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Ship Systems Integration & Design Department

Technical Report

UAV Mothership

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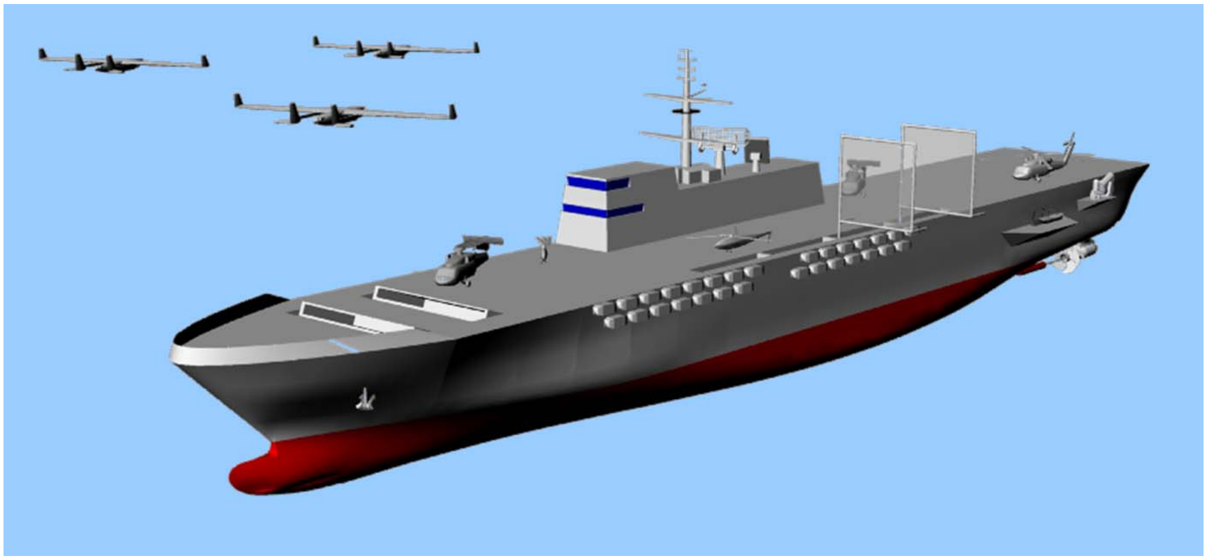

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Unmanned Aerial Vehicle(UAV) technologies have been rapidly advancing. Compact in size, diverse in application, and capable of autonomous operation, UAVs are appealing for a variety of military missions. The US Navy is exploring the potential use of unmanned vehicle systems for intelligence gathering and reconnaissance missions such as Anti-Submarine Warfare, search and rescue, and combat surveillance. UAVs reduce the risk of human loss, reduce monetary risk, and have extended operation flexibility and endurance. Large scale "swarms" of UAVs could scan a much larger combat area in less time than traditional airborne systems. The US Navy is currently reevaluating its approach to combat surveillance by modeling the effectiveness of a UAV swarm and may conclude that a swarm is indeed the most effective strategy. The need to integrate unmanned aerial systems on board a mothership capable of launching, recovering, commanding, and maintaining UAVs has driven the development of this concept ship designed around the function of its aircraft systems. It includes such features as automated shipboard fixed-wing UAV launching for fast deployment, a large helicopter flight deck for sequential vertical take-off, and catch nets that deploy from the flight deck for UAV recovery. The design presented in this study demonstrates the size and layout of a feasible ship that meets the demand for a UAV Mothership.

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Abstract

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Acronyms

A-160	- Hummingbird, Boeing unmanned helicopter
ASSET	-Advanced Submarine and Ship Evaluation Tool
ASW	- Anti Submarine Warfare
CIC	- Combat Information Center
FW UAV	- Fixed Wing Unmanned Aerial Vehicle
IR	- Infrared
KB4	- Killer Bee, Swift Engineering UAV
KG	- Keel to Center of Gravity
KTS	- Knots
MCR	- Maximum Continuous Rating
MW	- Mega Watts
PMM	- Permanent Magnet Motor
RA	- Righting Arm
SAR	- Search and Rescue
SH-60	- Seahawk
SSCS	- Ships Space Classification System
STUAS	- Small Tactical Unmanned Air System
SWATH	- Small Waterplane Area Twin Hull
SWBS	- Ship Work Breakdown Structure
TCS	- Tactical Control System
UAV	- Unmanned Aerial Vehicle

Introduction

Objective

To design an Unmanned Air Vehicle Mothership (UAV-M) capable of simultaneous mass operations of several different types of Unmanned Air Vehicles (UAVs).

Background

Advancing technologies in unmanned aerial vehicles used for combat area surveillance have great potential for the US Navy because of their low cost, expendability, operational flexibility and long range. An airborne swarm of UAVs can provide real time combat information of a large, potentially hostile area and could soon replace manned aircraft for Naval missions such as Anti-Submarine Warfare.

Sensor packages have been developed for various surveillance missions including Anti-Submarine Warfare, and could be installed onboard UAVs for aerial reconnaissance. For example, Magnetic Anomaly Detection picks up variations in the magnetic field surrounding a submarine and may eliminate the need for sonar buoys. UAVs could likewise be outfitted with infrared cameras, radar, or visual sensors to perform reconnaissance missions. By installing these sensor packages on many unmanned drones instead of a single larger manned helicopter, the probability of finding hostiles increases and the risk to personnel and equipment decreases.

To make unmanned aerial systems possible at sea, the US Navy requires an integrated shipboard system capable of operating and maintaining UAVs. This concept design demonstrates an effective solution to how such a UAV carrying ship might be configured and operated.

Requirements

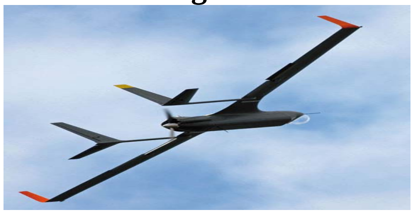
Given Requirements

The notional mission requirement for the UAV-M includes the launch and recovery of a “mass swarm” of small reconnaissance FW UAVs, 49 to 59 kg each. The mass swarm would consist of 50 small UAVs, and would require an additional 50 UAVs to be mission ready for continuous surveillance, 100 total. UAVs currently in competition for the Navy’s procurement are the Swift designed Killer Bee (KB4) and the Integrator by Insitu. The UAV-M must adequately launch and recover both of these FW UAV types. The design also requires that 12 larger rotorcraft UAVs be launched, recovered and stowed. The Boeing A-160 Hummingbird and the Northrop Grumman MQ-80 Fire Scout are in competition for this award. Since the A-160 Hummingbird is the larger of the two VT UAVs, accommodating it will be the focus of the ship’s conceptual design. In addition to the UAVs, the ship must also carry five SH-60 Seahawks are required. Physical dimensions for each aircraft are listed in Figure 1.

KillerBee

Wing Span: 3 m
Weight: 49 kg
Length: 2 m

Integrator



Wing Span: 4.8 m
Weight: 59 kg
Length: 2.1 m

A-160 Hummingbird

Main Rotor Diameter: 11.9 m
Weight: 1,815 kg
Endurance: 20+ hrs
Length: 10.7 m

SH-60 Seahawk

Main Rotor Diameter: 16.36 m
Weight: 9,927 kg
Length: 19.7 m
Height: 5.18 m

Main Rotor Diameter: 8.4 m
Weight: 1,430 kg
Endurance: 8 hrs
Length: 7 m

Figure 1: Aircraft Specifications

The UAV-M's hull design must meet additional requirements for stability and propulsion. The design must allow flight operations in sea state 5. The ship must incorporate a full electric propulsion system with a range of 4500 nm at 22 knots sustained speed. The ships complement is to be minimized and there must be stores available for 30 days of un-resupplied operations. Of course, the UAV-M is also required to meet naval classification standards, and have the survivability features of design requirements of a naval combatant.

More generally the overall architecture of the ship is to compliment the launch, recovery, and command of the aerial vehicle operations. The hull form chosen must also provide adequate seakeeping performance to allow for safe mission operations.

Deduced Requirements

In addition to the given requirements above, the UAV-M was also designed to meet derived requirements, which ensure that the Mothership can perform its missions and fulfill US Navy standards for combat operations.

To ensure that a swarm of unmanned aerial vehicles can effectively provide reconnaissance of combat zones, a target swarm deployment time of 40 minutes was derived. It was determined that a minimum recovery time was not required because the UAVs have long endurance capabilities and the UAV-M carries two swarms of fifty for continuous surveillance.

For the launch and recovery of manned and unmanned rotorcraft, requirements were deduced from two unique operating scenarios. In the first scenario, a team of four unmanned rotorcraft is launched sequentially with one SH-60. In the second, three SH-60 helicopters take off in sequence. To be capable of both operations, the UAV-Mothership must have a total of five helicopter landing pads, with three of the five large enough for SH-60 Seahawks.

Concept Summary

The UAV-M concept is a monohull with a large helicopter landing flight deck and compact starboard superstructure similar to current LHA and LHD Amphibious Assault Ships. Helicopters are stored aft below deck via two inboard elevators while fixed wing UAVs are stored forward in a compartment below compressed air launchers under the flight deck. FW-UAVs are recovered in 10m x10m nets that deploy from under the flight deck. Principal characteristics are listed below in Table 1, along with an artist's rendering of the UAV-M in Figure 2.

LOA:	**161 m**
LWL:	**150 m**
Beam:	**22.8 m**
Draft:	**5.34 m**
Depth:	**15.6 m**
Total Volume:	**46,795 m^3**
Displacement	**11,693 mt**
Crew:	**350**
Propulsion:	**4 x Wartsilla Diesel Generators**
Power:	**30 MW**
Speed:	**22 kt**

Table 1: Principal Characteristics

Figure 2: UAV-M Concept

Concept Generation

Aircraft Operations

After brainstorming and developing concepts of operation, all options were methodically analyzed for suitability in the UAV-M's design. The general layout of the ship includes UAV storage on the hangar deck and helicopter flight operations on the flight deck. Fixed wing UAV launch and recovery are placed on the hangar deck. Similar to any air capable ship, aircraft take off and land forward with the ship is heading into the wind.

