



# Naval Surface Warfare Center Carderock Division

West Bethesda, MD 20817-5700

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Ship Systems Integration & Design Department

Technical Report

## Arctic Patrol Vessel

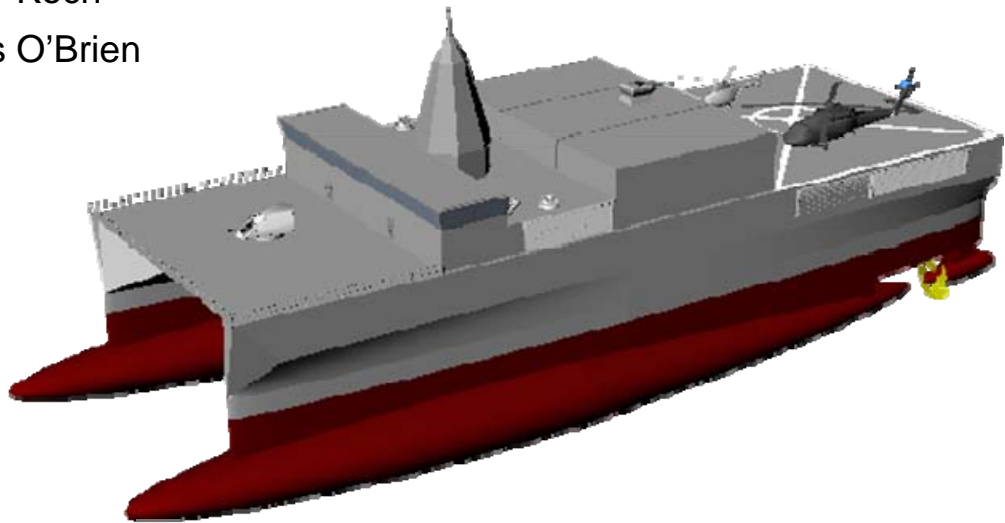
By

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Maureen Gilmour

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Arctic Patrol Vessel

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The Arctic Patrol Vessel must conduct long endurance patrol missions in the Arctic, where it will detect and interdict foreign vessels, and be resilient to the harsh environment of the area. Requirements developed for the APV include an endurance of approximately 7,000 nautical miles, a minimum operating temperature of -40° F, operation in sea state 6 and survivability in sea state 8+, operation in the Marginal Ice Zone, and resistance to topside icing. The APV is a SWATH ship with a full load displacement of 6,482 long tons and a top speed of 20 knots. The ship is outfitted with towed array sonar, surface/air radar, and small interdiction and rescue craft.

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## **Abstract**

The Naval Research Enterprise Internship Program (NREIP) has charged the Arctic Patrol Vessel Team with the task of designing an Arctic Patrol Vessel (APV) in the Center for Innovation and Ship Design at Carderock, West Bethesda. The vessel must be capable of long endurance patrol missions in the Arctic, where it will detect and interdict foreign vessels, and must be resilient to the harsh environment of the area.

Requirements developed for the APV include an endurance of approximately 7,000 nautical miles, a minimum operating temperature of -40° F, operation in sea state 6 and survivability in sea state 8, operation in the Marginal Ice Zone, and resistance to topside icing.

The APV is a Small Waterplane Area Twin Hull (SWATH) ship with a full load displacement of 6,482 long tons and a top speed of 20 knots. To accomplish its mission, the ship is outfitted with towed array sonar, surface and air radar, and small interdiction and rescue craft.

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# 1. Introduction

## *1.1 APV Design Team*

The Arctic Patrol Vessel Team is comprised of four interns in the Center for Innovation in Ship Design. The group includes:

<u>Name</u>	<u>School</u>	<u>Degree</u>
Kevin Byers	Virginia Tech	Ocean Engineering
Maureen Gilmour	Northwestern University	Manufacturing and Design Engineering
Greg Koch	University of Michigan	Naval Architecture and Marine Engineering
Tom O'Brien	Lehigh University	Mechanical Engineering

Funded by the Office of Naval Research, the interns worked under the Naval Research Enterprise Internship Program (NREIP). The team was overseen by full time employees in the Center for Innovation in Ship Design (CISD) at the Naval Surface Warfare Center Carderock Division (NSWCCD). This ship design internship was performed over the course of ten weeks in the summer of 2009. The primary goal of the project dealt with mission development and ship concept design for an Arctic Patrol Vessel.

## *1.2 Background Information*

The thinning ice in the Arctic region has opened up the area to commercial shipping and the possibility of exploiting the rich natural resources of the area. In 2007, Russia planted a flag on the ocean floor at the North Pole, claiming land outside of its 200 nautical mile exclusive economic zone. Since then, the countries bordering the Arctic, the United States, Canada, Norway, and Russia have been moving to secure their respective territories in the Arctic region.

The area houses a large supply of untapped oil and other natural resources. The area is also important for bordering countries' national security interests. If the warming trend continues in the Arctic, these resources will become accessible to the surrounding countries; therefore, it is in the United States' best interests to secure its national interests and economic assets in the region.

Currently, the United States Navy does not possess ships capable of a long-term mission in the Arctic region. The harsh conditions of the area, as well as the lack of large outposts near the Arctic Ocean, make current Navy vessels inadequate for such a task.

## 2. Mission

The mission of the Arctic Patrol Vessel project is to anticipate the requirements for the mission and to design a vessel capable of long endurance patrol missions in the Arctic. The ship must detect and interdict foreign vessels, perform search and rescue operations, be resilient to the harsh environment of the area, deter aggression in the Arctic, and secure US interests.

### *2.1 Requirements*

General ship design requirements (see Appendix A) provided by the Center for Innovation in Ship Design include safe navigation in Arctic waters, long endurance patrols, and the detection and interdiction of foreign ships and submarines. Specific requirements were derived from these general requirements to accomplish the missions provided.

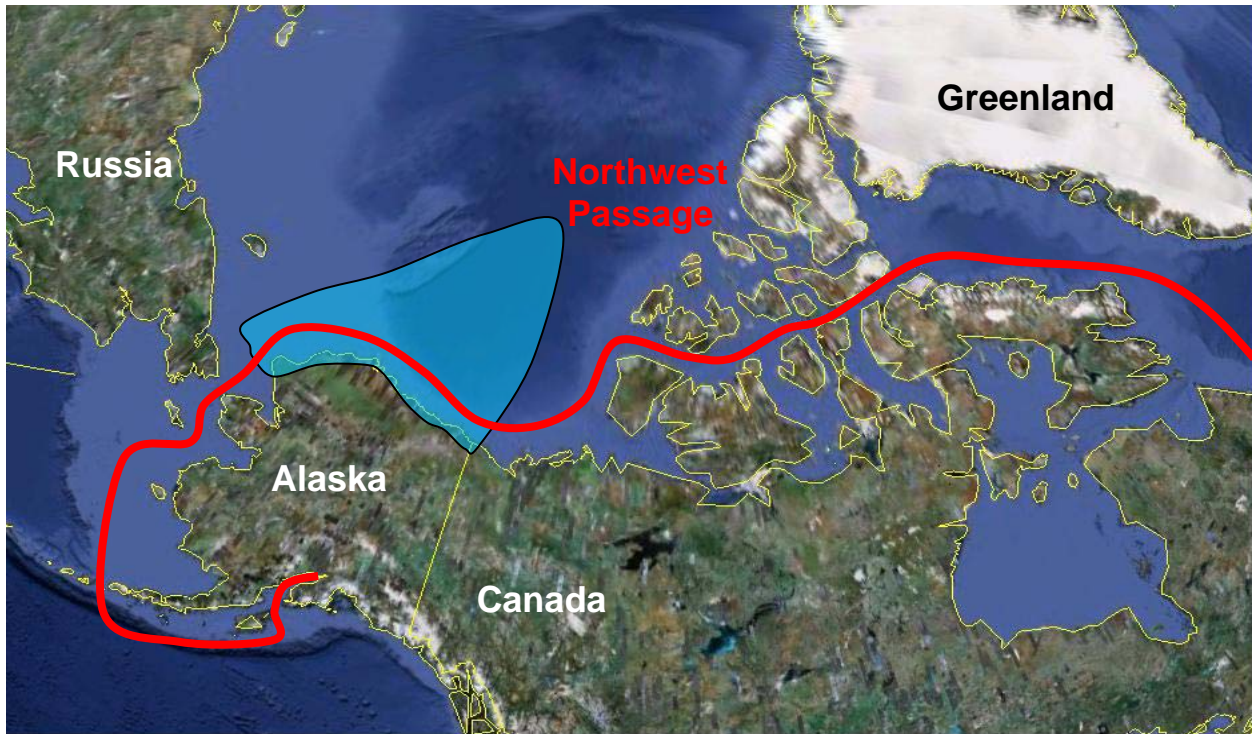
The ship must be capable of operating in an ice environment, including surface ice and topside icing. Cold weather operation must extend to temperatures as low as -40° F which can occur in the region. The Arctic Patrol Vessel (APV) must also be capable of full operation in sea state 6 and survivable to sea state 8 due to the harsh sea conditions commonly found at the Bering Sea.

