AIRCRAFT CARRIER ANTI-AIR SELF DEFENSE SYSTEM DESIGN AND ANALYSIS

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(ABSTRACT)

U.S. Navy ships are highly susceptible to the threat of high speed cruise missiles. Aircraft carriers are no exception. These ships must be deployed with an effective anti-air self defense system to ensure the survivability of the ship and enable it to meet its mission. Based on a pre-determined threat scenario and various performance requirements, this report selects various radar and weapons systems from existing assets to form an integrated anti-air self defense system.

The report is broken down into two sections: concept design and preliminary design. Concept design consists of defining the requirements and establishing the basic combat systems functions necessary to perform anti-air self defense. Also, a maintenance philosophy is discussed which will assist in defining the type of maintenance facilities required aboard ship. Preliminary design looks at the various assets available that would enable us to design a system that would meet the stated requirements. Preliminary design develops a topside arrangement consisting of the major sensors, missile systems, and gun systems as well as a below deck arrangement of the major command and control

facility necessary to run the combat system. In preliminary design the integrated performance of the anti-air self defense system is determined with respect to system coverage, kill probabilities, overall system reliability and availability.

The results of the report show that in order to meet the required kill probabilities a four tier anti-air self defense system is required consisting of standard missile, NATO seasparrow missile, rolling airframe missile and close in weapon system (25mm gun system). The report also shows that in order to meet the overall system reliability and availability required to simultaneously engage and defeat high altitude missiles, low altitude missiles and conduct flight operations, four air surveillance radars are required: SPS-52 and SPS-49 for high altitude missile and TAS and SPS-67 for low altitude missiles.

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2.0. INTRODUCTION

An aircraft carrier is the single most expensive and arguably the most valuable asset that exists within the Department of Defense. The United States could ill afford to lose such an asset to an enemy attack. Attack on carriers could come in several forms: other ships, aircraft, missiles or combinations thereof. The most devastating and difficult to defend against is the anti-ship cruise missile. In order to defeat this threat the aircraft carrier must possess a self defense system capable of detecting, tracking, and engaging the missiles. Figure 1 is a pictorial of the ship, a notional air defense system and the threat scenario that will be defined later in the report. Figure 1 represents a single layer of defense consisting of the surveillance, track, and engagement functions. In order to meet the reliability, availability, and kill probabilities desired for an extremely effective combat system, several layers of the anti-air self defense system will likely be needed.

The Navy has evolved into two basic types of combat systems: AEGIS which is found on our latest destroyers and cruisers and ACDS or Advanced Combat Direction System which is found on aircraft carriers and amphibious ships. The fundamental difference between these two systems lies within the type of sensor suite they employ (i.e. AEGIS has the

SPY-1 phased array radar and ACDS has a suite of rotating air and surface search radars). This report will focus on an ACDS type system, specifically the anti-air defense portion of that system.

Designing a carrier combat system is a very difficult task to accomplish. There are hundreds of subsystems that make up a combat system that all must work together to meet a common goal. From a level I systems engineering standpoint, the design of this system involves the identification of a threat (or need), identification of requirements that the system must meet (range, kill probability, overall system reliability, and availability), and selection of various combat system elements that will meet the requirements and defeat the threat. The emphasis of this report will to be to define basic requirements for the combat system, choose radar and weapons systems from existing resources, and assess the performance of the combined combat system against a given set of requirements. This report assumes independent aircraft carrier operations and does not take into account battle group operations. It must also be noted that some of the quantative factors used in this report are assumed because of either classification reasons or the data was not readily available. This report does not seek a definitive system design but rather prescribes a systems engineering process by which the anti-air self defense system should evolve.

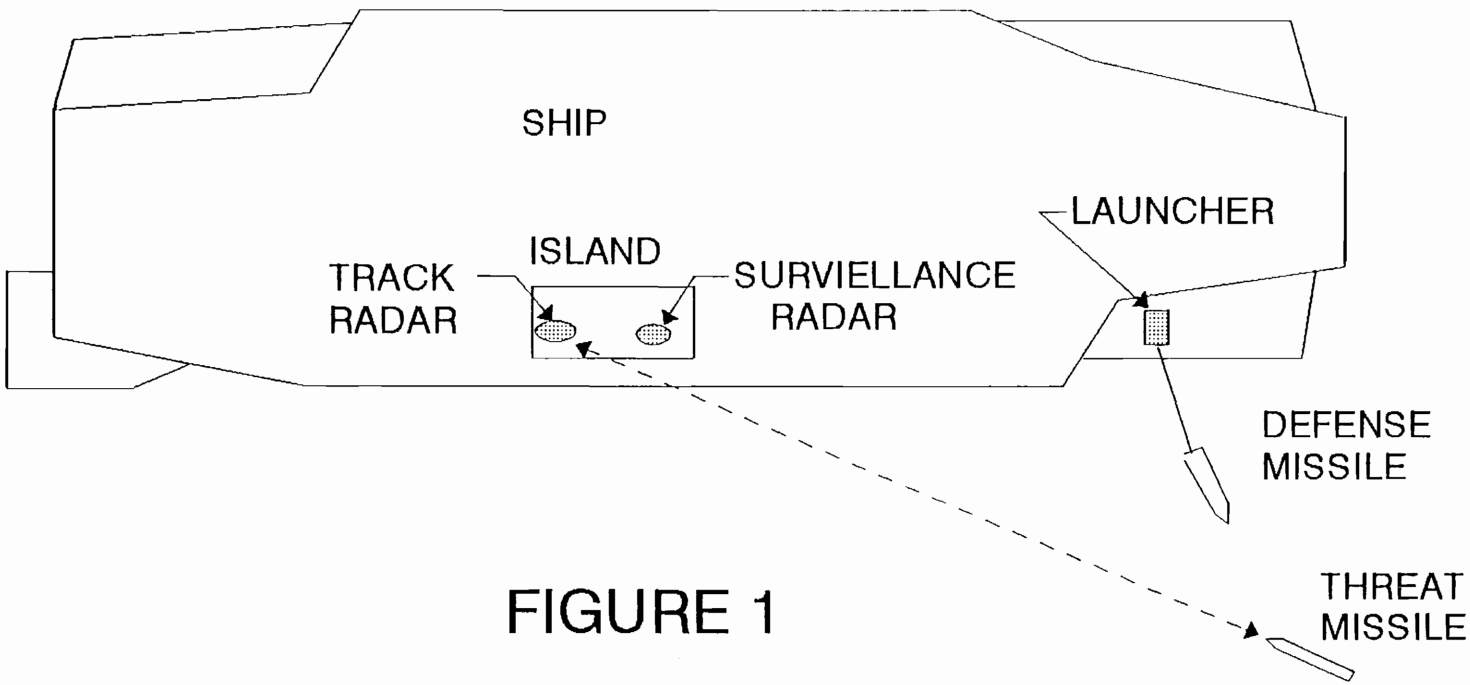


FIGURE 1

THREAT VS ANTI AIR SELF DEFENSE

3.0. CONCEPT DESIGN

3.1. Design Approach - Systems Engineering

Systems engineering involves the systematic process by which a complex system must evolve to ensure that the end product will meet the stated need. (i.e fill a deficiency or counter a threat). The emphasis of systems engineering is to quantify the requirements for the system at the beginning of the process. The idea is to enable the system to evolve in the direction that ensures it will be successful. Ambiguous and poorly defined requirements can ultimately lead to a project that will be forced to redirect which could lead to cost overruns and potential program failure.

Figures 2 and 3 depict the function flow or functional allocation diagram for our system. Based on our threat (which is covered in the next section), a mission statement and requirements for a ship are generated. From these diagrams we can see that the threat that generates the ship is not the same threat that generates the anti-air self defense system. The anti-air defense system, although extremely important, is not the major mission of the ship. Launching and recovering aircraft in order to put ordnance on a target and engage enemy aircraft and ships is the major mission of the ship. Defending itself against anti ship cruise missiles would be considered a secondary mission requirement. (Note: Elements 2.1 through 2.4 are only a

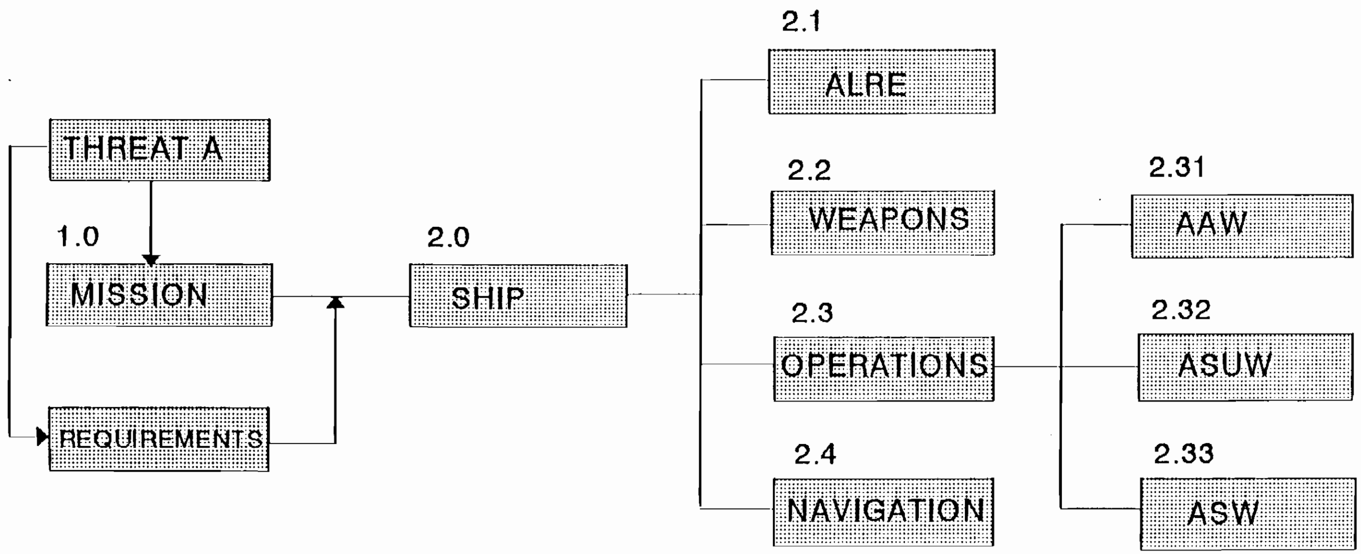


FIGURE 2
FUNCTIONAL ALLOCATION DIAGRAM
(SHIP)

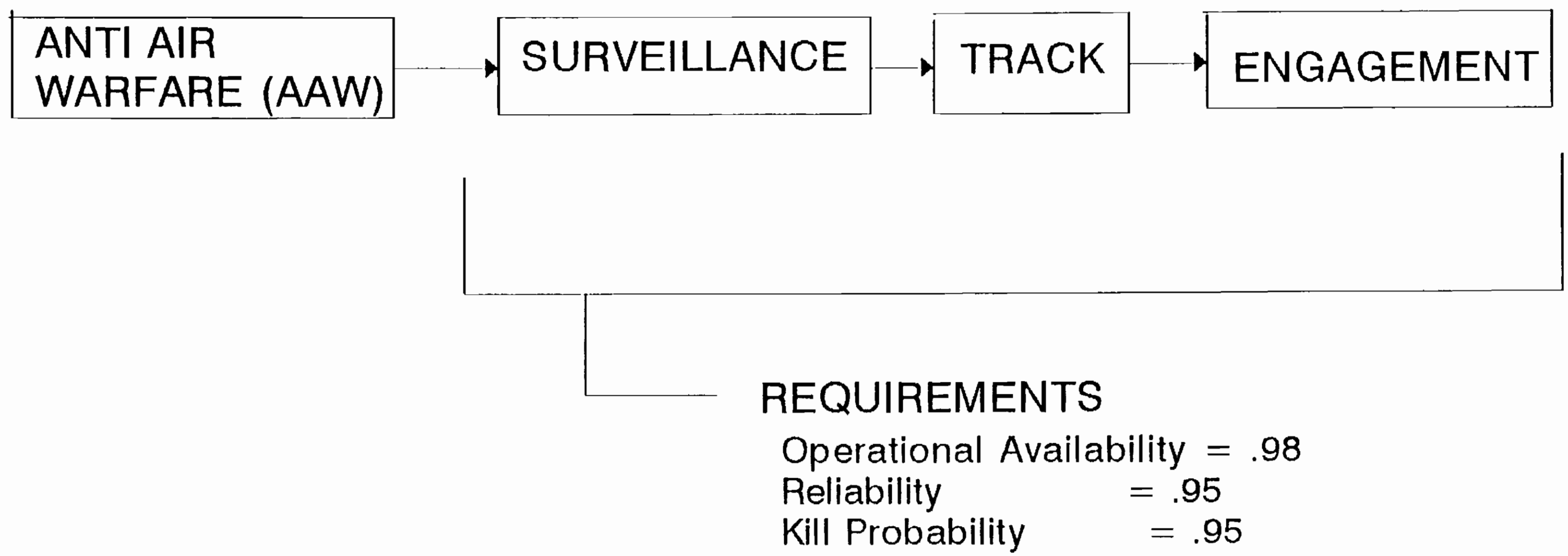


FIGURE 3

FUNCTIONAL ALLOCATION DIAGRAM (AAW)

small part of all the functions that a carrier must perform in order to meet its mission.)

Surface ship combat systems must defend against enemy threats in three arenas: Air (AAW), Surface (ASUW) and Sub-Surface (ASW), as shown by elements 2.31, 2.32, and 2.33 of Figure 2.

Figure 3 represents the major functions that the anti-air self defense system must perform. A more in depth discussion of each function is provided in section 3.3 of this report. In section 4.0 of this report surveillance, tracking and engagement systems will be selected from existing navy assets to form an anti-air self defense system.

3.2. Requirements Definition

For the purposes of this report it is given that we have a ship (in this case an aircraft carrier). The needs statement or deficiency is that the ship requires a system to defend itself against air threats. Without such a system the ship would be unable to defend itself from enemy air attacks and greatly reduce the survivability of the ship. Obviously, the type of threat that the ship is expected to face will play the most important role in defining the requirements for the anti-air defense system.

Our threat is defined as the anti-ship cruise missile.

This is the ship's toughest threat to defend against. These missiles, which can be launched from other ships, aircraft, or shore facilities, travel at very high speeds (in excess of Mach 3 or about 2205 miles/hour or 3234 ft/sec), low to the water (as low as 10 feet), and can maneuver making it difficult to maintain a track of the missile. Due to the curvature of the earth and radar clutter (or noise) created by ocean waves, the low flying missiles are hard to detect. Furthermore, when detection does occur, there is little time to react. To defeat this threat we must develop a combat system that can automatically detect the target as far away from the ship as possible, layer the missile and/or gun systems to provide complete coverage and integrate the tracking and fire control systems to provide as quick a response as possible.

For the purposes of this report the following threat scenario of 5 inbound cruise missiles with the following characteristics will be utilized:

Missile	Speed	Altitude	*Tip Over Distance
1	3000 fps	50,000 ft	250,000 ft
2	2000 fps	40,000 ft	300,000 ft
3	1500 fps	30,000 ft	350,000 ft
4	3200 fps	20 ft	N/A
5	3200 fps	20 ft	N/A

* Horizontal distance from the ship that the incoming missile tips over and dives toward the ship.

In addition to the above threat scenario, the following requirements shall be used to design the anti-air self defense system:

- The ship must be able to defend itself against airborne attacks by means of ship's armament.

- The anti-air self defense system must be capable of performing simultaneous defense of both high flying anti-ship cruise missiles and low flying (less than 50 ft.).

- The total anti-air self defense system shall have a kill probability of .95 for high altitude cruise missiles and .85 for low altitude cruise missiles.

- The total operating time for the radar system will be 2000 hours.

- Each radar and associated weapons system shall have an operational availability of .98.

- The total combat system shall have a reliability of

.95 for high altitude missiles and .90 for low altitude missiles.