Fixed Wing UAV Launch

The UAV-M must be capable of launching a swarm of fifty fixed wing UAVs for surveillance operations. Swift Engineering, Inc., the developer of the Killer Bee, has developed a trailer-based compressed air launching unit for the Killer Bee seen in Figure 3. Two operators can remove a KB4 from storage, mount it on the launch pad, bring its control systems online, and launch the KB4 in 10 minutes. Based on this land based sequence of operations, the procedure appearing in Table 2 and Table 3 were deduced for launching a single fixed-wing UAV, and a swarm of 50 UAVs from multiple launchers.

Figure 3: Killer Bee Compressed Air Launcher.

Operation	**Time Required** (minutes)	**Description**
Aircraft Handling	2	Remove UAV from storage; deliver to launch assembly line
Fueling	2	Aircraft are always stored without fuel
Sensor Pack Installation	2	UAVs can carry radar, IR camera, visual camera, magnetic anomaly detector
Communications	2	Onboard computer is brought online; connection with CIC established
Launch	2	Compressed air launcher is prepared; launch when airspace is clear
Single Aircraft Total	**10**	

Table 2: Single Aircraft Launch Summary

	Single Launcher (minutes)	Four Launchers (min.)	Six Launchers (min.)
Prepare Stations	10	10	10
Launch First FW UAVs	10	10	10
Launch Entire Swarm	98	23	15
Total Launch Time	**118**	**43**	**35**

Table 3: Swarm Launch Summary

The launchers developed by Swift are used for operations on the UAV-M. Since they will be launched into the wind, the compressed air launchers are positioned forward in the ship. Given these considerations, the following options were considered:

Six Launchers, Bow Mounted – As depicted in Figure 4, UAVs are launched from the second and third decks located next to UAV storage units. This configuration maximized flight deck space available for rotorcraft and makes the operation of both fixed-wing UAVs and rotorcraft possible. However, this configuration is potentially vulnerable to bow slamming from large waves in heavy seas.

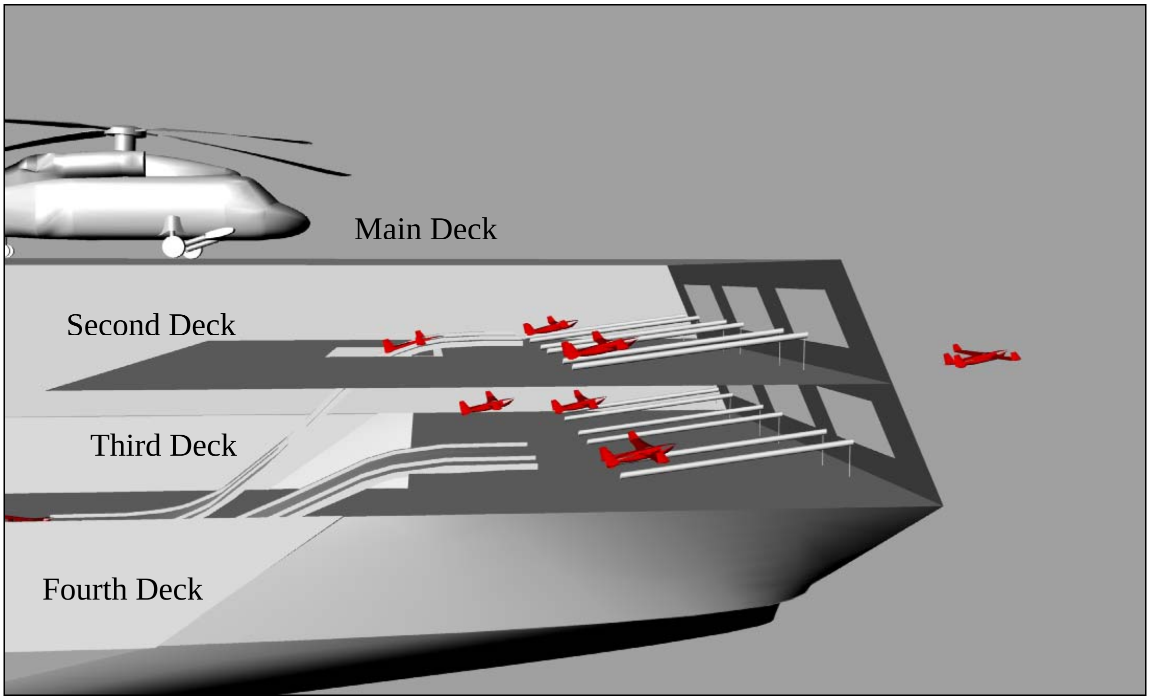


Figure 4: Six Launchers, Bow Mounted

Four Launchers, Bow Mounted - With a beam of over 22 meters it is possible to accommodate four launchers on the second deck, thus decreasing the vulnerability to bow slamming at the launch bays as seen in *Figure 5*. With only four launchers however, concurrent launch capability is reduced and the total swarm launch time is increased from 35 to 43 minutes.

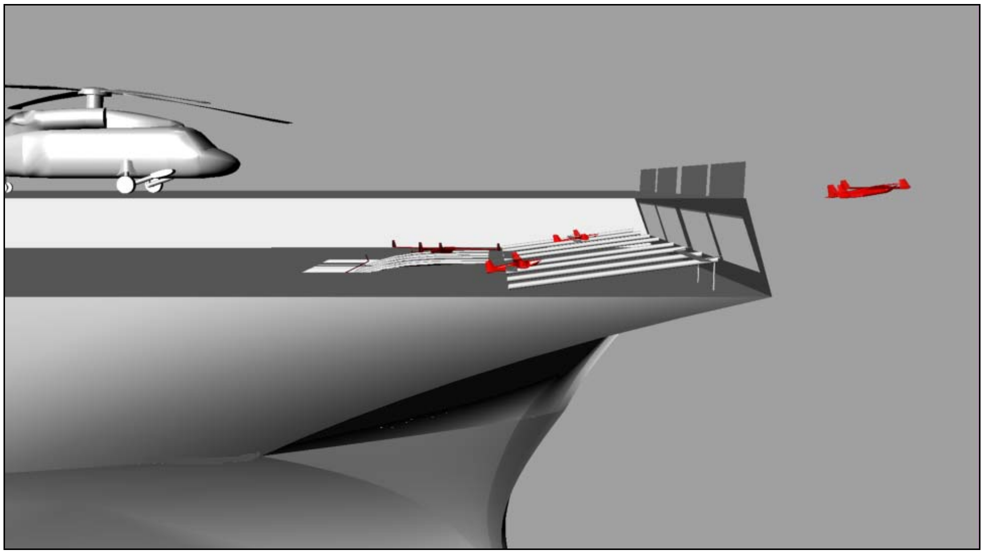


Figure 5: Four Launchers, Bow Mounted

Six Launchers, Top Mounted - Deploying the launchers through the flight deck of the ship (see *Figure 6*) can be accomplished if there is sufficient deck space for UAVs and rotorcraft. The UAVs can be transported from storage on the hangar deck to launch stations on the second deck by a simple UAV ramp system. Launching from the flight deck drastically minimized the threat of bow slamming and eliminates requirements for a minimum deck height. If arranged with sufficient space for helicopter pads, sequential operations are still possible.

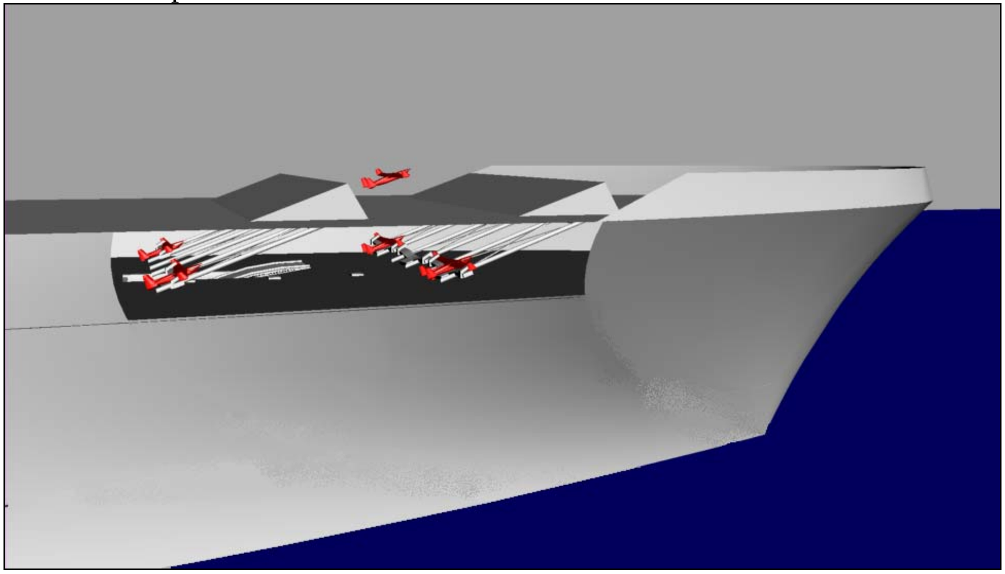


Figure 6: Six Launchers, Top Mounted

The top mounted configuration was chosen because the final hull arrangement has a suitably long flight deck, which is low relative to the waterline.

Storage, Assembly, and Launch Systems

Each component of the UAV-M was designed around the goal of recovering, handling, and launching a swarm of 50 UAVs as quickly and reliably as possible. To achieve this goal, many of the integrated systems are automated to reduce manning, conserve space, and expedite operations.

The launch process of a 50 UAV swarm begins on the third and fourth decks of the ship. UAVs such as the Integrator shown in Figure 7 are stored in the forward end of the ship below the launchers in secure racks. Two independent systems, symmetric to the ship's centerline, are arranged in parallel to provide redundancy when preparing UAVs for launch. First, an automated forklift similar to existing automated pallet loading systems removes a UAV from the rack and deposits it on a conveyer ramp on the third deck shown in Figure 8. The conveyer carries the aircraft to the second deck where a crew fuels and installs a surveillance package. The starboard conveyer accesses three forward launchers while the port conveyer accesses three rear launchers all on the second deck. The crew on the second deck then uses a hoist to transport aircraft to one of three launchers where the aircraft takes off as soon as airspace is clear shown in Figure 9.