The endurance range of the mission is set at 7,000 nautical miles at a speed of 12 knots. The APV's range is established by taking the minimum needed range to travel from Anchorage, Alaska through the Northwest Passage to the east coast of the United States.

A sonar system and unmanned aerial vehicles are employed in order to detect and interdict ships and submarines. The ship must also have the capability to carry a helicopter and boarding craft to be used on interdiction and search and rescue missions.

### *2.2 Operating Environment*

The Arctic Patrol Vessel must be capable of operating throughout the Arctic region. This area includes the Bering Sea, Northern Pacific, and the blue highlighted section of the Arctic Ocean as shown in Figure 1. Highlighted on the map is a route depicting the Northwest Passage. As the ice pack recedes, it will become possible for commercial ships to navigate this area. Therefore, it is essential that the APV have the endurance and capabilities to navigate the passage.

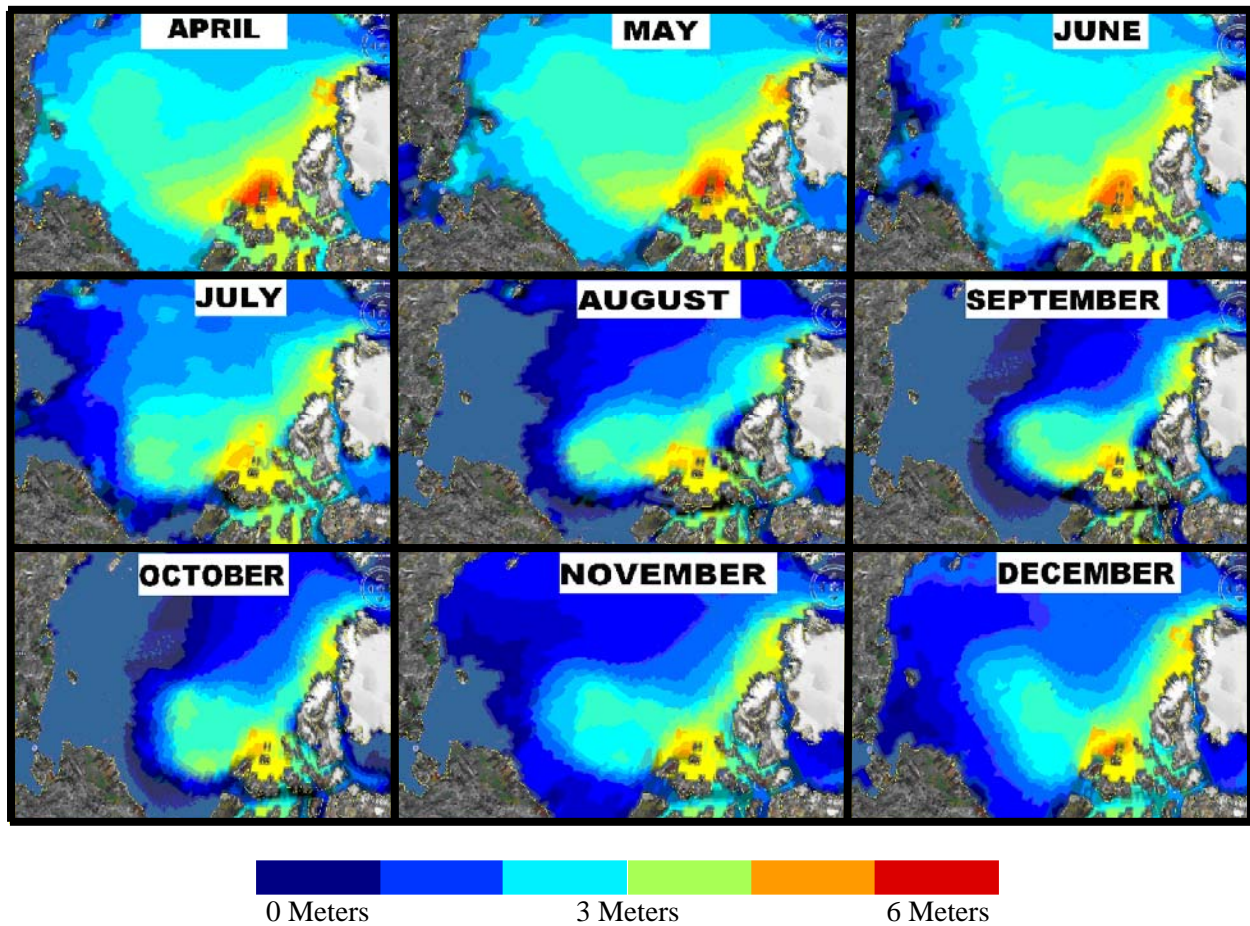


**Figure 1: Map of Arctic region with Northwest Passage highlighted**

The general requirements provided (Appendix A) state that the APV will be deployed on long endurance missions. This time frame is limited to the months of July through November because of Arctic temperatures and the immense area of the sea that is covered in ice in the winter and spring time. Because of the ice, the APV must be able to withstand ice collisions and have the ability to push through smaller amounts of ice.

Ice thickness data from 2007 and 2008<sup>1</sup> is shown in Figure 2. Red portions of the map represent areas where the ice is upwards of 6 meters thick, while dark blue represents areas where ice is less than 1 meter thick. The operating time period is defined by analysis of this data, and suggests that the Arctic is navigable in open water from the periods of July through November. This period will likely be extended if warming trends continue. The Marginal Ice Zone (MIZ) must also be considered when determining the ice capabilities of the ship. The MIZ ranges from open water to 90% ice pack coverage and is located in the area between solid ice and the open ocean.





**Figure 2. Ice thickness by month.<sup>1</sup>**

Wave height data from the National Buoy Data Center<sup>2</sup> is shown in Figure 3. The buoy being monitored is located in the Bering Sea, a portion of the patrol zone, and is the northern most buoy data available. While this buoy is in the southern portion of the APV's operating region, northern areas are assumed to produce similar data. Figure 3 shows significant wave heights over a period of 17 years broken down by month.

In the box and whisker plot shown in Figure 3, the red boxes represent the range between the lower quartile and upper quartile of the data collected. The black lines, or 'whiskers', represent the full range of data taken, from the lowest to highest recorded points.

It is evident on the plot that the smallest median significant wave heights are in June and July, but as the patrol period progress, waves get progressively larger with the largest significant wave heights occurring in November. The red boxes in Figure 3 cover Sea State 6 in October and November, but could reach up to Sea State 8. Therefore, the APV must be able to operate in Sea State 6 and be survivable in Sea State 8. If the warming trend in the Arctic Ocean continues, its waters will likely exhibit similar characteristics to the Bering Sea, making good seakeeping essential.

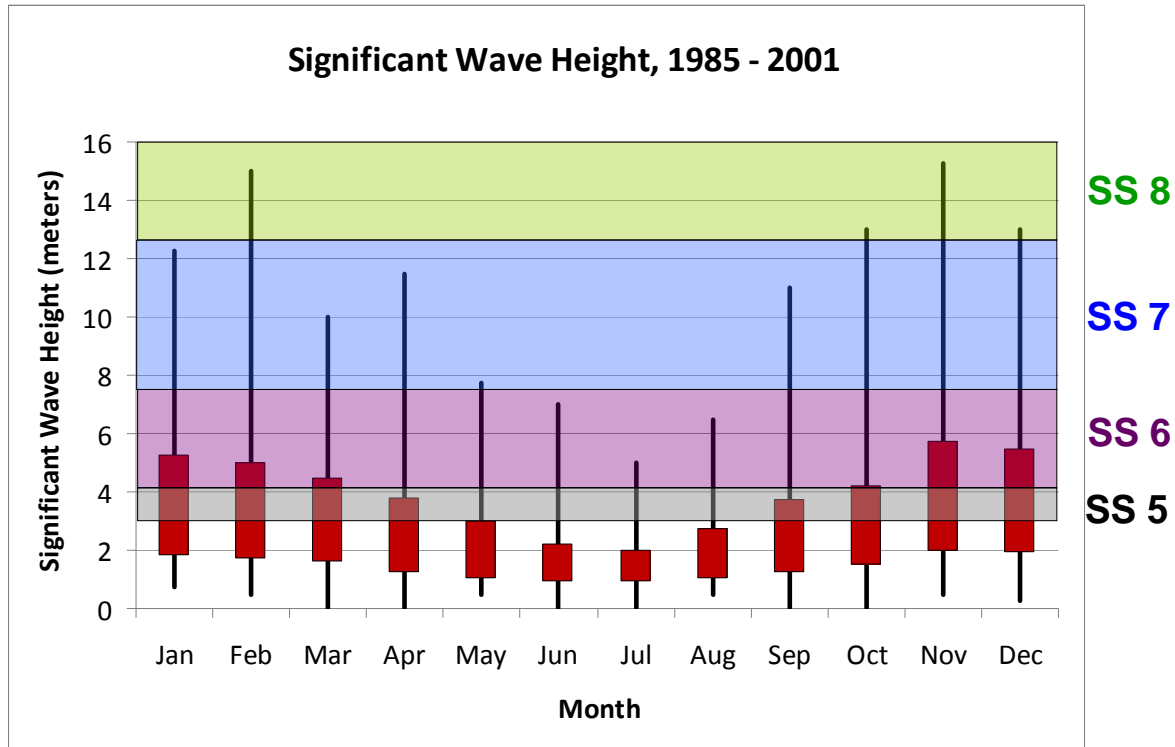


Figure 3. Significant Wave Height data, 300 nm North of Kodiak, AK in the Bering Sea.<sup>2</sup>

Topside icing conditions requirements for the APV are obtained from previous studies performed on similar ships. A Raytheon manual<sup>3</sup> for cold weather vessels as well as a study performed on the T-AGOS-19<sup>4</sup> yielded a maximum vertical icing rate of 34.8 lb/ft<sup>2</sup> and a maximum horizontal vertical icing rate of 48.7 lb/ft<sup>2</sup>.