- The ship must be capable of launching land attack missiles from a minimum distance of 500 miles. (Note: Although not an anti-air defense requirement, the outer layer defense element may be superseded by this requirement, therefore affecting kill probability.)

- The ship's self defense system must provide a layered defense with built in redundancy and 360 degrees of coverage for the most inner layer of defense.

- The combat system shall employ both active and passive weapons systems.

- The combat system shall possess the ability to survey the air arena out to 200 nautical miles from the ship.

- The combat system shall possess the ability to engage a cruise missile at no less than 10 miles from the ship.

- Combat system maintenance facilities shall be provided aboard the ship.

The requirements stated above apply to the functional process identified in figure 3.

For the combat system we will need to perform feasibility studies to determine what technologies exist that would allow us to meet these requirements. The ship's anti-air self defense system (excluding the aircraft) will have several technologies to choose from: Phalanx, Goal Keeper, NSSMS, VLS, RAM, SM, SSTD, etc.).

3.3. Combat System Functional Process

All combat systems essentially follow the same basic process.

SURVEILLANCE

SIGNAL PROCESSING

DETECTION AND TRACKING

INFORMATION DISPLAY & DECISION

ENGAGEMENT

The combat system must first survey the environment for potential hostile threats. The information, or reflected electromagnetic energy, received back by the ship must be processed in order to determine various characteristics of a potential threat (i.e. distance, altitude, speed, bearing, and most importantly identification). Once a potential threat has been detected the combat system must be able to track it. The tracking of this potential threat or target and it characteristics must be displayed in such a manner that an accurate decision can be made to engage or not engage the target. Distinguishing hostile contacts from friendly contacts is not necessarily an easy thing to accomplish. The combat systems communities within the Department of Defense would like this area to be infallible but events such as the Iranian Airbus and the most recent downing of two US Black Hawk helicopters show evidence that we still have room for improvement in this area.

The following discussion provides additional information about each of the combat system processes.

Surveillance

Surveillance from a ship must take place in three arenas: air, surface, and subsurface. Air and surface surveillance is accomplished by sweeping unidirectional radars or phased array radars. Subsurface surveillance will not be discussed in this report. Once a desired suit of radars is selected based on performance and cost much effort must go into locating them aboard ship. This is commonly known as a topside design and will be discussed in Section

4.1. of this report.

Signal Processing

The combat system must take the information gathered by the surveillance system and process the information. Much of this element lies within computer software and is invisible to the end user.

Detection and Tracking

For a combat system to be successful the sensor suite must not only detect a target but also maintain a track of the target. Without a track of the threat the fire control system can not lock on the target and fire.

Information Display and Decision

Information about a potential threat must be displayed so that decisions can be made regarding whether the contact is hostile or friendly. Much effort must go into this phase of the systems engineering analysis. There are a multitude of interrelationships internal to the combat system. Proximity, communications, and data entry are just some of the elements that must be thought out in order to build a functional combat system. Much effort must also go into the displays. There is an optimal amount of information that must be displayed. Obviously too little information could lead to a critical non response. But not so obviously is the latest problem of information overload. Considerable effort must go into deciding who needs to see what information.

Engagement

The final and perhaps the most critical part of the combat self defense system is engagement. Engagement involves locking on to a target and firing at it. Based on the information displayed by the combat systems you may decide that an engagement must take place. However, with todays fast moving threats (i.e. cruise missiles) not much time can elapse between detection and engagement if you expect to have a reasonable chance to destroy or distract the threat. In the event that a missile travelling at Mach 3 pops up from over the horizon and if the combat system is not on automatic, it is unlikely the threat will be defeated.

3.4. Maintenance Concept

Determining the maintenance philosophy that is most effective to keep the combat system aboard a ship up and running this early in the design is speculative at best. There are essentially two options: Organizational Level Maintenance (OLM) or Intermediate Level Maintenance (ILM).

3.4.1. Organizational Level Maintenance

OLM aboard a ship involves removal and replacement of components with spare parts (i.e. replaceable assemblies, modules, etc.) for both scheduled and unscheduled maintenance. The removed parts, if repairable, are packaged and shipped back to a shore based intermediate maintenance facility or shipped back to the manufacturer for repair or replacement.

3.4.2. Intermediate Level Maintenance

ILM aboard a ship involves the removal and replacement of components for both scheduled and unscheduled maintenance. Unlike OLM, the removed parts, if repairable, are repaired and tested aboard ship and put back into the ship's stock system as a replacement part. If not repairable they are discarded.

3.4.3. Shipboard Combat System Maintenance Philosophy

Both types of maintenance have their advantages and disadvantages. ILM requires expensive test equipment and a higher level of skilled maintenance personnel as part of the crew. However, ILM offers a quick turnaround on replacement parts. OLM requires that additional spares be purchased and stocked aboard ship. However, OLM will require less sophisticated work centers for the lower skill level maintenance personnel which is much less costly to the ship from a space and support services standpoint than the ILM shops that house the electronic test equipment. Also, manning requirements will be less for an OLM concept than for an ILM concept.

If we consider the combat system as a singular entity, then it is quite likely that an OLM type concept which would require less manning, less space, less support services (i.e. HVAC, electrical), and less life cycle costs, would be the most appropriate. However, knowing that the aviation community employs extensive ILM facilities aboard the ship and that the latest technology (CASS - Consolidated Automated Support System) provides standard test benches requiring only changes in software to test almost any modern electronics component, therefore leading to a sharing of electronics testing and repair facilities between the airwing and the Operations Department, an ILM type system would be most appropriate. The question that must be answered is what is more cost effective: building, manning, and maintaining an ILM afloat facility or purchasing additional spares and stocking them aboard shop while repairables are off-loaded to shore based facilities. This obviously is a study within itself. Without an in-depth study and based just on the facts above this report would select an intermediate level maintenance concept and share facilities that already exist within the aviation community.

Maintainability Requirements

In order to determine the overall operational availability for the anti-air self defense system maintainability factors (such as mean time between corrective maintenance, mean time between preventive maintenance, logistics and admin delays for obtaining spare parts) were assumed for each of the individual system components in order to allow an overall system operational availability to be calculated (see section 4.1.3.3.). The known maintainability factors for each of the subsystems will be the primary driver in determining the manpower, facilities, and spare parts required to keep the system operational and meet the predicted down time for which ever maintenance philosophy is adopted (ILM or OLM). Figure 3 indicates that an overall system operation availability of .98 is required for the combined surveillance, track, and engagement system.

3.5. Design Integration

In developing a complex system such as an aircraft carrier combat system it is important to initially set up and maintain an organization that is conducive to the integration efforts that must take place to design that system. All the technology in the world can be built into one ship but if it is not designed and integrated properly this system will operate less than optimally. The following list provides most of the design facets that are extremely important to combat system design:

a. Effectiveness (performance capabilities, coverage)
b. Arrangements (topside, manned below decks, and unmanned below decks)
c. Maintenance
d. Electromagnetic Interference
e. Radiological Hazards
f. Electrical
g. Structural
h. Reliability
i. Human Factors
j. Availability
k. Survivability (shock, blast overpressures, fragment hits), separation/redundancy)
l. Producibility
m. Logistics
n. Affordability
o. Safety
p. Integration
q. Flexibility

r. Weight/Moment

s. Manning

t. Training

u. Heat Dissipation

It is important that most, if not all, of the above design facets be co-located into a single design site integrated into a single design team.

4.0. PRELIMINARY DESIGN

Introduction

Preliminary design of the combat system is divided into two major disciplines: Topside Design and Below Deck Arrangements. Topside design consists of selecting the appropriate weapons and sensors, locating them aboard the ship, and assessing the systems integrated performance. Below deck arrangements involve the placement and layout of all the facilities needed to support the combat system.

4.1. Topside Design

Topside design for the ship's self defense system consists of selecting the major air and surface search radars as well as the weapons systems required to defeat the threat. (Note: an actual topside design for an aircraft carrier would include the sensors required for communications, navigation, and meteorological). Performance assessments are then made to determine the effectiveness of the self defense system and ensure the requirements stated in the concept design are met.

Placement of the sensors and weapon systems is perhaps the most critical portion of the design and quite possibly the most challenging. An aircraft carrier has over one hundred antenna systems. The integration of this many systems can be optimized only through a highly structured, iterative process.

Figure 4 depicts the basic process required to effectively perform a topside design. Based on the requirements and constraints, topside elements are selected, located/arranged on the ship, and their integrated performance determined. Performance is determined by calculating the combat system reaction times and kill probabilities based on range, speed, and coverage. Overall system reliability will be calculated based on the reliability of the individual systems. Electromagnetic compatibility (EMI/IMI), frequency compatibility, size, weight, radiological hazards (RADHAZ), waveguide restrictions, and cost are also factors that must be included in the design.

4.1.1. Selection of Sensors and Weapons Systems

Selection of the topside elements is segregated into four areas: Air Search, Surface Search, Active Engagement, and Passive Engagement. The following discussion provides background information on the latest available systems that could be employed in an anti-air self defense system. Surface search radars are also included since they can act as a back-up or supplement to the air search radar. It is necessary to consider as many of the major topside radar elements as possible in order to avoid frequency

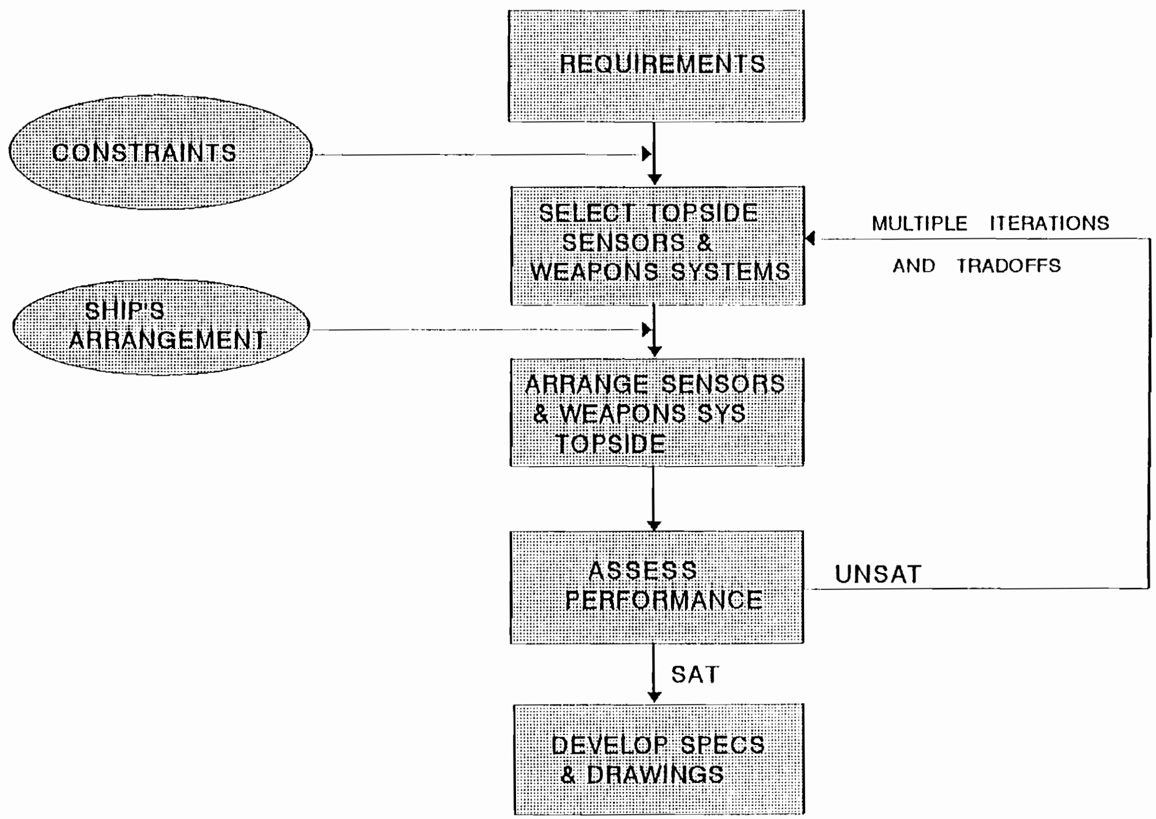


FIGURE 4 — TOPSIDE DESIGN PROCESS

incompatibilities or electromagnetic interference.

Air Search Radars

Long Range Air Search Radar

Two long range 3-dimensional rotating air search radars exist within the Navy: AN/SPS-48 and AN/SPS-52. The SPS-48 has a range of approximately 240 nautical miles and operates in the frequency range of 2900 to 3100 Mhz, and has a peak power output of approximately 2200 kw. An SPS-48 antenna system weighs approximately 4500 lbs. The SPS-52 also has a range of approximately 240 miles and operates in the frequency range of 2910 to 3100 Mhz. The SPS-52 has a peak power output of 1000 kw and weighs about 3200 lbs. For this report the SPS-52 will be utilized.

The Navy's long range 2-dimensional rotating air search radar is the AN/SPS-49. It has a range of approximately 200 nm and operates in the frequency range of 850-950 Mhz. The SPS-49 has a peak power output of approximately 280 kw and weighs approximately 3000 lbs.

Note: The SPS-52 radar is 3 dimensional while the SPS-49 is two dimensional. This means that both radars can provide range and bearing of a target but only the SPS-52 can provide altitude.

Short Range Air Search Radar

One of the Navy's most effective sensors against high speed missiles is the Mk 23 TAS (Target Acquisition System). In its normal operating mode TAS has a range of approximately 20 nm. It can also serve as a back up for the long range radar out to 100 nm. TAS has a peak power output of approximately 200 kw. TAS Mk 23 weighs approximately 2000 lbs. The frequency range of TAS is classified. TAS is designed to provide support to the NATO Sea Sparrow Missile System in the detection of low altitude anti- ship cruise missiles.

Surface Search Radars

Long Range Surface Search Radar

The Navy's latest surface search radar is the AN/SPS-67. Used for detection, ranging, and tracking of surface targets, the SPS-67 operates in the frequency range of 5450 to 5825 MHZ and has a peak output power of 285 kw. The SPS-67 has a range of approximately 50 nm and weighs approximately 500 lbs. The
SPS-67 will also be used to detect low flying anti-ship cruise missiles.

Short Range Surface Search Radar

The SPS-64 is one of the Navy's primary close in navigation radars. This radar can also be used as a back up to the SPS-67 surface search radar. The SPS-64 operates at a frequency of approximately 3000 Mhz with a peak output power of approximately 60 kw. The SPS-64 has a range of approximately 30 nm and weighs 330 lbs. This antenna does not play into the basic anti-air defense system but is a major antenna and must be considered for topside arrangement and electromagnetic interference analysis.

Active Engagement Suite

Land Attack

The most common land attack cruise missile is the Tomahawk (BGM-109). The Tomahawk has a range of 1500 nm and travels at approximately 550 miles per hour. The Tomahawk Sea Launched Cruise Missile (SLCM) is also designed to perform anti-ship missions and can carry either conventional high explosives or nuclear warheads. This missile does not play into the anti-air self defense system, however, depending on the configuration of the combat system, can have an impact on the kill probability of the anti-air defense systems.

Long Range Engagement Anti Air/Anti Surface

Standard Missile

The standard missile (SM) is a long range anti-air missile. It has a range of approximately 180000 ft (or about 30 nm) and travels at approximately 2700 ft/sec (or about Mach 2.5). The standard missile utilizes the SPG-51 illuminator or director. For the purposes of this report the range of the SPG-51 director is 100 nm. The SM vertical launch system weighs approximately 510000 lbs.

Medium Range Engagement

Nato Seasparrow

The NATO Seasparrow Surface to Air Missile system is a an all weather anti-air/anti-surface and anti missile system that consists of a launcher and radar illuminator. It is designed to engage a target between 3000 to 48000 feet (or about 8 nm). Its radar range is out to 300000 ft. The NSSMS travels at about 1050 ft/sec. Each system carriers 8 missiles, employs two directors and weighs about 28000 lbs.

