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New DP-Capable Icebreaker for the Great Lakes

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New DP-Capable Heavy Icebreaker for the Great Lakes

Summary

The United States Coast Guard's construction of a new heavy icebreaker for the U.S. Great Lakes is a major acquisition program (over $100 million) that will field a state-of-the-market, multi-mission cutter capable of effectively replacing two World War II vintage cutters, a single mission heavy icebreaker and a buoy tender with limited multi-mission capability. The new cutter's extensive dynamic positioning capability will be integral to her aids to navigation mission and the Coast Guard plans to test the DP system's ability to assist with the icebreaking mission as well.

Icebreaking on the Great Lakes

Prior to the 1930s, domestic icebreaking was not a concern to the public or the U.S. Coast Guard. The annual closing of the Great Lakes due to heavy icing was accepted as part of the change in seasons. However, as the demand for home heating oil and automobile fuels increased, there was a demand for year-round navigation on the lakes. During World War II, there was a demand for raw materials to support the steel plants on Lake Michigan and Lake Erie to support the war effort, and Congress funded the construction of a 290-foot heavy icebreaker. The U.S. Coast Guard Cutter MACKINAW (WAGB 83) was commissioned in 1944 and home ported in Cheboygan, Michigan.

MACKINAW is currently the only heavy icebreaking resource assigned to the Great Lakes, and it is capable of breaking level ice of 32 inches (0.8 meters) thickness at a speed of 3 knots. Although it was the world's largest and most powerful icebreaker when commissioned, it has become increasingly costly to support. A 1998 analysis of alternatives found that construction of a multi-mission heavy icebreaker was the best solution for a replacement. The old MACKINAW is scheduled for decommissioning in June of 2006. The venerable cutter is shown in Figure 1.

Fig. 1. USCGC MACKINAW (WAGB 83)

Beginning in 1986, the Coast Guard began replacing its aging fleet of World War II era 180-foot sea going buoy tenders. Three of these vessels were stationed on the Great Lakes and they had limited ice breaking capability. The recent replacement of two of these 180s with 225-foot sea going buoy tenders (USCGC HOLLYHOCK and USCGC ALDER) has significantly increased the Coast Guard's capabilities on the Great Lakes. These 225-foot, 2000 ton sea going buoy tenders are powered by two 3100 horsepower diesel engines, and their propulsion consists of a single controllable-pitch propeller, a 450 horsepower bow thruster, and a 550 horsepower stern thruster. The new ships' dynamic positioning systems and innovative buoy handling gear have revolutionized the way the Coast Guard maintains aids to navigation.

Fig. 2. USCGC HOLLYHOCK (WLB 214) on Lake Michigan.

The new 225-foot buoy tenders, while far more capable than the WWII-era 180s, are designed to break only 14 inch solid level ice going ahead, and their icebreaking capability astern is severely limited. One of the 225s is shown in Figure 2.

Operational Requirements

An extensive analysis of alternatives determined that a new multi-mission cutter was the most cost efficient way to maintain a heavy icebreaking capability on the Great Lakes. The primary requirements for a vessel capable of breaking heavy ice and servicing aids to navigation are:

- Ability to break 32” solid level ice at a speed of 3 knots ahead and 2 knots astern
- Ability to turn 180 degrees in a 300-foot wide channel
- Winter range based on 10 days of continuous operation at 65% of available horsepower, plus a 33% margin
- Maximum service life draft of 16.5 feet
- Meeting U.S. Navy intact and damaged stability criteria for two compartment flooding
- Accommodations for at least 48 crew
- Use of variable speed thrusters to meet positioning and maneuvering requirements
- Integration of buoy handling systems and small boat systems developed for the 225-foot buoy tenders
- An operational availability of at least 90% during critical Great Lakes seasonal buoy runs (November 1st to December 15th and again May 1st to June 1st) and the critical Great Lakes ice season (December 16th to April 30th).

