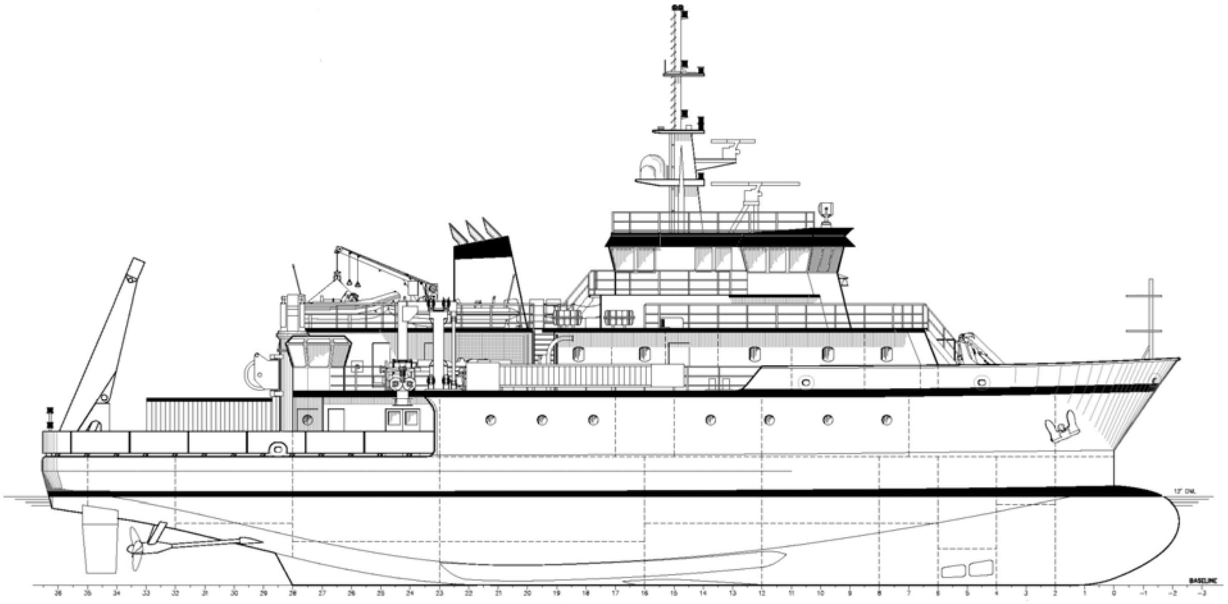
# Nichols Brothers RCRV Design Executive Summary

Prepared for
Department of the Navy
Washington, D.C.

**File No. 06059.11**
**12 November 2008**
**Rev. —**



THE GLOSTEN ASSOCIATES
*Consulting Engineers Serving the Marine Community*

# Nichols Brothers RCRV Design Executive Summary

## 1 Introduction

The Nichols Brother Boat Builders, Glosten Associates and Noise Control Engineering design team was selected by the government in response to NAVSEA Solicitation N00024-05-R-2230 for Phase I of the Regional Class Research Vessel. This resulted in the award of contract N00024-06-C-2256 to Nichols to accomplish the required design work and develop the list of deliverables outlined in the contact. This package is the Design Summary Report, deliverable DI-014, and represents the culmination of the design and final deliverable required under the terms of the contract.

## 2 Principal Characteristics

The Statement of Requirements (SOR) outlines the capabilities and requirements the RCRV must be designed to. The design team used its extensive experience in vessel design and construction to meet or exceed the requirements while providing the best platform to meet the needs of the science community for decades to come. The result of our design is a vessel with the following principal characteristics:

Principal Characteristics:

| | |
|---|---|
| Length Overall | 155'-0" |
| Length on Design Waterline | 152'-1" |
| Beam | 38'-0" |
| Depth, Baseline to Main Deck | 17'-6" |
| Total Installed Power, Continuous | 1,275 kW |
| Sustained Speed, Calm Water | 10.0 knots |
| Estimated Max Speed, Calm Water | 11.8 knots |
| Range, Sustained Speed | 5,400 nm |
| Endurance | 21 days |
| Single Staterooms 01 Deck | 6 |
| Double Staterooms 01 Deck | 3 |
| ADA Stateroom (Double+1 fold down) Main Deck | 1 |
| Double Stateroom Hold Deck | 7 |
| Design Draft | 12'-0" |
| Displacement at Design Draft | 1,035 LT |
| Lightship Weight (estimated) | 771 LT |

Maximum Capacities:

| | |
|---|---|
| Diesel Fuel, at 95% | 35,800 gal. |
| Ballast Water, at 100% | 26,300 gal. |

| | |
|---|---|
| Fresh Water, at 100% | 8,400 gal. |
| Sewage, at 100% | 7,200 gal. |

The above principal characteristics are all within the limits stated in the SOR.

Concurrent with the vessel design process, the vessel construction cost estimate was being developed and continually updated. A firm cost ceiling of $25 million was established for this vessel by NAVSEA. This hard cost ceiling, while ultimately proving to be unachievable, was still a major driver in the decision making processes occurring during the design.

# 3 Design Features

The full details of the design and capabilities of the RCRV are given in the deliverables that form Sections 1 and 2 of this package as well as the Appendix (Section 3). Our intent in this executive summary is to draw attention to some particular features and capabilities of our design and the methodologies utilized to arrive at the final design.

## 3.1 Optimized Hull

Two performance traits are highly important for a research vessel; clean water flow over the transducer fairing, achieved by minimizing bubble sweep down, and low fuel consumption, achieved by minimizing resistance. To optimize an underwater hull for these traits we employed Computational Fluid Dynamics (CFD) to explore over 5,000 unique designs. Each of these designs were evaluated against a set of constraints. The constraint set includes such limits as principal characteristics, stability, required deck areas, construction limitations, stern slamming, propeller clearances, etc. Approximately 1,500 of the designs met the constraint set and were evaluated for resistance and bubble sweepdown. The multi-objective optimization resulted in a 50% reduction in wave making resistance, 22% overall reduction in required power and 55% increase in robustness against bubble sweep down as compared to the baseline hull. The resulting hull is a credible near-optimum hull form, smartly balancing the two objectives.

Bubble sweep down was evaluated using streamlines generated by the potential flow CFD calculations. The streamline crossing the outer edge of the transducer fairing (critical streamline) is traced forward to the bow. Bubbles are assumed to be generated at the wavy free surface and thus the greater the distance between the wavy free surface and the critical streamline; the more robust the design is against bubble sweep down.

Reducing the required/installed power through optimization has a greater affect on lifecycle cost than any other design constraint. Minimizing bubble sweep down allows more time to be spent collecting data. These two aspects translate to an environmentally friendly design with direct cost savings to the end user.

## 3.2 Arrangements

The RCRV has capabilities similar to larger Ocean Class vessels but is a compact design that requires a highly efficient layout. All of the compartment areas on the vessel meet or exceed the SOR.

The mechanical systems, including the large traction winch, comprise the majority of the under deck space while the forward part of the hull houses seven (7) double staterooms. These rooms are envisioned to house scientific personnel and are separated from the engine room and bow thruster room with "buffer spaces" to minimize airborne noise.

The vessel has been arranged such that the science operations and associated spaces are almost entirely within the aft portion of the main deck. This allows personnel to accomplish their task safely and efficiently. Particular attention has been given to work flow and access to and from the working deck, vans, and labs. Mess, hospital, ADA stateroom, galley and meeting spaces are also housed on the main deck. This arrangement permits ADA compliance without the use of an elevator. The forward most portion of the main deck is dry, chilled and frozen stores. These spaces are accessible by crane through a forward hatch allowing quick and straightforward provisioning.

The remainder of the double staterooms (3) and all single staterooms (6), are located above the main deck (01 Level). It is envisioned that the entire crew compliment can be located on this deck. The aft control house, emergency generator, incinerator and garbage storage are located on the aft end of the 01 Level.