The main battery of the APV is an enclosed, remotely operated 57mm naval gun. Self defense is provided by a Close-In Weapon System and remotely controlled small caliber weapons in enclosed, remotely operated turrets which will allow the APV to conduct operations while crewmen are sheltered from the cold.

Radar and sonar are necessary to allow the APV to detect and interdict foreign vessels. A passive towed sonar array enables the APV to obtain long-range scans of the surrounding area while an active/passive, hull-mounted sonar complements the towed array and obtains clearer readings of the short-range surroundings.

A helicopter and UAV's are necessary for the APV to scout out the best passageway through ice, detect and interdict vessels out of the APV's immediate range, and conduct search and rescue operations.

A patrol boat and rescue boat offer the easiest way to transport the APV's crew to areas of the water where the APV cannot traverse, and conduct rescue missions on the water.

Table 1 summarizes the APV’s environmental concerns and general requirements.

<b>Requirements</b>	
<b>General Requirements</b>	
Range (Northwest Passage)	7,000 nm @ 12 knots
Speed	20 knots
Self Defense	CIWS, small caliber armaments
Air/Surface Surveillance	Radar
Undersea Surveillance	towed and hull mounted sonar
Aircraft	helicopter, UAV's
Auxilliary Vehicles	patrol boat, rescue boat
<b>Environmental Concerns</b>	
Sea State Operational	6
Sea State Survivable	8+
Minimum Temperature	(-) 40°F
Ocean Ice Navigation	Ice Capable Classification, Marginal Ice Zone Operation
Vertical Topside Ice Load	34.8 lb/ft <sup>2</sup>
Horizontal Topside Ice Load	48.7 lb/ft <sup>2</sup>

**Table 1. Environmental requirements the APV must meet.**

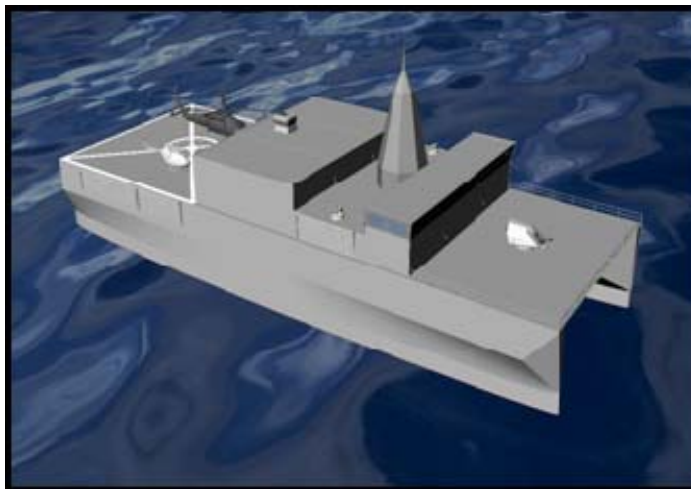
### 3. Design

Ship sizing is addressed using the Navy’s SWATH Design Synthesis Model, SWATY. Hull form development is guided by resistance predictions from the SWAD90 SWATH powering program<sup>9</sup>. The next several sections outline concept design decisions for the Arctic Patrol Vessel. Principal characteristics are found in the table below. These characteristics are discussed in more detail throughout the Design section.

Principal Characteristics	
Lightship (LT)	5,600
Full Load (LT)	6,480
Length Between Perpendiculars (ft)	260
Length Overall (ft)	290
Beam (ft)	93
Draft (ft)	28
Depth (ft)	58
Freeboard (ft)	30
Range at cruise speed of 12 knots (nm)	7,000
Top speed (knots)	20
Machinery	Integrated Electric
Generators	4 x 6.7 MW
Propulsion output (hp)	2 x 10,000

**Table 2. Principal characteristics of the APV**

Figure 4 below shows a perspective view of the Arctic Patrol Vessel. Additional pictures can be found in Appendix C.



**Figure 4. Arctic Patrol Vessel perspective view.**

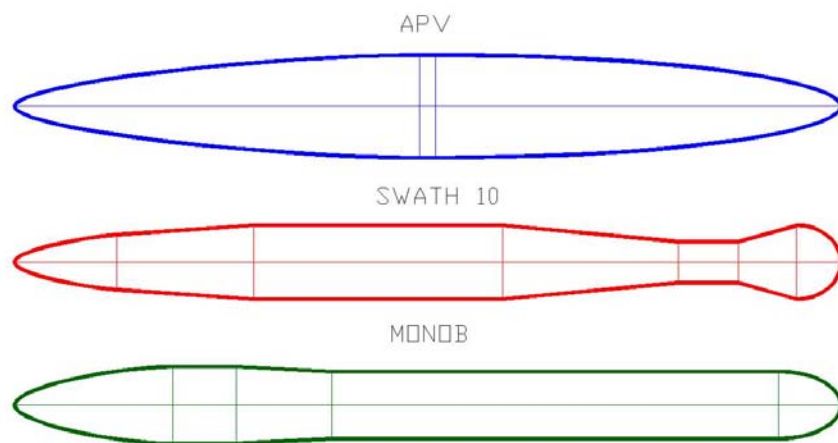
### 3.1. Hull Selection

Hull form alternatives considered included a traditional ice-breaking monohull and a SWATH. A traditional ice breaking monohull's advantages include proven ice breaking capabilities, a traditional hull form, and a smaller ship compared to a SWATH of similar payload. However, they have notoriously poor seakeeping. Alternatively, SWATH hulls offer excellent seakeeping. Although ice-breaking SWATH ships have not been built, two classes of ice-strengthened hulls are in service. Development of mission requirements indicated that operating in the MIZ was required rather than ice-breaking. Consequently, the APV features an ice-strengthened SWATH hull form to gain advantages of good seakeeping for personnel and mission system effectiveness.

### 3.2. Hull Design

The APV's SWATH hull can be represented by a series of truncated cones and cylinders with an elliptical nose section and a parabolic tail. By modeling it in this fashion, it is possible to estimate resistance using the SWAD90 resistance program. The shape of the hull can then be optimized by reducing the drag coefficient at the designated Froude number.

Figure 5 shows three of the hull forms analyzed. Many variations on these hulls were analyzed while determining the final design. The SWATH 10 and MONOB are previously tested hull forms developed for other naval applications. Those two hull forms were considered for use with the Arctic Patrol Vessel. However, MONOB optimized drag at a higher Froude number and the SWATH 10 hull was too slender for APV application. The APV Hull developed using the SWAD90 resistance program optimizes drag in the APV's primary speeds of operation.



**Figure 5. Hull forms considered for use with the Arctic Patrol Vessel**

Figure 6 shows the predicted coefficient of residual resistance plotted against Froude number for the three hulls displayed above. Residual resistance is optimized for the APV hull in a Froude number range of 0.2 to 0.33. This corresponds to speeds from 12 to 17 knots with a length of 260 feet.