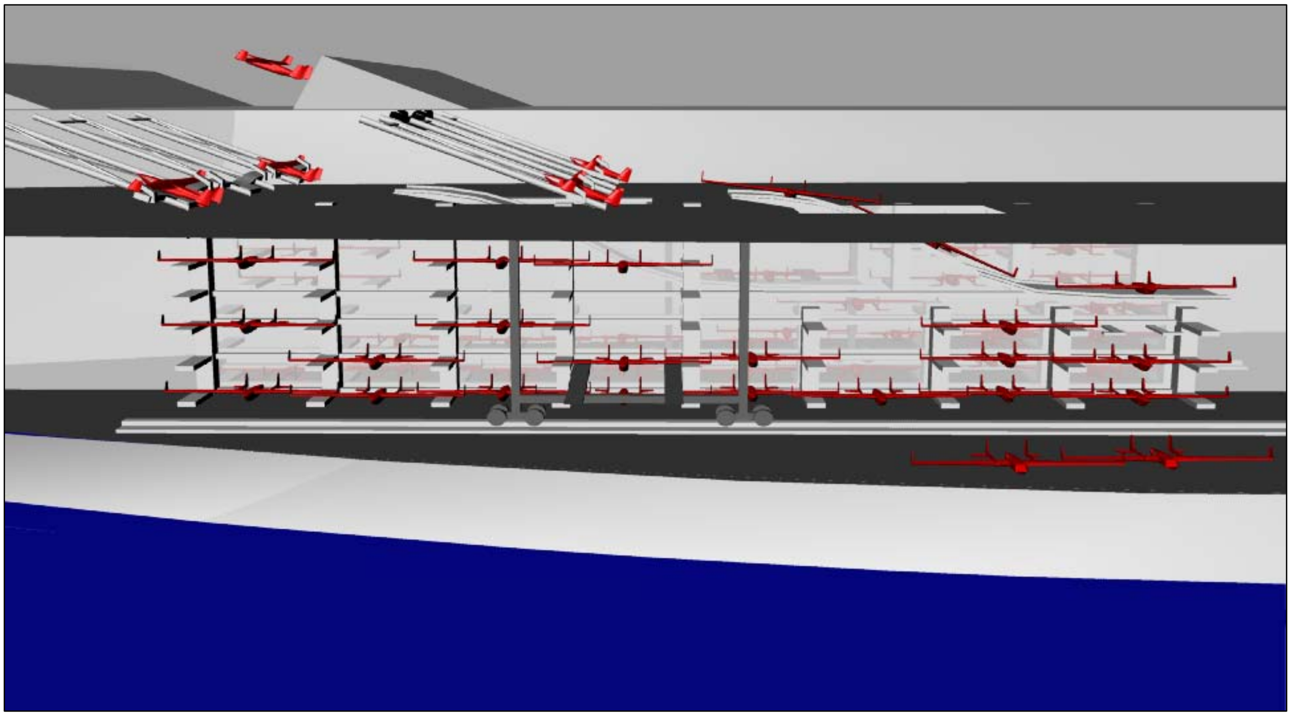


Figure 7: Cut-away View of Storage and Launch Stations

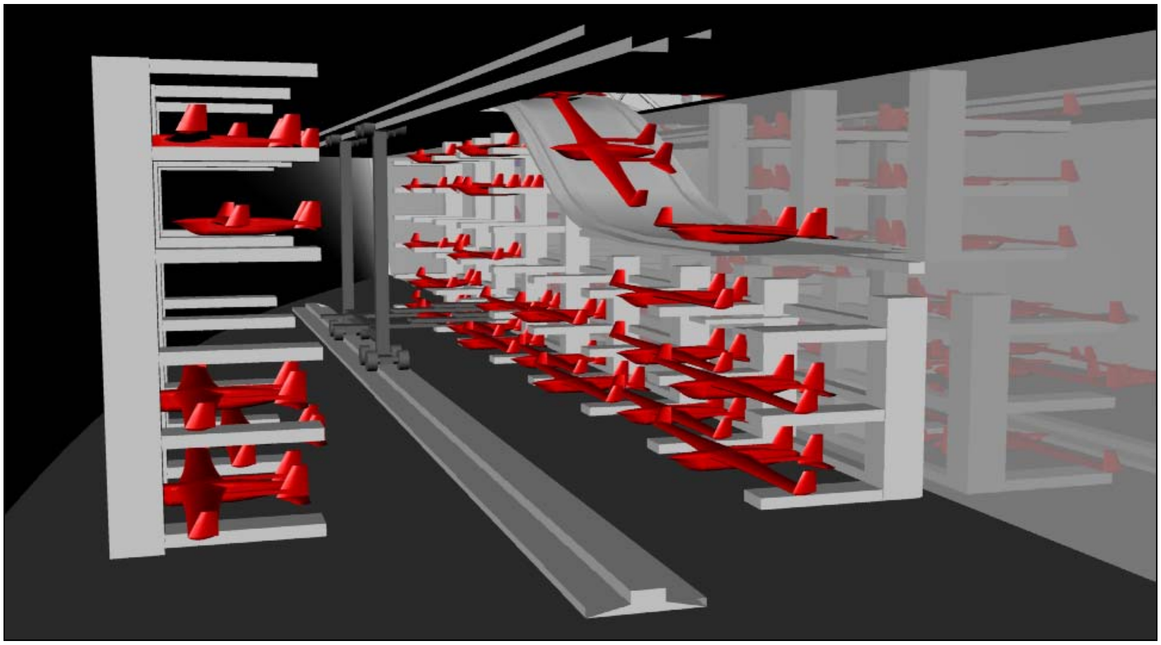


Figure 8: UAV Storage Racks on Third and Fourth Deck

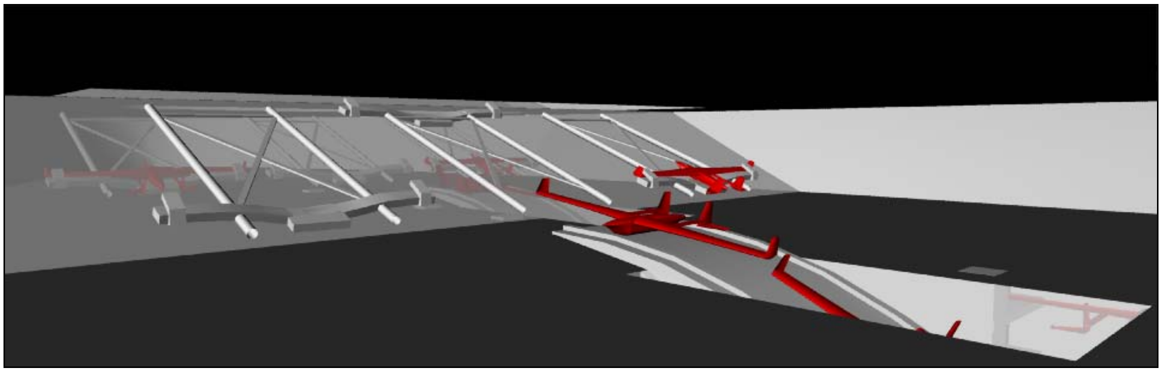


Figure 9: Fixed Wing UAV Launchers on Second Deck

Fixed Wing UAV Recovery

To enable continuous unmanned aerial surveillance, the UAV-M is equipped with two swarms of 50 fixed wing unmanned aircraft. The recovery and launch systems were designed so that the first swarm is recovered while the second is launched simultaneously. Safety and reliability were important objectives in the design of the recovery system, however the same timeliness required for launching UAVs was not as important for recovery since the UAVs can stay airborne for up to 24 hours.

The mechanism for UAV recovery is adapted from land based operation in which UAVs fly into nets and attach to the net with hooks. A second mechanism is available where a taut vertical cable is suspended and UAVs hook the wire at their wing tips and spin to a stop on the cable. The UAV-M utilizes nets which are a proven, reliable, and more readily adapted to a shipboard installation. Based on nets used in land based UAV development, the ship's nets will be 10m x 10m. The following recovery net arrangements were considered.

Outboard Nets - The first arrangement of nets allows concurrent fixed wing UAV and rotorcraft operations by extending the net below the flight deck on the port and starboard sides. In this way, helicopters can be landed while nets are extended. In addition, recovery of UAVs is accomplished below deck where they are also serviced and stored making transport simple and space efficient. To reduce the risk of aircraft crashing into the sides of the ship, the nets are spaced from the ship as seen in Figure 10 below, depicting the retraction of five different nets. Each net has a corresponding bay in the side of the ship that is three decks tall and sealed with a weather-tight door.

The outboard arrangement of nets is simple since as the nets include only one range of motion. Up to six nets on each side of the ship can be accommodated, depending on the size of the ship. However, the 10m x 10m bays on the sides of the ship make them more vulnerable and set requirements for a minimum bulkhead height. Most importantly, given the distance that the nets extend from the centerline of the ship and the roll of the ship during operations in sea state 5, the nets would often be submerged by ocean waves, rendering them useless for UAV recovery and subjecting the nets to extreme wave loads.

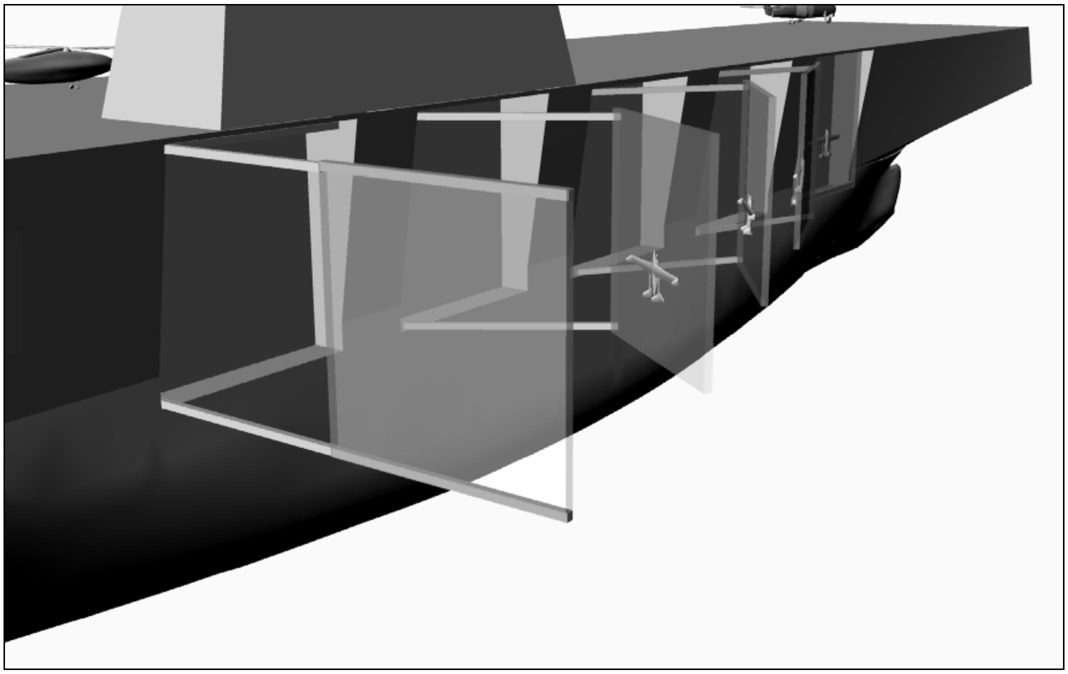


Figure 10: UAV Recovery with Outboard Nets

Top Mounted Nets - In this design, nets are elevated from bays in the flight deck and pivot to the outside of the ship as seen in the four bays in Figure 11. Top mounted nets are slightly more complex, involving two degrees of motion and only the port side of the ship can be outfitted with nets to protect the superstructure. In addition, rotorcraft operations are restricted when nets are deployed. However, top mounted nets are a better option for the UAV-M since they must operate effectively in sea state 5 and because there is no minimum requirement for the number of nets.