Rolling Air Frame Missile

The Rolling Airframe Missile (RAM) is an infra red (IR) or radar seeking anti missile system. It is designed to engage a target between 3000 to 20000 feet. RAM travels at about 2000 feet per second and weighs about 14560 lbs.

Short Range Engagement

The Close-in Weapon System or CIWS is considered the last line of active defense against an anti-ship missile. CIWS consists of a 20 MM gatling gun that fires approximately 3000 rounds per minute, a search radar and a track radar. CIWS has a firing range of about 6000 ft and a detection or radar range of about 30000 ft. CIWS has a maximum burst time of 6.5 seconds and weighs approximately 12150 lbs.

Passive Engagement Suite

Unlike the engagement systems discussed above, a passive engagement system attempts to confuse, distract, or jam the radar system of an incoming missile. US Navy ships employ two types of passive engagement systems: decoy launchers and electronic warfare systems.

Decoy Launchers

Decoy launchers offer passive protection against infra-red or radar guided anti-ship missiles. The system consists of tubes positioned around the ship that launch flares for heat seeking missiles or chaff clouds for radar seeking missiles in the hopes that the missile will be distracted away from the ship. The most current system in the fleet is the MK 36 SRBOC (Super Rapid Bloom Off-Board Countermeasures).

Electronic Warfare (EW)

Electronic warfare consists of two major elements: Electronic System Measures (ESM) and Electronic Counter Measures (ECM). On the ESM side of EW, the environment is scanned for radar emissions. Detected emissions are then analyzed by the system (i.e. compared to a library of friendly and hostile emitters) and classified as a friend or a hostile. EW systems can detect radar emissions beyond the ranges at which hostile missiles can lock on. ECM involves the emission of a counter signal in order to jam or confuse the threat. EW systems present a problem when arranging all elements topside. EW systems operate across a broad range of frequencies, therefore lending to potential interference with other sensors. The latest EW system to be employed by the Navy is the AN/SLQ-32. Most characteristics associated with the SLQ-32 are classified.

There are other ship's self defense systems in existence within the fleet. However, most are no longer in production and/or are inferior in performance capabilities to the systems listed above.

Figure 5 depicts the air surveillance envelopes based on sensor suite discussed above. Figure 6 depicts the air engagement envelopes.

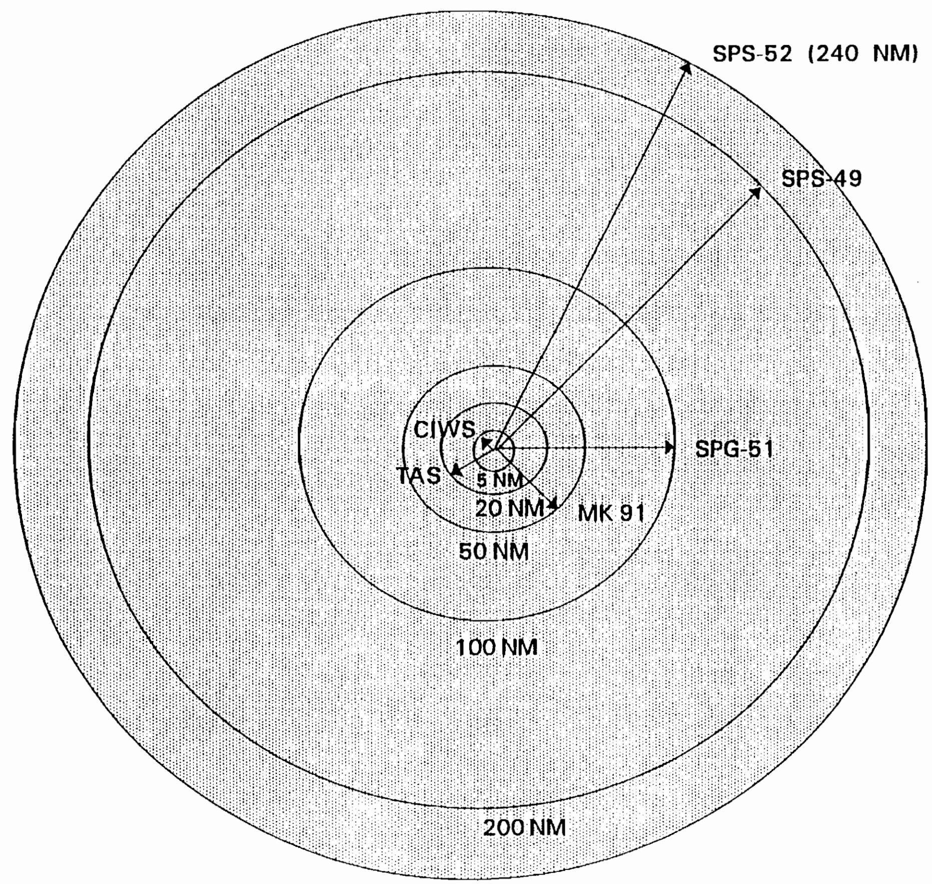


FIGURE 5 - Air Surveillance Envelope

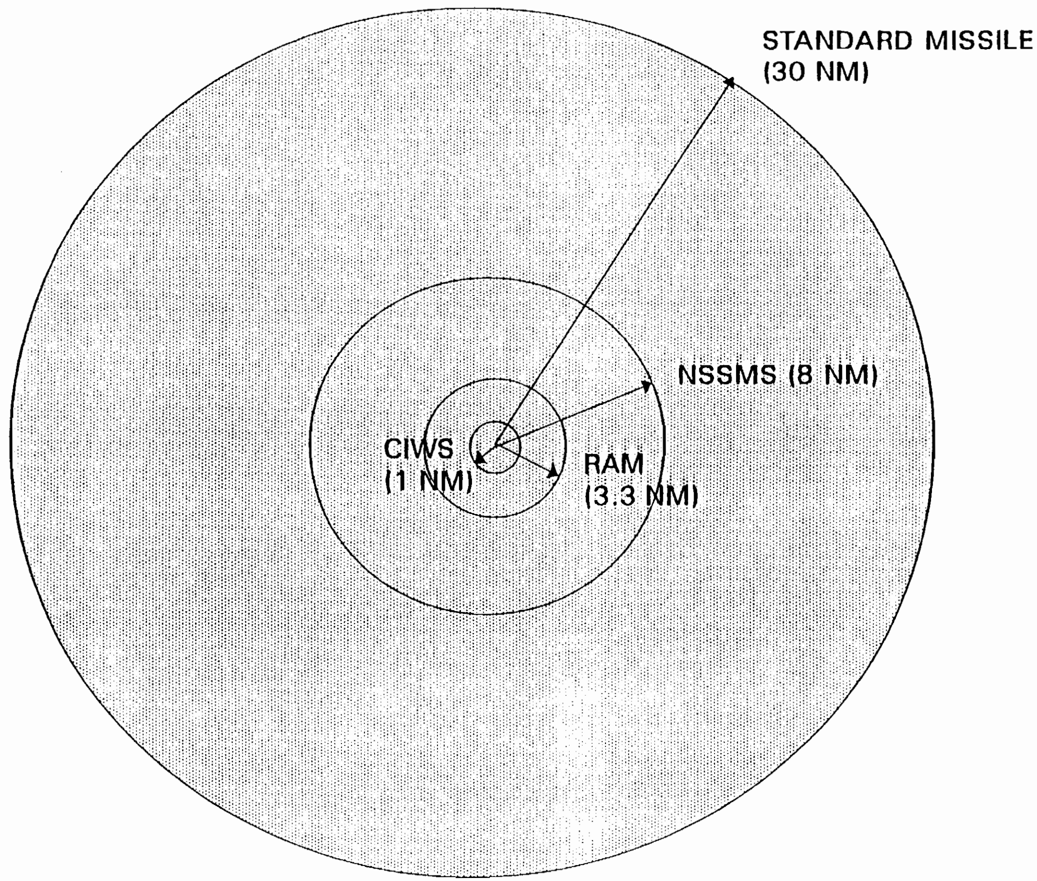


FIGURE 6 - Air Engagement Envelope

4.1.2. Topside Arrangements

The first step in topside design is to determine a mast configuration and locate the major mission related sensors. The major mission of an aircraft carrier is to launch and recover aircraft. Although this report is concentrating on ships self defense we will consider the major sensors necessary to carry out launching and recovering of aircraft. These sensors include the SPN-41 and SPN-46.

The SPN 41 system provides for aircraft instrumented landings. The SPN 41 consists of two antennas, one for azimuth and one for elevation and operates in the frequency range of 15.4 to 15.7 Ghz. The maximum power out is 2.2 KW and the total weight of both antennas is 2625 lbs. The SPN-46 radar serves as the final aircraft approach radar. With a range of 22.4 nm and limited coverage (astern), the SPN-46 is not considered a tactical radar. The SPN-46 operates in the frequency range of 33.4 Ghz and maximum power out of 50 KW. The antenna weighs 906 lbs and has a swing radius of 4'-2".

Figures 7, 8, and 9 show a basic diagram of the ship and its island. The ship's size and island location are generally a given at this stage of the design. It should be noted, however, that sponsons can be added (provided the ship does not have Panama Canal restriction, which aircraft carriers do not) to the ship or existing sponsons relocated

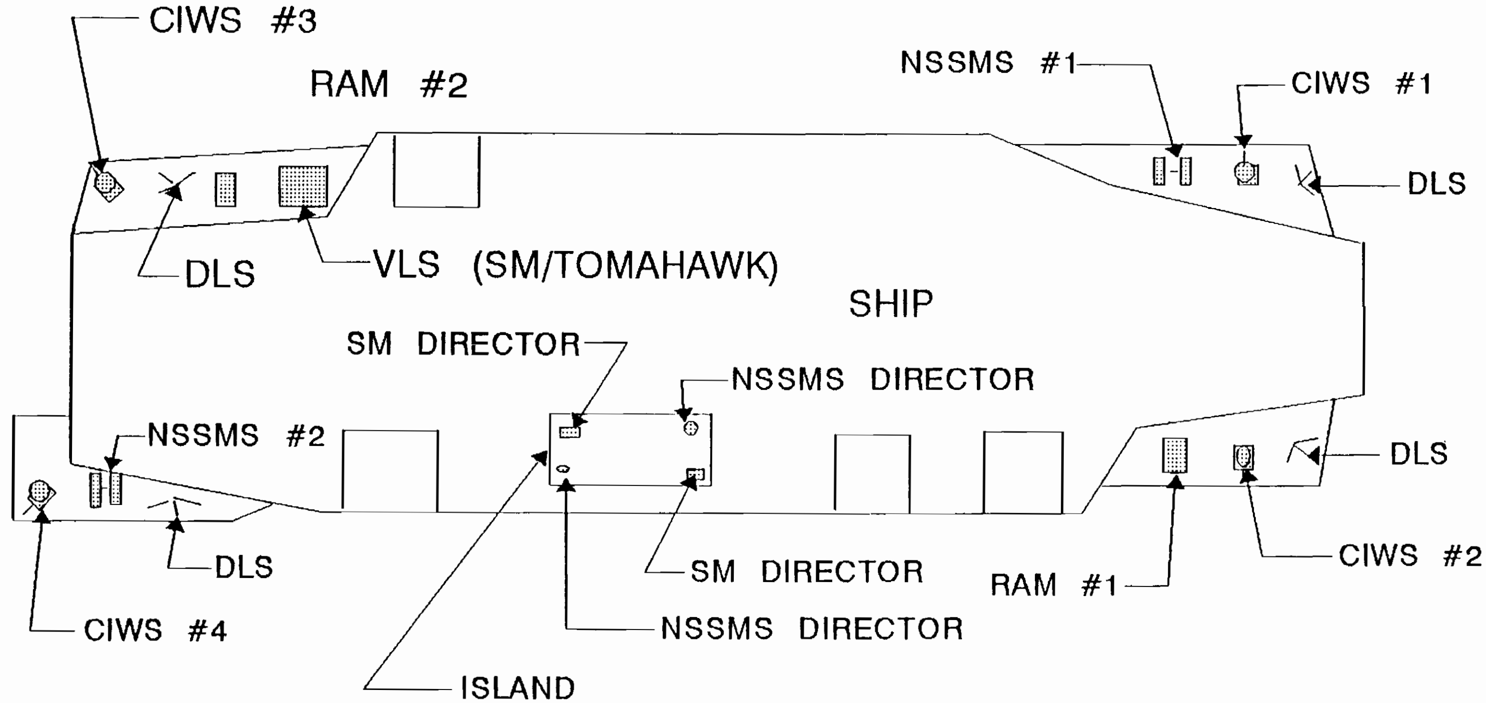


FIGURE 7

TOPSIDE ARRANGEMENT (PLAN VIEW)

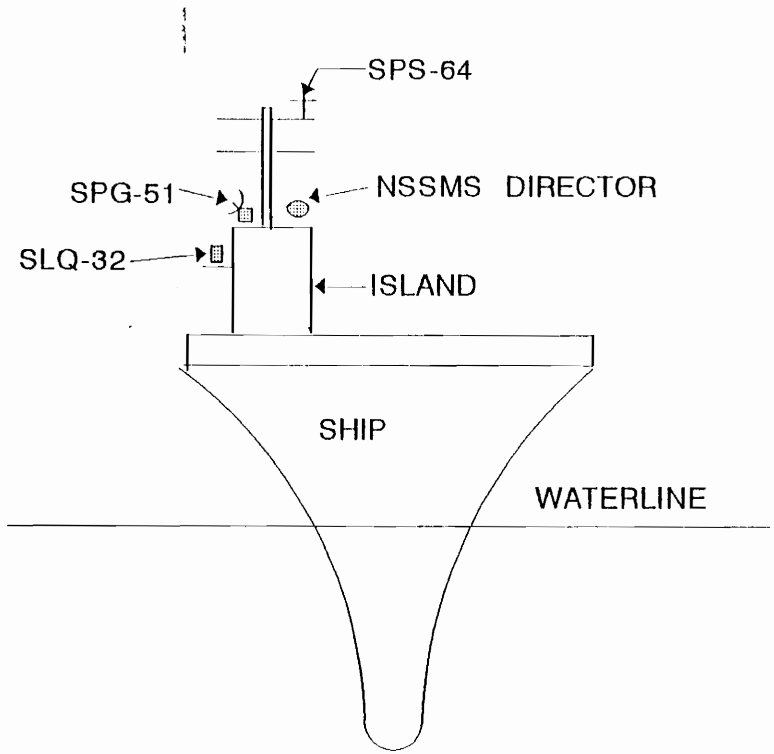


FIGURE 8

TOPSIDE ARRANGEMENT (BOW VIEW)

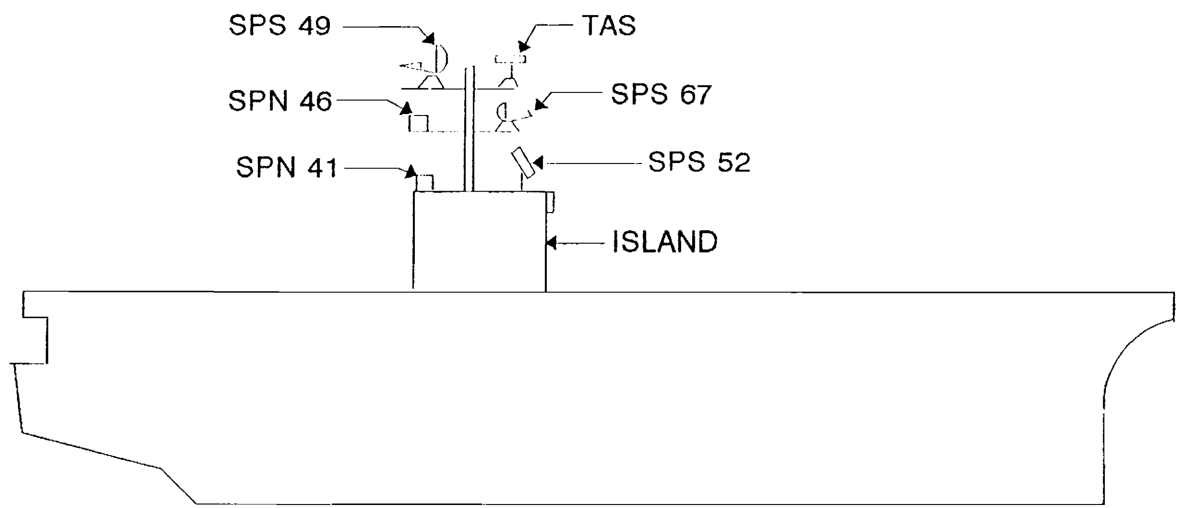


FIGURE 9

TOPSIDE ARRANGEMENT (STBD VIEW)

to better serve the design of the ship's self defense system.

