Define requirements in the fleet ∘ Provide a system model for critique
RECOGNIZE HUMAN INFORMATION PROCESSING CAPABILITIES	"Display information not data."	∘ Do not overload the user ∘ Use cognitive directness ∘ Draw on real world analogies ∘ Organize displays to manage complexity ∘ Use pictures instead of text ∘ Display information the way the user expects it.
MATCH THE SYSTEM WITH REAL-WORLD	"Speak the users' language."	∘ Access information logically ∘ Do not require the user to learn new methods / tools
PROVIDE CONSISTENCY AND ADHERE TO STANDARDS	"Follow expected conventions and accepted standards."	∘ Be consistent ∘ Keep displays simple ∘ Use traditional colors / icons / shapes / coding ∘ Show the user what they expect
USE RECOGNITION INSTEAD OF RECALL	"Make information visible or easily retrievable."	∘ Do not require the user to remember information displayed elsewhere ∘ Provide all the tools required to perform a task
PROVIDE AESTHETIC AND MINIMALIST DESIGN	"Do not provide irrelevant information."	∘ Contain only the information that is needed for that task.
ENSURE VISIBILITY OF SYSTEM STATUS	"Keep user informed of what is going on."	∘ Provide feed back to the user

Table 9: Usability Principles for Design

C. CHAPTER SUMMARY

A system design which focuses on the demands and desires of the intended-user is more likely to succeed than one which bases design decisions on limited technical and engineering inputs. By isolating and accommodating the user's desires the interface will ultimately reflect what users want; therefore the likelihood that the interface will be both usable and relied on will increase. User-interfaces employed on board surface ships must reflect the desires and demands of the fleet. User input during the initial design and subsequent development is the key to both fleet acceptance and the production of a quality interface.

V. SUMMARY AND CONCLUSION

The environment in which command and control decisions are made on board Navy ships is extremely complex. The advent of automated computer processing has increased the amount of data available to the operator; but this increase in volume has not reduced the associated workload on the operator. Changing mission requirements and technological advances have imposed additional responsibilities on the commander. Computer systems can be used to effectively harness the voluminous amounts of data and assist the operator in exercising command and control. The keystone to ship board command and control systems is the interface—the electronically mediated workspace used by the operator to access the underlying data.

To effectively design and build a user interface designers must understand both the required elements of ship board command and control, and also the way these elements are used during the command and control process. Following systematic design procedures, these mission essential elements are captured and translated into system characteristics. This research followed a set of systematic design procedures and produced a prototype interface for command and control on board LPD-17. This prototype is the beginning of the design phase. It is a design based on two simple straight-forward considerations: provide what the user wants, and tailor those wants with acceptable design principles.

APPENDIX A. THE VINCENNES INCIDENT

The following condensed details of the downing of Iran Air flight 655 by USS VINCENNES are taken directly from the official investigation. (Fogarty, 1988.):

Summary:

On 3 July 1988, the USS VINCENNES (CG 49), operating in the Southern Persian Gulf as a unit assigned to Commander, Joint Task Force Middle East, downed a civilian airliner, Iran Air flight 655 on a routine scheduled flight from Bandar Abbas to Dubai, with two SM-2 missiles [10].

Background scenario:

In the three day period prior to the incident, there was heightened air and naval activity in the Persian Gulf. Iraq conducted airstrikes against Iranian oil facilities and shipping 30 June through 2 July 1988. Iranian response was to step up ship attacks. Additionally, Iran deployed F-14's from Bushehr to Bandar Abbas. U.S. Forces in the Persian Gulf were alerted to the probability of significant Iranian military activity resulting from Iranian retaliation for recent Iraqis military successes. That period covered the fourth of July weekend.

During the afternoon and evening hours of 2 July 1988 and continuing into the morning of 3 July 1988, Iranian Revolutionary Guard Corps (IRGC) armed small boats (Boghammers, and Boston Whalers) positioned themselves at the western approach to the Straits of Hormuz (SOH). From this position, they were challenging merchant vessels, which has been a precursor to merchant ship attacks. On July 2 1988, USS ELMER MONTGOMERY [11] *was located sufficiently close to a ship attack in progress as to respond to a request for distress assistance and to fire warning shots to ward off IRGC small boats attacking a merchant vessel.*

3 July Surface Engagement:

On the morning of 3 July 1988, USS ELMER MONTGOMERY was on patrol in the northern portion of the Straits of Hormuz. At approximately 0330Z, USS MONTGOMERY observed seven small

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[10] A Standard missile (SM-2) is a medium range missile designed for surface-to-air engagements.

[11] USS ELMER MONTGOMERY is an Oliver Hazard Perry Class Frigate, designed for anti-submarine and anti-air warfare.

Iranian gunboats approaching a Pakistani merchant vessel. The small boats were reported by USS MONTGOMERY to have manned machine gun mounts and rocket launchers.

Shortly thereafter, USS MONTGOMERY observed a total of 13 Iranian gun boats breaking into three groups. Each group contained 3 to 4 gun boats with one group of four boats taking position off USS MONTGOMERY's port quarter. At 0411Z, USS MONTGOMERY heard the gun boats over bridge to bridge challenging merchant ships in the area. USS MONTGOMERY then heard 5 to 7 explosions coming from the north. At 0412Z. "Golf Sierra" [12] *directed USS VINCENNES* to *proceed north to the vicinity of USS MONTGOMERY and investigate USS MONTGOMERY's report of small boats preparing to attack a merchant ship. USS VINCENNES's helo (OCEAN LORD 25 / Lamps Mk III helo) on routine morning patrol, was vectored north to observe the Iranian small boat activity. USS VINCENNES was also monitoring a routine maritime patrol of an Iranian P-3 operating to the west. At approximately 0615Z, the USS VINCENNES's helicopter was fired upon by one of the small boats. USS VINCENNES then took tactical command of USS MONTGOMERY and both ships proceeded to close the position of the helicopter and the small boats at high speed. As USS VINCENNES and USS MONTGOMERY approached the position of the small boats, two of them were observed to turn towards USS VINCENNES and USS MONTGOMERY. The closing action was interpreted as a demonstration of hostile intent. USS VINCENNES then requested and was given permission by CJTFME to engage the small boats with gunfire. At approximately 0643Z, USS VINCENNES opened fire and was actively involved in the surface engagement from the time Iran Air flight 655 took off from Bandar Abbas through the downing of Iran Air flight 655.*

During the course of the gun engagement of the Iranian small boats, the USS VINCENNES, at approximately 0654Z, had maneuvered into a position one mile west of the centerline of civilian airway Amber 59. The USS SIDES [13]*, transiting from east to west through the SOH, was approximately 18 miles to the east and became involved in the evolving tactical situation.*

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[12] Golf Sierra is the call sign of the Anti-Surface Warfare Commander.

[13] USS SIDES, another Oliver Hazard Perry Class Frigate, was also assigned to the Persian Gulf.

Bandar Abbas / Iran Air flight 655 / air engagement:

On 3 July 1988, at approximately 0647Z, an Iran Air Airbus 300, Iran Air flight 655, took off from the Bandar Abbas joint military / civilian airport destined for Dubai airport. The flight was a routine scheduled, international flight via commercial airway Amber 59. [14]

Vincennes — Critical Decision Window:

At approximately 0647Z - Iran Air flight 655 was detected by the USS VINCENNE's AN/SPY-1A radar bearing 025 degrees, 47 NM [15]*, and was assigned TN 4131* [16]*. The aircraft continued to close USS VINCENNES with a constant bearing, decreasing range. At approximately 0649Z, USS VINCENNES issued warnings on Military Air Distress (MAD) (243.00 Mhz) and at 0650Z began warnings on International Air Distress (IAD) (121.5 Mhz) to TN 4131 located 025 degrees, 40NM from USS VINCENNES.*

At approximately 0650Z - several USS VINCENNES CIC personnel heard, on internal Combat Information Center (CIC) voice circuits, a *report of F-14 activity. A momentary Mode II-1100 IFF* [17] *indication was detected which was correlated with an Iranian F-14. This was reported throughout CIC over internal CIC voice circuits. Continuous MAD and IAD warnings were ordered at 30NM (5 total warnings on MAD and 4 total warnings on IAD). USS VINCENNES continued the surface engagement and experience a foul bore in Mount 51* [18]*. In order to unmask the after gun mount, full rudder (at 30 knots) was applied. This added to the increasing tension in CIC.*

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[14] Commercial air ways are 20 miles wide, the latitude and longitude of the center of the airlane are published and readily available.

[15] A nautical mile (NM) is a unit of measurement at sea, based on the length of a minute or arc of a great circle of the earth—equal to 2000 yards.

[16] Track number (TN) is how the Navy Tactical Data System (NTDS) distinguishes between different contacts. Each contact is assigned its own track number, commonly referred to as "track four one three one".