## Hull Form Analysis

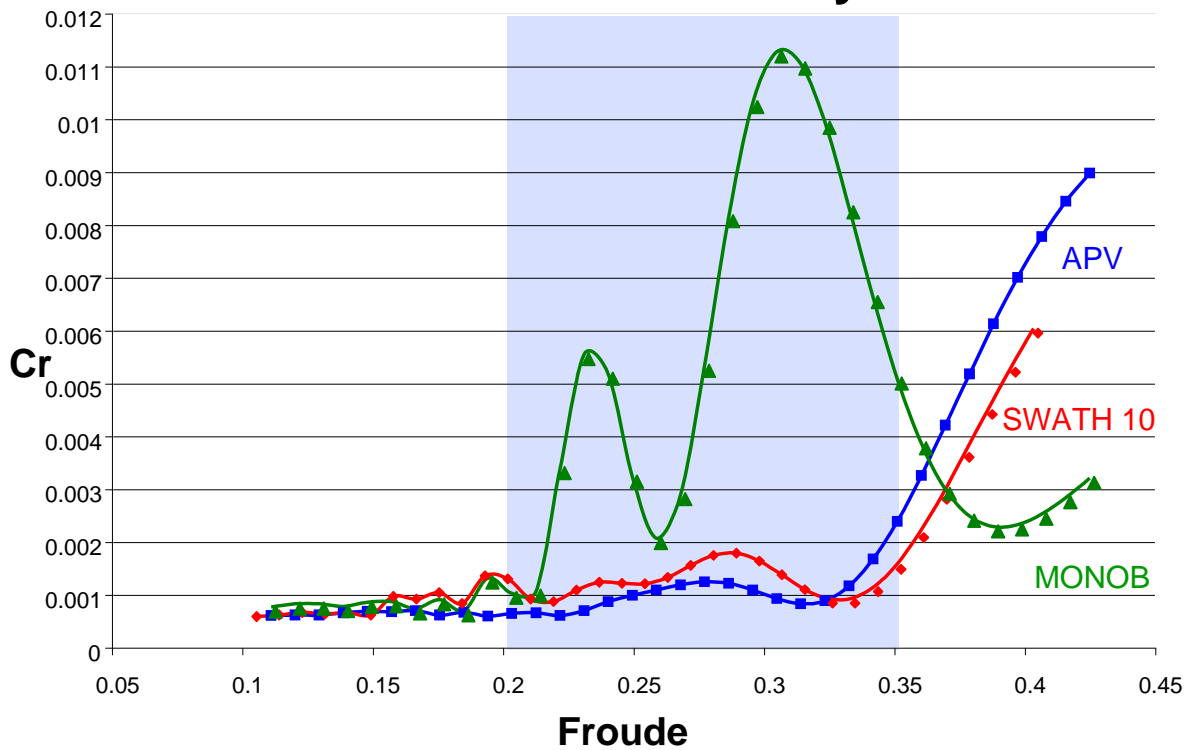


Figure 6. Plot of Coefficient of Residual Resistance versus Froude number

The Arctic Patrol Vessel hull was designed by optimizing previous hull designs. Table lists the hull form characteristics in more detail and provides dimensions for the length of each section, the diameter at each transition point, and also the strut thickness and shape. The hulls are each 260 feet long with a maximum vertical diameter of 22 feet and horizontal diameter of 33 feet. Each strut is offset 30 feet behind the nose of the hull and overhangs 30 feet off the tail of the hull.

Hull Form Characteristics	
Hull Centerline Submergence	17
Hull Centerline Separation	89
Diameter Ratio (Vertical: Horizontal)	1.5
Number of Strut Segments	3
1st Hull Segment Length	128
2nd Hull Segment Length	5
3rd Hull Segment Length	127
Hull Vertical Diameter at Transition 1	22
Hull Vertical Diameter at Transition 2	22
Strut Length	260
Strut Nose Length	130
Strut Tail Length	130
Strut Thickness	12
Strut Setback from Hull Nose	30

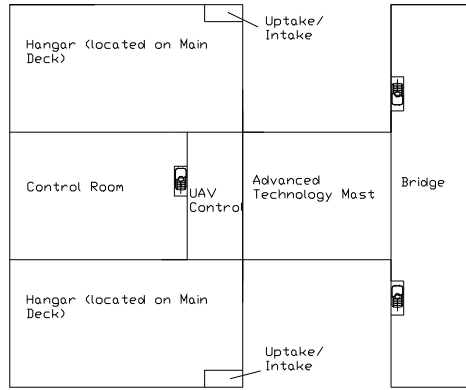
**Table 3. Hull form characteristics of the APV hull**

### ***3.3. General Arrangements***

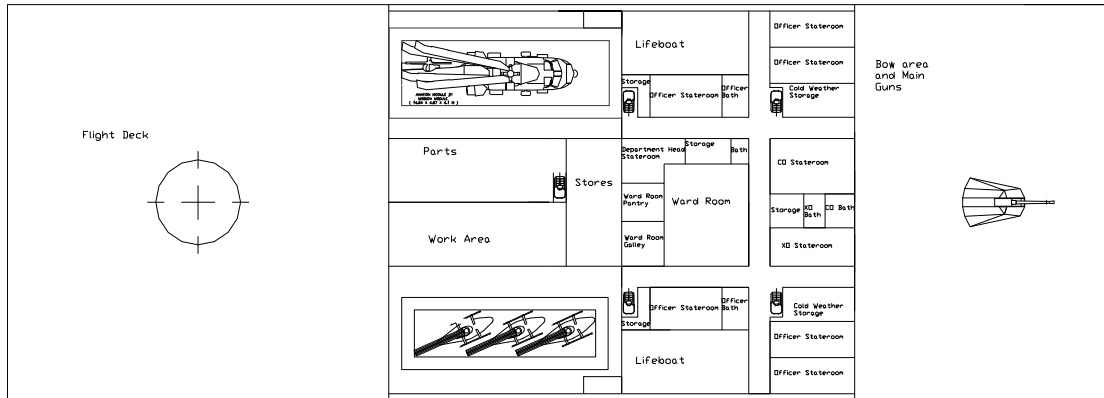
Deck plans for the 2<sup>nd</sup> deck, main deck, and 01 level are shown in Figure 7. The officers of the ship live on the main deck while the enlisted members live on the second deck. There is extra berthing for officers and crew in order to accommodate personnel for specific missions. Crew berthing is arranged to keep them away from the noise of the engines. Lifeboats are located on each side of the ship. The Tactical Towed Array Sonar (TACTAS) mission bay is located on the second deck, which keeps the crew out of the weather. Near the TACTAS mission bay are mission bays for small craft operations. The passageways on the ship are all 5 feet wide to give crew members easy access around the ship even when they must wear cold weather gear. The superstructure houses the flight control room. It is located between the hangars and above the work area and aviation storage. Two hangars are located port and starboard in the superstructure. Each is large enough for either one MH-60R Seahawk or three Fire Scout UAVs. This allows the Arctic Patrol Vessel the versatility to carry any combination of the above depending on the mission.

# General Arrangements

## 01 level



## Main Deck



## Second Deck

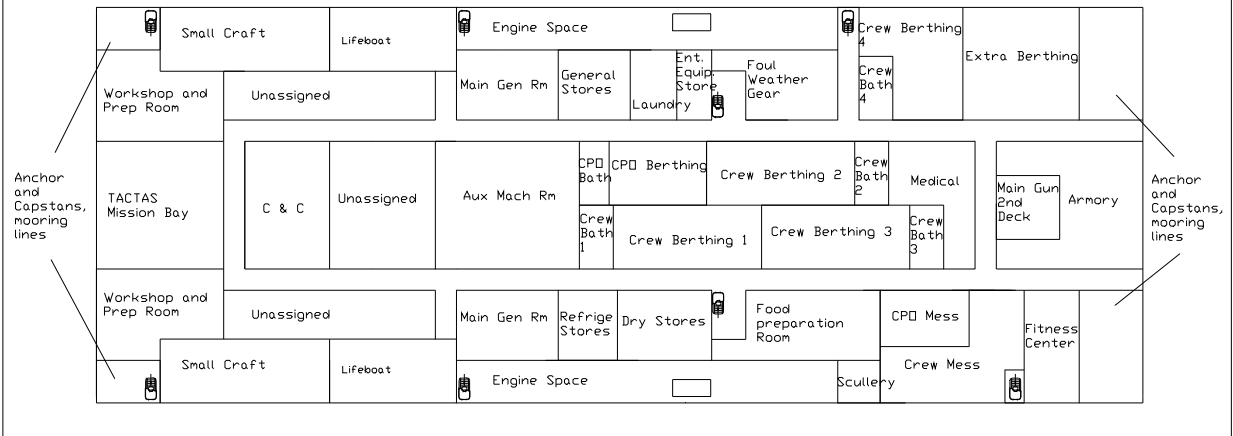
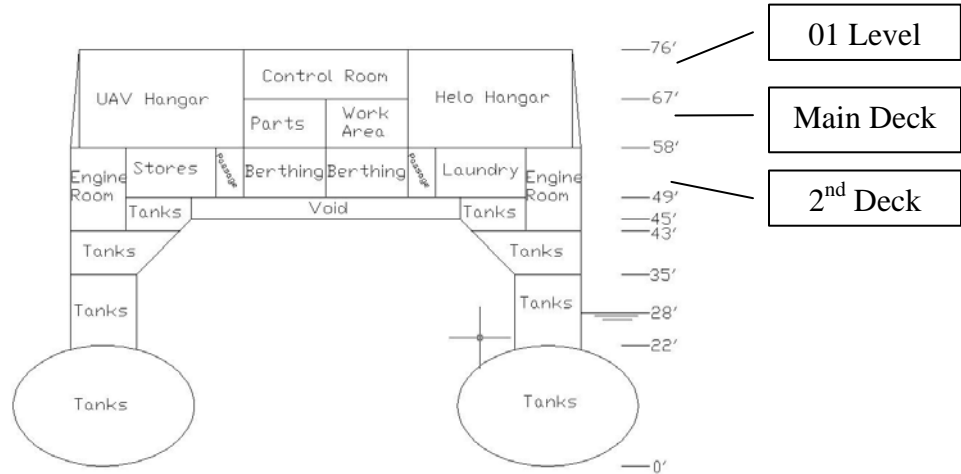