The following major radar and weapon systems are located on the island and sponsons:

- Air Traffic Control Radars
  - AN/SPN-41
  - AN/SPN-46
- Air and Surface Search Radars
  - AN/SPS-52
  - AN/SPS-49
  - TAS
  - SPG-51 (SM Director)
  - MK-91 (NSSMS Director)
  - AN/SPS-67 (Surface/Air)
  - AN/SPS-64 (Surface)
- Weapons Systems
  - Tomahawk/SM (1 VLS and 2 SPG-51 Directors)
  - NSSMS (2 Launchers and 2 MK 91 Directors)
  - RAM (2 Launchers)
  - CIWS (4 Mounts)
  - DLS (4 SRBOC)
  - EW (2 SLQ-32s)

All antennas listed above, with the exception of the SPN-41 and SPN-46, would perform best if located on top of the mast. Obviously, this is not possible; therefore tradeoffs must be made based on the function, size, weight, and electromagnetic characteristics of the antenna. The following discussion is provided regarding rationale behind the initial selection of the major sensor and weapons components.

Topside Arrangement Rationale

SPN-41 and SPN 46 - Both antennas must be located on the after portion of the island with an unobstructed view of the aircraft approach zone.

Mk 23 TAS - TAS must be located as high on the mast as possible. Weighing in at approximately 2000 lbs it is possible to construct a platform off the mast in which to locate TAS. Since the primary function of TAS is to track high speed low flying cruise missiles, the higher on the mast the greater the radar horizon. Based on the curvature of the earth our radar horizon is calculated from the following equation:

$$D = 1.23(h + hm)^{.5}$$

D - radar horizon, nm

h - height of weapon system above the waterline, feet hm - missile height, feet

SPS-52 - Without a doubt the most noticeable radar aboard a surface combatant ship, the SPS-52 must be located on top of the superstructure for two major reasons: weight and size. The SPS-52 weighs 3200 lbs and has a swing radius of 7 feet. Since this represents our front line air surveillance radar, it is desirable to place the antenna in front of the mast in order to provide a clear unobstructed view of the range ahead of the ship.

SPS-49 - This radar represents our second line air surveillance radar and will also serve as the front line air traffic control marshalling radar. For these reasons the radar must be located aft of the mast. With a weight of 3000 lbs and a swing radius of about 12 feet, we can locate it on a platform on the mast.

SPS-67 - This radar represents our first line surface search radar. It is desired to locate the SPS-67 as high on the forward side of the mast as possible.

SPS-64 - This radar represents our second line surface search radar and our first line navigation radar. It is also desired to locate this antenna as high on the mast as possible. It should be located in such a fashion that when combined with the SPS-67 there are zero "no coverage" zones.

VLS - This system represents the first line anti surface/anti air missile if employing the Standard Missile and our first line land attack weapon if employing the Tomahawk. It is desirable to locate this system in a survivable location that would not be subjected to heavy seas. Furthermore, because of the significant weight of this system, it is desired to locate it opposite the island.

NSSMS and RAM - These systems represent our second and third layer of defense. Locating one of these systems on each corner gives the ship complete coverage against anti-ship cruise missiles.

CIWS - This systems represents our last line of active defense against the cruise missile. With four systems employed (one on the each side of the bow and one on each side of the stern) complete coverage is provided.

EW - Two SLQ-32 systems (which acts as both an active and a passive weapon system) will be required to provide complete radar surveillance coverage. As we will discuss later in this report, it is extremely desirable to provide as much separation as possible between SLQ-32 and CIWS. Therefore, both SLQ-32 antennas will be located on the island (one on each side).

DLS - The MK 36 SRBOC represents the absolute last line of defense. Complete 360 degree coverage can be provided with four systems, one at each corner of the ship.

NSSMS and SM Directors - The directors are positioned at each corner of the island. Each pair of NSSMS directors correspond to the NSSMS launcher with the same field of view. Two SM directors are located on the island, one in each opposite corner from the NSSMS directors in order to provide 360 degrees of coverage and redundancy in the event that one director fails.

Tables 1 and 2 summarize the characteristics of the antenna and weapon systems selected for this ship while Figures 7, 8, and 9 depict the location of each system.

TABLE 1

ANTENNAS CHARACTERISTICS

SYSTEM	PRIMARY FUNCTION	RANGE (NM)	FREQUENCY	PEAK POWER (Kw)	SWING RADIUS (FT)	WEIGHT (LBS)	*MTBF (HRS)
SPS 52	3-D AIR SEARCH	240	2900-3100 MHz	1000	7	3200	10000
SPS 49	2-D AIR SEARCH	*200	850-950 MHz	280	12	3000	12000
TAS	AIR TRACKING	20	CLASSIFIED	200	9	2000	5000
SPS 67	SURFACE SEARCH	*50	5500-5800 MHz	285	5	442	14000
SPS 64	SURFACE SEARCH	*30	3000 MHz	60	6	330	13000
SPN 41	AIR TRAFFIC CONTOL	*20	15.5 GHz	2.2	N/A	2625	11000
SPN 46	AIR TRAFFIC CONTROL	22	33.4 GHz	50	4	900	10000
SPG 51	SURFACE AND AIR TRACK (SM)	*100	10 GHz	30	N/A	550	4000
MK 91	SURFACE AND AIR TRACK (NSSMS)	50	10 GHz	2	N/A	3300	3500
SLQ 32	ELECTRONIC WARFARE	CLASSIFIED	CLASSIFIED	CLASSIFIED	N/A		20000
CIWS	AIR TRACKING	5	12.5-18 GHZ	CLASSIFIED	8	SEE WEAPON SYSTEMS	3000

* VALUES ASSUMED FOR THE PURPOSES OF THIS REPORT

TABLE 2

WEAPONS CHARACTERISTICS

SYSTEM	FUNCTION	RANGE (NM)	SPEED (fps)	DETECT TO FIRE TIME (SEC)	WEIGHT	**Pk	**MTBF (HRS)
SM	ANTI-AIR MISSILE	30	2700	15	*510000	.8/.7	1500
NSSMS	ANTI-AIR MISSILE	8	1049	11	28000	.8/.7	1000
RAM	ANTI-AIR MISSILE	3.3	1995	5	14560	.8/.7	1000
CIWS	ANTI-AIR GUN	1	**1000	5	12150	^.5-.75	800
DLS	MISSILE DISTRACTION						
SLQ 32	ELECTRONIC WARFARE						

Pk - Kill Probability. Values listed are for a 2 shot/1 shot salvo
MTBF - Mean Time Between Failures
* Includes verticle launch system
** Values assumed for this report
^ CIWS has a maximum burst time of 6 sec. The probability of kill is directly proportional to burst time. .5 PK corresponds to a 1 sec burst time and .75 corresponds to a six second burst time. Assume the relationship is linear.

4.1.3. Performance Assessment

4.1.3.1. Coverage

Combat system performance is significantly impacted by the placement or location of weapons systems. The goal of locating the topside elements is to avoid having zones of no coverage and provide zones of overlapping coverage.

Coverage is determined by developing a blockage assessment model (BAM). After a 3-D model of the topside arrangement is developed, which includes all sensors, weapons systems, structure, deck systems, etc., a computer analysis of the 3-D model can be run for each antenna and weapon system to determine individual systems coverage characteristics. Figure 10 shows a typical BAM and Figure 11 shows a typical 3-D model. Figure 10 indicates that this unnamed antenna or weapon system has a major blind spot between 225 and 0 degrees in azimuth and up to nearly 90 degrees in elevation.

It is beyond the scope of this report to build a 3-D model and perform BAM assessments.

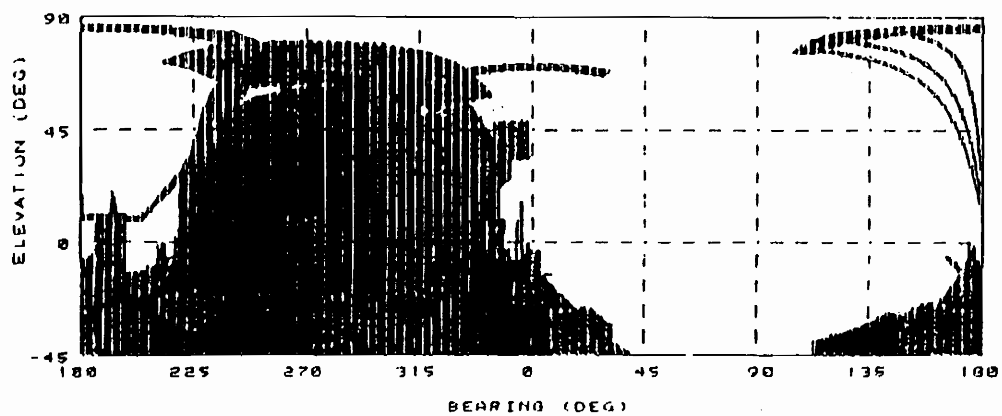
4.1.3.2. Reliability

Reliability is defined as the probability that a system or product will perform as designed for a given period of time when used under the required operating conditions. Reliability is a function of the systems failure rate or

BAM.ANALYSIS>

BAM OPTICAL COVERAGE

DATA FILE: USER2:[SOVKAM.BAM]TEST.ANA;1
RUN DATE: 1-MAY-90 AT: 13:17:59



VIEWPOINT (x,y,z):

434.00, 17.00, 111.20

DESCRIPTION:

THE TOTAL BLOCKAGE FOR THIS PLOT IS : 46.1 %

FIGURE 10 - Blockage Assessment Model (BAM)

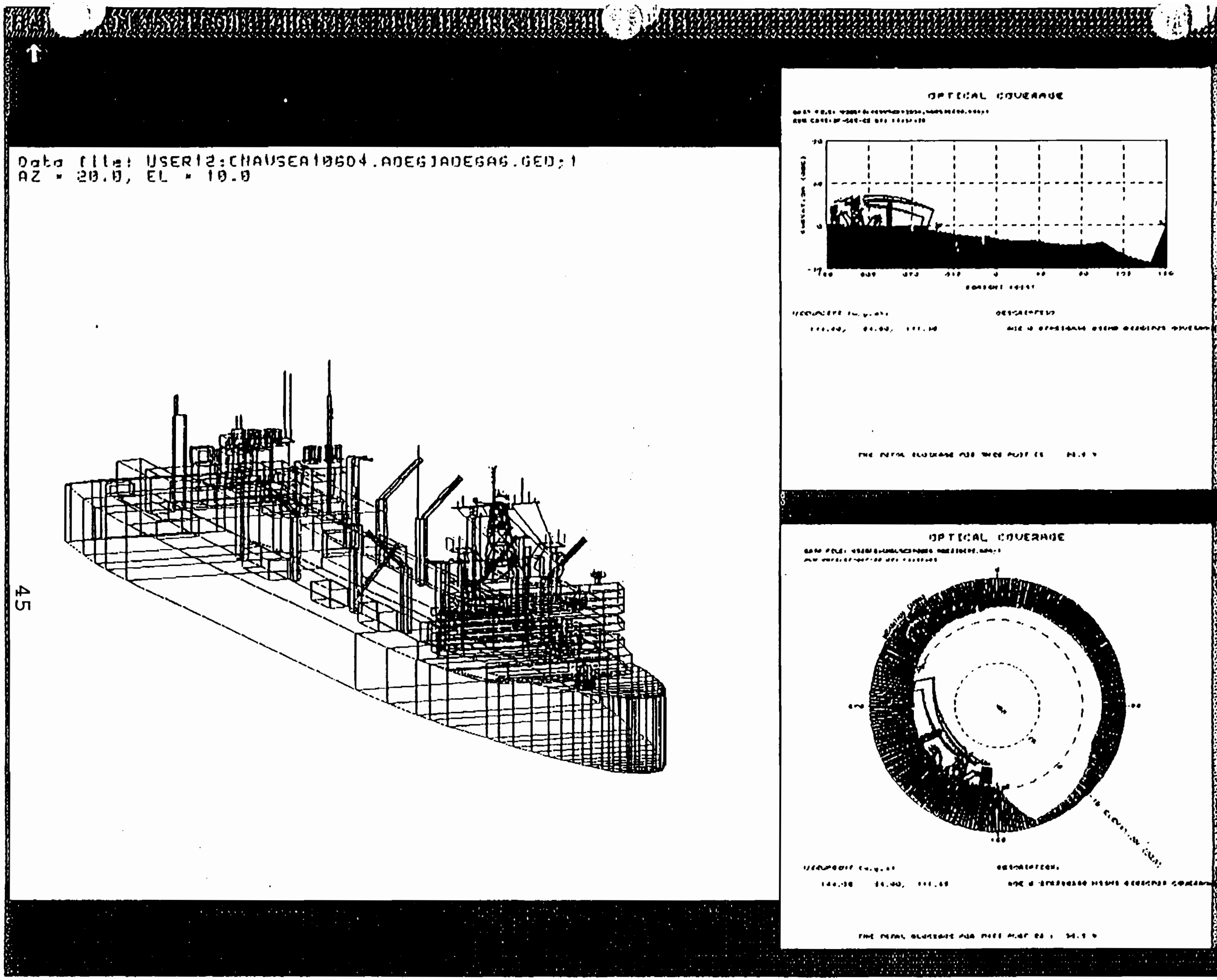


FIGURE 11 - 3-D SHIP MODEL

time between failures and the total operating time. MTBF (mean time between failures) information is indicated in Tables 1 and 2. Reliability can be calculated from the following equation:

$$R(t) = e^{-(1/MTBF)t}$$

R(t) - Reliability over time (t)

MTBF - Mean Time Between Failures, hours

t - time, hours

Based on the requirements stated in the concept design, the air defense system must perform two missions: one against high flying cruise missiles and one against low flying cruise missiles. Figure 12 shows the process for each. Appendix A provides the calculations for the reliability of each subsystem. From these calculations the overall reliability for the high altitude defense system is .97 and for the low altitude defense system is .90.