[17] Identification Friend or Foe (IFF) is an electronic challenge and reply system that uniquely identifies aircraft. This system is required on all aircraft.

[18] Mount 51 is the forward 5 inch gunmount located on the forecastle; the after gunmount, Mount 52, is located near the stern.

At approximately 0651Z - as TN 4131 closed to 28 NM, USS VINCENNES informed CJTFME that she had a closing Iranian F-14, which she intended to engage at 20NM unless it turned away. USS VINCENNES requested concurrence. CJTFME concurred but told USS VINCENNES to warn the aircraft before firing. Warnings continued, but no response from TN 4131 was received, nor did it turn away.

At approximately 0652Z - warnings continued over both IAD and MAD. Still no response. Although TN 4131 reached the 20 NM point, the CO decided not to engage. The order was given to illuminate the contact with fire control radar. There were no ESM[19] *indications. TN 4131 was ascending through 10,000 feet.*

At approximately 0653Z, at 15-16 NM, the last warning over IAD was given by USS SIDES to the aircraft bearing 204 degrees to USS VINCENNES, range 15.5 NM. During the last 30 seconds of this minute, the CO made his decision to engage TN 4131.

At approximately 0654Z, the CO turned the firing key. Two SM-2 Blk II missiles left the rails. They intercepted Iran Air flight 655 at a range of 8 NM from USS VINCENNES at an altitude of 13,500 feet.

(Fogarty, 1988. pp. 4-6.)

[19] Electronic Surveillance Measures (ESM) is used to detect electronic emissions, it is used to assist in identification. Its function is similar to a high-tech radar detector, commonly used in cars.

APPENDIX B. SCREENS OF THE COMMAND FUNCTION

This Appendix displays the supplemental interface screens of the Command Function. The prototype displays included in this appendix are:

- Aviation Department
- Combat Systems
- Deck Department
- Embarked Forces
- Engineering Department
- Navigation
- Operations Department
- Supply Department
- Special Evolutions Default
- Aircraft Launch
- Small Boat Operations
- Man over board
- Special Report
- Underway Replenishment
- Ship Defense

Each screen is a collection of information display elements. The display elements of each screen are listed in Tables 7 and 8, on pages 33 and 35 respectively. Certain screens are not included in this section. The Main Default Screen, and the Sea Detail Screen are on page 37 and 39. Displays for anchoring, and damage control—fire and flooding—have already been designed and developed NAVSEA sponsored contractors. These displays should be iteratively reviewed to ensure they provide the basic user-defined requirements, and that they adhere to sound design principles. A weapon firing display is also not included. This interface in-and-of-itself is worthy of extensive research and should be addressed separately.

These displays are prototypes, and accordingly they represent a proposed draft of the Command Function characteristics. To ensure a successful design of the of the Command Function interface, these displays must be continually critiqued and modified *with the intended user in mind.* The prototype screens that follow are reproductions from an interface development tool, Asymetrix™ Multimedia Toolbook™; they were designed to be displayed on a 21 or 25 inch high-resolution color graphics monitor.