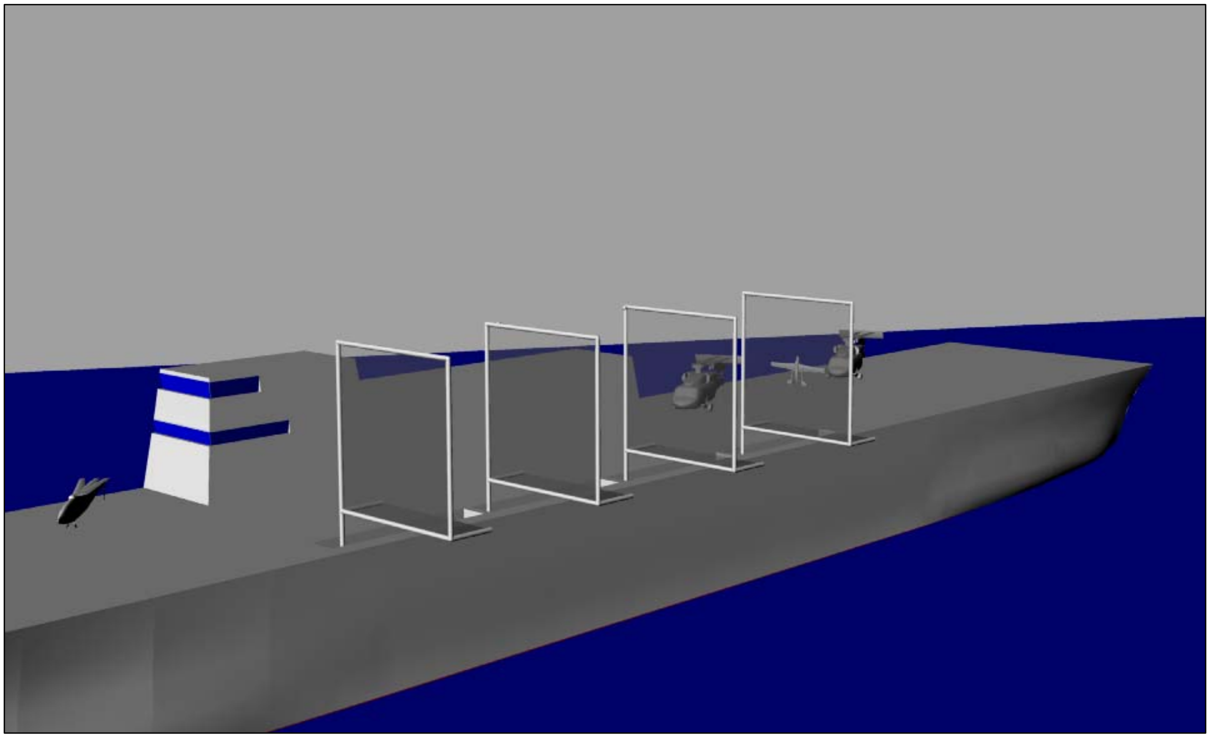


Figure 11: Top Mounted Recovery Nets

Full Recovery System

Once the unmanned aircraft has flown into a net and the net has retracted into the ship, it is detached from the net and transported by a hoist to a temporary storage rack, which can accommodate the entire swarm of 50 UAVs. The temporary storage rack allows complete swarm recovery before post-mission-maintenance is started on the UAVs. The UAVs are then de-fueled, washed down, and repaired before returning to racks in the bow of the ship where they can be quickly accessed for the next launch.

To meet the requirement of recovering downed UAVs, a boom is mounted aft of the ship’s superstructure where it can retrieve downed aircraft from the water. The ship is also equipped with RHIBs that can assist in this process.

Rotorcraft Operations

The layout of the flight deck is largely based on existing helicopter landing ships such as the LHD 1 Wasp class. The UAV-M's flight deck accommodates two smaller landing pads for A160 Hummingbirds and three larger pads for SH-60 Seahawks or A160 Hummingbirds shown in Figure 12. Two inboard elevators are positioned at the aft end of the ship. With all four nets deployed, one larger helicopter pad is still available.

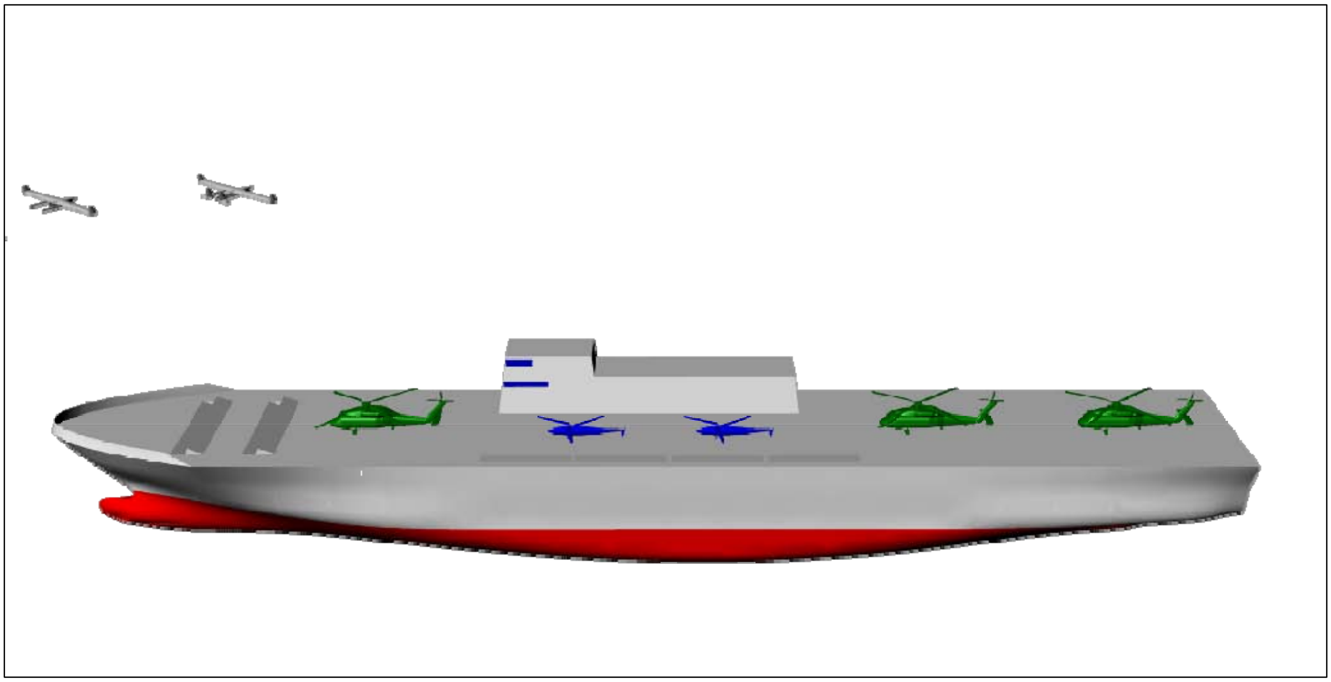


Figure 12: View of Flight Deck

With the implementation of top mounted UAV launchers and recovery nets that deploy from the flight deck of the ship, the UAV-M is optimized for reliability, effectiveness, and total systems integration.

Hull Form

Various hull forms were considered throughout the UAV-M design process. The monohull form is the most traditionally used in aircraft carrying ships and was initially chosen for this concept. It was thought the volume and stability provided by a monohull would be necessary for the UAV-M's aircraft operations and storage. After estimating volume it was later determined the monohull provided excess volume, which proved to be a problem throughout the design.

Weight, volume, and power requirements eventually drove the hull size and shape to a scaled LPD 17 hull form seen in Figure 13. Abundant analytical data on this hull was available at Carderock and applied to the at UAV-M concept where applicable. This hull form provides adequate stability with acceptable resistance.

Some analysis was conducted for the use of SWATH and trimaran hulls in the concept but never proved to be a definitive solution. Both designs have advantages, such as increased stability and large deck area. After further stability and sea keeping analysis it may be determined that a SWATH or trimaran hull would provide a suitable platform for the UAV-M.

Figure 13: LPD 17

Propulsion

The UAV-M propulsion system meets the requirement for a full-electric system capable of 22 knots sustained speed and a range of 4500 nm. The design includes the same four Fairbanks Morse Colt-Pielstick PC2.5 STC diesel engines that are used in the LPD-17. Power is distributed throughout the ship with five large switchboards. Two motor drives control two permanent magnet motors (PMM), which are currently in development, powering hybrid contra rotating propulsion, employing two ABB group type 16 azimuthing electric propulsion drives (Pods) and two shafts with fixed pitch propellers. The propulsion arrangement is shown in Figure 14.