At the highest enclosed level is the pilot house with excellent visibility forward and aft and bridge wings to improve side visibility.

The top of the pilot house is an observation deck easily accessed by stairs. This observation deck receives almost unobstructed sun and is outfitted for installation of incubators.

## 3.3 Science Outfit Arrangement

Considerable effort was expended to optimize the arrangement of the full suite of science outfit required by the SOR. Of particular note in this design are the following science outfit arrangement features:

- The entire aft working deck area is clear of unnecessary gear and can be serviced by the main crane, allowing maximum flexibility for locating and supporting science packages;

- The main lab and wet labs, located adjacent to the main working deck, exceed the required floor areas and are configured to allow efficient use of the space with open, rectangular floor plans;

- The traction winch wire is led to a flagging sheave mounted on the crane pedestal, which allows ideal wire routing through the large A-frame or out to the end of the crane boom;

- Scientific stores, located directly below the aft working deck, are easily accessed through a large flush quick-acting hatch with the main crane or via internal stairs;

- The 01 Level winch deck area has been configured to support a range of Owner-furnished winch and handling system options with particular focus on providing safe access for personnel between working decks when winch wires are deployed.

- The aft control station, located on the 01 Level, provides a centralized location for operation and control of scientific deck gear from a climate-controlled space. The control station incorporates a unique shape and carefully located windows (optimized using a detailed 3-D model of the aft deck area) to allow virtually unobstructed sight lines covering the entire main deck and 01 Level scientific work areas, including the installed science gear (main crane, A-frame, winches and winch wire leads).

## 3.4 Intact and Damage Stability

The structural arrangements and careful weight estimations noted herein allowed the RCRV to comply with all required intact and damage stability requirements. Our design achieved our goal of allowing the flexibility to support a diverse range of scientific missions with a minimum of operating restrictions.

Damage Stability, not normally applied to vessels of this size, is a significant design driver for the RCRV, adding noticeably to the cost and complexity of this vessel. The requisite subdivision to achieve damage criteria compliance is achieved by adding more transverse watertight bulkheads than typically found on vessels of comparable size. The addition of bulkheads creates more complex machinery arrangements and increases to the number of watertight doors, bulkhead penetrations, and separate ventilation zones – at the same time, the final RCRV configuration achieves robust damage survival capability with minimal operator intervention.

Load cases, as specified by the SOR, demonstrate full compliance with all intact and damage criteria as well as the maximum navigational draft and trim limits. Compliance is achieved in the delivery and end-of-life conditions throughout the vessel burn sequence, including cases which apply the full 45 LT science deck load. While the vessel is not required to meet icing criteria by the SOR or regulatory compliance, icing conditions can be accommodated in this design by addressing appropriate ice weight and weight center as a payload line item – standard practice in the research fleet when operating in prescribed icing zones.

## 3.5 Working and Load Line Draft

In compliance with the SOR, the RCRV has a draft less than 12’-0” in the end of service life condition. Stability and scantling calculations have accounted for an increased draft up to 13’-0”, still allowing for a significant voluntary reduction in load line draft (or increase in freeboard). This permits the sill heights of various exterior doors to be reduced facilitating easier crew movements while maintaining future loading flexibility.

## 3.6 Maneuverability

The RCRV exceeds the maneuvering requirements stated in the SOR while achieving a low cost, quiet, and low maintenance solution by using a large bow thruster, electric propulsion motors, and independently controlled rudders.

## 3.7 Sea keeping

A research vessel with good sea keeping properties allows scientific exploration and analysis to continue in adverse weather conditions. The RCRV achieves high operability by using several performance enhancing features: stern centerline skeg, single chine hull, large bilge keels and a passive anti-roll tank. The RCRV exceeds the SOR's seakeeping requirements and will prove to be a comfortable research platform.

## 3.8 Structure

Structural arrangements for the RCRV were examined in depth to maximize space, minimize weight and lower vertical center of gravity, or KG. Overall structural weight savings reduce construction cost and allow larger science payloads at the same draft. A lower vertical center of gravity improves stability and allows for future growth. These goals affect the structural arrangements as discussed below.