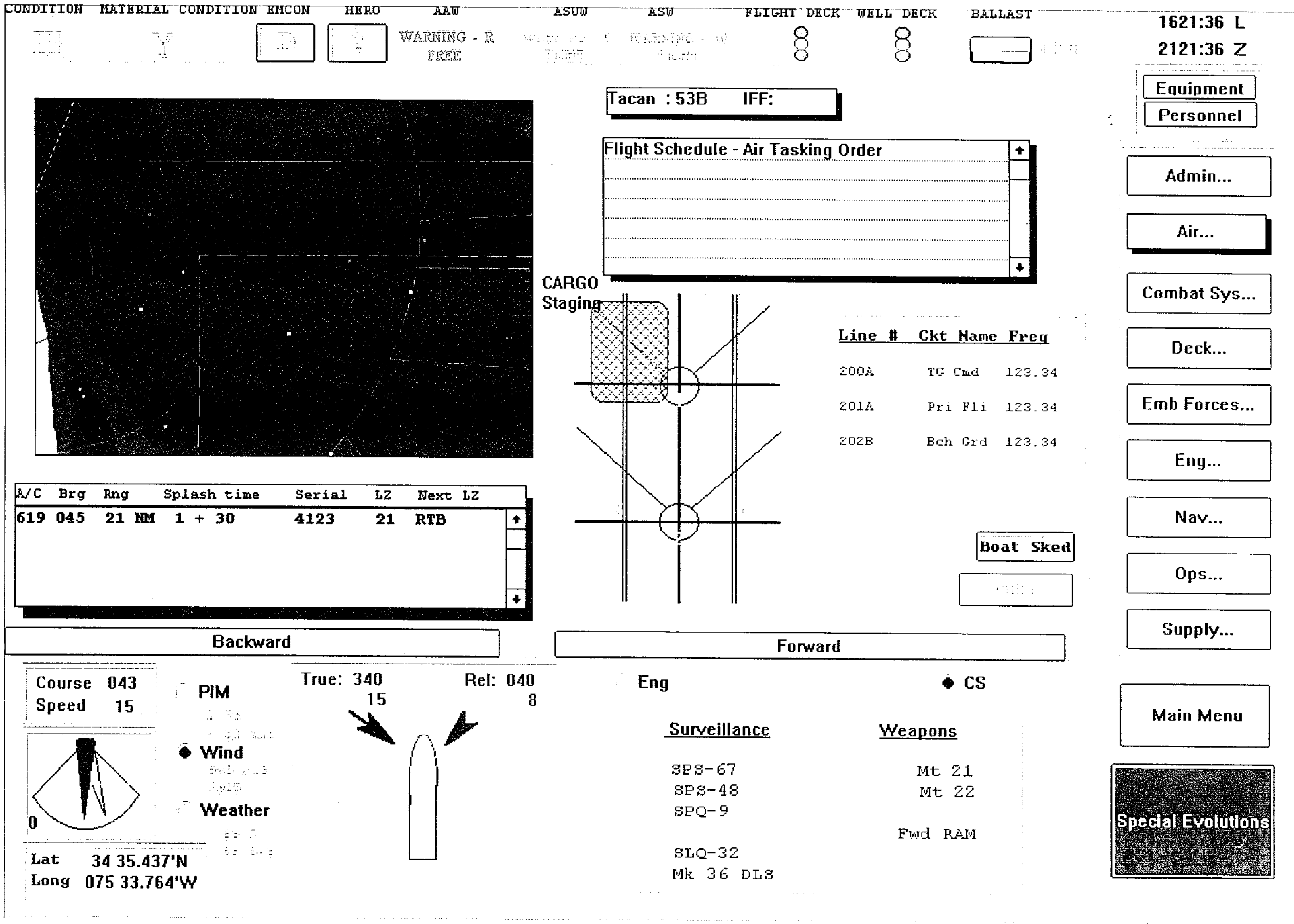

Figure 5: Aviation Department Screen

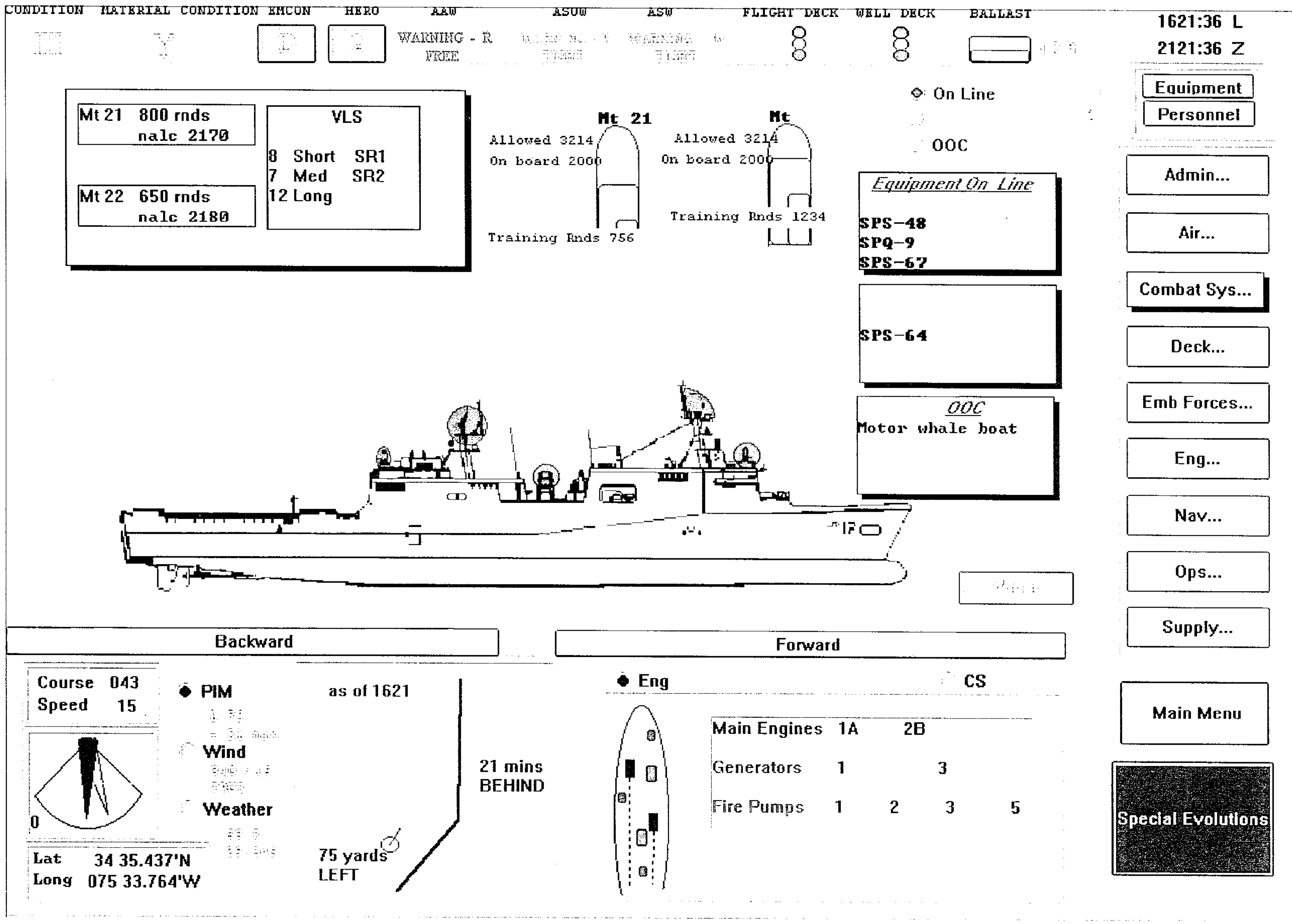

Figure 6: Combat Systems Screen

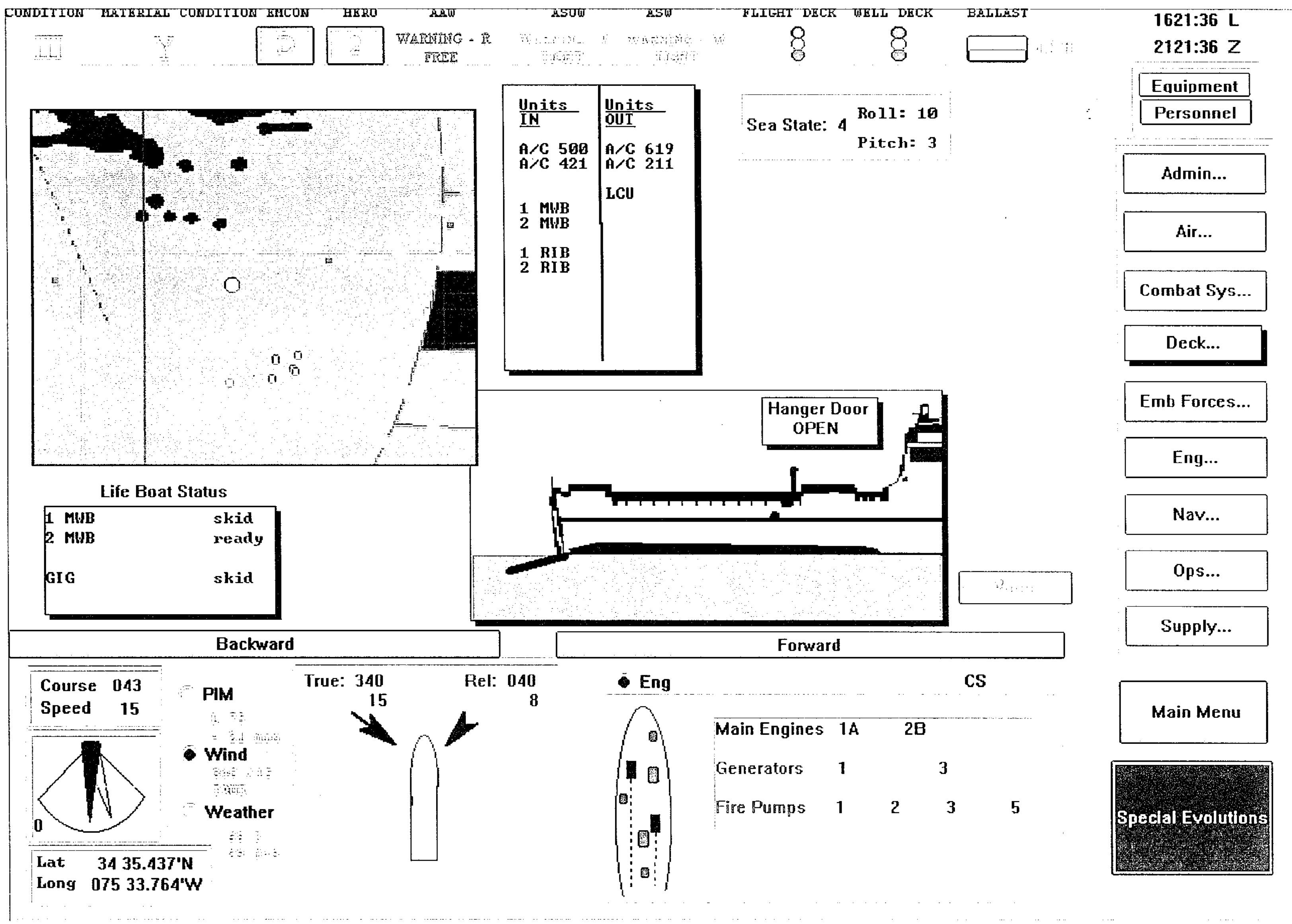