Coast Guard naval architects provided a point design based upon the Double-Acting Tanker (DAT) designs developed for the Baltic Sea. The old MACKINAW has a bow propeller that creates a low pressure area under the ice directly ahead of the ship, enhancing icebreaking capability but compromising performance in open water. The principle behind the DAT concept is that the ship travels ahead in open water and thus has a highly hydrodynamic shaped bow and sides. When it sails in ice however, it travels astern where the reinforced stern hull form is used to break the ice. The azimuthing podded propulsion system is used to create the low pressure area and produce a water stream between the ice and the hull, greatly reducing drag through the ice.

Extensive open water and ice basin model testing was conducted to evaluate and refine the performance of the hull form and validate the feasibility of the dual-mission ship. Two bow configurations and three stern forms were tested. Model tests were performed to compare azimuthing podded propulsion with a more conventional (controllable pitch, twin screw, single rudder) configuration and, once the greater maneuverability of the azimuthing pods was demonstrated, several pod locations were tested.

The resulting hull form, shown in Figure 3, is a compromise that effectively meets the conflicting design requirements for heavy icebreaking (heavy, wide, and deep) and aids to navigation (shallow draft and highly maneuverable). The new cutter's form is very full for an icebreaker in order to meet endurance requirements. The discharge of gray water or sewage is not permitted on the Great Lakes, so holding tank capacities were designed to equal those of potable water tanks. The new ship's length overall was dictated by the requirement to turn around in a 300-foot wide channel, and its service life draft was limited to 16.5 feet due to the shallow channels it will be required to operate in. Sea keeping and maneuverability considerations limited the beam to 58 feet. Main deck freeboard is limited to 8 feet in order to service aids to navigation.

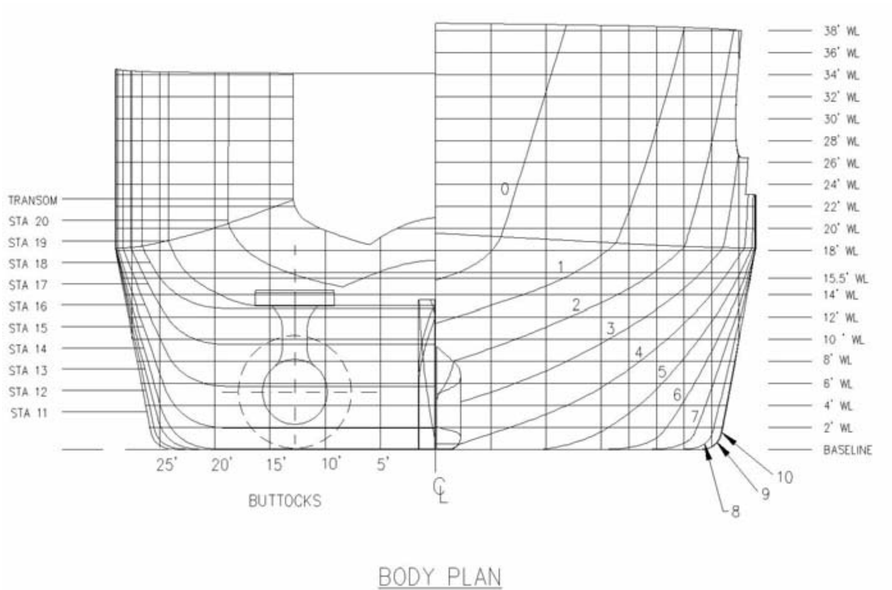


Fig. 3. Hull form of USCGC MACKINAW (WLBB 30)

The structural arrangement developed for the new cutter is unique for an icebreaker because the sides of the cutter are transversely framed, while the bottom and decks are longitudinally framed. This arrangement was adopted to reduce structural weight and the cost of fabrication. Both the ice belt plating and structural framing are 7/8" high strength steel.

New Construction

Construction of the new heavy icebreaker, which will also be named MACKINAW, began in September 2003 at Marinette Marine Corporation in Marinette, Wisconsin and the new cutter was launched in April 2005. The new ship's primary missions are heavy icebreaking and aids to navigation, with secondary missions of pollution response, law enforcement, and waterways safety and security. The new MACKINAW will have an integrated medium-voltage electrical power plant, a fully integrated bridge, azimuthing podded propulsion augmented by a 750 horsepower bow thruster, and an advanced dynamic positioning system. Figure 4 details the differences between the old and new cutters.