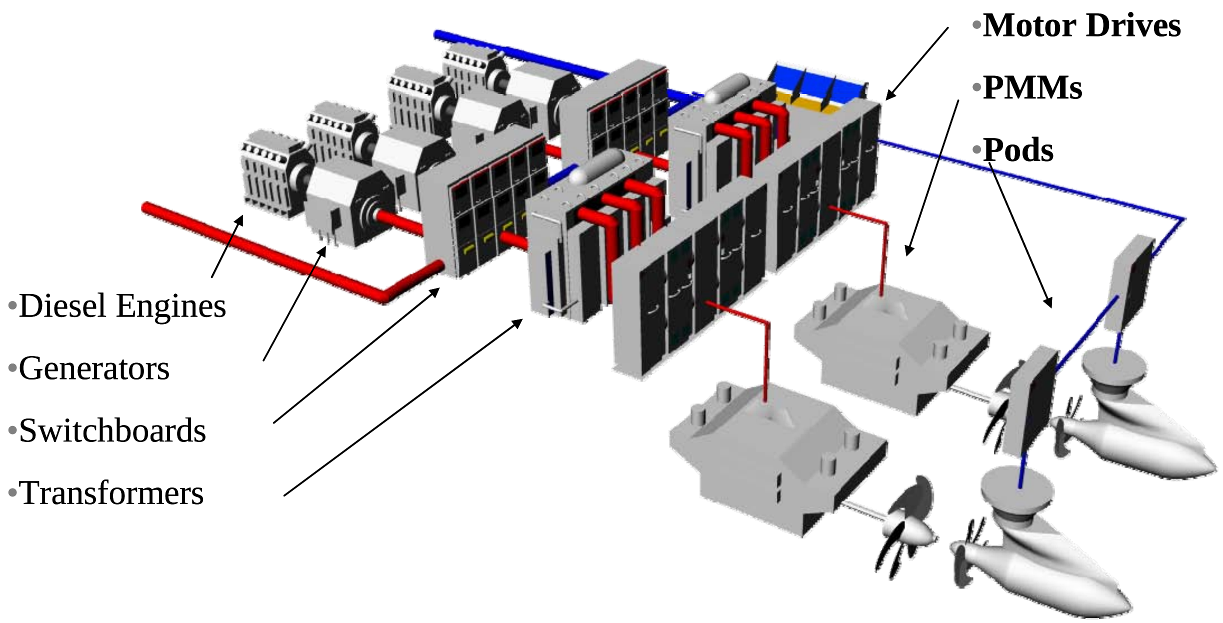


Figure 14. Propulsion Arrangement

Many other system configurations were looked at such as an all gas turbine ship or a combination gas turbine and diesel ship. The all gas turbine ship was not chosen because of its low efficiency at low MCR, which will be discussed later in this section. The combination system was not chosen because of the extra manning power it would take to maintain two different engines. Also, to place most of the ships power into one engine introduces a reliability risk because of the possibility that that engine could fail. It is because of these reasons the UAV-M is an all diesel ship.

Model test data from the LPD 17 was used to estimate power requirements for the UAV-M, which scales to the LPD 17 by a linear factor of 0.77. A speed power curve was then generated to acquire the power at 22 knots, as shown in Figure 15.

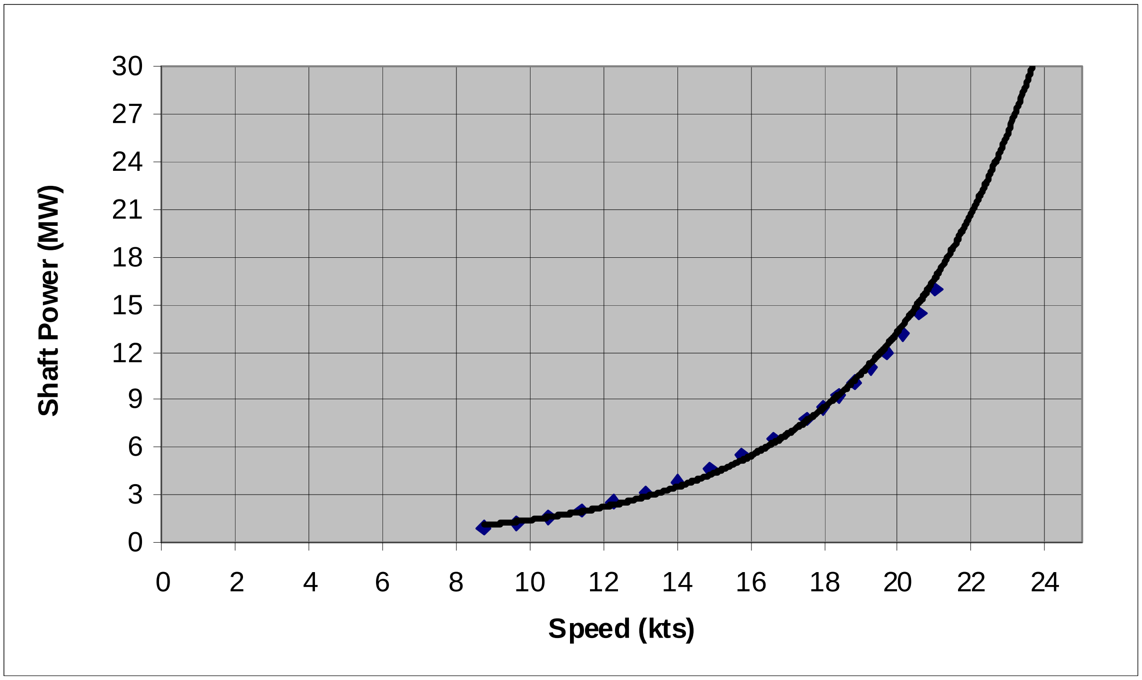


Figure 15. Speed - Power Curve

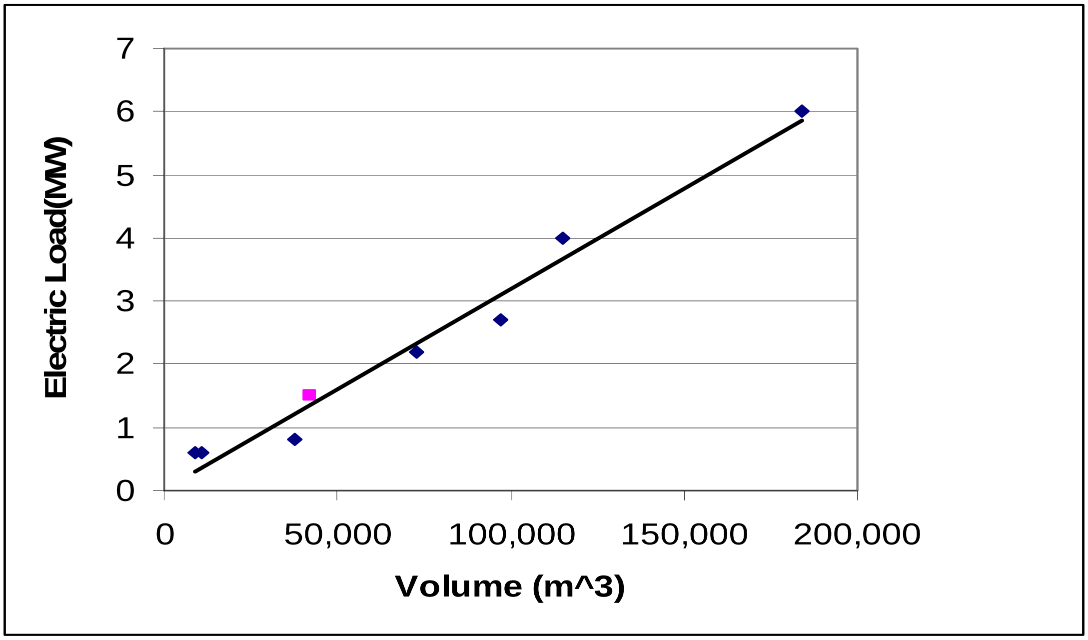


Figure 16: Electric Load

At this point, two types of prime movers were considered: gas turbines and diesel engines. Gas turbines are lightweight, but require more installed volume than diesel engines due to the large intake and exhaust systems. Diesel engines are very fuel efficient when operating at their maximum continuous rating (MCR) and require a much lower installed volume than gas turbines. Even though they are heavier, the advantages of diesel engines outweighed those of the gas turbines. Since the predicted power requirements for the UAV-M correlate closely to those of the LPD-17 class, it is possible to use the same propulsion system. The LPD-17 carries four diesel engines to provide redundancy: two 16V and two 18V Colt-Pielstick PC2.5 STC by Fairbanks Morse. This means that if one of the four diesel generator sets fails, the ship can still maintain a speed of 21 knots on the three remaining sets with an 80 percent MCR and a full hotel load.

The next important decision that was made concerned the motor. Induction motors and permanent magnet motors were considered. At this scale, compared to PMMs, induction motors are heavier and less power dense**.** Because the weight of an electric propulsion system is already so large, PMMs were chosen.

PMMs have only recently been given serious consideration for US Naval application. Further development of the technology would be required for use on the UAV-M. At this time, the use of PMMs is considered a risk, and should be reassessed in future development.

The UAV-M is propelled by a contra-rotating podded propulsion system. The two motors drive two hybrid shafts that will each turn a 3.5 meter diameter propeller. This diameter was calculated using the equation:

$$PROP.DIAM. = \frac{1}{5}\sqrt{\frac{Ps}{Speed}}$$

Where Prop Diam. is in meters, Ps in KW and Speed in KTS.

Installed downstream of these propellers are two Azipod type 16 pods. The power ratio is 70/30, shaft power to pod power. This type of propulsion was chosen because of its high efficiency. Naval tests have proven this system to be 6 to 15 percent more efficient then conventional types of propulsion. This form of propulsion is also very attractive because of redundancy and the low speed maneuverability provided by the steerable pods.

Principal Characteristics

General Arrangements

The size and arrangement of the UAV-M was governed by the requirement for weight and volume of shipboard systems, aviation space on the hangar deck, and a flight deck large enough for five helicopters to take off sequentially. General arrangements for the concept, shown in Figure 17 and Figure 18, are primarily based on launch, recovery and stowage of all aircraft. The individual spaces are based on SSCS area and volume estimations. The general arrangements provided are a rough outline of the ship's internal systems and were also used to estimate KG for the ship. Stairwells are indicated with a small box that is centered by an "S".