Figure 7: Deck Department Screen

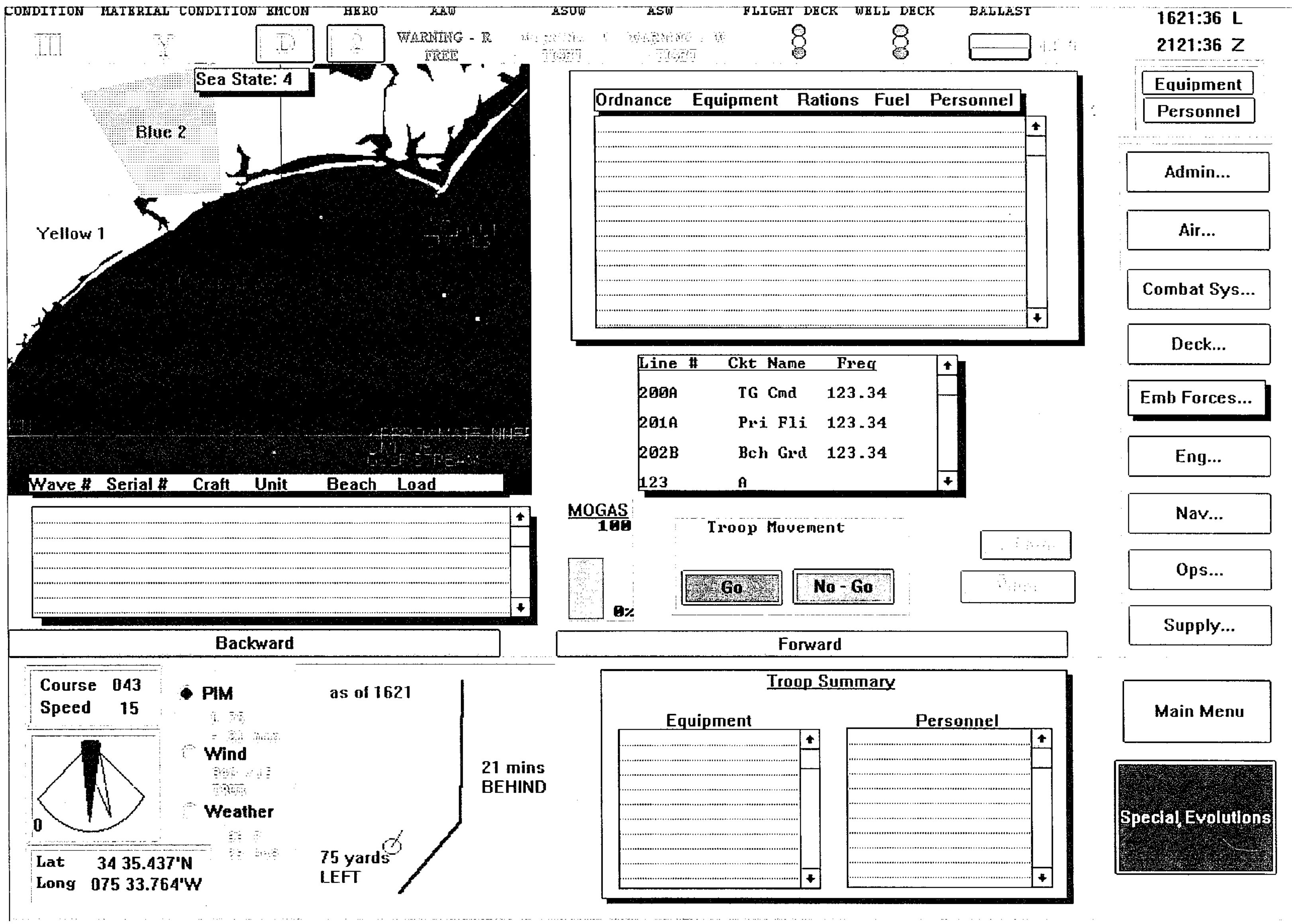

Figure 8: Embarked Forces Screen

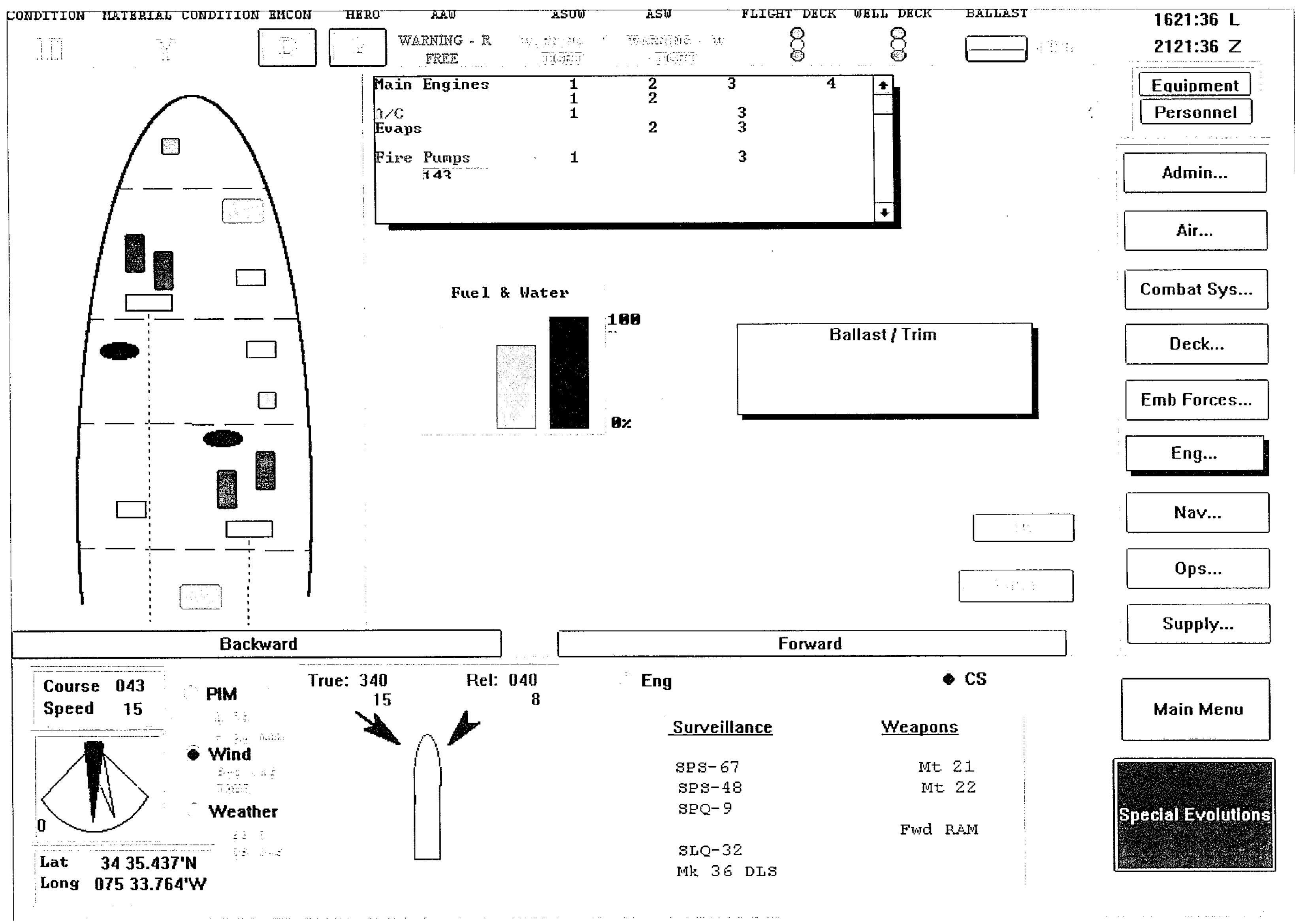

Figure 9: Engineering Department Screen