	WAGB 83	WLBB 30
Length Overall	290’	240’
Beam (maximum)	74’	58.5’
Draft (maximum)	19’	16’
Displacement	5,252 T	3500 T
Power (total)	10,000 hp	9,500 hp
Propulsion	Twin shafts	3.36MW azipods
Maximum Speed	18.7 kts	16 kts
Fuel Capacity	350,000 gals	138,000 gals *
Range @ 12 kts	41,000 nm	4,000 nm
Crew	75	55 **

Fig 4. Old (WAGB 83) vs. New (WLBB 30)
* Provides 10 days endurance at 65% power.
** Does not include 15 shore side support personnel

The new multi-mission MACKINAW (70 total) replaces both the old MACKINAW (75 crew) and ACACIA (48 crew) for an overall savings 53 of personnel.

<u>Propulsion System</u>

The new MACKINAW’s design is based on the use of twin azimuthing podded propulsion units, the first of its kind aboard a USCG vessel. Each unit contains an electric motor driving a 10-foot fixed-pitch propeller, and the propulsion units can be slewed through 360 degrees providing outstanding maneuverability. One of the units is seen during assembly in Figure 5. The design eliminates the need for conventional shaft lines, rudders, and steering gear. Electrical power for propulsion, bow thruster, and ship service loads is provided by a state-of-the market AC/AC integrated diesel-electric power plant utilizing three medium-speed diesel engines / generator sets that produce 3130 kW each. A separate auxiliary diesel generator will provide 718kW when at anchor or away from shore ties.

Fig. 5. Assembly of one of the 3.36MW azimuthing podded propulsors.

The power plant was sized such that one generator could carry all the ship service loads while propelling the ship at 12 knots, two generators could allow station keeping for aids to navigation work or enable a 14 knot cruise, and three generators could enable a 15 knot cruise or breaking 32” level ice at 5 knots.

Risk Management

There is considerable risk in the design and construction of a one-off vessel designed to fill two conflicting requirements---heavy ice and aids to navigation. The new MACKINAW is a class of one, we only have one chance to get it right, and the Coast Guard Acquisition Directorate applied an aggressive risk management strategy including:

- Applying lessons learned the recent development and construction of 14 coastal and 16 sea going buoy tenders
- Model tests in open water and ice (testing different bow and stern configurations)
- Computer generated visibility and accessibility studies
- Full-scale mockups of critical spaces (pilothouse, engineering control center, galley)
- A computer generated Performance System Dynamic Analysis (PSDA)
- DNV Watch 1 bridge, ABS unmanned engine room
- Budgeting for the recapitalization of major systems
- Civilian port engineers and a full-time training specialist

In addition to extensive ice trials, the Coast Guard Operations Directorate will conduct extensive Operational Testing and Evaluation (OT&E) to determine the effectiveness and suitability of the new cutter. The OT&E will provide information on tactical employment of the vessel and suggestions for fine-tuning of systems. The OT&E will evaluate:

- Bridge and Engineering Watches
- Damage Control
- Habitability
- Power
- Sea Keeping
- Maneuverability
- Ship Control and Station Keeping
- Buoy Handling
- Endurance / Range
- Reliability / Maintainability / Operational Availability
- Command / Control / Communications / Computers / Intelligence

OT&E is scheduled for December 2005. Ice Trials are scheduled in January 2006 and again in April of 2006.

Performance Projections

A Propulsion System Dynamic Analysis (PSDA) conducted an extensive computer-modeled analysis of the new cutter’s projected performance. Some of the PSDA’s projections are detailed in Figure 6.

Icebreaking	Conditions	Contract Specification	PSDA Projection
Light solid level ice, continuous	14" plate ice	> 10 kts ahead	12 kts ahead
Heavy solid level ice, continuous	32" plate ice	> 3 kts ahead > 2 kts astern	4.5 kts ahead 4.9 kts astern
Moderate brash ice, continuous	12' brash ice	Continuous motion	5.4 kts ahead 8.7 kts astern
180 degree turn in 300' channel	32" plate ice	< 5 minutes	5.5 minutes ahead in 270' 3.0 minutes astern in 250'
Circumnavigate 1,000' x 105' vessel	8' brash ice	< 12 minutes	< 9 minutes ahead < 10 minutes astern
Icebreaking endurance	65% power	15 days	Uses 120,000 gals (10,000 gal reserve)
Open Water			
Sustained speed	Calm seas	> 15 knots	16 knots
Acceleration from DIW	Calm seas	No spec	0-12 kts in 50 seconds 0-16 kts in 100 seconds
Crash stop	Calm seas	< 1,000'	778' using pod reversal 841' using shaft reversal
Endurance at 12 kts cruise	Calm seas	4,000nm	Uses 86,000 gals (44,000 gal reserve)