4.1.3.3. Availability

Availability is defined as the probability that a system will operate in its actual environment when called upon. Availability is a function of mean time between maintenance (MTBM) and mean down time (MDT). Both MTBM and MDT are based on scheduled (or preventive) and unscheduled (or corrective) maintenance actions. The following relationship is used to calculate the system's availability:

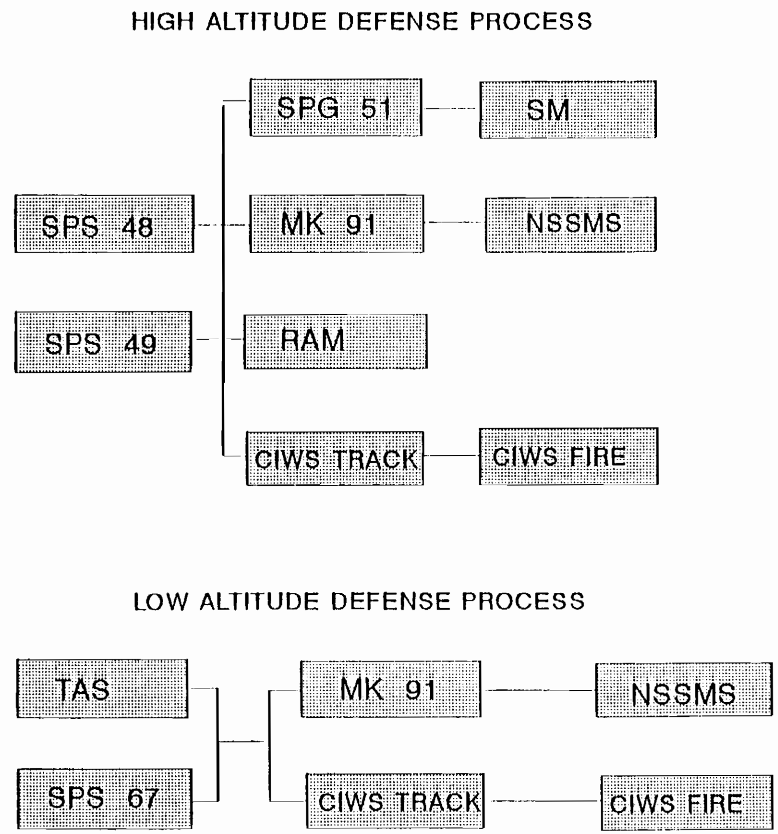


FIGURE 12 – AIR DEFENSE MISSION PROCESS

$$A = MTBM/(MTBM+MDT)$$

A - availability

MTBM - mean time between maintenance, hours

MDT - mean down time, hours

Appendix B shows the availability calculations for each sub system as well as the overall availability (A) for each of the following functional flow processes selected for this paper:

SPS 52 -> SPG 51 -> SM   A = .975

SPS 49 -> RAM   A = .985

TAS -> MK91 -> NSSMS   A = .974

SPS 67 -> CIWS(track) -> CIWS (fire)   A = .978

The requirements in concept design indicate that an availability of .98 is required for each of the major weapons system processes.

4.1.3.4. Reaction Time and Kill Probabilities

The goal of the combat system is to defeat an incoming missile threat(s). Time management is a major consideration in order to reach this goal. Based on the speed, bearing, and altitude of the incoming threat and the speed and location of the own ships weapons, it can be determined when to fire which missile for any given threat scenario. For the purposes of this report we will use the following scenario:

Missile	Speed	Altitude	*Tip Over Distance
1	3000 fps	50,000 ft	250,000 ft
2	2000 fps	40,000 ft	300,000 ft
3	1500 fps	30,000 ft	350,000 ft
4	3200 fps	20 ft	N/A
5	3200 fps	20 ft	N/A

* Horizontal distance from the ship that the incoming missile tips over and dives toward the ship.

Figure 13 provides a basic radar picture as time t=0 seconds. At this time the SPS 52 radar picks up 3 inbound missiles. The reaction time calculations start at the time the first missile is detected. Appendix C provides the detailed calculations that determines the time that each weapons system should be fired. Table 3 provides a summary of these calculations for all five missiles.

TABLE 3

REACTION TIME TABLE

Time	Missile 1	Missile 2	Missile 3	Missile 4	Missile 5
0	SPS 52 Contact	SPS 52 Contact	SPS 52 Contact		
281.67	SM2 Track				

296.67	SM Ready To Fire				
355.00	SM Fire				
359.00	SM Fire				
366				TAS Track	
377				NSSMS Ready to Fire	
377				Fire NSSMS #2	
379				Fire NSSMS #2	
381.67	NSSMS #2 Track				
389.24				CIWS Track	
395.28				Intercept	
397.28				Intercept	
398.62				Hits Ship	
421.32		SPG-51 Track			
421.67	Intercept				
425.67	Intercept				
436.32		SM Ready to Fire			
430.67	Confirm Kill				
432.67	NSSMS #2 Fire				
434.67	NSSMS #2 Fire				
392.28					CIWS #4 Track

393.28					Fire CIWS #4
397.35					Intercept
398.62					Hits Ship
468.97	Intercept				
470.97	Intercept				
475.97	Confirm Kill				
477.97	Fire RAM #1				
480.19	Intercept				
481	Hits Ship				
560.86			SPG 51 Track		
564.66		SM Fire			
568.66		SM Fire			
571.33		NSSMS #1 Track			
575.86			SM Ready To Fire		
631.33		Intercept			
635.33		Intercept			
640.83		Confirm Kill			
651.57		NSSMS #1 Fire			
653.57		NSSMS #1 Fire			
697.33		Intercept			
699.33		Intercept			
704.33		Confirm kill			

706.33		CIWS Track			
706.33		Fire RAM #2			
711.33		Fire RAM #2			
713.83		Intercept			
718.83		Intercept			
721.33		Hits Ship			
760.86			NSSMS #2 Track		
773.19			SM Fire		
777.19			SM Fire		
840.86			Intercept		
844.86			Intercept		
849.86			Confirm Kill		
883.10			NSSMS #2 Fire		
885.10			NSSMS #2 Fire		
928.86			Intercept		
930.86			Intercept		
935.10			Confirm Kill		
937.50			RAM #2 Fire		
940.86			CIWS Track		
942.50			RAM #2 Fire		
947.52			Intercept		
952.52			Intercept		

957.52			Confirm Kill		
958.52			Fire CIWS #3		
959.92			Intercept		
960.86			Hits Ship		

Table 3 shows that the combat system will successfully engage missiles 1 and 2 with SM, NSSMS, and RAM. Missile 3 can be engaged with SM, NSSMS, RAM, and CIWS. There is a high probability that missiles 1, 2, and 3 will be defeated.

Figure 14 shows the radar picture at t=366 seconds (i.e. when missile 4 is detected). Missiles 4 and 5 present a significantly more difficult problem. The low altitude does not allow the ship's radars to detect and track the missiles until they are within 17.39 nm of the ship. If the missile is traveling at 3200 feet per second (or Mach 3), a total flight time of only 32 seconds will exist between detection and ship impact compared to 481.67 seconds, 721.33 seconds, and 960.86 seconds for missiles 1, 2, and 3 respectively. If we assume that missile 5 follows missile 4 on the same bearing then missile 5 may not be able to be detected until after missile 4 is destroyed. In this case missile 5 will have a total flight time of 6.335 seconds. CIWS may be the only system that can engage missile number 5.

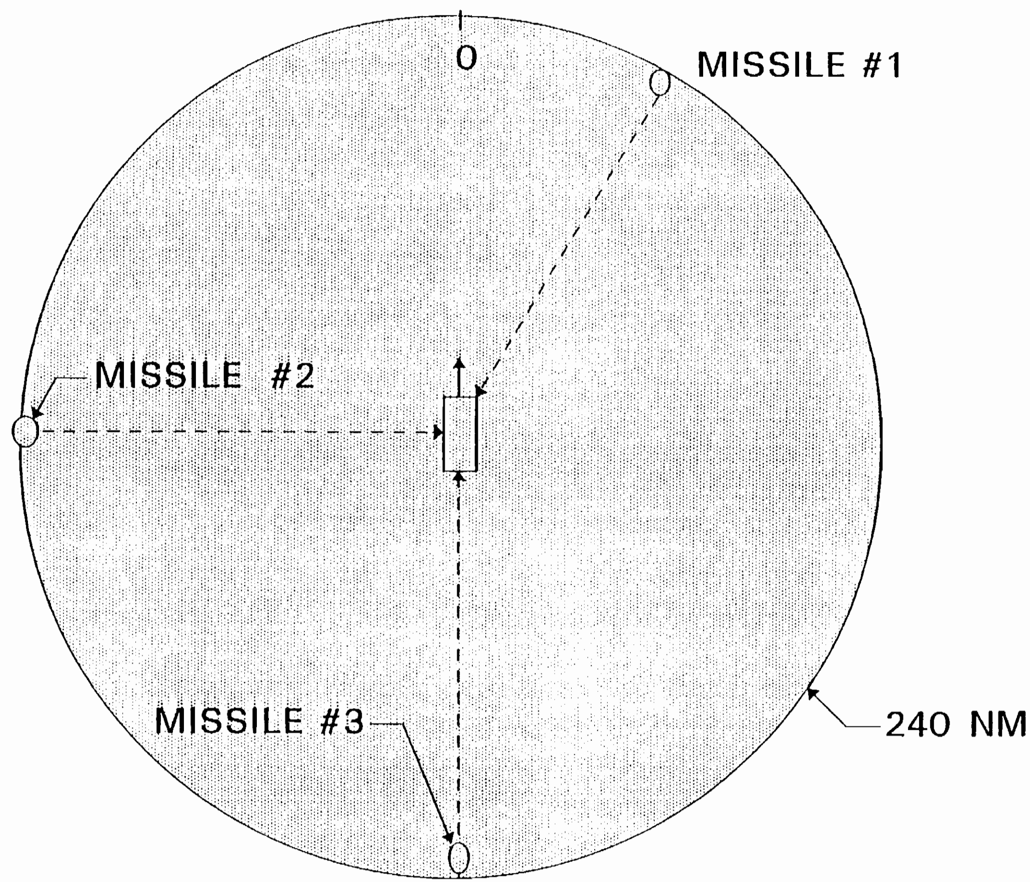


FIGURE 13 - Radar Picture at Time t=0 seconds

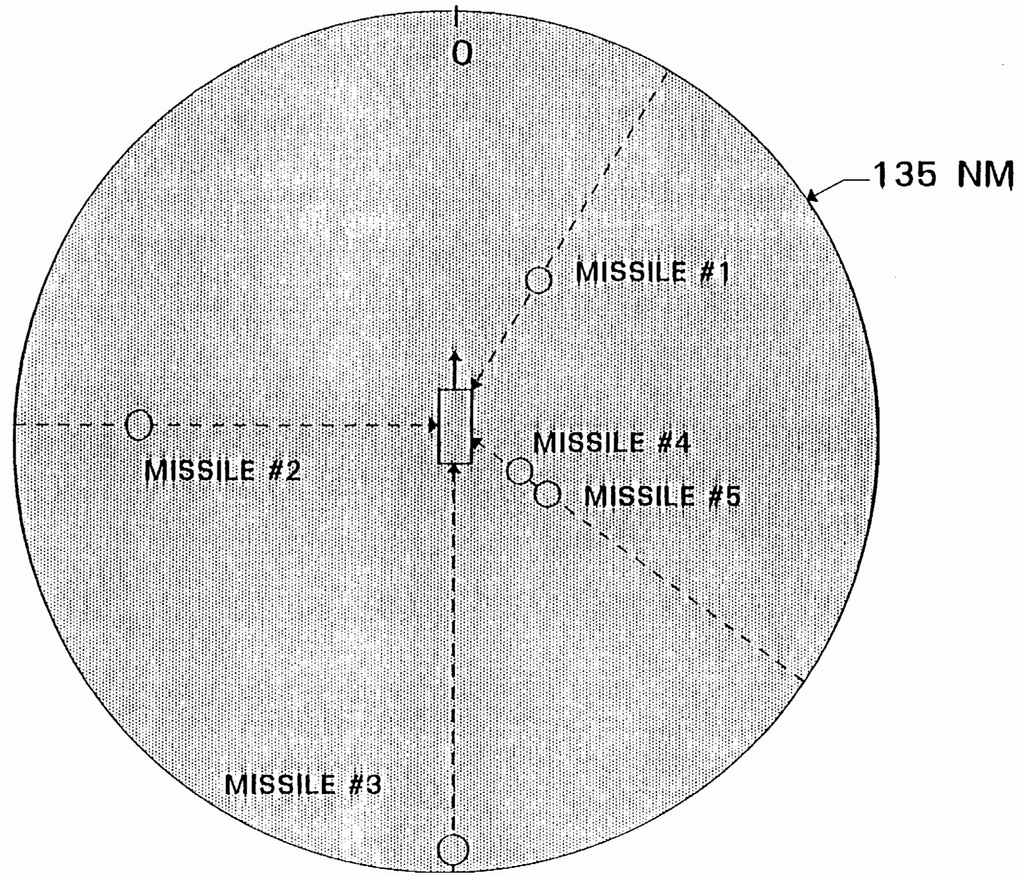


FIGURE 14 - Radar Picture at Time t=366 seconds

Kill Probabilities

In accordance with the requirements specified in section 3.2. of this report, the ship can be configured to launch either the standard missile or tomahawk from the vertical launch system depending on the specific mission of the ship. Appendix D and Table 3 were developed based on employing SM. If the mission so dictates that only Tomahawks are loaded in the VLS, then the probability of defeating the missile scenario given above is reduced given that Tomahawks can not be used against air threats. Table 4 shows the kill probabilities with and without SM for the threat scenario defined above.

TABLE 4

Kill Probabilities

	Missile1	Missile2	Missile3	Missile4	Missile 5
Pk w/SM	.998	.992	.996	.8	.7
Pk w/OSM	.940	.960	.982	.8	.7

Based on the above kill probabilities, the number of missiles that can be expected to hit the ship while deploying SM is 2.27 and without SM is 2.52. Calculations are shown in Appendix D.

Table 4 shows that for missiles 4 and 5 (which are low altitude missiles) the kill probability requirements can not be met for this scenario. Also, the kill probability for missile 1 does not meet the requirements if SM-2 missiles are deployed. Possible means to increase the kill probability against missiles 4 and 5 is to relocate the TAS to the highest possible point on the mast. This will increase the radar horizon, which will increase the distance away from the ship that the missiles can be detected.

The above kill probabilities are based on having all systems available and does not factor in reliability of each system. From section 4.1.3.2. of this report, there is only a 3% chance that the system which will engage missiles number 1, 2 and 3 will fail sometime during the deployment. There is a 10 percent chance that the system to engage missiles number 4 and 5 will fail during the deployment. From section 4.1.3.3. of this report, there is only a 2% chance that any of the combat subsystems will not be available when called upon.

4.1.4. Electromagnetic Interference (EMI)

The island aboard an aircraft carrier is small considering the number of high power antennas that must be located upon it. As one might expect, electromagnetic interference and frequency incompatibilities are common problems aboard the ship. The following discussion looks at potential problems areas that can inhibit the performance of the combat system. The goal is to identify potential EMI or RADHAZ problems before the ship is under construction. Once the ship is built or under contract, it is a very expensive prospect to relocate antennas.

EMI is defined as an electromagnetic disturbance, either intentional, unintentional, or natural, which interrupts, obstructs, or otherwise degrades or limits the effective performance of electrical, electronic, or electronically controlled mechanical equipment. For EMI to exist, three entities must be present: source, propagation, and observer. The source is the object emitting the electrical energy. Propagation refers to the transmission medium. The observer is the receiver of the energy provided by the source via propagation. Some typical causes of EMI peculiar to the ship are antenna physical proximity, same frequency of operation, reflections, broad band noise (BBN) and intermodulation interference (IMI). BBN is electromagnetic energy generated by miscellaneous structures installed on the ship such as chains and lifelines. Intermodulation interference occurs when the ship's structure absorbs electromagnetic energy and then radiates it back out.

Two tools most commonly developed to determine the electromagnetic compatibility and the frequency compatibility of the topside design is the EMI Source/Victim Matrix and the Frequency Spectrum Utilization chart, respectively. A typical matrix and chart are shown as Figures 15 and 16 respectively.

Commonly used methods to prevent or minimize EMI are:

- maximize blockage between source/victim antennas
- blanking (eliminate the ability for a source or a victim antenna to emit or receive a certain frequency)
- use composite materials for lifeline or chains in order to reduce BBN
- Filtering
- Apply Radar Absorbent Material (RAM)

Antennas listed in Table 1 that are potential interference problems are SPS 52/SPS 64, SPN-41/CIWS, and SLQ-32/Everything. Knowing that SLQ-32 is a broad band receive antenna, we would expect interferences from various shipboard emitters. Based on past data we know that the interference between SLQ-32 and CIWS is significant. From a topside arrangement perspective it is important to locate SLQ-32 and CIWS with as much distance and blockage between the two as possible. A compromised alternative is to locate the two vertical to each other.