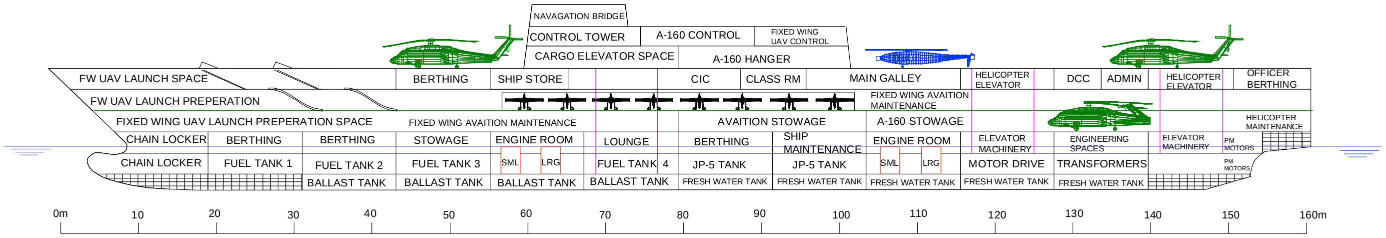


Figure 17: Inboard Profile View

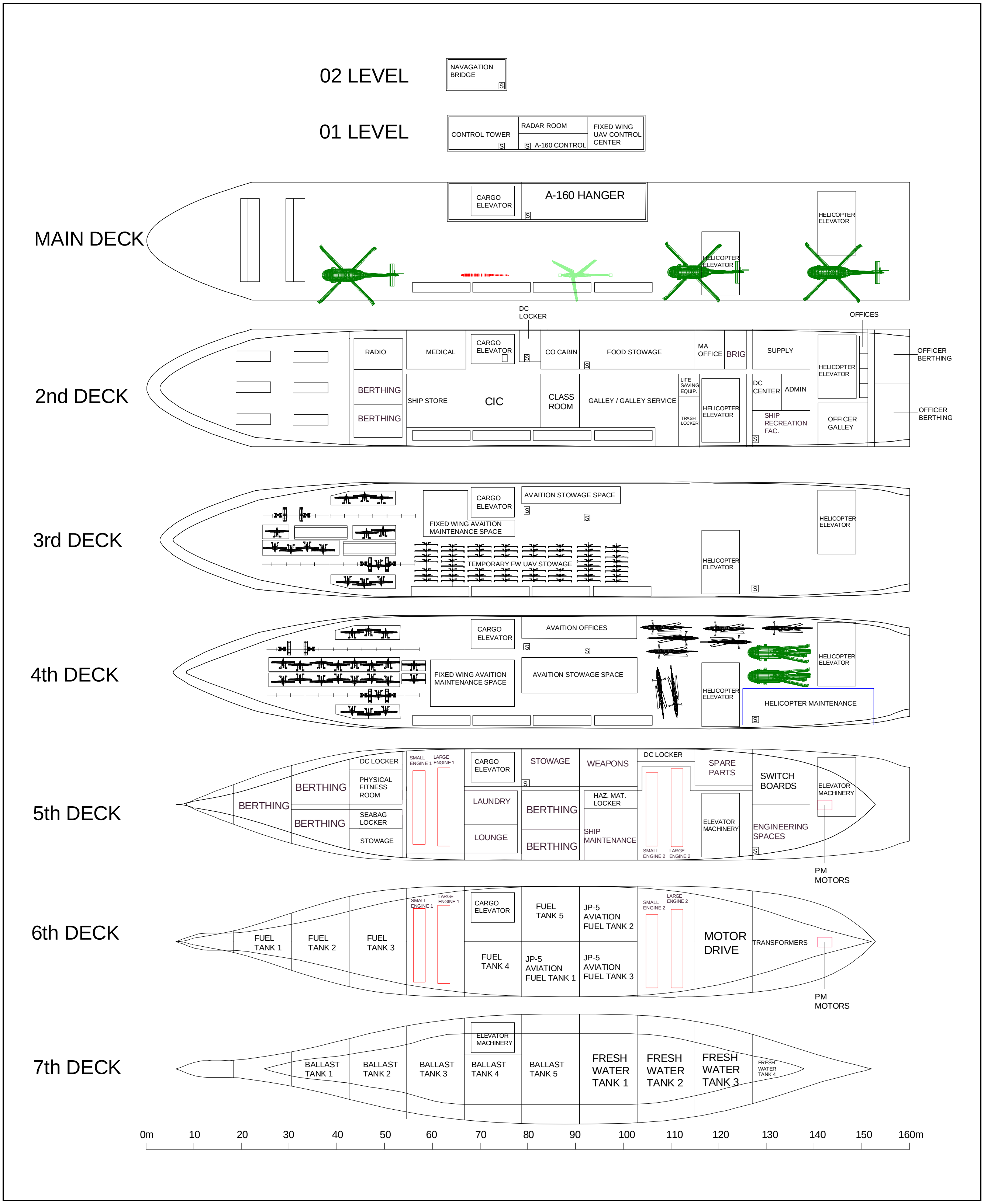


Figure 18: General Arrangements

Command & Manning

An estimation of the manning requirements of flight systems on the UAV-M was performed based on notional helicopter and UAV operations. After initial research on the autonomous capabilities of UAVs, assumptions for manning requirements were derived to safely and effectively launch, command, and recover aircraft. UAVs are semi-autonomous, allowing them to maintain stable flight and follow a programmed course, however they are closely monitored with human control. It is assumed that a single operator would be able to command three fixed-wing UAVs simultaneously while maintaining safe and effective operations. The total crew of the UAV-M is 350; details appear in Appendix C – Manning .

Weight and Volume Estimations

SWBS Weights

Weight estimates for the UAV-M were performed using known values and by scaling weight groups of existing ships in the US Navy fleet. The 100 SWBS weight group was scaled with similar ships by total interior volume. The ship's 200 and 300 SWBS groups were determined directly by three digit weights and using data from the LPD 17 whose propulsion system is almost identical to the UAV-M. The remaining SWBS groups and loads were calculated by two and three digit group estimations both directly calculated and scaled with similar ships such as the LHD-8 and LPD-17. Two digit SWBS groups for the entire ship are listed in Appendix A. Table 4 summarizes the UAV-M weight estimation.

SWBS	WT (mt)	KG (m)
W100	4,729.0	9.19
W200	584.6	3.60
W300	728.6	3.60
W400	475.1	13.63
W500	1,185.8	10.44
W600	665.1	10.66
W700	70.1	13.99
Lightship	8,438.3	8.90
10% Design Margin	843.8	0.89
Deadweight	*2,280.8*	3.22
TOTAL	**11,563.0**	**8.50**

Table 4: Weight Estimation Summary

SSCS Volumes

The UAV-M's volume was driven by the requirement to launch, recover, stow, and maintain 100 fixed-wing UAVs, 12 rotorcraft UAVs, and 5 SH-60 helicopters. The concept has been configured to launch and recover three SH-60 and two A-160 helicopters sequentially, thus the overall length and beam are what is required by the *Air Capable Ship Facilities Bulletin* for safe flight deck operations [2].

Volume estimations were done initially by scaling the concept with ships of like attributes using SSCS group data acquired from ASSET, similar to how weight estimations were performed. As the concept was developed, more accurate volume requirements for propulsion and flight operations were determined and space requirements were modified. This progression is shown below in Table 5.

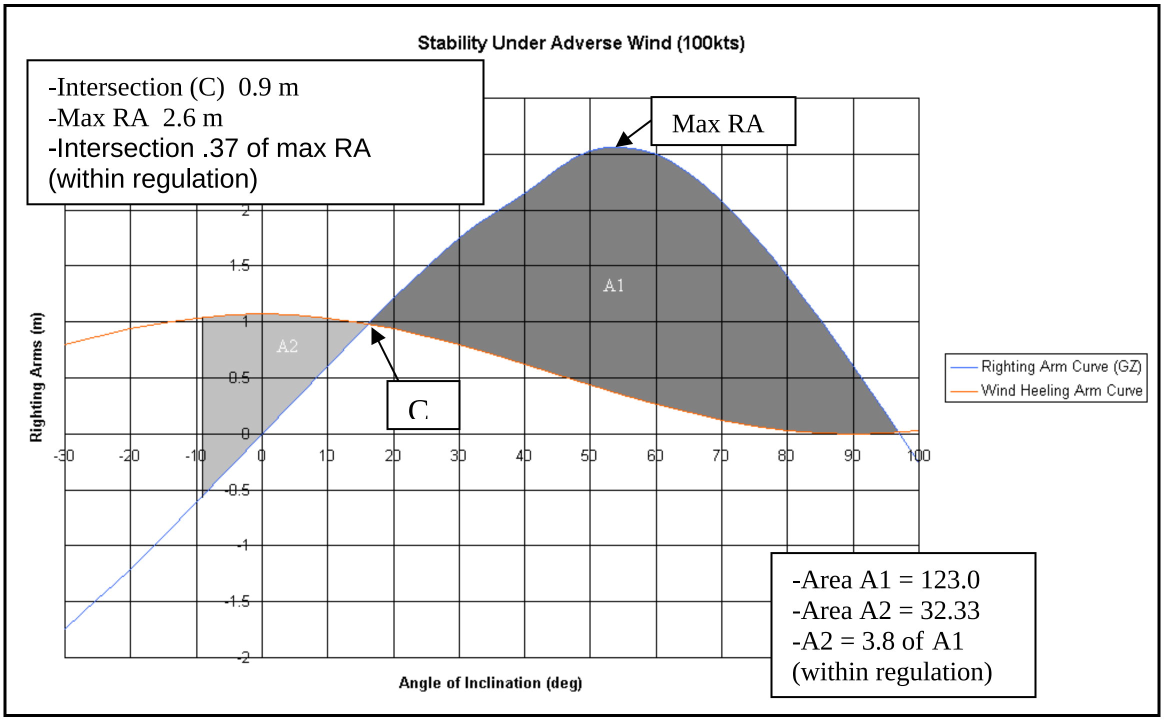
SSCS	Area m^2	Volume m^3
1. Mission Support	6,674	18,340
2. Human Support	7,837	5,094
3. Ship Support	4,603	12,390
4. Ship Machinery	1,919	5,458
Total	**21,030**	**40,980**

Table 5: SSCS Volume Estimates

Stability Analysis

Stability analysis has been performed for Adverse Wind and Sea Conditions, and Underwater Flooding using the hydrostatics program MaxSurf.

The requirements defined by the Navy Design Data Sheet 079-1 for Stability Under Adverse Wind and Sea Conditions states 1) the heeling arm at the intersection of the righting arm and heeling arm curves (point C) is less than six-tenths of the maximum righting arm (RA), and 2) the area represented by A1 in Figure 19, is no less than 1.4 times that of R2. Figure 19 shows Righting Arm and Wind Heeling Arm curves along with their relationships as directed by the regulation. Both requirements are met [3].