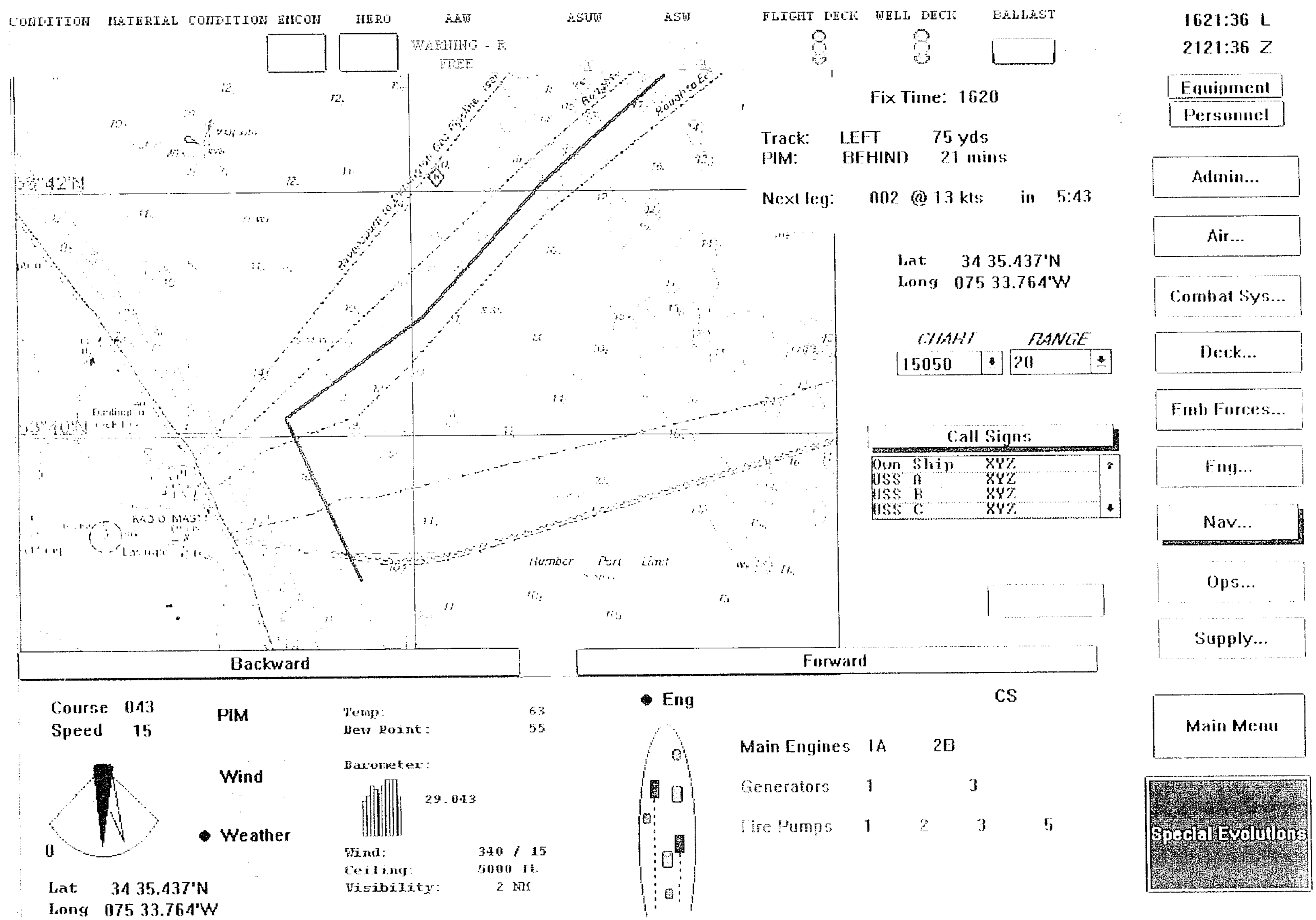

Figure 10: Navigation Screen

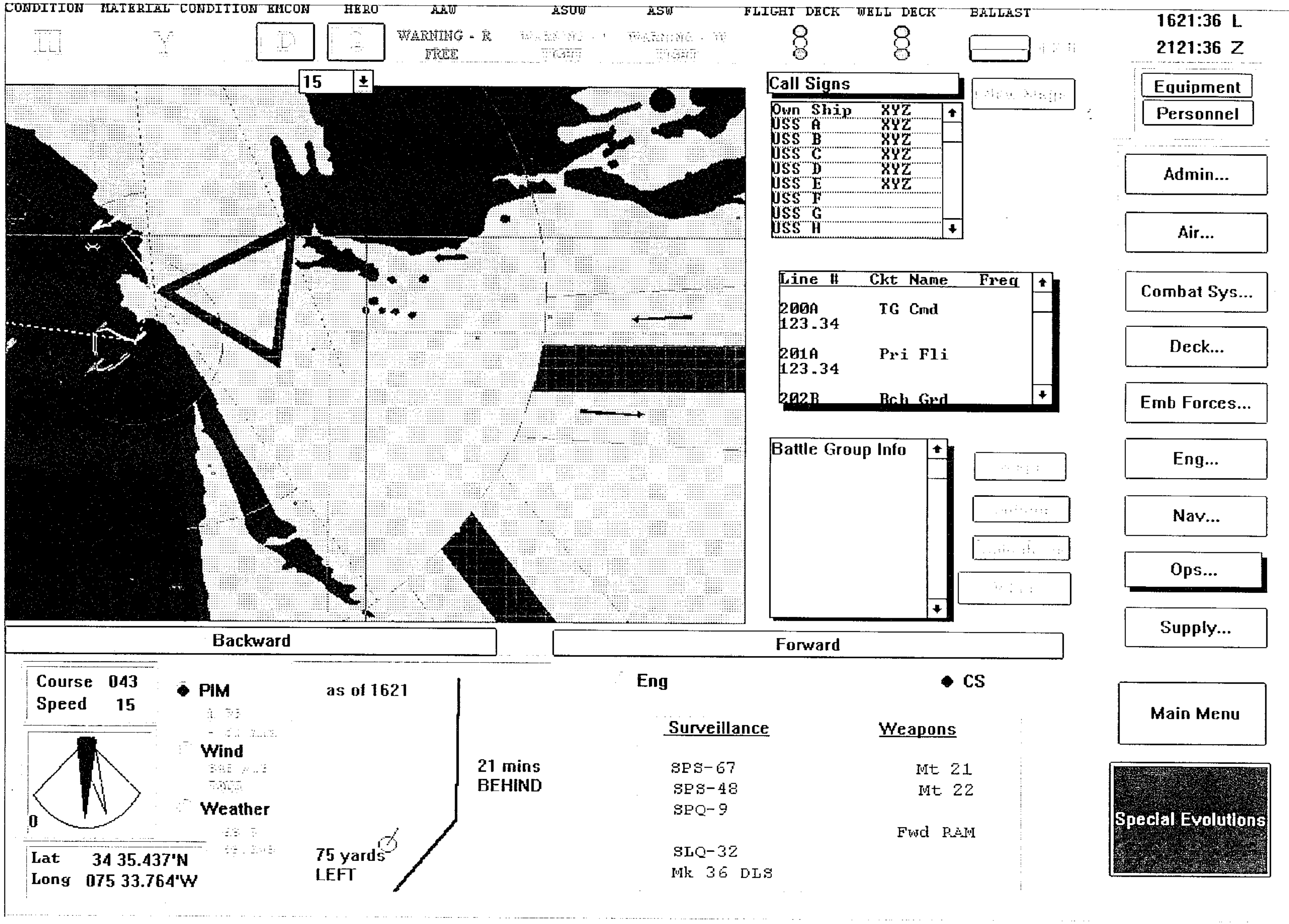

Figure 11: Operations Department Screen

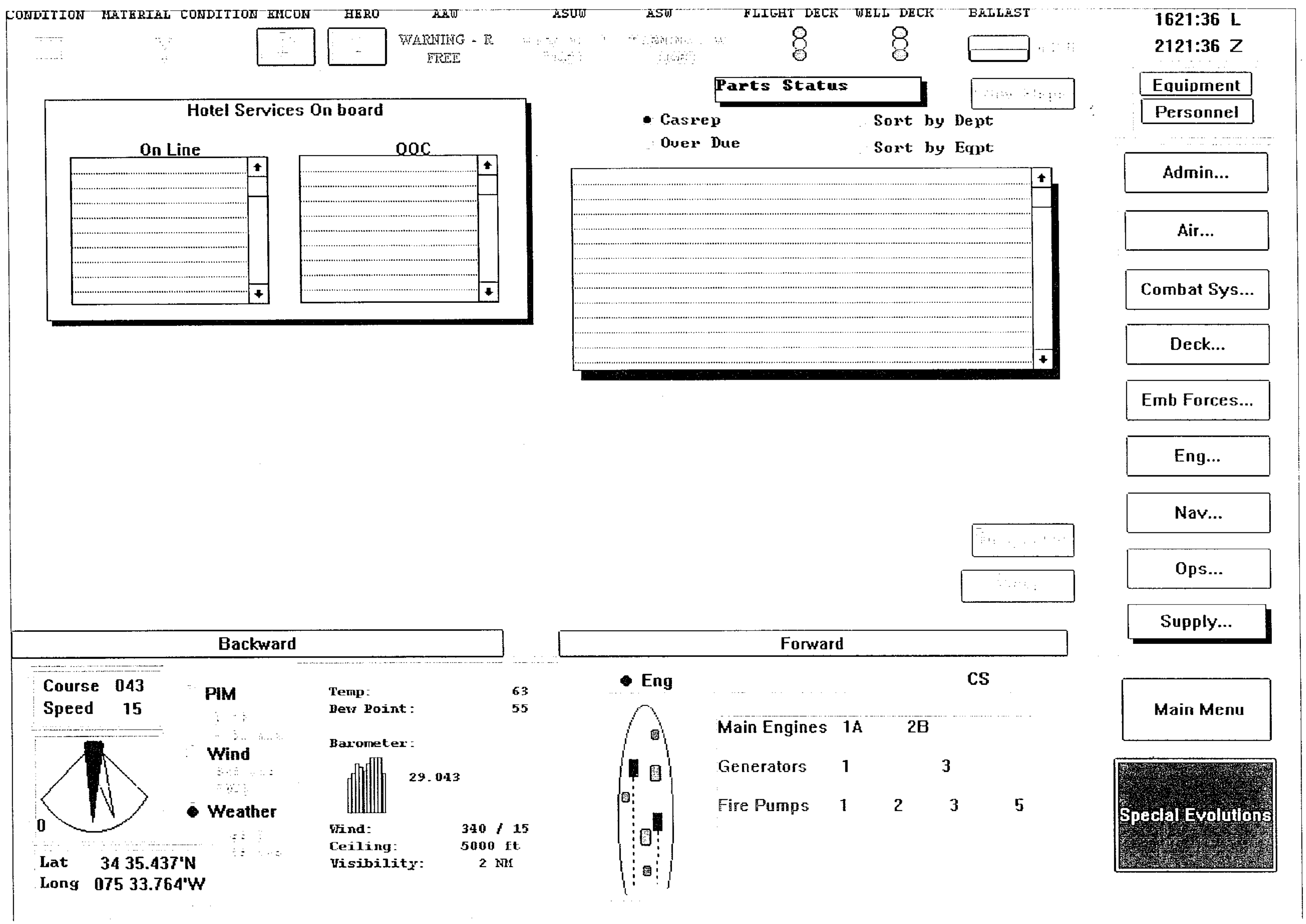

Figure 12: Supply Department Screen