Figure 7. General arrangements

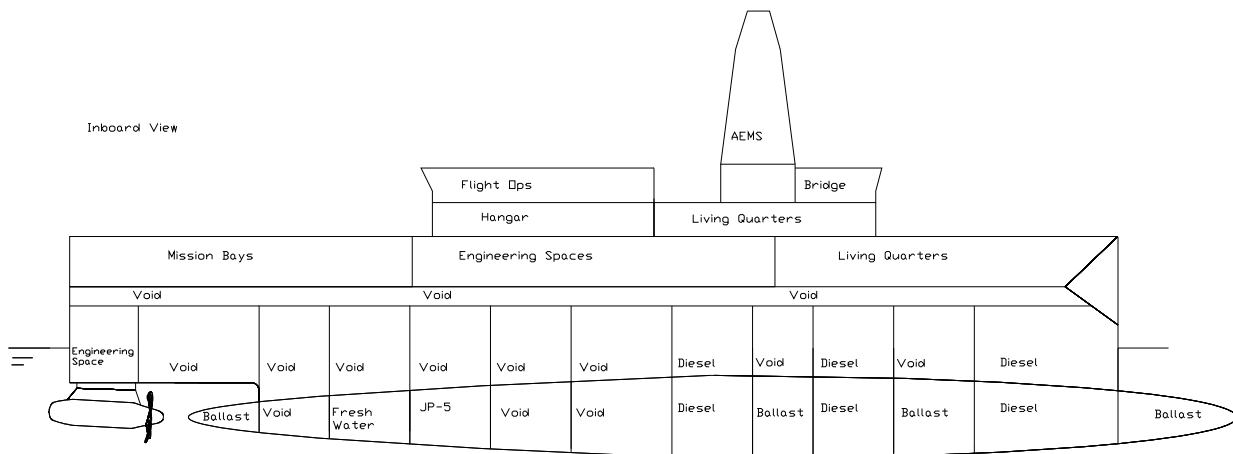


A section drawing can be seen in Figure 8. There is one deck in the cross-structure and two decks in the superstructure. The oval hulls shown in the view help to dampen ship motions in rough seas. The horizontal to vertical diameter ratio is 1.5:1 which also helps to reduce the draft of the ship while maintaining the same displacement.



**Figure 8. Cross-sectional amidships view**

The inboard profile of the APV is shown in Figure 9. This view shows the tanks arranged in the struts and hulls. The hulls are offset forward allowing for the use of podded propulsion. There are engineering spaces in the struts above the pods. However, most engineering spaces are located in the cross-structure. The engines' location in the box gives the crew easy access, and creates an easier working environment. Diesel fuel and ballast is primarily located in the forward compartments of the hulls and struts which offsets the forward longitudinal center of buoyancy due to the forward position of the hulls.



**Figure 9. Inboard profile of general arrangements.**

### 3.4. Weights Summary

Using a preliminary weight estimate made with the SWATY SWATH synthesis model, alterations were made to account for systems which were not applicable or could not be input into the program. Table 4 shows a one-digit weight breakdown of the APV.

<b>ARCTIC PATROL VESSEL WEIGHTS SUMMARY</b>	
SWBS GROUPS	Total Weight (long tons)
100	2,480
200	908
300	150
400	155
500	475
600	350
700	85
Lightship	4,603
Margin (9%)	417
Lightship + Margin	5,020
Loads	885
- Mission	83
- Diesel Fuel	620
- JP5	100
- Misc	81
Service Life Margin	575
Full Load	6,480

**Table 4. Weight group breakdown with centers of gravity.**

The lightship of the APV is 5,020 long tons with a 9% margin for weights. Variable weights of payload, fuel, ballast, crew, and stores add another 880 long tons. At the beginning of the life cycle of the ship, the service life margin of 575 long tons will be fulfilled through fuel and ballast compensation. As weight is added to the ship over the duration of its service life, fuel and ballast will be removed from the ship resulting in a constant draft over the lifetime of the ship. This brings the total weight of the ship to 6,480 long tons.

### 3.5. Stability

Stability was calculated both transversely and longitudinally. Table 5 summarizes key aspects to the ship's intact stability, including centers of gravity, centers of buoyancy, and metacentric heights.

Transversely, the metacentric height is 13.8 feet, 14% of the beam. The longitudinal metacentric height is 79 feet. The longitudinal center of buoyancy (LCB) is at 106.5 feet from the forward perpendicular and the estimated longitudinal center of gravity (LCG) is located at 107.5 feet resulting in trim by the stern of 3 feet, less than 1 degree. General design refinement involving arrangements, machinery location, and hull form optimization is recommended to reduce trim even further.

Intact Stability	
<b>Hull Characteristics</b>	
Displacement (LT)	6,465
Water Plane Area (ft <sup>2</sup> )	4,681
Tons per Inch Immersion (LT/inch)	11.15
Length Overall (ft)	260
Draft (ft)	28
<b>Transverse Stability</b>	
BM (Transverse) (ft from keel)	34.0
KB (ft) (ft from keel)	13.4
KM (ft) (ft from keel)	47.4
KG (ft) (ft from keel)	33.7
GM (Transverse) (ft) (ft from keel)	13.8
<b>Longitudinal Stability</b>	
BM (Longitudinal) (ft from FP)	84.0
LCB (ft from FP)	106.5
KM (Longitudinal) (ft from FP)	190
LCG overall (ft from FP)	107.5
GM (Longitudinal) (ft from FP)	82.8
<b>Trim</b>	
LCB (ft from FP)	106.5
LCG (ft from FP)	107.4
GM (Longitudinal)	82.8
Draft (ft)	28.00
Trim (ft)	3.00
Angle of Trim (degrees)	0.67
Draft Forward (ft)	26.5
Draft Aft (ft)	29.5

**Table 5. Stability calculation summary.**

Damage stability was not analyzed due to time constraints. However, the subdivision shown in the general arrangement drawings is similar to other SWATH designs. Comprehensive damage stability analysis is recommended for continued development of the APV concept.

### 3.6. Propulsion and Powering

#### 3.6.1. Powering

Resistance was estimated with the SWAD90 program. An 8% margin and a model to full scale correlation allowance of 0.0006 are included in the estimation. A conservative propulsive coefficient of 0.66 is used to estimate the shaft horsepower from the effective horsepower. Figure 10 shows the effective and shaft horsepower versus speed. The APV's cruise speed of 12 knots requires 3,100 shp (4.1 MW). The 20 knot top speed is estimated to require 30,000 shp (22.5 megawatts).