- Direct comparison between longitudinal and transverse framing schemes shows a weight savings for longitudinal framing. In addition, flat bar longitudinals, spaced 24" apart, combined with transverse webs spaced 48" apart, result in a very advantageous tonnage frame arrangement. This system provides 8' between deep tonnage frames thereby allowing more efficient use of under deck space. For this reason, longitudinal framing was chosen.

- The deckhouse plate thickness has been decreased as much as possible while still meeting ABS rules. This helps reduce weight and lower the KG.

- Three deckhouse plate framing methods were evaluated: "L" shaped angles, bulb flats and flat bar stiffeners. Of the three systems, bulb flats have the lowest weight per foot, but the highest cost due to availability. Flat bar stiffeners are easy to weld, easy to paint, easy to maintain, and can be bought as flat bar or cut from plate. They have a weight per foot only slightly greater than bulb flats and result in a significantly reduced cost. This option also ensures a better paint coating is achieved and thus reduces maintenance over the life of the vessel.

## 3.9 Structural Weight Estimating

The structural weight of RCRV has been developed utilizing basic weight estimating approaches combined with state of the art three dimensional computer modeling. The 3D modeling tool used is Rhinoceros 4.0 SR4 (Rhino), 2008. The combination of 3D modeling and tabular spreadsheet calculations allow for a very accurate weight estimate to be developed.

The transverse center of gravity (TCG) on the RCRV is slightly to port as a result of equipment and arrangement requirements. This offset TCG heels the vessel significantly to port when the SOR required deck load is removed. All load cases required by the SOR include this large science deck load so the TCG shift is not readily noticeable.

For Phase 2 of the design it would be advisable to reexamine the offset TCG. One corrective measure that has been examined to a preliminary degree is mirroring the traction winch and science stores about the vessels centerline. This change would result in a near zero TCG. Small heel angles (less than 0.5 degrees) without the large scientific deck load would be achievable.

## 3.10 Tonnage

The RCRV is required by the SOR to have a domestic gross tonnage less than 300 tons. A tonnage report including a sketch and calculations demonstrating compliance is provided in an Appendix to this report.

Deep tonnage frames (side and bottom extensions to existing framing) are used to reduce the measured volume of the hull to meet the 300 ton limit. This requirement results in additional weight to the below main deck structure in addition to the many tonnage openings above main deck. These additional measures translate to an increased procurement cost but are likely to reduce life cycle cost due to lowered operating costs as the vessel is not required to be USCG inspected.

## 3.11 Propeller Design

Propellers are the largest contributor to underwater noise. Significant time and effort was invested to develop a propeller that would achieve the SOR required propulsive coefficient of 0.6 and the ICES noise requirement at 6 knots. Using the wake survey data from the Phase I model testing and the selected propulsion motor characteristics, our propeller designer developed a 5-bladed, 6’6” diameter propeller that meets ABS Ice Class D0 requirements. The propeller has 25 degrees of skew with tip rounding to reduce vortex shedding and an anti-singing trailing edge for quiet operation. The resulting propulsive coefficient (efficiency) is 0.63. The propeller and propulsion motor were matched to achieve full power at 200 rpm with no cavitation. During cavitation testing at the model basin the design proved to be free of cavitation through the full speed range and loading conditions. The RCRV is able to exceed the underwater radiated noise requirements at over 6 knots in large part due to a well designed propeller.

## 3.12 Propulsion System/Power Generation

The selected propulsion system configuration is twin screw conventional shaft driven fixed pitch propellers directly coupled to low rpm/variable speed AC motors. An electric driven, azimuthing bow thruster is provided for increased maneuverability. Propulsion power is developed from an integrated diesel electric system supplied by three identical generators. The primary advantages of this system are:

- low underwater radiated noise
- low initial capital costs
- low anticipated operating costs
- low maintenance costs

An integrated diesel electric propulsion system was dictated by the SOR. The additional SOR requirements of ICES radiated noise criteria and the cost cap greatly influenced the propulsion study results. The tradeoffs between cost, noise generation and maneuverability were evaluated and the proposed system was determined to be the propulsion configuration that could best meet the stated design goals.