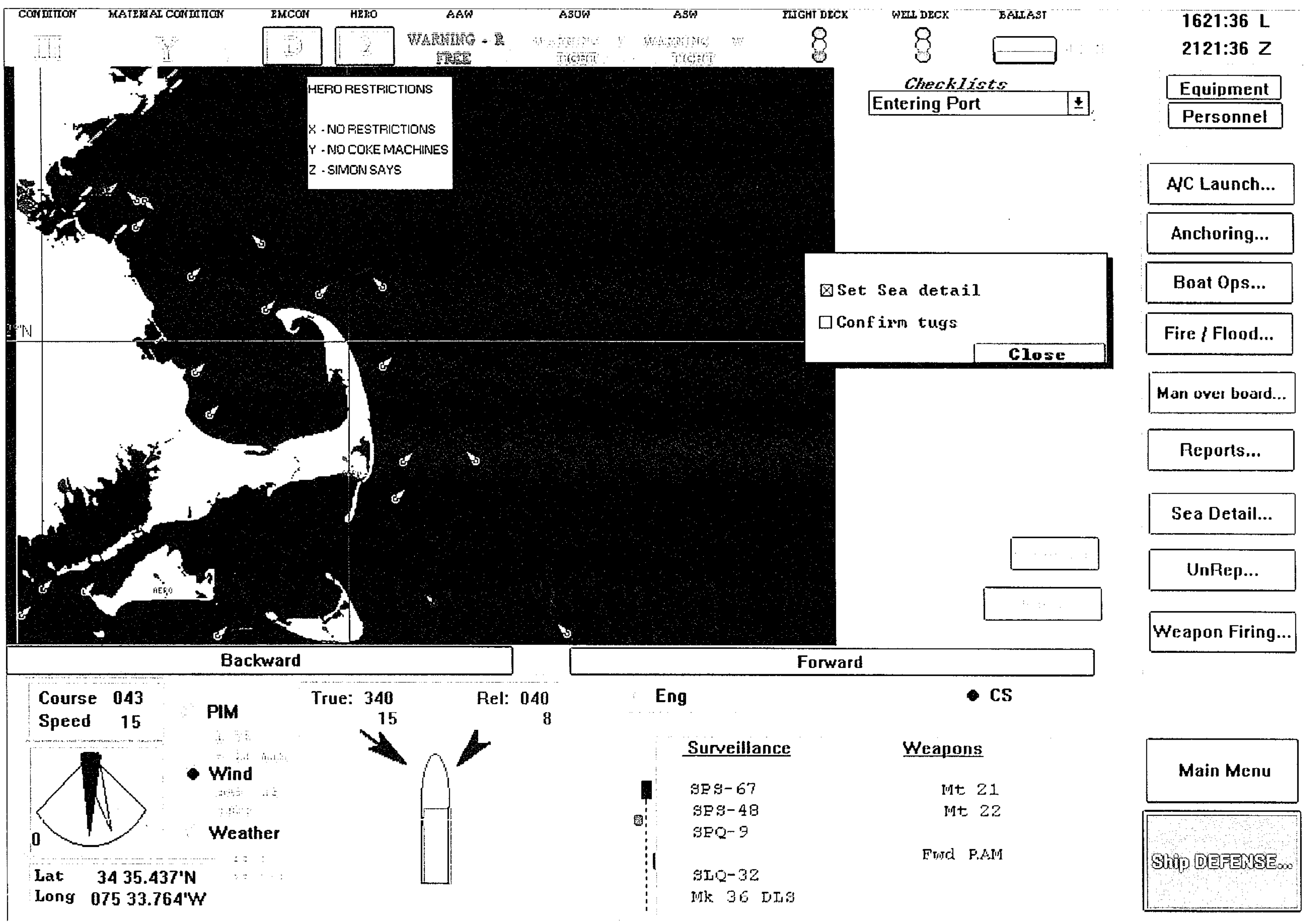

Figure 13: Special Evolutions Screen

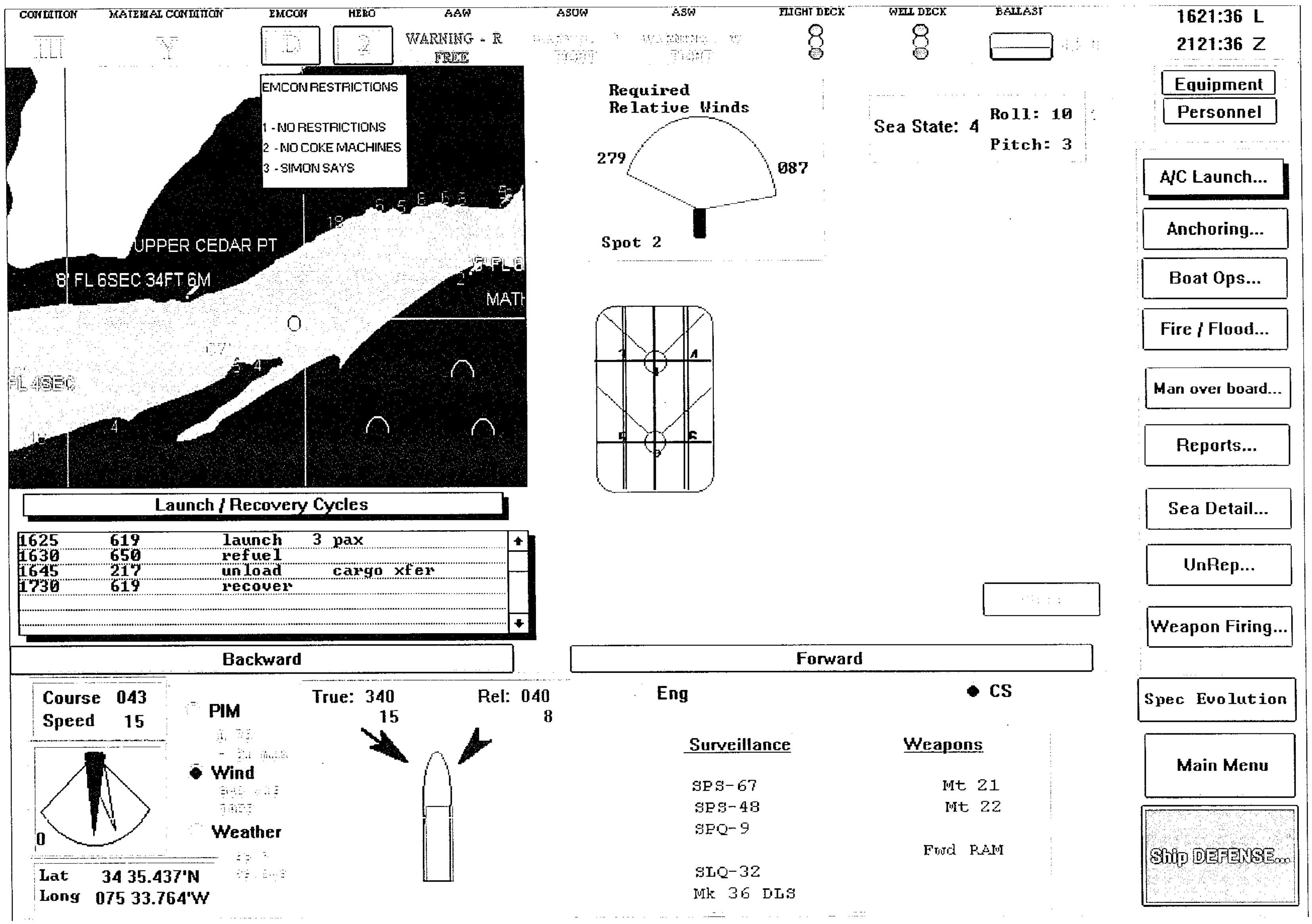

Figure 14: Aircraft Launch Screen

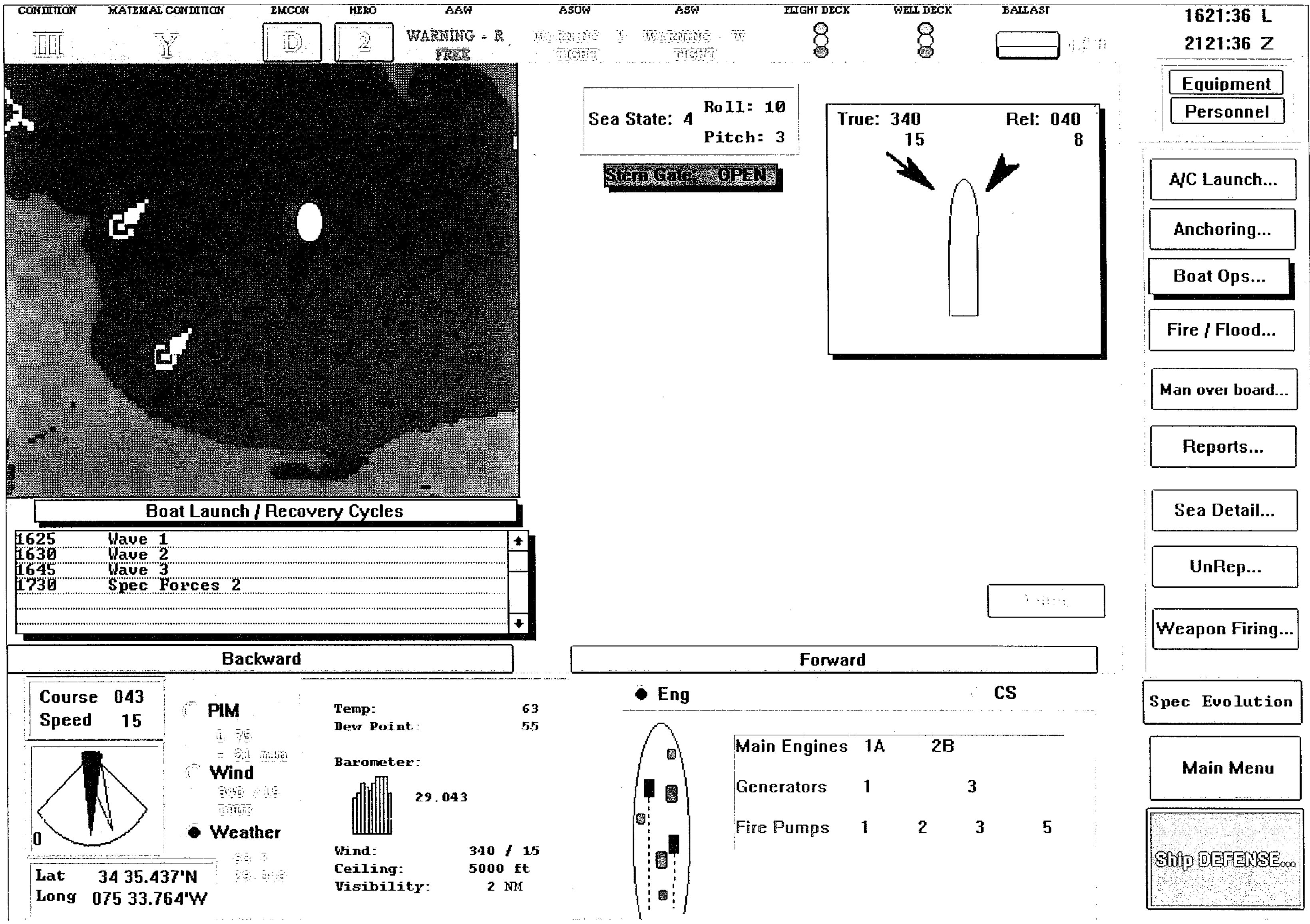