Fig. 6. Performance projections from the PSDA

During builder's sea trials conducted on Green Bay in early September the new MACKINAW achieved 16.1 knots into a 2- to 4-foot chop. This confirms the validity of the PSDA speed projection and indicates that the icebreaking projections should be valid as well. Figure 7 shows the azimuthing podded propulsors just prior to launch on April 2nd, 2005.

Fig. 7. MACKINAW's stern just prior to launch. Pods are slewed inboard to protect them during the side launch.

Application of Dynamic Positioning

The new MACKINAW's primary dynamic positioning system is ABS DPS 1 system due to the single bow thruster. The DP system consists of one main bridge DP operator station adjacent to the helm amidships plus two bridge wing joystick units. The primary DP system is fitted with redundant wind sensors, redundant DGPS units, and two gyrocompasses that provide not only heading inputs but also provide vessel pitch and roll measurements.

An independent backup joystick system interfaces with the gyros and wind sensors only, providing joystick control. An additional DP control station will probably be added to the new cutter's aft-facing conning station after delivery from the builder.

In addition to interfacing with autopilot functions, the primary DP system software has the following specialized modes and functionalities:

- Autopilot (transits to a waypoint)
- Auto track (follows a series of waypoints)
- A relaxed station keeping mode
- Up to 20 centers of rotation

The relaxed station keeping mode (Kongsberg GreenDP®) keeps the vessel in a watch circle defined by the operator and is designed to reduce both fuel consumption and greenhouse gas emissions. The feature will also mean less mechanical wear and tear on vessel thrusters which should result in lower maintenance costs and increased reliability.

Centers of rotation have been configured for the ship's center of gravity, the bow, the stern, all four buoy deck chain stoppers, and the center of both boat davits. Autopilot modes are fully integrated in the DP system.

The application of DGPS and DP has revolutionized the way the Coast Guard services floating aids to navigation, allowing much safer and efficient operations. Up until recently, WWII-era buoy tenders had nine or ten crew on the bridge to position a buoy using radar, visual bearings, and horizontal sextant angles. It took months to develop the ship handling skills required to accurately position a buoy in a 4- to 6-foot sea. Today a three person bridge watch, using DP to maneuver to the buoy's assigned position and hold that position indefinitely, can quickly position a buoy with far greater accuracy and efficiency.

Greatly improved buoy and chain handling equipment has reduced the buoy deck gang from eight down to four crew, and buoys are serviced with much greater safety. The Coast Guard also intends to investigate the application of dynamic positioning and joystick control functionality in icebreaking. DP systems previously utilized aboard Coast Guard buoy tenders required the bow thruster to be on-line to provide DP operations. Bow thrusters are secured and not utilized when breaking ice, protecting the bow thruster machinery from damage from the ingestion of chunks of ice. The new MACKINAW's DP system treats the each of the three thrusters---two azipods and a bow thruster---independently, the three thrusters can be added or deleted at the touch of a button, and the system will try to hold station on just one thruster if required. The concept of DP or simple joystick control of the vessel with the bow thruster secured presents an opportunity for greater control in close aboard situations.

Figure 8 shows the old MACKINAW and a 140-foot Coast Guard icebreaking tug (WTGB) in the distance attempting to free an ore carrier beset in over twelve feet of brash ice in the Rock Cut of the St. Mary's River. Brash ice is the aaccumulation of ice made up of fragments not more than six feet across. The ore carrier, 1,000 feet long with a beam of 105 feet, spent nearly a week stuck in this narrow cut which is blasted from bedrock. The old MACKIAW doesn't have the maneuverability and ship control required to circumnavigate the beset freighter in this 300-foot wide channel, and can only work at flushing the area directly in front of it. The smaller WTGB could maneuver alongside the freighter in the cut in open water, but doesn't have the power to deal with the deep brash ice.