-Intersection (C) 0.9 m
-Max RA 2.6 m
-Intersection .37 of max RA
(within regulation)

Max RA

C

-Area A1 = 123.0
-Area A2 = 32.33
-A2 = 3.8 of A1
(within regulation)

Figure 19: Stability Under Adverse Wind

As required by the regulation for Underwater Flooding, the UAV-M has been designed to withstand flooding from damage to 15 percent of the ship's length below the waterline. Applying a 15 percent loss to the design increases our draft by 1.16 meters, which allows 1.02 meters between the main deck and the waterline [3].

Further development of the UAV-M design will require additional stability analysis for High Speed Turning, Lifting Heavy Weights Over the Side, and Reserve Buoyancy.

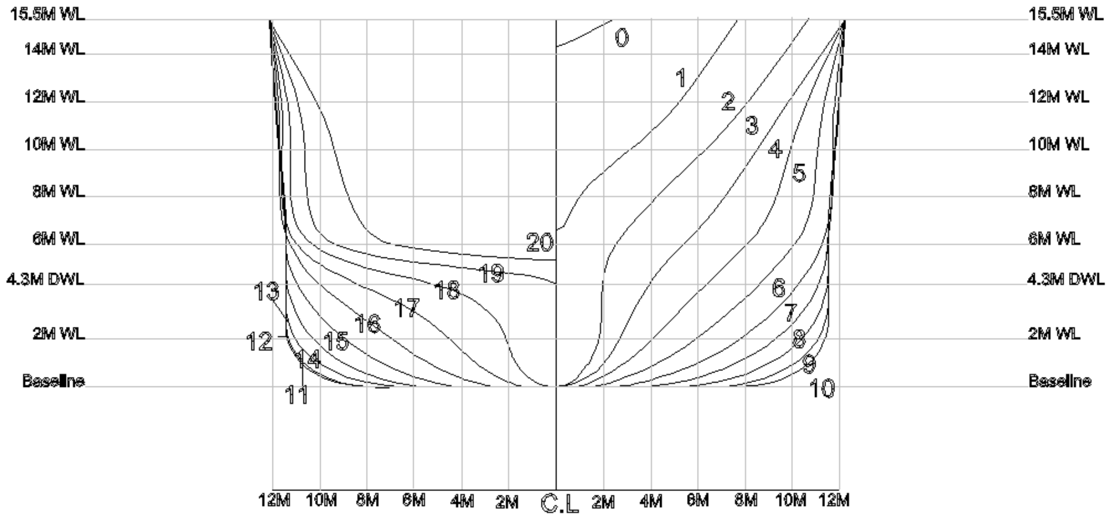


Figure 20: Body Plan

Hydrostatic data shown in Table 6 represents the MaxSurf analysis on the UAV-M hull modeled (Figure 20) in the Rhinoceros 3-D modeling program. Additional analysis should be conducted after more consideration has been given to the hull shape for an Azipod propulsion system.

Displacement (lt)	11,400
Volume (displaced) (m^3)	11,100
Draft amidships (m)	5.34
WL length (m)	150
Beam max extents on WL (m)	22.9
Wetted area (m^2)	3,760
Max sect. area (m^2)	116
Waterplane area (m^2)	2,670
Prismatic coeff. (Cp)	0.642
Block coeff. (Cb)	0.620
Max section area coeff. (Cm)	0.967
Waterplane area coeff. (Cwp)	0.779
KB (m)	2.99
KG fluid (m)	8.50
BMt (m)	9.03
BML(m)	296
GMt corrected (m)	3.52
GML (m)	291
KMt (m)	12.0

Table 6: Hydrostatic Data

Conclusions

Summary of Risks

Throughout the UAV-M design process, several assumptions were made that must be identified as developmental risks.

A-160 Rotors - Boeing's A-160 Hummingbird is currently designed with fixed, non-folding rotors. The assumption was made that a folding rotor Hummingbird could be developed for compact storage on the UAV-M.

FW-UAV Launch/Recovery - The ship's FW-UAV launch and recovery timing sequences were based on land tests, and because limited information was available on FW-UAV operations, assumptions were made regarding shipboard UAV operations. Additional testing may prove that shipboard FW-UAV operations require special consideration.

Pods - The US Naval fleet does not currently fit ships with podded propulsion systems. Additional analysis would need to be conducted into fields such as noise and magnetic signature reduction for pods to fulfill the mission of a US Naval combatant.

Seakeeping and Stability Analysis - At this point in the design, minimal hydrostatic analysis have been performed. Further development of the concept will require additional seakeeping and stability research.

Recommendations

The UAV-M is currently in the earliest stages of conceptual design and requires significant further effort before it can be considered a viable ship concept. Seakeeping and stability, including hydrostatics for damage stability, are two of the largest dependent factors for determining feasibility of this design, and currently minimal analysis has been performed.

The development of the FW UAV launch and recovery systems were based on the publicly released design characteristics of land based launchers, catch nets, and UAVs. Specifically, concerns regarding the net recovery system in rough seas need to be resolved. Additional undisclosed specifications and test data need to be obtained from the manufacturers to accurately design and implement the systems. The Navy's STUAS Tier II competition, which is to select a UAV of this class for wide-spread future use, needs to be resolved so that the design can be finalized with focus on one UAV type. For example, if the Killer Bee UAV is chosen over the Integrator, the UAV-M's total volume requirement could be reduced and the design would still meet the requirements for swarm operations.

The current UAV-M is a monohull, which has shown to be a viable option in this stage of the design. However, other hull forms should not be ruled out. It is widely accepted that SWATH hullforms offer better seakeeping properties, which could be advantageous for UAV operations at higher sea states. A trimaran hullform may offer more deck area, which may allow more recovery nets. This would be desired if a requirement were introduced for faster swarm recovery.

Concept Conclusion

Unmanned Aerial Vehicles are quickly becoming an integral part of the United States' defense capabilities. Over the last decade for example, the unmanned General Atomics MQ-1 Predator has provided invaluable surveillance information to combat ground crews fighting in Afghanistan, Pakistan, Bosnia, Serbia, and Iraq. This has proven that unmanned aerial technology has extensive potential for strategic defense in the future. Unmanned aircraft such as the Predator have been used to reduce the risk of casualties in hostile zones. Since the cost of a manned fighter can be many times higher than that of an unmanned drone, their use in military applications carries much less monetary risk. Without the weight of pilots and related systems, UAVs are capable of endurance of over 24 hours in some cases. Given the extensive capabilities of UAV technology, some US Navy ships are already being retrofitted to carry UAVs. To meet demands for the increasing use of UAVs, the future fleet will almost certainly include ships that are specifically designed around the operation of UAVs.

From the command of 50 fixed-wing UAVs to the operation of 17 VT aircraft to the rapid deployment of an unmanned swarm, every aspect of the UAV-M concept is designed around the function of its primary mission. All given requirements were met, although there is uncertainty as to the ability to safely and effectively operate in sea state 5. Although the current UAV-M concept is not the only solution to fleet deployment of UAVs, this design represents an early stage study of a feasible and capable ship to serve as a naval base for unmanned aerial vehicle operations.

Appendixes

Appendix A – Detailed Weight Breakdown

SWBS 100

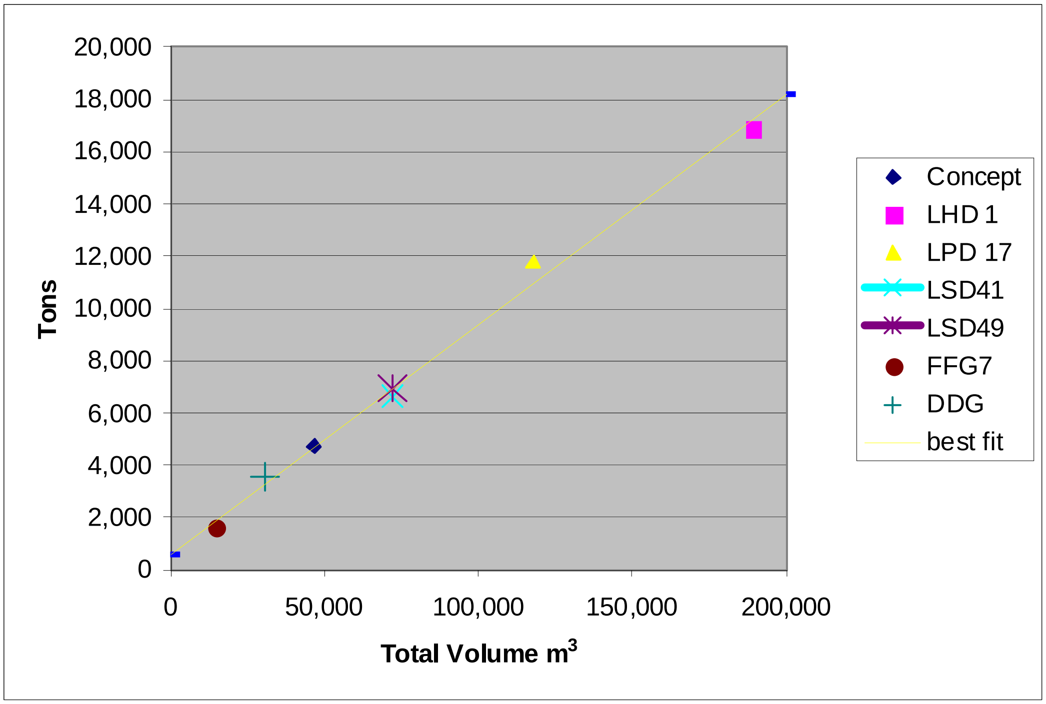


Figure 21: SWBS 100 Estimation

SWBS 200

	WT [MT]		VCG [m]	
200 PROPULSION PLANT	584.6		4.80	
210 ENERGY GEN SYS (NUCLEAR)		0		0
220 ENERGY GENERATING SYSTEM (NONNUC)		0		
230 PROPULSION UNITS		338		4.43
240 TRANSMISSION+PROPULSOR SYSTEMS		36		3.50
250 SUPPORT SYSTEMS		146.1		6.89
260 PROPUL SUP SYS- FUEL, LUBE OIL		59.5		3.00
290 SPECIAL PURPOSE SYSTEMS		5		3.75

SWBS 300

	WT [MT]		VCG [m]	
300 ELECTRIC PLANT, GENERAL	728.6		4.34	
310 ELECTRIC POWER GENERATION		347.9		3.68
320 POWER DISTRIBUTION SYS		125.7		2.45
330 LIGHTING SYSTEM		53		9.00
340 POWER GENERATION SUPPORT SYS		140		6.71
390 SPECIAL PURPOSE SYS		62		2.50