VICTIM (RECEIVER) / SOURCE (EMITTER)	AN/SLQ-32(V)3	AN/SPS-64	AN/SPS-67	AN/SSR-1	AN/URN-25	HF Receivers	MK 1 MOD 0 SGSI	MK 15 MOD 12 CIWS	MK 23 MOD 8 TAS	MK 57 MOD 3 NSSMS	MK XII AIMS	GPS	OMEGA	RADHAZ	RF Burns	UHF Receivers	VHF Receivers
AIMS MK XII IFF	4H K,M				2B												
AN/SLQ-32(V)3		2						5S•		5S•				1P			
AN/SPS-64	4K	8J															
AN/SPS-67	4K 1G •		8J														
AN/URN-25	4H,M										4B						
HF Transmissions	2A			3B•	2A 2C•	4B	7E	7R		7J•	5A			1O	1O	6A	6A
Hull Generated BBN/IMI						5D										5D	5D
MK 15 MOD 12 CIWS	4K,L							7O•						1F,O			
MK 23 MOD 8 TAS	4H,K							7Q•			2N						
MK 57 MOD 3 NSSMS	4H,I,J									4J,O•				1F,O			
UHF Transmissions	8F			1B	1A•									1O		4B	
VHF Transmissions																	4B

EMI CATEGORY

1. Physical proximity
2. Adjacent frequency-equipment responds to high power or spurious outputs
3. Transmitter can operate at receiver
4. Equipment operates in same frequency band
5. Broadband Noise (BBN)/ Intermodulation Interference (IMI)
6. Harmonic relationship
7. Responds to out-of-band frequencies
8. Reflections

EMI FIX

A. Bond/ground IAW MIL-STD-1310E
B. Frequency management
C. Install F/C 1 URN-25
D. Clean up BBN/IMI sources
E. NAEC F/C 19 & 20 (SGSI)
F. Bel CAM Cutouts
G. Install ECP 336 and 312 (AN/SLQ-32)
H. Frequency sectoring (software program)
I. Install ECP 322 (AN/SLQ-32)
J. Install RAM
K. Blanking
L. ECP 327 (High Rep rate blanking) (AN/SLQ-32)
M. ECP 326 (Band 1 blanking) (AN/SLQ-32)
N. Repair/align equipment
O. Operational procedures
P. Post warning signs
Q. ORDALT 15204/ECP-CIWS-4296
R. EMI filters or additional shielding
S. Increase antenna to antenna isolation

• TOP 100 PROBLEM

695011

FIGURE 15

EMI Source/Victim Matrix

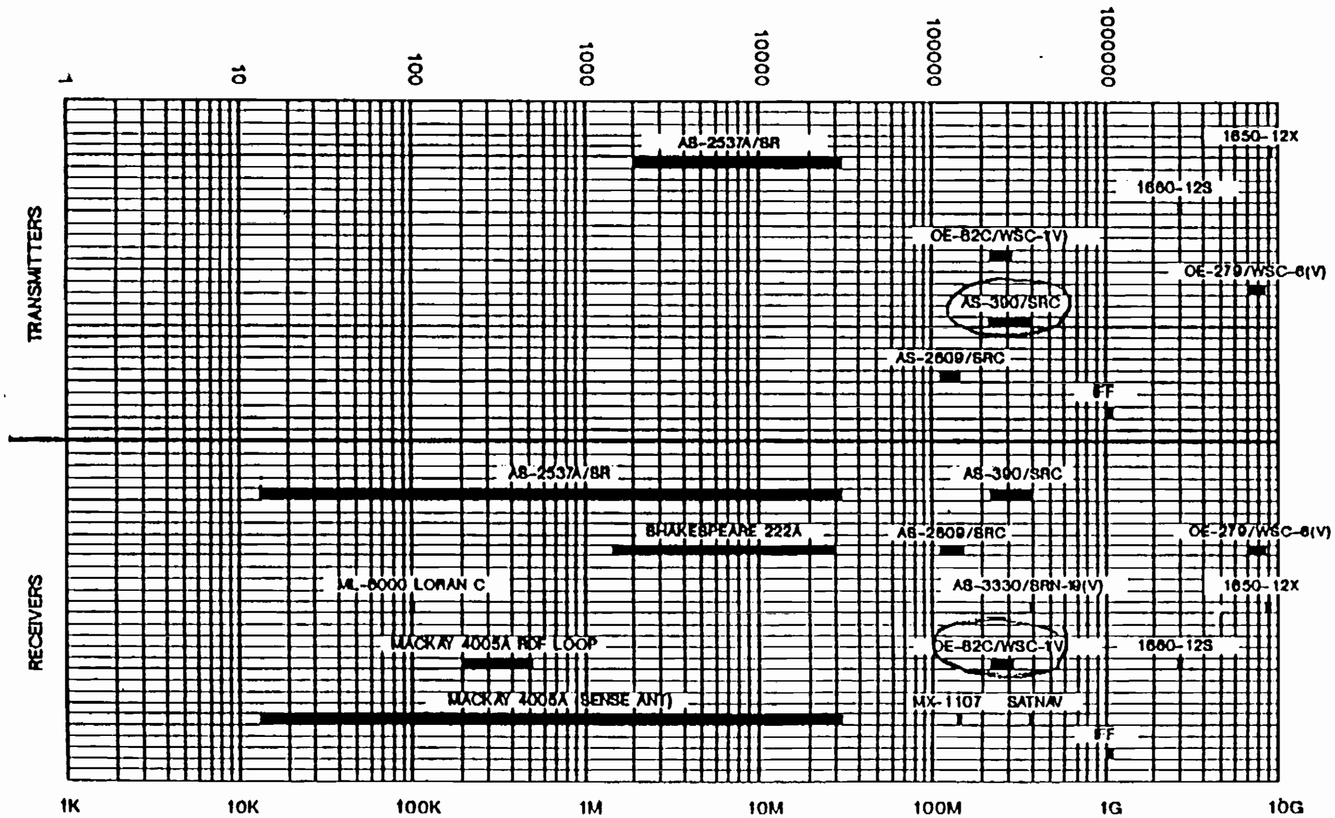


FIGURE 16 - Frequency Spectrum Utilization Chart

4.1.5. Weights

Tables 1 and 2 show the weight of each antenna and weapons system. It is of particular importance to note the total weight of the elements placed on the mast. The structural loading of the mast is a prime concern. Structural margins must be built into the mast to allow for growth. As the aircraft carriers are required to perform additional roles, growth in topside antenna systems can be expected. Table 1 indicates that 6672 lbs have been placed on the mast. An actual structural design of the mast is beyond the scope of this report.

In the overall design of the ship it is important to accurately determine the center of gravity of the ship. Topside weapons and antennas have a significant impact on the center of gravity. To provide input to the weight estimate of the ship two parameters must be provided: weight and location. Based on the location, moment calculations can be performed from which a center of gravity can be located. Moments are calculated by multiplying the weight of the object by the location of the object in three dimensions. Typically, the center of gravity reference points are the forward perpendicular or midship for the longitudinal center of gravity (LCG), the centerline of the ship for the transverse center of gravity (TCG), and the baseline of the ship for the vertical center of gravity

(VCG). A typical weight/moment calculation is provided below.

Element - SPS-52	Weight - 3200 lbs
LCG - 700 ft	Moment - 3150000 lb-ft
TCG - 90 ft	Moment - 405000 lb-ft
VCG - 170 ft	Moment - 765000 lb-ft

4.2 Combat System Below Deck Arrangement

Introduction

An aircraft carrier is a very complex system consisting of thousands of subsystems. In order to maintain operational control over this complex system a very structured organizational matrix is required. There are approximately 17 departments that make up the organizational structure of an aircraft carrier. The department that is responsible for the operation and maintenance of the combat system is known as the Operations Department and is one of the most manpower intensive departments aboard the ship as shown in Table 5. Figure 17 shows an organizational flow chart for the Operations Department relative to other departments on the ship and to the areas that make up the Operations Department.

Although the Navy establishes guidelines for the departmental structure aboard navy ships, it fails to establish the divisional structure within each department. This effort is left up to the individual ships, thus contributing to non standard organizations and uncontrollable ship's configuration changes to meet the particular desires of the individual crews. The following discussion will look at the required departmental facilities necessary to operate and maintain the anti-air defense system aboard the ship.

TABLE 5

DEPARTMENTAL MANNING

* Ship Side:	Officer	Enlisted	Total
1. Air Dept	22	764	786
2. Engineering Dept	16	462	478
3. Supply Dept	14	482	496
4. Operations Dept	37	385	422
5. Weapons Dept	11	450	461
6. AIMD Dept	9	269	278
7. Reactor Dept	17	217	234
8. Deck Dept	6	95	101
9. Admin Dept	11	91	102
10. Comm Dept	4	74	78
11. Medical Dept	6	31	37
12. Navigation Dept	2	13	15
13. Dental Dept	5	13	18
14. Chaplain Department	4	7	11
15. Safety Dept	1	7	8
16. Legal Department	2	5	7
	=========	=========	=========
Totals =	167	3365	3532

**AIRWING:	Officer	Enlisted	Total
1. VF1 (F-14)	35	230	265
2. VF2 (F-14)	35	230	265
3. VFA1 (F/A-18)	23	170	193
4. VFA2 (F/A-18)	23	170	193
5. VA (A-6)	46	240	286
6. VAW (E2-C)	35	140	175
7. VAQ (EA-6B)	42	150	192
8. VS (S-3)	40	164	204
9. HS (H-3)	25	300	325
	=========	=========	=========
Totals =	304	1794	2098

Total = 5630

* Ships side numbers where taken from the CVN 69 SMD dtd 24 June 1987.
** Squadron numbers where obtained from Lt Cmdr Crum, Sqn Manpower Section, Navy Annex, 614-5297.

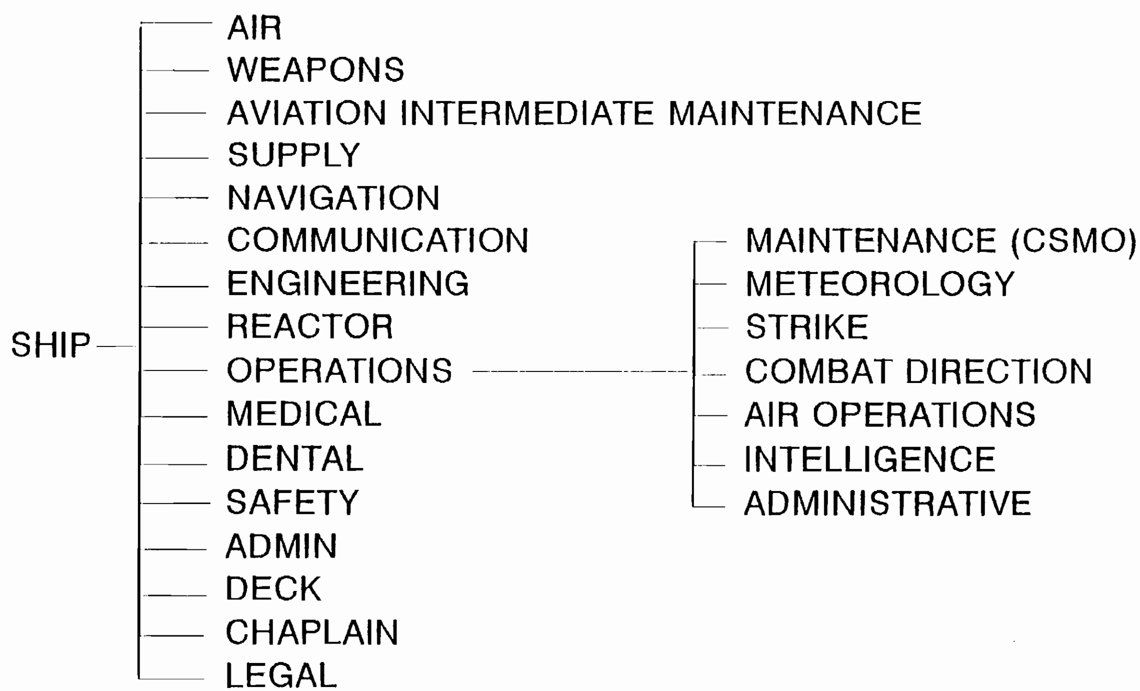


FIGURE 17
ORGANIZATIONAL FUNCTIONAL FLOW DIAGRAM (SHIP)

4.2.1. Types of spaces

There are five basic types of spaces found within any department: operational spaces, administrative spaces, maintenance spaces, stowage spaces, and equipment rooms. Operational spaces are those that contain man-machine interfaces with the exception of maintenance. Examples of operational spaces with the ship are the Pilot House or Bridge and the Combat Direction Center. Administrative spaces are simply the offices. Oddly enough, this is a very difficult area to define. Every sailor aboard the ship would like to have their own office or desk, but for a ship with 6000 personnel this would be impossible. Maintenance spaces refer to the facilities required to perform preventive and corrective maintenance on equipment. Maintenance facilities come in two types: shops and work centers. Shops are industrial type facilities where equipment or material is brought to repair or manipulate. Work centers are gathering places where tools and emergency (or ready spare) parts are kept. Work centers are for the crews that must go out into the ship to repair equipment in place. Stowage spaces can be broken down into two types: storerooms and issue rooms. Storerooms are unmanned spaces that are used for back up spare parts or material. Issue rooms are manned storerooms. Although each department will have some requirement for a ready service storeroom, the bulk of the storerooms and issue rooms are owned and operated by the supply department. Equipment rooms are normally unmanned spaces strategically located throughout the ship that contain the major pieces of equipment necessary to operate the ship or in this case the combat system. Examples of equipment rooms are Radar Rooms, Fan Rooms and Switchboard Rooms.

Two major areas of the combat system organization are of particular interest: maintenance and combat direction.

4.2.1.1 Combat System Maintenance Spaces

Within the operations department the Combat Systems Maintenance Officer (CSMO) is responsible for the all non-propulsion electronics and combat systems related equipment. To manage this large task, the maintenance is broken down into four major areas as shown in Figure 18. Weapons systems, radar systems and tactical data systems are of particular interest to this report. Relative to the systems identified in topside design of this report, the responsibilities for maintaining weapons and radar systems would be assigned as follows:

OEM - NSSMS, RAM, SM/Tomahawk, CIWS, DLS

OER - SPS 52, SPS 49, TAS, SPS 67, SPS 64, SPG 51, Mk 91, SLQ-32, SPN 41, SPN 46, CIWS Radar

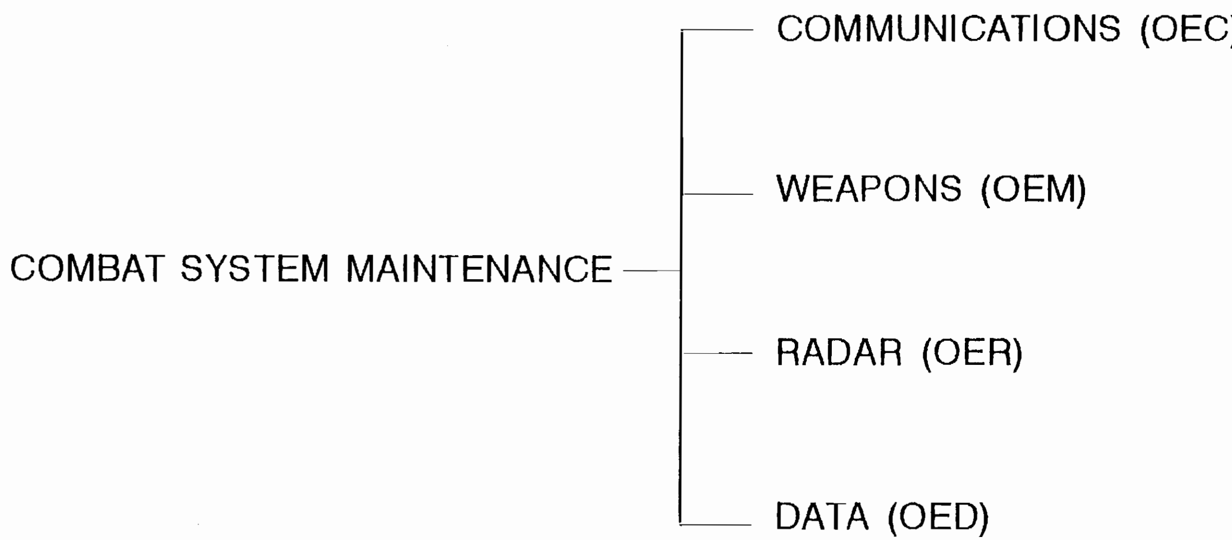


FIGURE 18

ORGANIZATIONAL FUNCTIONAL FLOW
DIAGRAM (COMBAT SYSTEM MAINTENANCE)

OEC will not be discussed since it would only involve maintenance for communications related electronics equipment. OED involves maintenance for all tactical data systems (i.e. tactical computers and related equipment).