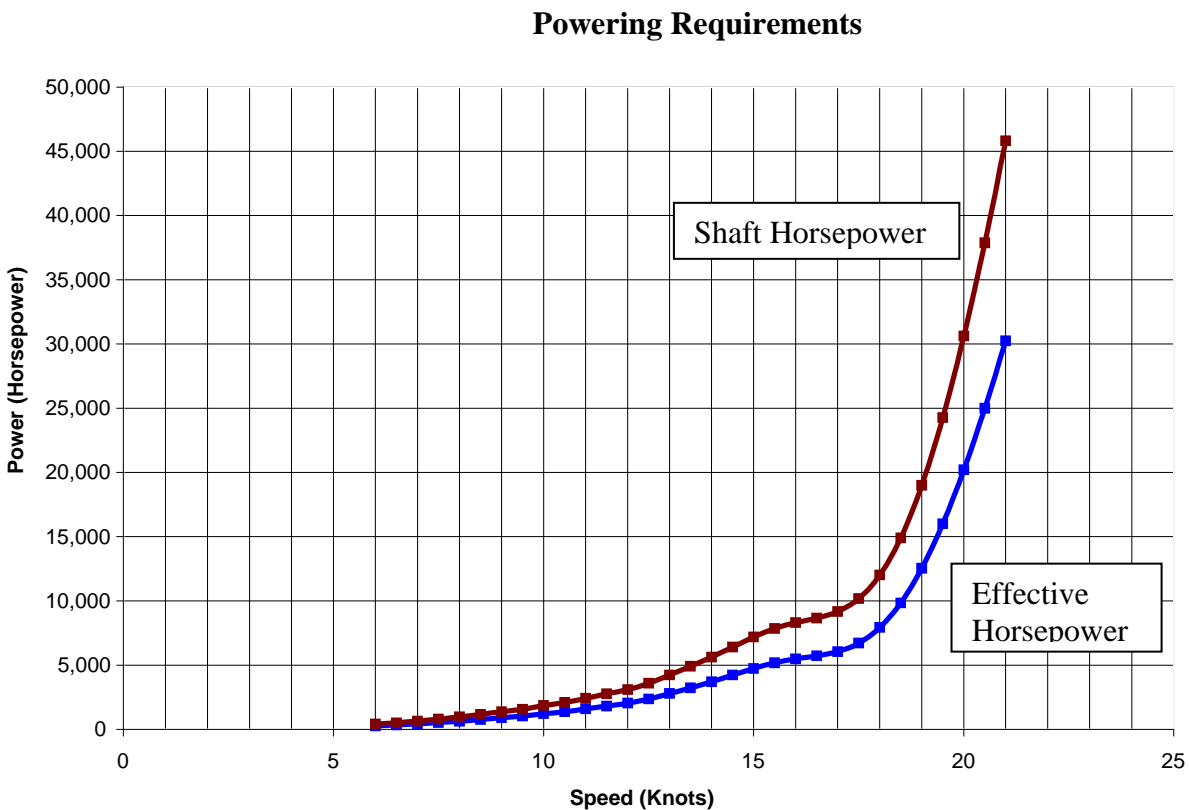


Figure 10. APV powering curve depicting speed vs. horsepower

### **3.6.2. Propulsion**

The APV features a twin Azipod steerable propulsor system from ABB Marine. The system gives the APV excellent maneuverability and improved fuel efficiency. Two ICE V18 Azipods provide the 30,000 shp or 22.5 MW needed at 20 knots. These pods are designed to encounter ice flows on a regular basis. Their stainless steel prop and modified pod shape deflect, break and take impact from ice flows being pulled from the surface of the water. As the normal operating environment will include consistently rough seas and heavy ice flows, there is great benefit to using Azipod for the APV's propulsion system.

### **3.6.3 Integrated Electric System**

From propulsive efficiency calculations and estimations on the hotel load for ship systems and heating, an estimated maximum load of 27 MW is required. Various electrical power generation options were evaluated on their ability to provide for this load before a diesel electric system was selected.

The APV has four diesel generator sets. It is possible to turn different engine and generator sets on and off to achieve the required power for a specific mission to reduce fuel consumption. Four 20V Colt-Pielstick PA68s from Fairbank Morse Engine are the most power dense units, and therefore the best option available. Each engine and generator set gives 6.75 MW of power.

### **3.6.4. Electric Load**

Total electrical load including propulsion and hotel loads was estimated to be 27 MW. The 3 MW hotel load was determined by an evaluation of ships of similar size and capability.

## ***3.7 Environmental Concerns***

### **3.7.1. Ice Classification**

The American Bureau of Shipping ice classification system defines a set of parameters to be used for a ship operating in ice including an icebreaking, ice capable, and ice strengthened ship. The APV operates as an ice capable ship allowing it to perform operations in the marginal ice zone with thin, first year icebreaking capabilities. It will be designated as an A1 ice classed ship.

Ice strengthening is centered around the waterline and extending downward to the hulls and upwards along the strut above the waterline, forming an ice belt. The bow, midbody, and stern areas of the hull must be strengthened in accordance with American Bureau of Shipping Ice Classification standards. There is still much research to be done into the ice capabilities of SWATH ships. The added structural weight and exact location of the ice strengthened area

must still be determined. For the purposes of weight estimation, a 10% addition of structural weight was added to the SWBS 100 group, resulting in an increase of 220 tons.

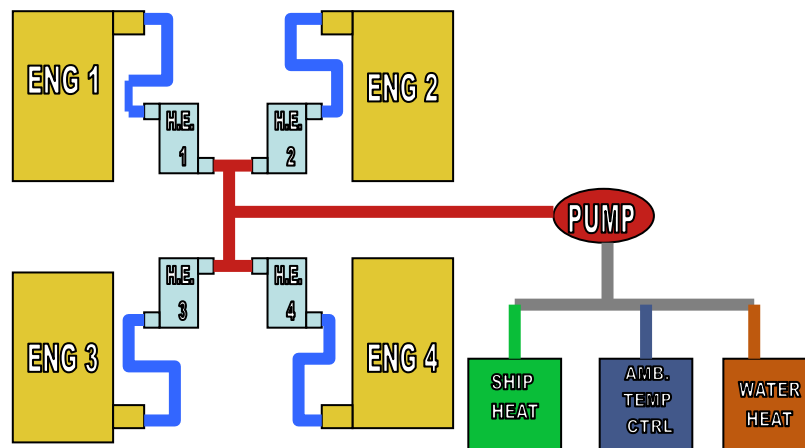
### 3.7.2. Topside Icing

Accounting for topside icing is crucial to gaining an accurate estimate of an arctic-venturing vessel's stability in cold climates. Topside icing tends to build up on deck around machinery, railings, and other topside equipment.

To minimize icing, it is important to design the deck and superstructure to prevent topside ice from gathering. Deck machinery is to be enclosed and an advanced enclosed mast system houses sensors and radar in this design.

Current ice prevention chemicals include various coatings that use nanotechnology to prevent ice from forming. Baseball bats and mallets are the typical tools of ice removal. Both ice prevention and ice removal techniques require constant care to prevent dangerous situations from arising.

A new technique for combating topside icing uses small air-to-liquid marine heat exchangers to capture heat from the exhaust and transfer it to ship heating systems through a pump. Figure 11 shows the heat exchanger-engine system.



**Figure 11. Heat Exchanger-engine system diagram.**

ENG = engine. H.E. = heat exchanger.

The scope of this project did not allow for integration of the heat exchanger system in the APV's weight calculations. However, it is an intriguing idea for maximizing efficiency of deck, bulkhead, and mast heating systems and warrants further study.

A quantitative analysis of the APV's stability under the most severe icing conditions was also performed. Results from previous icing studies performed for the T-AGOS-19<sup>4</sup> and

information from a Raytheon manual on environmental conditions<sup>3</sup> faced by Arctic-faring ships were used to estimate ice accumulation on the APV. This results in a maximum accumulation of 665 long tons of uniformly distributed ice with a center of gravity 73.1 feet above the keel. The topside icing reduces the transverse metacentric height to 7.2 feet compared to 13.8 feet in the absence of topside icing. Longitudinally, the load has a center of gravity 116 feet from the bow. This results in a 9 ft reduction in longitudinal metacentric height, which amounts to 74.3 feet. Intact stability with topside icing is summarized in Table 6.

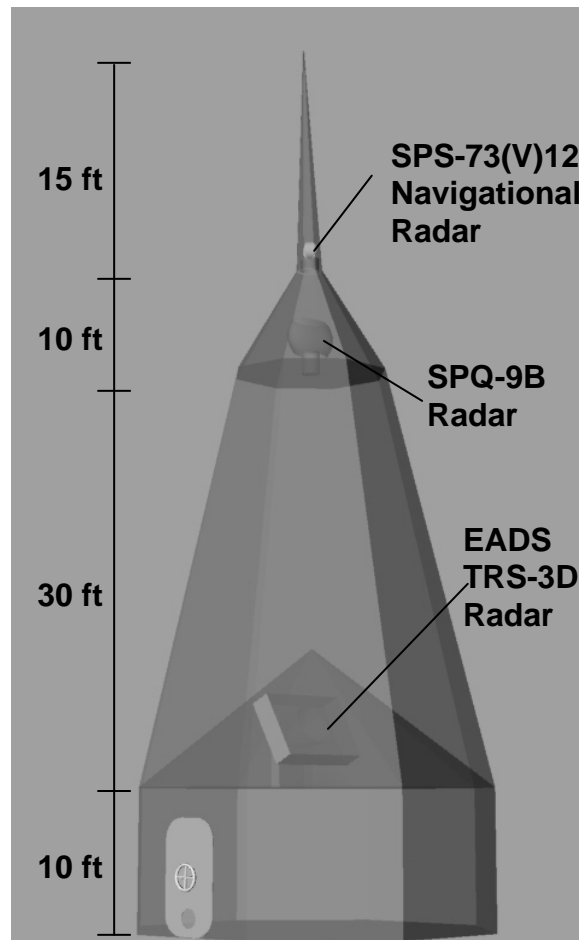
<b>Stability with Topside Icing</b>	
<b>Hull Characteristics</b>	
Displacement with Icing (LT)	7,130
Water plane Area (ft <sup>2</sup> )	4,681
TPI (LT/inch)	11.15
Length Overall (ft)	260
Draft (ft)	31
<b>Transverse Stability</b>	
BM (Transverse) (ft from Keel)	31
KB (ft from Keel)	13.4
KM (ft from Keel)	44.3
KG with Icing (ft) (ft from Keel)	37.1
GM (Transverse) with Icing (ft)	7.2
<b>Longitudinal Stability</b>	
BM (Longitudinal) (ft from FP)	76.2
LCB (ft from FP)	106.5
KM (Longitudinal) (ft from FP)	182.6
LCG overall (ft from FP)	108.5
GM (Longitudinal) (ft from FP)	74.3
<b>Trim</b>	
LCB (ft from FP)	106.5
LCG (ft from FP)	108.5
GM (Longitudinal)	74.2
Draft (ft)	31.00
Trim (ft)	7.00
Angle of Trim (degrees)	1.54
Draft Forward (ft)	27.5
Draft Aft (ft)	35.5

**Table 6. Stability with topside icing**

Design features such as reduced deck machinery, the advanced enclosed mast, and increased deck camber are assumed in the design to reduce topside icing. Such features were not used in the earlier studies used to estimate icing on the APV. Consequently, the results are assumed to be conservative.