Figure 15: Small Boat Operations Screen

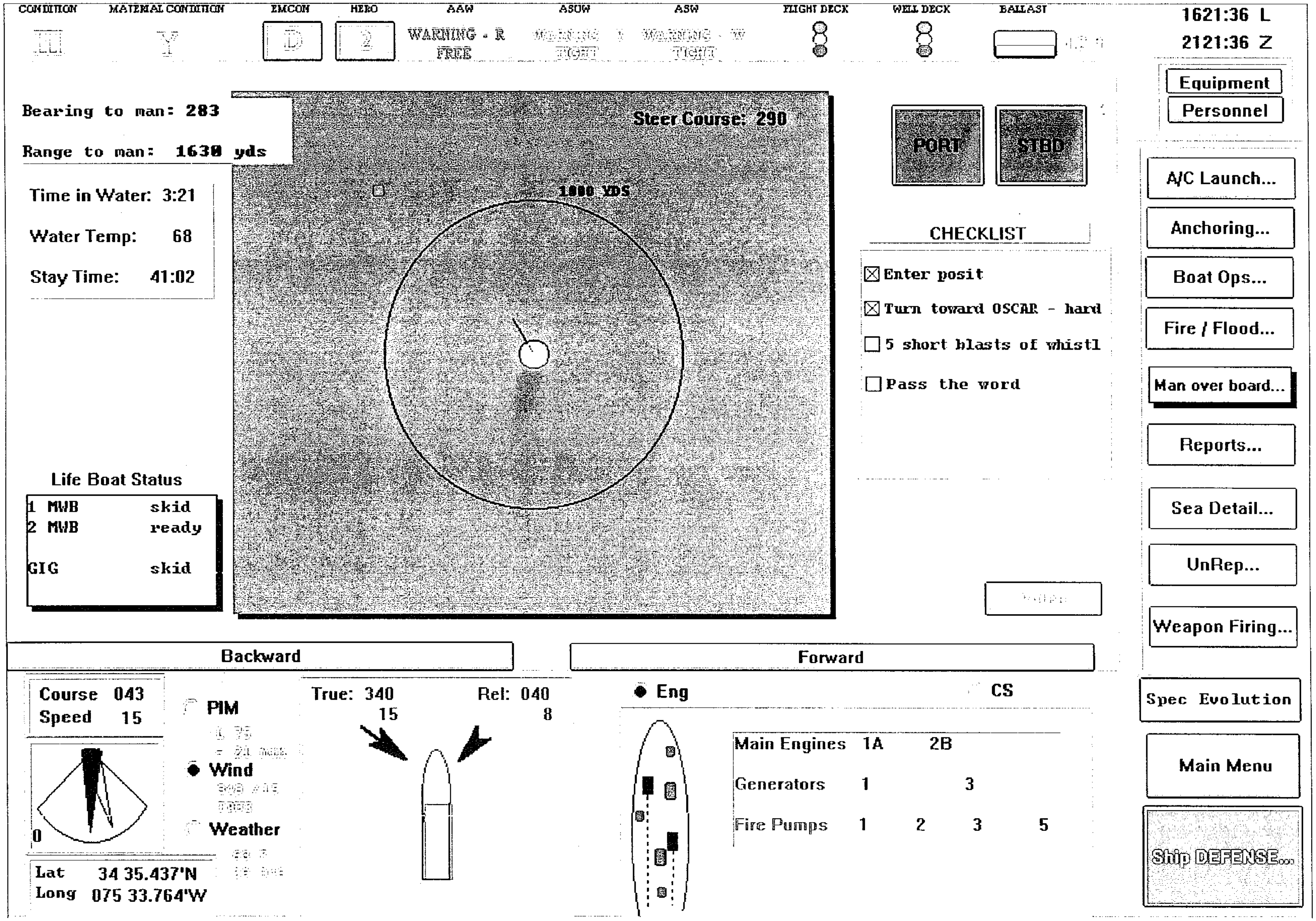

Figure 16: Man over board Screen

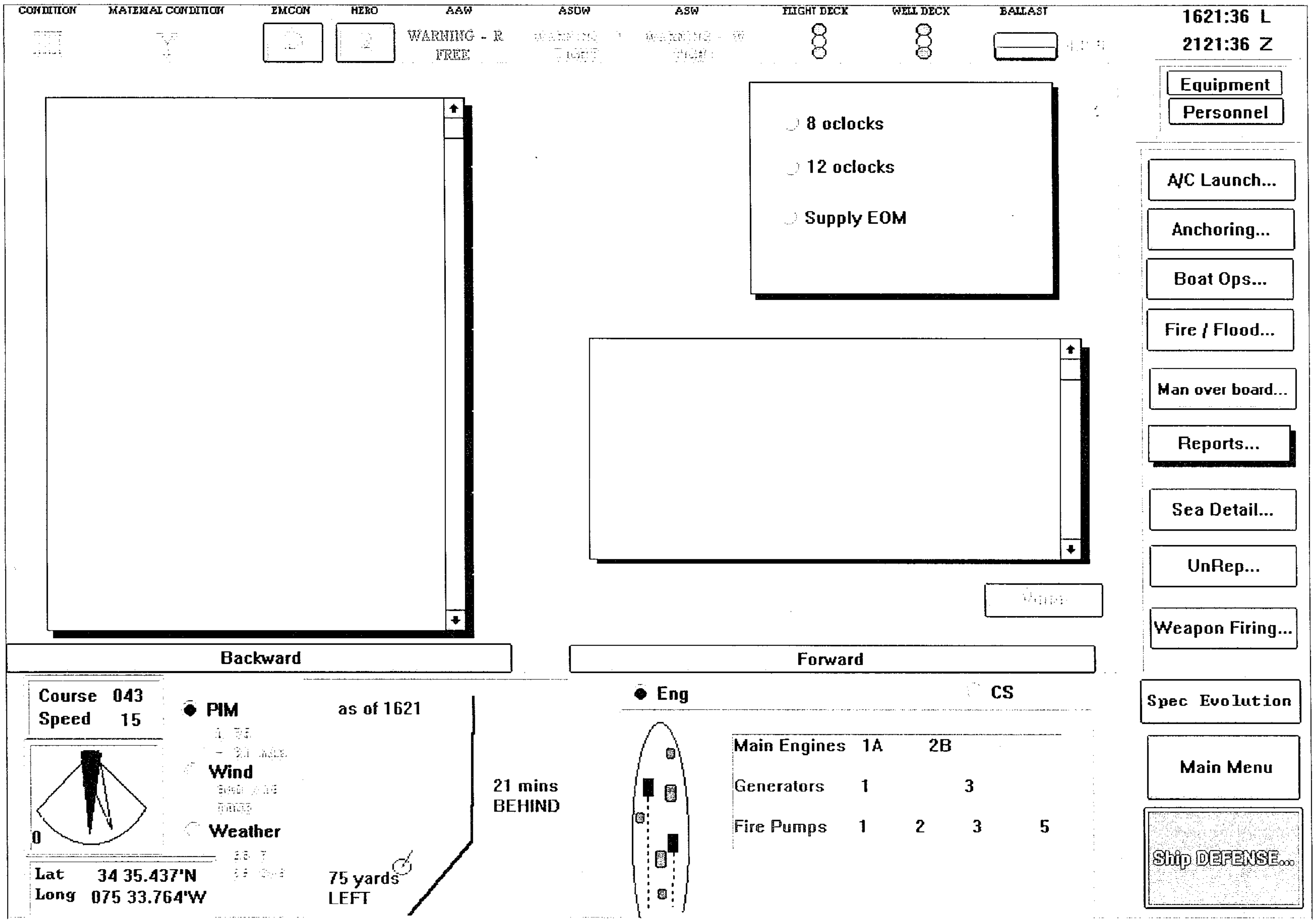

Figure 17: Special Reports Screen