Based on the above information we can determine that the Combat Systems Maintenance Division of the Operations Department would require the following facilities:

Combat Systems Maintenance Office

OEC/OEM/OER/OED Division Office

Combat Systems Maintenance Shop

Combat Systems Test Equipment Storeroom

OEC Workcenter

OER Workcenter

OEM Workcenter

OED Workcenter

4.2.1.2. Combat Direction Center (CDC)

CDC is in essence the heart of the combat system. From section 3.3. of this report there are six major functions of a combat system: surveillance, signal processing, detection and tracking, information display, decision, and engagement. CDC provides an area aboard the ship that allows the information display and decision support functions to take place. Engagement to a large extent also takes place from within CDC. Even though the launchers are located topside, the decision and fire control for the launchers are controlled from within CDC.

CDC is broken down into four areas: anti-air warfare (AAW), anti-surface warfare (ASUW), electronic warfare (EW), and anti-submarine warfare (ASW) as illustrated in Figure 19. Electronic warfare and antisubmarine warfare are specialized warfare elements of the combat direction system and for the purposes of this report do not have active weapons systems.

Allocating functional responsibilities within CDC to accomplish AAW and ASUW can take two different paths depending on the level to which the combat system is integrated. The first path produces an independent warfare area arrangement within CDC. Figure 20 show a basic functional layout of CDC applying this type concept. This arrangement is based on display sensor information from each of the main radars, making a decision regarding a potential threat, and if necessary making a recommendation to engage the threat. Another possible path is to arrange CDC based on the major functions being performed: displaying sensor information, decision, and engagement. Figure 21 depicts a possible space arrangement based on this functional flow process. This arrangement is only possible if the combat system is completely integrated. The software associated

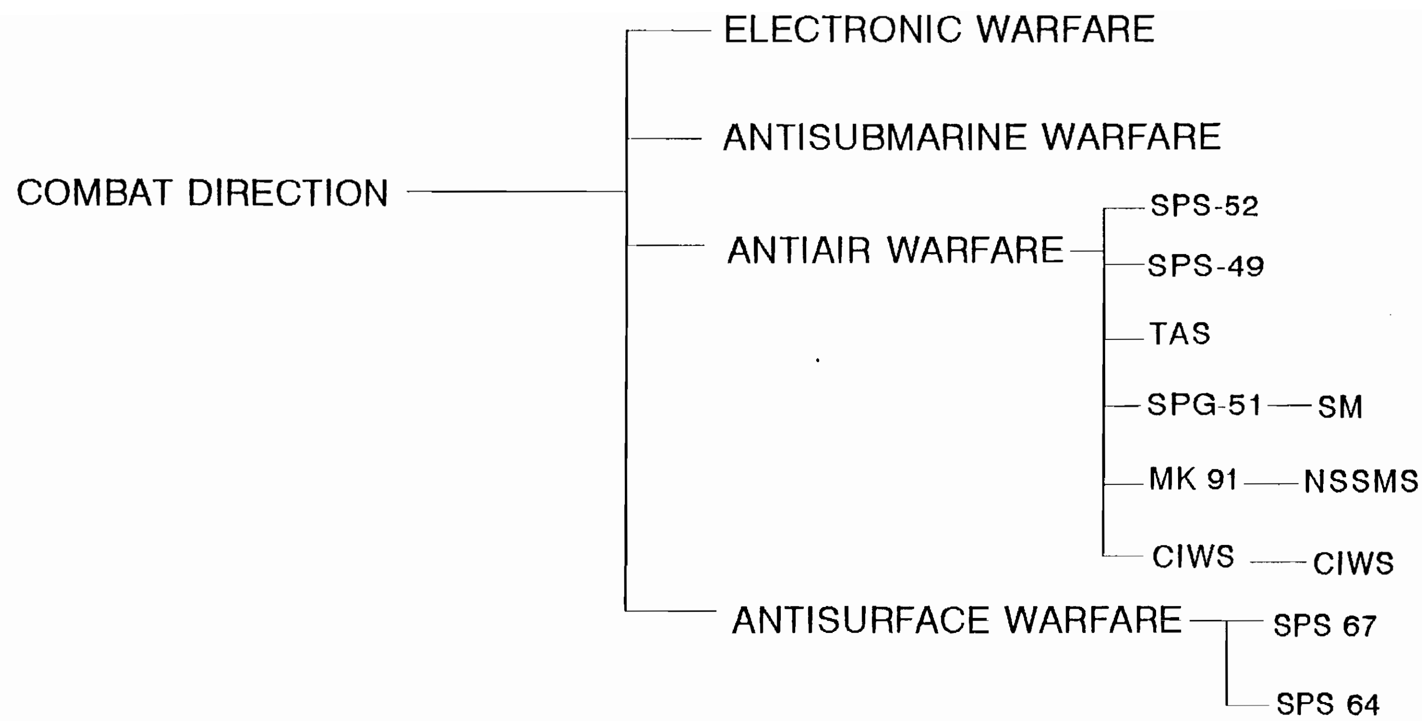


FIGURE 19

ORGANIZATIONAL FUNCTIONAL FLOW DIAGRAM (COMBAT DIRECTION)

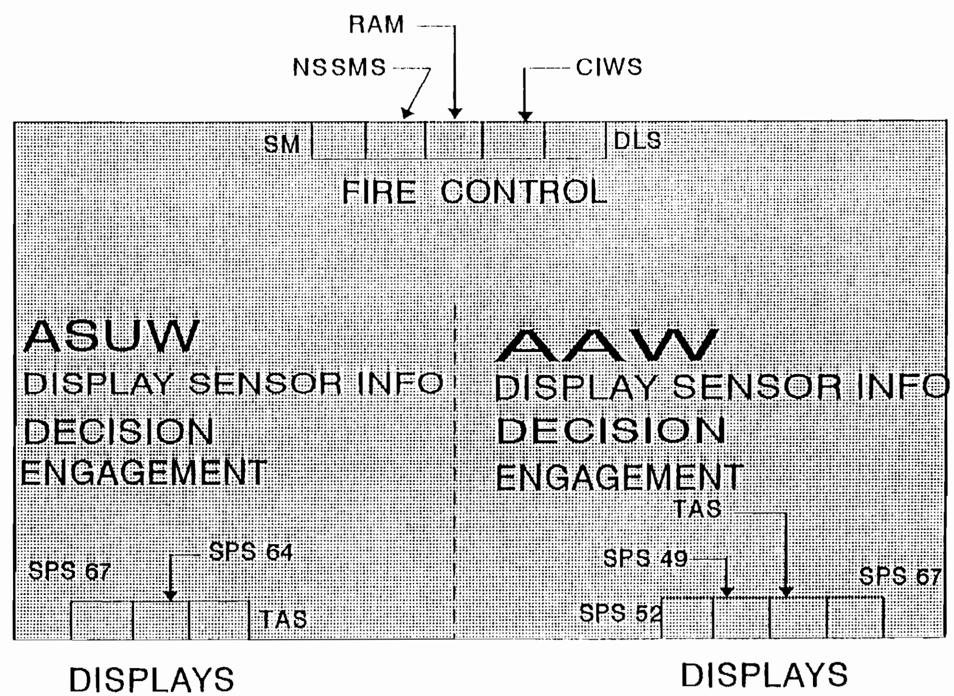


FIGURE 20

CDC ARRANGEMENT

(INDEPENDENT WARFARE AREAS)

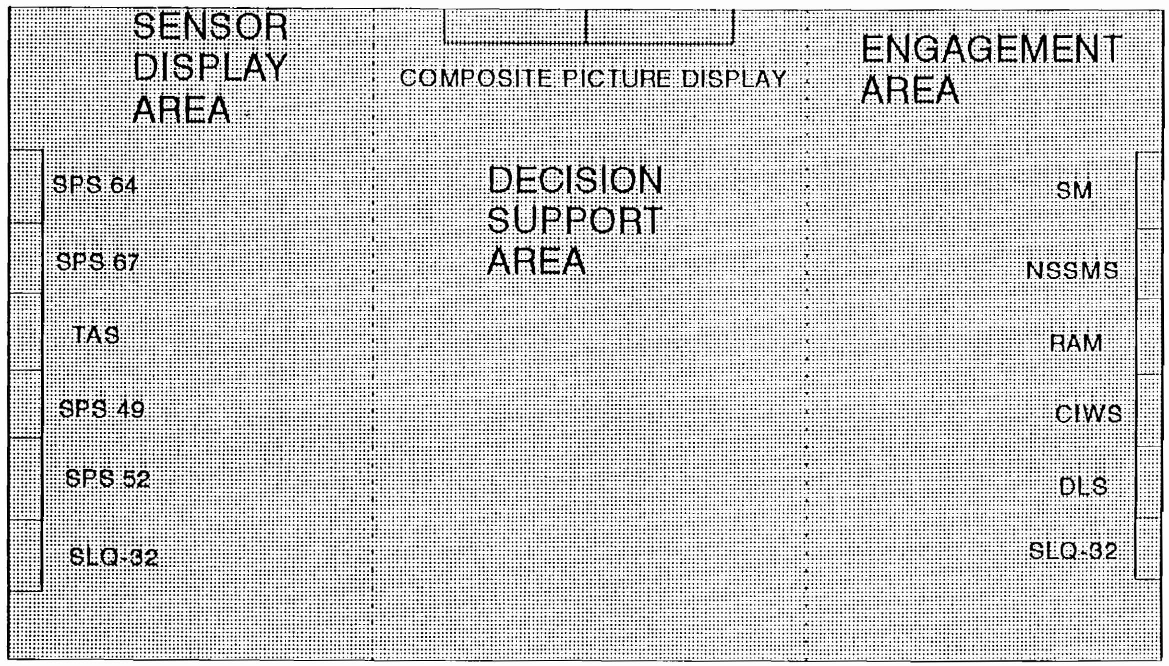


FIGURE 21

CDC ARRANGEMENT

(COMPOSITE WARFARE AREAS)

with processing data from the topside sensors must be developed in such a manner that a composite picture is painted on the display screens within CDC. This will allow for a more complete tactical picture to be painted for any given scenario and will not create a situation that forces individual warfare areas to compete for engagement resources. The tactical picture can be reviewed by a decision support group and determine the appropriate engagement scenario.

The location of CDC within the ship is also an important issue that must be addressed to ensure survivability. Accessibility and producibility must also be considered in the trade-off. Aboard existing aircraft carriers, CDC is typically located on the 02 level forward or on the 03 level amidship. Each location has its advantages and disadvantages. The 02 level forward offers greater protection from an explosion or a bomb attack on the flight deck. However, the further away from amidship the greater the movement of the ship due to pitching. Also, vibration from the bow catapults and its effect on sensitive electronic equipment must be considered. The 03 level amidship offers excellent accessibility and producibility. Proximity to the island, port and starboard passages, and minimized cable runs from topside equipment make this an excellent location. However, this location is not desired from a survivability standpoint. Being located just beneath the flight deck, an accident or bomb attack could eliminate the space, thus rendering the ship defenseless to incoming air, surface and subsurface attacks. A final location option would be to locate CDC on the third deck amidships. This would offer the most survivable location on the ship. However, production costs would be higher due to the increase in cable runs. Access to the space would also be more difficult. Based on the above information, the 03 level would be the preferred location for CDC.

5.0. SUMMARY

The design of any complex system involves many iterations in order to converge on a balanced design. This report develops a first iteration concept and preliminary design for an aircraft carrier anti-air self defense system. In an actual design many trade-offs (i.e. cost/performance) and design iterations would be made in order to determine the final product.

The following provides a summary of the stated requirements from concept design and the corresponding calculated values that resulted from preliminary design.

TABLE 6

Requirements/Design Values Summary

	High Flying Cruise Missile		Low Flying Cruise Missile	
	Requirement	Calculated Value	Requirement	Calculate Value
Kill Probability	.95	.99	.85	.75
Reliability	.95	.97	.90	.90
Availability	.98	.98	.98	.974

A potential problem area appears in the kill probability for the low flying cruise missile. In the stated scenario there are two low flying cruise missiles that follow one behind the other. This combat system has a kill probability of only .75 for missile 5 (18 percent below the requirement). The recommendation is to relocate the TAS radar onto the top of the mast in order to obtain the earliest detection of the missile. This will increase the ability to either maintain a longer fire burst from CIWS or allow RAM to obtain a shot at the second missile in addition to CIWS, therefore increasing the kill probability.

Since it is a very tedious process to perform all the time and distance calculations for each weapon system as it engages each threat missile, the process detailed in Appendix C should be developed in the form of a computer program or spread sheet. This project only analyzes one threat scenario. In an actual design many threat scenarios would need to be analyzed.

APPENDIX A - RELIABILITY CALCULATIONS

	MTBF (hrs)	1/MTBF	R(t)=e^(-1)/MTBFt
SPS 52	10000	0.0001	0.818729
SPS 49	12000	0.000083	0.846480
TAS	5000	0.0002	0.670318
SPS 67	14000	0.000071	0.866877
SPG 51	4000	0.00025	0.882496
MK 91	3500	0.000285	0.866877
CIWS (Track)	3000	0.000333	0.846480
SM	1500	0.000666	0.935506
NSSMS	1000	0.001	0.904836
RAM	1000	0.001	0.904836
CIWS (Fire)	800	0.00125	0.882496

The total operating time for SPS 52, SPS 49, TAS, and SPS 67 is 2000 hours. This is equal to approximately one 3 month deployment. These systems must be available 24 hours a day for the entire deployment. Assume the total operating time for SPG 51, MK 91, and CIWS (track) is 500 hours. Assume the total operating time for SM, NSSMS, RAM, and CIWS (fire) is 100 hours.

From Figure 12 the high altitude defense mission reliability
Rspg51*RSM2= 0.825580 =Z1
Rmk91*Rnssms= 0.784382 =Z2
Rciws*Rciwsf= 0.747016 =Z3
is R= [Rsps52+Rsps49-(Rsps52*Rsps49)]*[1-(1-RZ1)*(1-RZ2)*(1-Rram)*(1-RZ3))]
R(against high Flier)= 0.970940

The Low altitude defense mission reliability is
Rmk91*Rnssms = 0.784382 =X1
Rciws*Rciwsf = 0.747016 =X2
R=[Rtas+Rsps67-(Rtst*Rsps67)]*[X1+X2-(X1*X2)
R(against low flier) = 0.903957

APPENDIX B - AVAILABILITY CALCULATIONS

Operational Availability = MTBM/(MTBM+MDT)
MTBM = 1/(1/MTBF+1/MTBMs)
MDT = (λ Mct + fpt Mpt)/(λ+fpt))+LDT+ADT

MTBM = Mean Time Between Maintenance (hrs)
MDT = Mean Down Time (hrs)
MTBF = Mean Time Between Failure (hrs)
λ = Corrective Maintenance Rate
Mct = Mean Corrective Maintenance Time (hrs)
Mpt = Mean Preventive Maintenance Time (hrs)
fpt = frequency of preventive maintenance (hrs)
LDT = Logistics Delay Time (hrs)
ADT = Administrative Delay Time (hrs)

Assume LDT and ADT = .5 hours (all spare parts and material will be supplied from within the ship).