### 3.8 Mast Design

The APV's mast will mimic the design of the Advanced Enclosed Mast Systems (AEMS) found on the Navy's latest Amphibious Transport Dock (LPD) ships. The AEMS houses radar and sensor antennas in a carbon fiber housing. It provides protected access for servicing the interior systems without braving the conditions outside the ship. It also protects the radar and sensor systems from the elements, and minimizes topside ice accumulation. The mast is shown in Figure 12.



**Figure 12. Mast design and layout.**

The APV's AEMS houses an EADS-TRS-3D surface/air radar system, an SPQ-9B surface/air system, and an SPS-73(V)12 navigational radar as well as sensors and antennas.

The AEMS is approximately 20-25 feet in base diameter and approximately 50 feet tall. A 15-foot-long antenna section is housed on the top, containing the navigational radar as well as several sensor systems.



The base, approximately 10 feet tall, houses the base access route to the EADS radar area. The second section is approximately 30 feet tall, and houses the EADS radar system and a foldable access ladder to the top section. The top section is approximately 10 feet tall and houses the SPQ-9B radar. The antenna section, which decreases in diameter as it gets taller, houses the small SPS-73(V)12 navigational radar at its base and includes antennas and sensors. The smooth surface of the octagonal structure of the mast will allow for minimal ice formation and simplify removal of ice if necessary.

### **3.9. Crew**

A rough estimate of the APV's crew size, obtained through research into ships of similar size and mission as the APV, results in approximately 100 enlisted and 12 officers, which totals to 112 crew.

### **3.10. Mission Systems**

#### **3.10.1. Sonar**

The APV's mission to detect and interdict foreign ships requires sonar systems capable of detecting submarines at long distances. SWATH ships have been equipped with low frequency towed arrays. Navy combat ships have hull-mounted sonar to provide active and passive detection in the mid-to-high frequency ranges. The APV design includes both a hull mounted and towed array sonar.

The Tactical Towed Array Sonar (TACTAS) system is a medium frequency, medium range, passive sonar system. Its medium frequency will detect submarines at a satisfactory range. Therefore, the TACTAS array will be the primary sonar for the APV.

The AN/SQS-56 is currently used on USN warships<sup>5</sup>. It is a dome-encased sonar system that operates at mid-frequency and mid-range in both active and passive modes. This complements the passive mode TACTAS system. The hull mounted sonar provides continuous sonar coverage when the TACTAS is not in use.

Finally, the United States does not possess comprehensive data on the Arctic Ocean floor due to restrictions on research vessels navigating in the area. Therefore, a commercially available, hull mounted, bottom mapping sonar dome is included in the APV's design to add significant data to the US's knowledge of the ocean floor. The Advanced Mine Detection Sonar, or AMDS, was originally developed for the detection and disarming of mines, but has recently been used for bottom mapping missions. Because it is encased in a dome and not towed, it can constantly run without interference with the APV's other missions.

These sonar systems will not interfere with one another, because they all have systems that purposely seek out and block other sonar signals.

### **3.10.2. Radar**

The APV must detect surface ships and planes as well as submarines. It must also be able to navigate safely and detect icebergs or other objects on the water. Therefore, the vessel needs radar systems for both navigation and surface and air detection purposes.

For the surface and air detection radar, the APV will carry the EADS TRS-3D model, a relatively new radar model with a low weight antenna, optional automatic detection and initiation of defense sequences, easy integration with weapons systems, and a medium range. Currently, the Coast Guard and the Navy have the TRS-3D on their cutters and frigates.<sup>5</sup>

To complement the EADS TRS-3D radar, the APV houses the AN/SPQ-9B surface/air detection radar, which specializes in cutting through ‘clutter’ to aid other radar systems. It is a small system that does not require excessive space, and will enable the APV to see through surface ice and other ‘clutter’ to detect surface threats.

For navigational radar, the APV carries the AN/SPS-73(V)12 navigational radar system. Its light weight and non-interference with other radar systems make it optimal for the APV’s mission. It is one of the most advanced navigational radar systems currently in use on Navy ships. Its small size makes it easy to install in the APV’s AEMS.

### **3.10.3. Armaments**

In order to carry out the mission of interdicting foreign vessels and deterring aggression in the Arctic region, the APV carries several weapons systems.

#### **3.10.3.1. Main Gun: BAE Systems Mk110 Mod 0 57 mm naval gun**

The Bofors 57 mm Mk3 is used as a main gun on numerous naval vessels of the APV’s size, capability, and requirements. The Mk110 mod 0, an American variant of the Mk3, has been chosen by the USCG for their new National Security Cutter, and by the US Navy as a close-in weapon for the Littoral Combat Ship and the DDG 1000 series. With a maximum range of nine nautical miles and the ability to fire six mode programmable Mk 295 mod 0 ammunition, the Mk 110 mod 0 gives the APV devastating all-target capability.<sup>6</sup>

#### **3.10.3.2. CIWS: Lockheed Martin Oerlikon Contraves’ MDG-351 Millennium**

To protect itself from inbound enemy threats, the APV is equipped with the Millennium Gun Close-In Weapon System (CIWS). The Millennium Gun operates in the same manner as the Phalanx found on most U.S. naval combatants. The APV needs an enclosed structure to minimize ice buildup, therefore the Millennium Gun is ideal. Figure 11 shows the Millennium Gun.



**Figure 13. CIWS Millennium Gun,**

**3.10.3.3. .50 Caliber: Oto Melara Model 517 remote controlled 12.7 mm naval turret**

As a part of the basic requirements of close-in defense, most naval ships have multiple .50 caliber Browning machine guns on their deck. However, those guns would expose the APV's crew to the harsh elements and sub-zero temperatures of the Arctic. The Oto Melara Model 517 naval turret<sup>7</sup> provides equivalent fire power from an enclosed, remote controlled turret allowing the gunner to operate, load, and recock the gun from a sheltered position. The turret comes equipped with a day camera and a laser sight for checking aim at short distance. Figure 12 depicts the Oto Melara Model 517.



**Figure 14. .50 caliber machine gun**

### **3.10.4. Aviation**

#### **3.10.4.1 Multi-Mission Helicopter: Sikorsky MH-60R Seahawk**

The APV is a multi-role Arctic Patrol Vessel which must be able to undertake a variety of missions. An MH-60R Seahawk helicopter will assist in accomplish these objectives. The MH-60R is a multi-mission helicopter, with the ability to effectively engage in rescue ops, ASW, ASuW, ASST, and VRETREP. The multitude of tasks that the MH-60R can complete allows the APV to have an extended fighting range, patrolling range, and radar range. The attributes of the MH-60R make it an evident choice for the APV.

#### **3.10.4.2 VTOL UAV: Northrop Grumman MQ-8B Navy Fire Scout**

The APV has the ability to carry three MQ-8B Fire Scouts while also carrying one MH-60R SeaHawk to aide in surveillance, ice flow navigation, ASW, and ASuW.

### **3.10.5. Auxiliary Craft**

#### **3.10.5.1 Intercept and Interdiction Craft: 36' SeaArk Marine Dauntless RAM**

Part of the APV's mission requirement is to interdict non-U.S. ships and transport cargo and personnel to remote research facilities. To complete these missions, the APV needs a small craft. The SeaArk Dauntless Patrol Craft is superior to a standard RHIB because of its enclosed cabin, which protects the crew and boat from the Arctic environment. The Dauntless is stowed in an enclosed space on the APV to resist icing and ease the boarding process in cold weather. It is lowered from a side-mounted, telescopic, single-point davit system.

#### **3.10.5.2 Fast Response Rescue Craft: Husky Airboats Nattiq**

The second small craft aboard the APV is specifically designed for rescue operations in the marginal ice zone and on ice. The Nattiq<sup>8</sup> is an air propeller boat designed to be operable on ice and water. The nineteen ft, 2,900 lb Nattiq has a 355 hp engine and is able to move 6 people or 1,200 lb at 31 knots in open water and 61+ knots on top of solid ice. A hydraulically activated, spiked, stainless-steel plate on the transom provides for controlled stopping on ice. The Nattiq gives the APV extended range when going to ice covered ports and when making rescue missions. Figure 13 shows the Nattiq Rescue Boat.



**Figure 15. Nattiq Rescue Boat**

## 4. Summary and Conclusion

The Arctic Patrol Vessel addresses an evolving need for a United States naval presence in the Arctic. This project outlines requirements for a ship of this nature. The ship must be capable of persistent operation in the Arctic environment while performing its mission effectively and reliably.