Fig. 8, USCGC MACKINAW assists a 1000-foot iron ore ship beset in the 300' wide Rock Cut of the St. Mary's River

The design requirement for a 180 degree turn in 32-inch solid level ice was developed for this situation. The 300-foot wide Rock Cut, blasted from bedrock, doesn't leave much margin for error. Tank tests have shown that the new MACKINAW should be capable of a U-turn within 250 to 270 feet in 32-inch solid level ice, and its maneuverability should be even better in brash ice. During upcoming ice trials we will confirm the tank test data and investigate the application of DP and joystick control of the new cutter in this situation.

Application of Simulation

A DP simulator that has all the functionality of the pilothouse's primary DP console is providing an excellent ship handling tool for use by the cutter's Precommissioning Detail. As the crew awaits delivery they are also taking full advantage of an Integrated Bridge System (IBS) simulator (RADAR, ARPA, ECDIS, actual ship's controls, and visual scene). Both simulators incorporate an accurate hydrodynamic model of the new MACKINAW, and the new ship's operating area, the Mackinac Straits and the St. Mary's River, have been modeled as well. The crew was virtually driving the ship prior to launch.

The new MACKINAW is the Coast Guard's first azipod ship and it's also the first azipod ship to sail the Great Lakes. In preparation for builder's sea trials, the Great Lakes pilots assigned to the project worked closely with the new Coast Guard crew and spent several days on the simulators to learn the handling characteristics of the ship. Actual underway experience showed the hydrodynamic model proved to be very accurate, but it will be fine-tuned upon commissioning of the DP system.

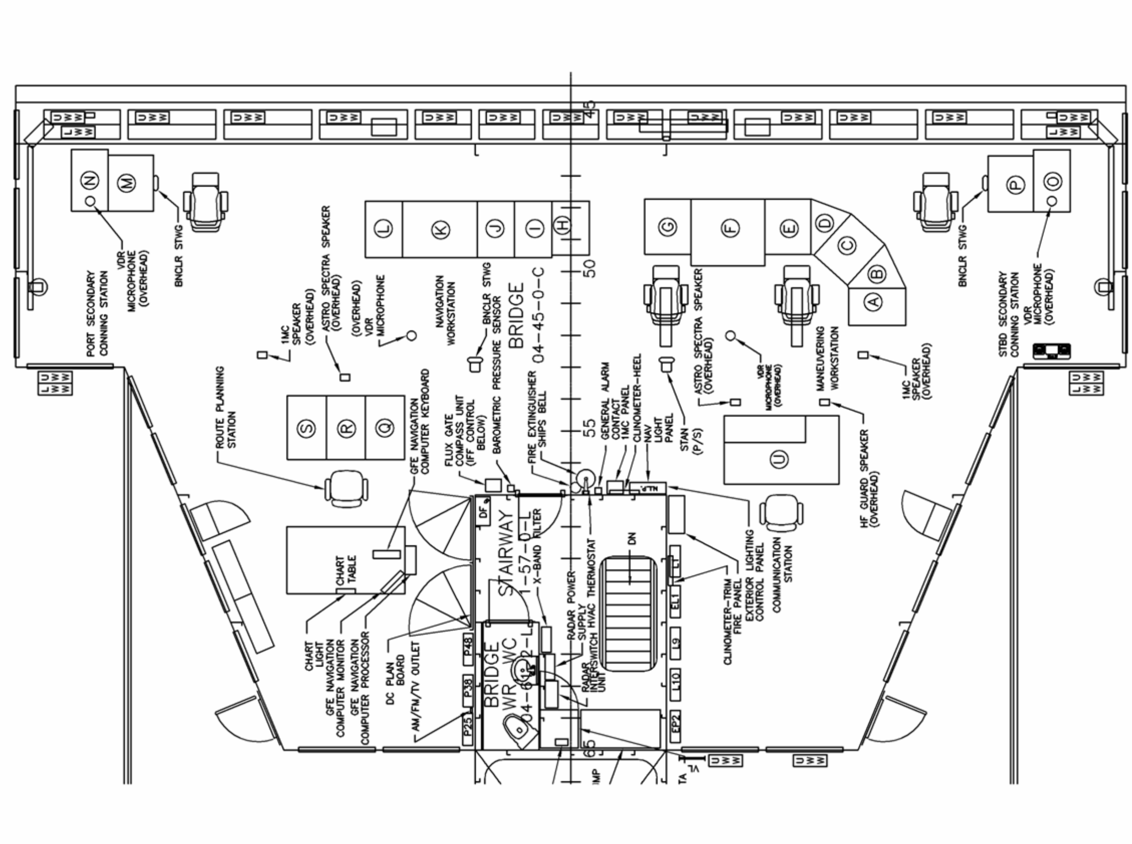
The new cuter will have an onboard training room, and just prior to delivery both the IBS and DP simulators will be installed aboard. After delivery from the builder, the IBS simulator will be expanded to include three 42” flat screen monitors for a 120 degree field of view and the DP simulator will be integrated into the IBS installation. MACKINAW is the first Coast Guard cutter to have an onboard simulation capability, but it has already proven its value for part task training, full mission training, and critical mission rehearsal.