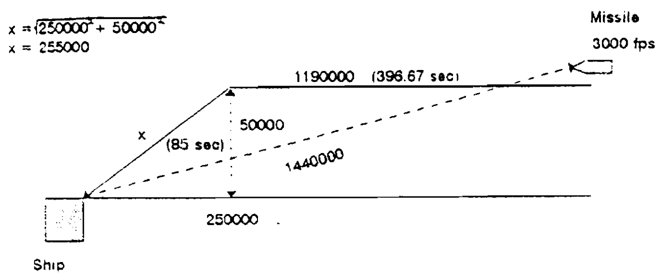
	MTBF	MTBMs	MTBM	λ	Mct	Mpt	fpt	MDT	Ao
SPS 52	10000	200	196.0	0.0001	5	2.5	200	3.000	0.984
SPS 49	12000	200	196.7	0.00008	4	2	200	2.500	0.987
TAS	5000	200	192.3	0.0002	4.5	2	200	2.500	0.987
SPS 67	14000	200	197.1	0.00007	3	1.5	200	2.000	0.989
SPG-51	4000	900	734.6	0.00025	4	2	900	2.500	0.996
Mk91	3500	850	683.9	0.00028	6	3	850	3.500	0.994
CIWS track	3000	800	631.5	0.00033	4.5	2	800	2.500	0.996
SM	1500	750	500	0.00066	5	2.5	750	3.000	0.994
NSSMS	1000	500	333.3	0.001	4	2	500	2.500	0.992
RAM	1000	500	333.3	0.001	5.5	0.25	500	0.750	0.997
CIWS fire	800	400	266.6	0.00125	3	1.5	400	2.000	0.992

Ao(SPS52-SPG51-SM) = 0.975
Ao(SPS49-RAM) = 0.985
Ao(TAS-MK91-NSSMS) = 0.974
Ao(SPS67-CIWSt-CIWSf) = 0.978

Appendix C - Reaction Time Calculations

Assumptions:
1. Kill confirmation time = 5 seconds
2. Time between firings for SM = 4 seconds
3. Time between firings for NSSMS = 2 seconds
4. Time between firings for RAM = 5 seconds
5. CIWS Maximum burst time = 6 seconds
6. Time between non-kill confirmation and firing next weapon = 2 seconds

I. Missile 1



Note: All distances are in feet.

- Assume missile is detected at maximum range of SPS 52 radar.
- Total flight time = 85.00 + 396.67 = 481 seconds.
- Total flight distance = 255000 + 1190000 = 1445000 feet.

a. REACTION TIME TABLE

TIME (SEC)	EVENT	THREAT - DISTANCE FROM SHIP (FT)	REMARKS
0	SPS52 DETECT	1445000	
281.67	SPG51 TRACK	600000	
296.67	SM READY	554990	
355.00	SM FIRE	380010	See part b. for calculations
359.00	SM FIRE	368000	
381.67	NSSMS TRACK	300000	
421.67	SM INTERCEPT	180000	

425.67	SM INTERCEPT	167990	
430.67	CONFIRMATION	152990	
432.67	FIRE NSSMS #2	146990	See part b. for calculations
434.67	FIRE NSSMS #2	140990	
468.97	INTERCEPT	38090	See part c. for calculations
470.97	INTERCEPT	32090	
475.97	CONFIRMATION	17090	
477.97	FIRE RAM #1	11090	
480.19	INTERCEPT	4430	See part c. for calculations
481	HITS SHIP	0	

b. Defense Missile Firings

1. SM Fire

```
                                                      Threat
2700 fps->                                           <-3000 fps
 |------------------------->|<-------------------------|
Ship      66.67 sec        180000     66.67 sec = 200010 ft
```

Fire SM when missile is 180000 + 200010 = 380010 ft.

2. NSSMS Fire

```
                                                        Threat
1049 fps->                                             <-3000 fps
 |-------------------------->|<------------------------|
Ship        45.76 sec        48000       45.76 sec = 137280 ft
```

Fire NSSMS when missile is 48000 + 137280 = 185280 ft
(note: can not fire NSSMS until after confirmation of SM miss)

c. Defense Missile Time to Intercept

1. NSSMS

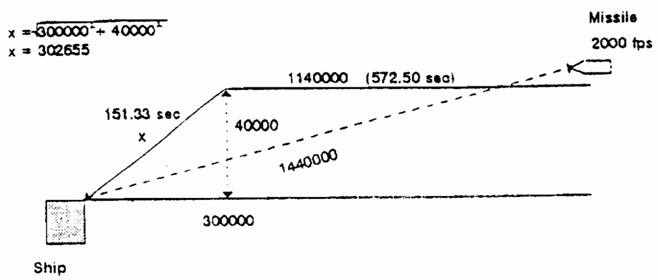
```
1049 fps->                   <-3000 fps
  |------------>|<---------------|
  0             x             146990 ft
```

1049t = x
3000t = 146990 - x
4049t = 146990
t = 36.3 seconds
x = 38090 feet

2. RAM

$$1995t = x$$
$$3000t = 11090 - x$$
$$4995t = 11090$$
$$t = 2.22$$
$$x = 4430$$

II. Missile 2



Note: All distances are in feet.

- Assume missile is detected at maximum range of SPS-52.
- Total flight Time = 151.33 + 572.50 = 721.33 seconds.
- Total flight distance = 302655 + 1140000 = 1442655 feet.

a. Reaction Time Table

Time (sec)	Event	Threat - Distance from ship (feet)	Remarks
0	SPS 52 Detect	1442655	
421.32	SPG 51 Track	600000	
436.32	SM Ready	570015	
564.66	SM Fire	313340	See part b. for calculations
568.66	SM Fire	305335	
571.33	NSSMS Detect	300000	
631.33	Intercept	180000	
635.33	Intercept	171995	
640.83	Confirmation	160995	
651.57	Fire NSSMS #1	139520	See part b. for calculations
653.57	Fire NSSMS #1	135515	
697.33	Intercept	48000	
699.33	Intercept	43995	
704.33	Confirmation	33995	
706.33	CIWS Track	30000	

706.33	Fire RAM #2	30000	See part b. for calculations
711.33	Fire RAM #2	19995	
711.33	Intercept	14995	See part c. for calculations
713.83	Intercept	5995	
721.33	Hits Ship	0	

b. Defense Missile Firings

1. SM Fire

```
                                                                Threat
2700 fps->                                                     <-2000 fps
  |------------------------->|<----------------------|
Ship       66.67 sec        180000     66.67 sec = 133340 ft
```

Fire SM when missile is 180000 + 133340 = 313340 ft.

2. NSSMS Fire

```
                                                                 Threat
1049 fps->                                                      <-2000 fps
  |-------------------------->|<-----------------------|
Ship         45.76 sec        48000        45.76 sec = 91520 ft
```

Fire NSSMS when missile is 48000 + 91520 = 139520 ft

3. RAM Fire

```
                                                                Threat
1995 fps->                                                     <-2000 fps
  |-------------------------->|<-----------------------|
Ship         10.03 sec        20000        10.03sec = 20060 ft
```

Fire RAM when missile is 20000 + 20060 = 40060 ft
(note: can not fire RAM until after confirmation of NSSMS miss)

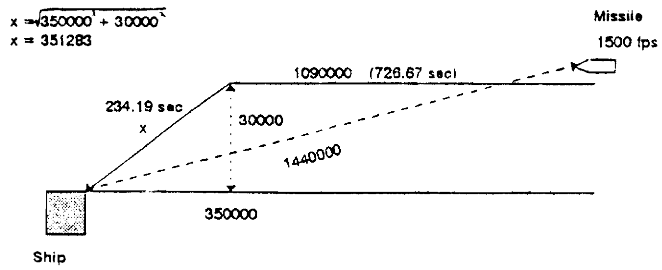
c. Defense Missile Time to Intercept

1. RAM

```
1995 fps->                  <-2000 fps
  |------------>|<---------------|
  0             x            30000 ft
```

```
1995t = x
2000t = 30000 - x
3995t = 30000
    t = 7.5 seconds
    x = 14995 feet
```

III. Missile 3



Note: All distances are in feet.

- Assume missile is detected at maximum range of SPS-52.
- Total flight Time = 234.19 + 726.67 = 960.86 seconds.
- Total flight distance = 351283 + 1090000 = 1441283 feet.

a. Reaction Time Table

Time (sec)	Event	Threat - Distance from ship (feet)	Remarks
0	SPS 52 Detect	1441283	
560.86	SPG 51 Track	600000	
575.86	SM Ready	577493	
760.86	NSSMS Track	300000	
773.19	SM Fire	281505	See part b. for calculations
777.19	SM Fire	275498	
840.86	Intercept	180000	
844.86	Intercept	173993	
849.86	Confirmation	166493	
883.10	Fire NSSMS #2	116636	See part b. for calculations
885.10	Fire NSSMS #2	113633	
928.86	Intercept	48000	
930.86	Intercept	44993	
935.10	Confirmation	38633	

937.50	Fire RAM #2	35038	See part b. for calculations
940.86	CIWS Track	30000	
942.50	FIRE RAM #2	27533	
947.52	Intercept	20000	
952.52	Intercept	12503	
957.52	Confirmation	5003	
958.52	Fire CIWS #3	3503	
959.92	Intercept	1403	See part c. for calcuations
960.86	Hits Ship	0	

b. Defense Missile Firings

1. SM Fire

```
                                                               Threat
2700 fps->                                                   <-1500 fps
  |------------------------>|<----------------------|
Ship       66.67 sec       180000     66.67 sec = 101505 ft
```

Fire SM when missile is 180000 + 101505 = 281505 ft.

2. NSSMS Fire

```
                                                                 Threat
1049 fps->                                                     <-1500 fps
  |-------------------------->|<-----------------------|
Ship        45.76 sec        48000        45.76 sec = 68637 ft
```

Fire NSSMS when missile is 48000 + 68637 = 116636 ft

3. RAM Fire

```
                                                                Threat
1995 fps->                                                    <-1500 fps
  |-------------------------->|<----------------------|
Ship        10.03 sec        20000         10.03sec = 15038 ft
```

Fire RAM when missile is 20000 + 15038 = 35038 ft

c. Defense Missile Time to Intercept

1. CIWS

```
1000 fps->                       <-1500 fps
  |------------>|<---------------|
  0             x               3503 ft

1000t = x
1500t = 3503 - x
2500t = 3503
    t = 1.40 seconds
    x = 1403 feet
```

IV. Missile 4

```
   _                                                 Threat
  |_|<--------------------------------<- 3200 fps
  Ship
```

Radar Horizon (RH) = 1.23(Sensor Height + Missile Height)$^{.5}$
TAS Height = 180 feet
RH = 1.23 180 + 20
RH = 17.39 NM or 104369 feet
Total Flight Time = 104369ft/3200fps = 32.62 seconds

Assume missile is detected at 104369 feet from the ship.

a. Reaction Time Table

Time (sec)	Event	Threat - Distance from Ship (ft)	Remarks
0 (366)	TAS Track	104369	
11 (377)	NSSMS Ready	69169	
11 (377)	Fire NSSMS #2	69169	
13 (379)	Fire NSSMS #2	62769	
23.24 (389.24)	CIWS Track	30000	
27.23 (393.23)	Intercept	17025	See part b. for calculations
29.23 (395.23)	Intercept	10833	
32.62 (398.62)	Hits Ship	0	

b. Defense Missile Time to Intercept

1. NSSMS

```
1049 fps->                       <-3200 fps
   |------------->|<---------------|
   0              x              69169 ft
```

1049t = x
3200t = 69169 - x
4249t = 69169
t = 16.23 seconds
x = 17025 feet

V. Missile 5

```
                                                   Threat
 |_|<----------------------------------<- 3200 fps
 Ship
```

Missile 5 follows missile 4 by 5 seconds.
CIWS acquires missile 5 after 2nd NSSMS shot kills missile 4.

Time (sec)	Event	Threat - Distance From Ship (feet)	Remarks
0	CIWS #4 Track	20273	
1	CIWS #4 Fire	17073	
5.065	CIWS Intercept	4065	See part b. for calculation
6.335	Hits Ship	0	

b. Defense Missile Time to Intercept

1. CIWS

```
1000 fps->                      <-3200 fps
  |------------>|<---------------|
  0             x               17073 ft
```

$$
\begin{aligned}
1000t &= x \\
3200t &= 17073 - x \\
4200t &= 17073 \\
t &= 4.065 \text{ seconds} \\
x &= 4065 \text{ feet}
\end{aligned}
$$

CIWS can get off a 5 second burst.

APPENDIX D - PROBABILITY OF KILL CALCULATIONS

Kill Probability (Pk) Calculations w/SM

Assumtions

SM Pk (2 shot) =	0.8	(1 Shot) =	0.7
MSSMS Pk (2 Shot) =	0.8	(1 Shot) =	0.7
RAM Pk = (2 Shot)	0.8	(1 Shot) =	0.7
CIWS Pk (1 sec burst) =	0.5		
CIWS Pk (2 sec burst) =	0.55		
CIWS Pk (3 sec burst) =	0.6		
CIWS Pk (4 sec burst) =	0.65		
CIWS Pk (5 sec burst) =	0.7		
CIWS Pk (6 sec burst) =	0.75		

Probility of defeating each missile can be calculated from
Pk = 1-(1-SMPK)(1-NSSMSPk)(1-RAMPk)(1-CIWSPk)

From Table 3 we see that the following occured
Missile 1 was engaged with 2 SM Shots, 2 NSSMS Shots, 1 RAM Shot
Missile 2 with 2 SM Shots, 2 NSSMS Shots, 2 RAM Shots
Missile 3 with 2 SMs, 2 NSSMSs, 2 RAMs, and 2 sec CIWS burst
Missile 4 with 2 NSSMS
Missile 5 with 5 sec CIWS burst

Missile 1	Pk1 =	0.988
Missile 2	Pk2 =	0.992
Missile 3	Pk3 =	0.9964
Missile 4	Pk4 =	0.8
Missile 5	Pk5 =	0.7

The expected number of hits on the ship can be calculated from
P(1 hit) = 1-(PK1)(Pk2)(Pk3)(Pk4)(Pk5)
Total Hits on shipP(1 hit)xnumber of missiles

P(1 hit) =	0.453122
Number Hits on ship =	2.265610

APPENDIX D (cont)

Kill Probability (Pk) Calculations w/o SM

Assumtions

SM Pk (2 shot) =	0	(1 Shot) =	0.7
MSSMS Pk (2 Shot) =	0.8	(1 Shot) =	0.7
RAM Pk = (2 Shot)	0.8	(1 Shot) =	0.7
CIWS Pk (1 sec burst) =	0.5		
CIWS Pk (2 sec burst) =	0.55		
CIWS Pk (3 sec burst) =	0.6		
CIWS Pk (4 sec burst) =	0.65		
CIWS Pk (5 sec burst) =	0.7		
CIWS Pk (6 sec burst) =	0.75		

Probility of defeating each missile can be calculated from
Pk = 1-(1-SMPK)(1-NSSMSPk)(1-RAMPk)(1-CIWSPk)

From Table 3 we see that the following occured
Missile 1 was engaged with 2 NSSMS Shots, 1 RAM Shot
Missile 2 with 2 NSSMS Shots, 2 RAM Shots
Missile 3 with 2 NSSMSs, 2 RAMs, and 2 sec CIWS burst
Missile 4 with 2 NSSMS
Missile 5 with 5 sec CIWS burst

Missile 1	Pk1 =	0.94
Missile 2	Pk2 =	0.96
Missile 3	Pk3 =	0.982
Missile 4	Pk4 =	0.8
Missile 5	Pk5 =	0.7

The expected number of hits on the ship can be calculated from
P(1 hit) = 1-(PK1)(Pk2)(Pk3)(Pk4)(Pk5)
Total Hits on shipP(1 hit)xnumber of missiles

P(1 hit) =	0.503752
Number Hits on ship =	2.518760

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