The APV's hull form is a Small Waterplane Area Twin Hull (SWATH) design. While a SWATH ship has not been tested in heavy ice packs, the advantages a SWATH brings in seakeeping make up for any range lost from not being able to perform as an ice breaking ship. The APV is powered by a twin Azipod system, which improves fuel efficiency and maneuverability. A diesel electric system provides the APV's power, featuring four diesel generator sets. This system allows the APV to turn different engine and generator sets on and off to achieve the required power for a specific mission and reduce fuel consumption. To reduce topside icing, the deck and superstructure are designed to prevent ice formation, deck equipment is enclosed, and an AEMS houses radar and sensors. Additionally, a heat exchanger system was examined for assistance in heating the main deck, equipment enclosures, railings, and the AEMS. The APV's detection systems include sonar and radar systems. Its weapons include a 57 mm gun and a Close-In Weapons System. It carries a helicopter, unmanned air vehicles, a patrol boat, and a rescue boat for various missions.

In the continuation of the design, the APV team recommends development in the following areas:

- Further optimization of the hull to reduce resistance at higher speeds, and reduce trim.
- Seakeeping analysis of the hull form.
- Determination of SWATH capabilities in ice.
- Evaluation of the efficiency of podded propulsion on SWATH hulls.
- Development of a topside ice removal system design, including possibilities of an integrated heat exchanger system.
- Damage stability analyses.
- Propulsion optimization.

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## **Appendices**

### **Appendix A: General Ship Design Requirements**

#### **Arctic Offshore Patrol Vessel**

##### **Introduction**

1. The Arctic is expected to become subject to more commercial exploitation and international controversy as the resources become more economically viable and as the ice pack recedes.
2. It is likely in the future that a significant amount of effort will be required to patrol the region and to protect US economic and national interests. It is expected that an Arctic patrol vessel may be required to provide a dedicated independent capability to undertake patrol and support diplomatic initiatives with military capability.
3. Two common modes of operation are anticipated:-
  - a. The first is the routine patrol of the geographic area of interest to the US. This mode will require long endurance missions undertaken in extreme conditions on a routine basis, and may include an element of icebreaker capability.
  - b. The second is the provision of a limited offensive capability, primarily to deter acts of aggression but in addition to interdict other forces and protect US assets.

##### **Aim**

4. To design an Arctic Offshore Patrol Vessel capable of undertaking both long patrol deployments in extreme conditions and to undertake limited offensive missions to protect vital US interests in the Arctic. To identify technical issues and requirement associated with the design that requires further investigation and development.

##### **Ship Design Requirements**

5. The ship shall be capable of undertaking the following missions:-
  - a. To navigate safely arctic waters.
  - b. Undertake long endurance patrol missions in Arctic Waters without recourse to a base port.
  - c. To detect and interdict non US ships and submarines .
  - d. To transport personnel and cargo to remote Arctic ports and research facilities.
  - e. The ship design requirements shall identified by the project team following a general study of Arctic Ocean geography and climate. The project team shall identify an appropriate level of Ice classification for the vessel as well as whether the vessel has a requirement to operate as an icebreaker.



- f. The project team shall also investigate the relevant aspects of international maritime law to understand the limitations and requirements present on vessels due to the disputed ownership of Arctic waters.

### **Areas Of Technology Exploration**

6. The requirements associated with the support and operations of a vessel independently, over large distances in an extreme climate.

### **Constraints**

7. The vessel's cost shall be minimized by use of commercial standards where appropriate.
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 and also to meet the classification and safety regulations relating to a vessel with an appropriate Arctic operating regime.

### **Approach**

10. The team shall generate a concept of operations and operational requirements for the vessel following a review of Arctic Ocean geography and maritime law.
11. The team will review requirements and then brainstorm potential ideas.
12. Suitable ideas shall be assessed for architectural impact and technical feasibility.
13. The competing ideas shall be reduced to a preferred concept using a decision making process.
14. A ship design synthesis model shall be developed.
15. 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.
16. The implications of any new technology or operational issues shall be noted. Recommendations for follow-on work shall be documented.

### **Deliverables**

17. All work will be documented in a CISD Project Technical Report. The final report and presentation shall be suitable for unclassified, public release.
18. 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.

19. The team will develop and give informal intermediate presentations and a final project presentation.
20. 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.
21. 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.

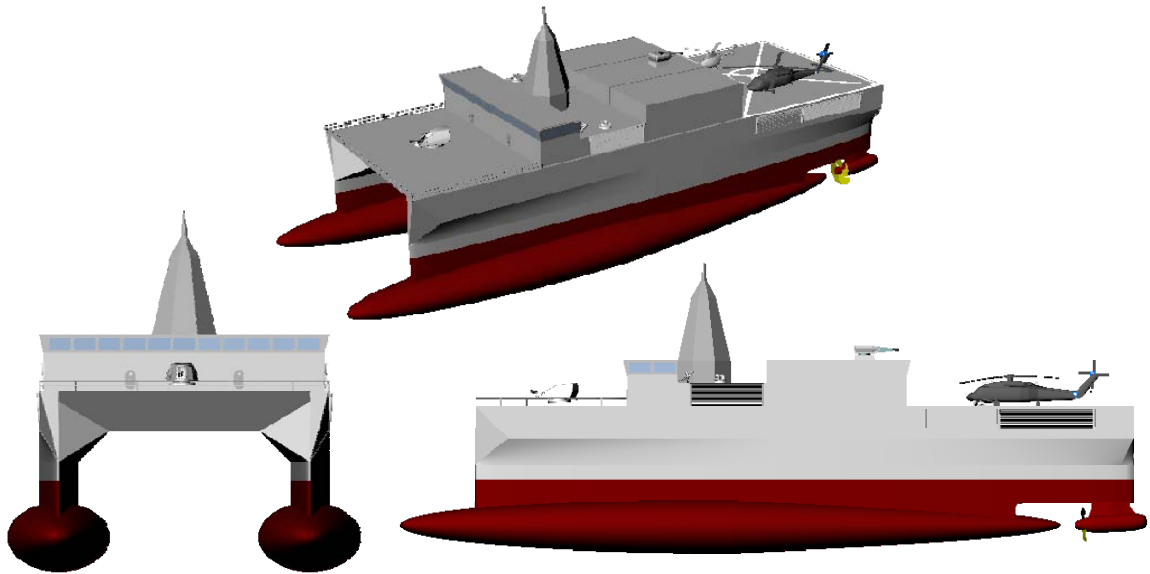
# Appendix B: Icing Calculations

Piece	Dimension (ft <sup>2</sup> )	V/H	Distance from Keel (ft)	Distance from Aft (ft)	Weight of ice (LT)	Quantity	Net weight(lb)
Flight Deck	8,370	H	57.9	45.0	182.0	1	182.0
Hangar Door	1,674	V	66.9	90.0	36.0	1	36.0
Hangar Sides	1,620	V	66.9	117.5	32.5	2	64.9
Hangar Roof	4,950	H	75.9	117.5	107.6	1	107.6
Main deck sides Hangar	83	H	57.9	117.5	1.8	2	3.6
Hangar fore	810	V	71.4	145.0	16.2	1	16.2
Mast	3,927	V	91.9	172.0	78.7	1	78.7
Officer Quarters	495	V	62.4	172.5	9.9	2	19.8
Bridge Sides	180	V	71.4	190.0	3.6	2	7.2
Main Deck sides Bridge	83	H	57.9	190.0	1.8	2	3.6
Roof of Bridge	1,800	H	75.9	190.0	39.1	1	39.1
Bridge, Officers Fore	1,674	V	66.9	200.0	33.5	1	33.5
Forward Deck	5,580	H	57.9	230.0	121.3	1	121.3
					<b>Total Weight (LT)</b>	<b>664</b>	
<b>Vertical Load (lb)</b>	<b>564,084</b>			<b>Vertical CG (ft from keel)</b>	<b>73</b>		
<b>Horizontal Load (lb)</b>	<b>1,024,163</b>			<b>Horizontal CG (ft from aft)</b>	<b>145</b>		
<b>Surface Area Vertical</b>	<b>12,567</b>						
<b>Surface Area Horizontal</b>	<b>21,030</b>						

APV Icing Characteristics			
	<b>Surface Area (ft<sup>2</sup>)</b>		
Horizontal	21,030	<b>Raytheon Research</b>	
Vertical	12,567	Vertical load lb/ft <sup>2</sup>	34.8
Total	33,597	Total load lb/ft <sup>2</sup>	117.8
		% Vertical Load	0.3
		<b>T-AGOS Testing Results</b>	
%Vertical	0.4	Horizontal load lb/ft <sup>2</sup>	48.7
%Horizontal	0.6	CG T-AGOS (ft from aft)	80.7
		Length of T-AGOS (ft)	190
lb/ft Vertical	44.9	Beam T-AGOS (ft)	80
Total Vertical load	564,084	Beam APV	93
		Horizontal load APV	1,024,163

## Appendix C: Additional Pictures of the APV

### APV



### APV with Aircraft and Boats