SWBS 400

	WT [MT]		VCG [m]	
400 COMMAND & CONTROL TOTAL	475.1		13.6	
410 COMMAND+CONTROL SYS		54.2		15.1
420 NAVIGATION SYS		17.2		14.9
430 INTERIOR COMMUNICATIONS		95.8		11.1
440 EXTERIOR COMMUNICATIONS		63.0		16.4
450 SURF SURV SYS (RADAR)		40.2		22.4
460 UNDERWATER SURVEILLANCE SYSTEMS		0.0		0.3
470 COUNTERMEASURES		160.7		10.4
480 FIRE CONTROL SYS		16.9		20.8
490 SPECIAL PURPOSE SYS		27.4		14.4

SWBS 500

	WT [MT]		VCG [m]	
500 AUXILIARY SYSTEMS, GENERAL	1,185.8		10.4	
510 CLIMATE CONTROL		205.9		11.2
520 SEA WATER SYSTEMS		163.8		8.7
530 FRESH WATER SYSTEMS		28.0		7.0
540 FUELS/LUBRICANTS, HANDLING+STORAGE		57.7		3.4
550 AIR, GAS+MISC FLUID SYSTEM		92.7		9.6
560 SHIP CNTL SYS		27.5		3.9
570 UNDERWAY REPLENISHMENT SYSTEMS		14.0		14.4
580 MECHANICAL HANDLING SYSTEMS		465.2		12.6
590 SPECIAL PURPOSE SYSTEMS		131.0		8.9

SWBS 600

	WT [MT]		VCG [m]	
600 OUTFIT+FURNISHING,GENERAL	665.1		10.7	
610 SHIP FITTINGS		49.0		16.4
620 HULL COMPARTMENTATION		130.6		9.8
630 PRESERVATIVES+COVERINGS		326.6		9.8
640 LIVING SPACES		53.2		10.6
650 SERVICE SPACES		21.3		14.0
660 WORKING SPACES		45.2		12.8
670 STOWAGE SPACES		32.8		9.4
690 SPECIAL PURPOSE SYSTEMS		6.4		10.4

SWBS 700

	WT [MT]		VCG [m]	
700 ARMAMENT	70.1		14.0	
710 GUNS+AMMUNITION		19.8		15.7
720 MISSLES+ROCKETS		7.9		17.1
730 MINES		0.0		
740 DEPTH CHARGES		0.0		
750 TORPEDOES		0.0		
760 SMALL ARMS+PYROTECHNICS		17.5		16.5
770 CARGO MUNITIONS		0.0		
780 AIRCRAFT RELATED WEAPONS		13.3		6.9
790 SPECIAL PURPOSE SYSTEMS		11.7		13.2

SWBS Loads

TOTAL		2,280.8	3.2
F10	**SHIPS FORCE + EFFECTS**	56.0	13.6
F20	**MISSION REL. EXPEN.**	106.0	8.4
F30	**SHIPS STORES**	126.1	5.7
F40	**FUELS + LUBRICANTS**	1,781.8	2.5
F50	**LIQ+GAS (NON FUEL)**	210.9	2.5
F60	**CARGO**	0.0	0.0

Appendix B – Detailed Volume Breakdown

	Group	Area	Volume
		m^2	m^3
1	**MISSION SUPPORT**	6,674	18,338
1.1	COMMAND,COMMUNICATION+SURV	628	1,690
1.2	WEAPONS	60	163
1.3	AVIATION	5,524	14,867
1.4	AMPHIBIOUS	0	0
1.5	CARGO	281	756
1.6	INTERMEDIATE MAINT FAC	37	100
1.7	FLAG FACILITIES	17	45
1.8	SPECIAL MISSIONS	41	110
1.9	SM ARMS,PYRO+SALU BAT	86	240
2	**HUMAN SUPPORT**	7,837	5,094
2.1	LIVING	904	2,434
2.2	COMMISSARY	603	1,624
2.3	MEDICAL+DENTAL (MEDICAL)	187	503
2.4	GENERAL SERVICES	310	835
2.5	PERSONNEL STORES	56	151
2.6	CBR PROTECTION	140	376
2.7	LIFESAVING EQUIPMENT	20	54
3	**SHIP SUPPORT**	4,603	12,389
3.1	SHIP CNTL SYS(STEERING&DIVING)	78	210
3.2	DAMAGE CONTROL	113	291
3.3	SHIP ADMINISTRATION	166	443
3.5	DECK AUXILIARIES	324	872
3.6	SHIP MAINTENANCE	177	477
3.7	STOWAGE	525	1,414
3.8	ACCESS	3,132	5,676
3.9	TANKS	1,117	3,007
4	**SHIP MACHINERY SYSTEM**	1,919	5,458
4.1	PROPULSION SYSTEM	95	255
4.2	PROPULSOR & TRANSMISSION	186	500
4.3	AUX MACHINERY	1,636	4,402
UAV-M Total Required		**21,031**	**40,978**

Appendix C – Manning Analysis

Aviation Watch Station

	Per 12 hr. shift	x 2
UAV #	100	
UAV # In AIR	50	
UAV per Controller	3	
Pilots per watch	17	34
Mission Control Officers	1	2
Total	18	36
Fuel	6	12
Launch	6	12
Stow	0	0
Retrieve	20	40
Software tech	6	12
Maintenance	6	12
Total	44	88
A-160	12	
Pilot per helicopter	1	
Total	12	
Fuel	4	
Stow	4	
Software tech	4	
Maintenance	4	
Maintenance Total	28	
SH-60 #	5	
Pilots	10	
On board tech	5	
General Maintenance	17	
Total	37	
Total Airman	139	188

General Manning

Officers SH-60	10
Officers A-160	12
Air Opp Officers	2
Gen. Ship Officers	16
Air Opp E-7 & Above (E)	10
Gen E-7 & Above (E)	20

		General	Air
E-6 & Below	280	126	154
E-7 & Above (E)	30	20	10
Officers total	40	16	24

MANNING TOTAL	350

Appendix D – Requirements

Unmanned Aerial Vehicle Mothership (Large)

Introduction

1. It is likely in the future that a significant amount of maritime organic air power will be provided through the use of unmanned aerial vehicles. Such vehicles may require to be stowed, maintained and operated from a dedicated Mothership. The Mothership is effectively an aircraft carrier for Unmanned Air Vehicles.

2. Two common modes of operation are anticipated:-
   a. The first being a provision of a mass "swarm" of small, inexpensive, reconnaissance UAVs operating in conjunction with each other. For example, Scan Eagle or Killer Bee.
   b. The second is the provision of single high endurance missions by larger, UAVs. For example, A-160 or Fire Scout.

Aim

3. To design a Unmanned Aerial Vehicle Mothership capable of allowing the simultaneous massed operations of several different types of UAVs. To identify technical issues and requirement associated with the design that require further investigation and development.

Ship Design Requirements

4. The ship shall be capable of undertaking the following missions:-
   a. Launch, command and recover swarms of up to 100 UAVs in the 100-150lb weight category.
   b. Launch, command and recover a force of 12 A-160 UAVs.
   c. Provide continuous airborne surveillance of the CV-UAV and surrounding airspace.
   d. Launch, command and recover 5 SH-60 helicopters.
   e. Provision of theatre UAV reconnaissance.
   f. Provision for storage and maintenance of all organic UAV assets.

5. The ship design shall meet the specific requirements detailed below:-
   a. The ship shall achieve a maximum speed to allow take off operations to be undertaken in still air, with a margin. The vessel shall be able to undertake flight operations in sea state 5.
   b. The ship shall demonstrate a cruise range of 4500 Nm at 22 knots with a stores endurance of 30 days.
   c. The ship shall be able to maintain, service and operate the embarked UAVs and aircraft.
   d. The ship shall be able to recover downed UAVs from the surface.
   e. The complement of the ship design shall be minimized.

  f. The ship shall be designed to meet an appropriate naval classification regime. In addition it shall be designed with appropriate survivability features.
  g. The ship shall feature an integrated full electric propulsion system.

Areas Of Technology Exploration

6. The requirements associated with the support and operations of Unmanned Air Vehicles. In particular investigations of flight deck design for swarm operations and overall architecture for efficient UAV operations. Investigation of the difficulties of command and control from a single ship of swarms of UAVs.

7. The hullform of the design shall be considered based on the architectural requirements of the ship, in addition to the requirement for adequate seakeeping.

Constraints

8. The report and design shall be unclassified, including all supporting analysis and data, all underpinning information is to be amended as necessary to allow this to occur.

9. The vessel shall be designed to meet the implied design requirements of a naval combatant.

Approach

10. The team will review requirements and then brainstorm potential ideas.

11. Suitable ideas shall be assessed for architectural impact and technical feasibility.

12. The competing ideas shall be reduced to a preferred concept using a decision making process.

13. A ship design synthesis model shall be developed.

14. A complete ship synthesis shall be undertaken. A balanced ship design shall result with performance analysis and a general arrangement developed. Recommendations for follow-on work shall be documented.

15. The implications of any new technology or operational issues shall be noted. Recommendations for follow-on work shall be documented.

Deliverables

16. All work will be documented in a CISD Project Technical Report. The final report and presentation shall be suitable for unclassified, public release.

17. During the first 2 weeks the team will produce a team project plan of actions, assignments and milestones to be presented to CISD leadership for approval. During the project this plan shall be maintained.

18. The team will develop and give informal intermediate presentations and a final project presentation.

19. The resulting ship design shall be detailed including a single sheet summary of design and performance characteristics, a comprehensive SWBS breakdown, a hullform body plan and a full general arrangement drawing.

20. The team will be encouraged to produce a technical paper from the final report that would be published at a professional society conference in the future.

Appendix E – Works Cited

[1] J. Pike, “UAV Tactical Control System”, *FAS Intelligence Resource Program*,November 26, 1999. [Online]. Available: http://www.fas.org/irp/program/collect/uav_tcs.htm. [Accessed: July 2, 2009].

[2] “Air Capable Ship Facilities Aviation Facilities”, *Bulletin NO.1k*, pages numbers 51-54, January 30, 2008.

[3] “DDS079-1 Stability & Buoyancy of US Naval Surface Ships”, pg. 8, August 1, 1975.