Pilothouse Arrangement

The contract for the new ship specified Det Norske Veritas Watch One (DNV W1) standards for the pilothouse. The Coast Guard will never operate the vessel with only one person on watch on the bridge, but used the DNV W1 standards as drivers for visibility, functionality, and ergonomics. In addition, the contract called for a single bridge integrator. Previous “integrated” bridges on the new buoy tenders included RADAR/ARPA, ECDIS, DP, and controls from different manufacturers and the builder was tasked with integrating the systems. The Coast Guard recognized the inherent risks in this process, and decided to specify a single equipment supplier (as much as possible) and tasked that integrator with maximizing the functionality of the pilothouse.

The resulting bridge will be the envy of the Coast Guard fleet for years to come. The pilothouse extends the full beam of the ship to protect personnel from the elements and includes three conning stations, a communications station, and a route planning station that can double as a command and control area. Although the integrator had produced several integrated bridges, the MACKINAW’s is their largest ever, and their first as lead integrator on a DNV W1 bridge.

Figure 9 details the MACKINAW’s pilothouse design and equipment layout.



Pilothouse Equipment Legend:

A – MPCMS
B – Gyro & searchlight controls
C – ECDIS
D – Communications
E – RADAR
F – Primary Conning Station
G – RADAR
H – Helm
I – Primary DP
J – ECDIS
K – Work surface / chart table
L – SONAR or CCTV
M – MPCMS or CCTV
N – Port Conning Station (ECDIS display over)
O – Starboard Conning Station
P – MPCMS or CCTV (ECDIS display over)
Q – MPCMS
R – Communications
S – ECDIS
T – Overhead console (forward bulkhead)
U – GMCSS, communications

Fig. 9. The pilothouse of the new MACKINAW (MPCMS is the Main Propulsion Control and Monitoring System)

Conclusions

A thorough analysis of design alternatives determined that a multi-mission, DP-capable, azipod ship is the best option for maintaining heavy icebreaking capability on the Great Lakes. The design incorporates a number of innovative technologies include an integrated electric propulsion system, azimuthing podded propulsion, computer based propulsion control and monitoring, and a truly integrated bridge system. Extensive use of simulation has allowed the first crew to become familiar with the ship's navigation, ship handling, and dynamic positioning systems well before actually boarding the new cutter.

The U.S. Coast Guard and the Great Lakes maritime are looking forward to the delivery of the new MACKINAW around November 1st. Figure 10 shows the new cutter underway on September 9th during builder's sea trials. Following further outfitting and some minor modifications such as the addition of AIS, the cutter will commence ready-for-sea certification, operational testing and evaluation, and ice trials. The old icebreaker MACKINAW and buoy tender ACACIA are funded to operate through next June, so the new cutter will have no operational tasking until commissioning in June of 2006. The new multi-mission, DP-capable cutter should be worthy of the legendary name MACKINAW and will serve the Great Lakes for many, many years.

Fig.10. Underway during builder's sea trials September 9th, 2005.