The range of propulsion system configurations investigated included: conventional shafting/propellers (the selected configuration), Z-drives and podded propulsors in both single and twin screw configurations. Power generation configurations investigated included: both AC and DC propulsion technologies as well as the number and size of the generators developing power.

### 3.13 Noise and Vibration

The RCRV will be a quiet ship both aboard ship and in terms of underwater radiated noise. Noise Control Engineering (NCE) has performed the following noise and vibration reports:

- Airborne Noise
- Sonar Self Noise
- Underwater Radiated Noise
- Vibration

The SOR requires the vessel to meet the ICES underwater radiated noise requirements at 6 knots, with a design goal of meeting the ICES requirements at 8 knots. The NCE noise predictions indicate that the required ICES compliance at 6 knots will be met and that it is possible the RCRV will comply with ICES at 8 knots.

To comply with the ICES requirements, the following noise treatments have been incorporated into the design:

- Double isolation mounts for the main generator sets.
- Single isolation mounts for all other rotating or reciprocating machinery in the engine room and propulsion motor room.
- Local damping on foundations of the propulsion motors and several other key auxiliaries in the engine room and propulsion motor room.

Furthermore, to comply with the airborne noise requirements of the SOR acoustic treatments will be applied throughout the vessel. Acoustic insulation will be applied to the bulkheads and deck heads in the engine room, bow thruster room and all fan rooms. In addition, floating floors will be installed in the hold level accommodation spaces.

To reduce air and structure borne noise from the bow thruster, both source and pathway acoustic treatments will be used. The bow thruster itself is specified as a new quieter model made by Tees White Gill and extensive use of damping material in the bow thruster room and the forward stores room combine to keep airborne noise quieter than required by the SOR.

## 4 Known Areas of Non-Compliance with the SOR

During Contract Design Review (CDR), three areas of non-compliance with the SOR were discussed. These were:

- Trim requirement exceeded in all SOR load cases (Now Resolved)
- Engine Exhaust not monitored at each cylinder
- Not all SOR required galley equipment is shown in the galley design

Since the Contract Design Review, the design team has corrected the issue of vessel trim with the addition of two forward fuel oil storage tanks. This is shown in the revised Intact and Damage Stability Report. The RCRV now complies with the SOR required trim in all required load cases.

The SOR Section 233b cylinder exhaust temperature monitoring requirement has not been met. The engine manufacturer, Caterpillar, does not offer the option of individual cylinder temperature monitoring on this model of engine (Model C18). This feature is reserved by Caterpillar for larger diesel engines.

Regarding the galley equipment, SOR Section 651 gives a list of required galley equipment. The RCRV design, includes a fully outfitted galley capable of serving 30-32 persons, but does not include all the equipment listed in Section 651. It was not readily apparent how the remaining galley equipment was going to fit into the galley space available. Compromises were made to provide the most functional galley possible. SOR requirements specifically missing or deviated from are:

- Current arrangement includes 5 sinks (vice 8 required by SOR)
- No lavatory sink (adjacent to galley vice in galley)
- No 2nd pot wash sink
- No pot sanitizing sink
- Pre-wash and silverware sink smaller than required

# 5 Conclusions

The RCRV design as presented in the following deliverables represents a highly capable research platform that meets or exceeds all significant contractual requirements. This vessel will be a valuable asset to the nation's UNOLS research vessel fleet. We are hopeful funding will be found in the future to allow construction of this vessel.

Significant contributions to the vessel design were made by the following sub-consultants and model basin:

- Bulgarian Ship Hydrodynamics Center – Model and Cavitation Testing
- Friendship Systems (Germany) – Hull Optimization
- Maumee Bay R&D Ltd – Propeller Design