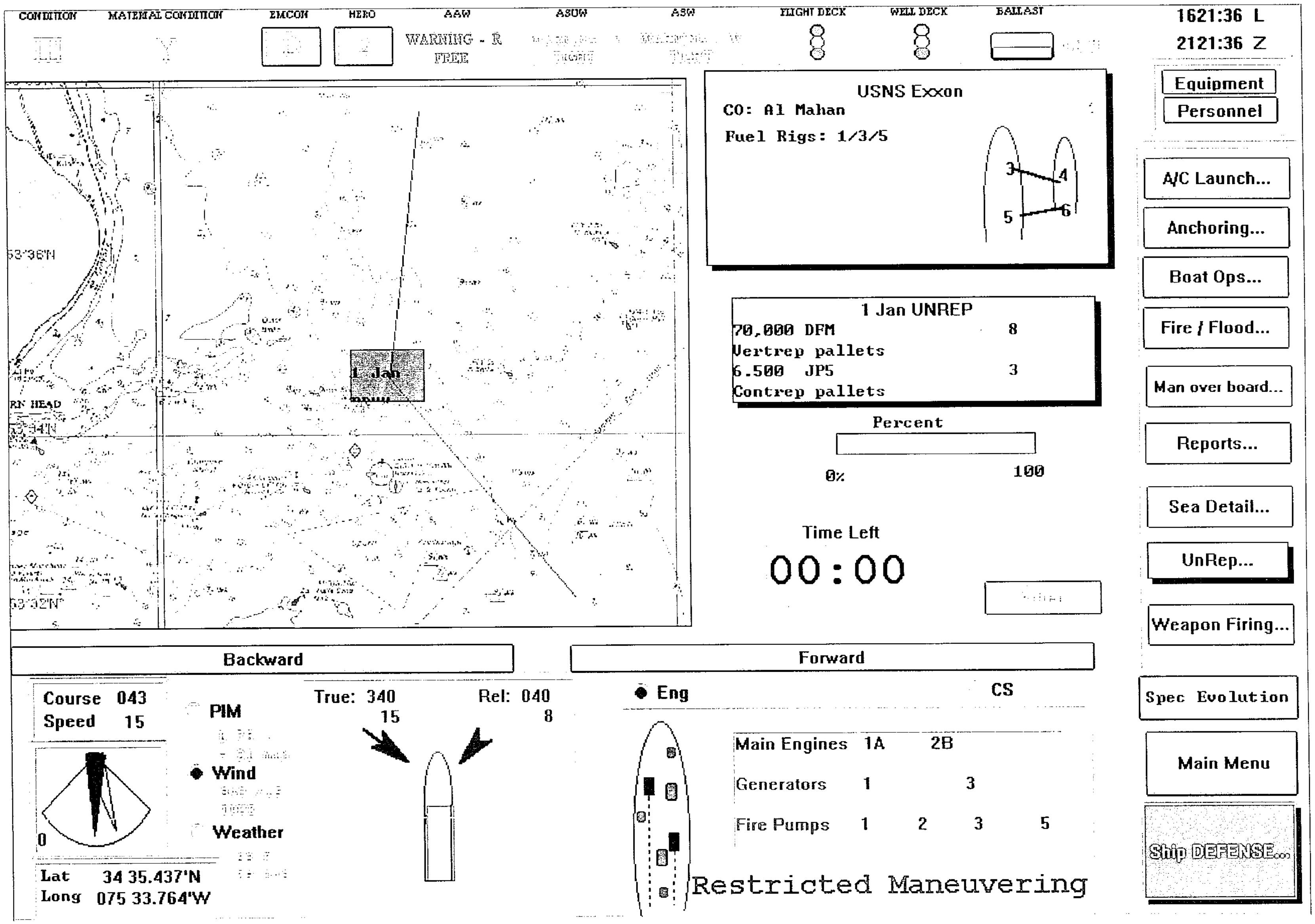

Figure 18: Underway Replenishment

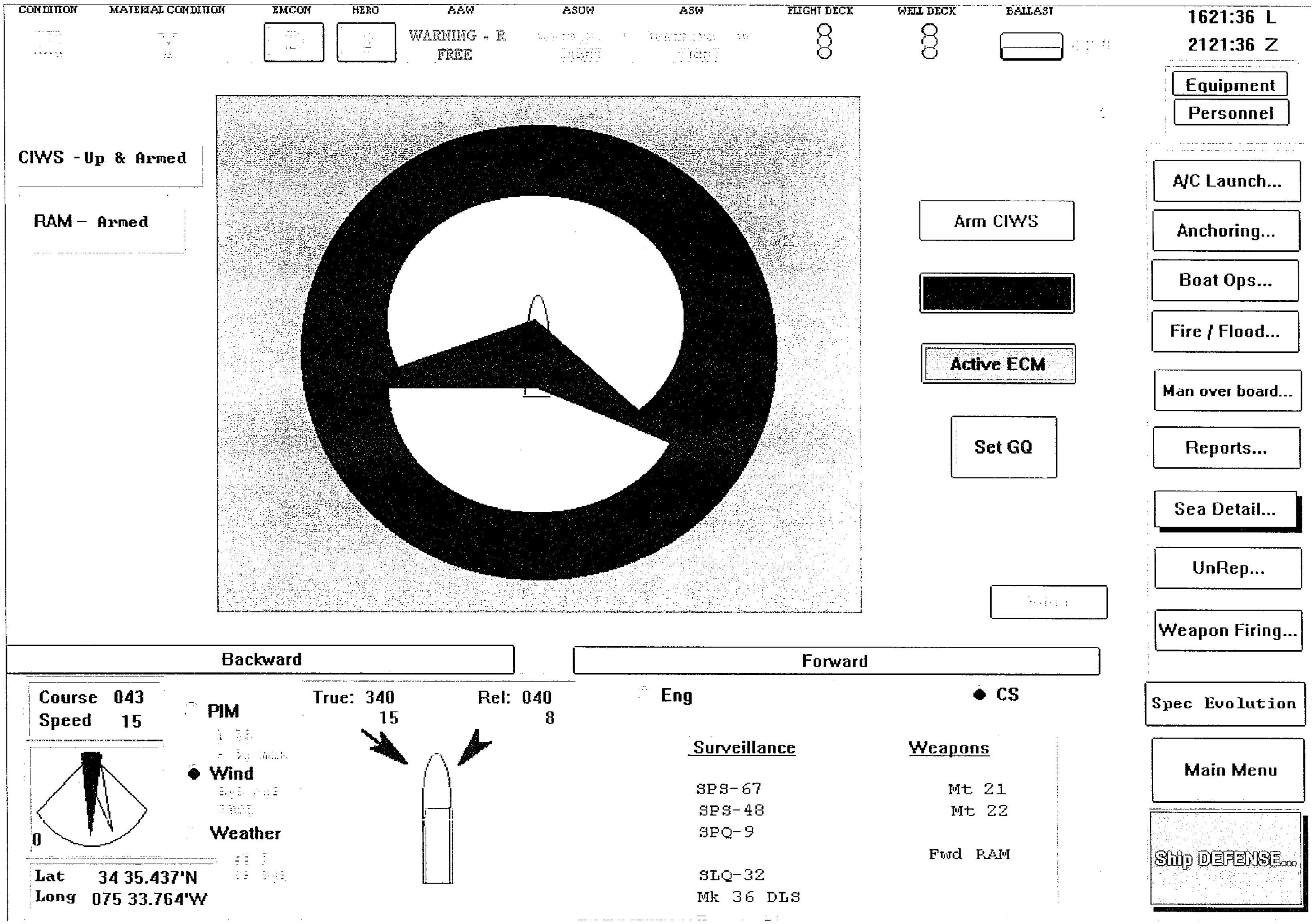

Figure 19: Ship Defense Screen

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