Ollis Class Double-Ended Passenger Ferry
Design for Staten Island Ferry

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Continuing the tradition of service provided by New York City Department of Transportation, Staten Island Ferry (SIF) Division, the new Ollis Class Ferry will be a welcome addition to the fleet. Designed to meet the future needs of the ferry system, the design incorporates the latest regulatory and environmental requirements while drawing from many of the best aspects of the existing fleet. Elliott Bay Design Group (EBDG) worked closely with the entire Staten Island Ferry team to ensure the functionality of the ferries would be as desired.

The design of the Ollis Class Ferry is developed looking forward to meet the future needs for renewal of the Staten Island Ferry fleet. As ridership continues to grow over the life of these new vessels passenger load and unload times at the terminal are likely to increase while the overall schedule must remain the same. Therefore these vessels will be required to operate at greater speeds than any of the vessels in the current fleet. In order to meet this requirement hullform and weight optimizations were performed throughout the design process. As a result, the new Ollis Class Ferry design will be among the fastest Voith Schneider Propeller driven, double-ended vessels in the world.

New regulations place ever tighter requirements on the design for safety and environmental requirements. The vessels will be ABS classed to the Rules for Service on Rivers and Intracoastal Waterways and will meet the requirements of USCG Subchapter H including NVIC 9-97 CH-1. The engines will be some of the first to meet the new EPA Tier 4 emissions standards.

This paper follows the design process, from an initial fleet analysis, which included development of a concept design of the vessel among other options, through model testing and completed contract design.

KEY WORDS: ferry; passenger ferry; double-ended ferry; Staten Island Ferry; vessel design;

NOMENCLATURE

ABS American Bureau of Shipping
ADA Americans with Disabilities Act
BHP Brake Horsepower
CFR Code of Federal Regulations
CFD Computational Fluid Dynamics
CPP Controllable Pitch Propeller
DID Directions in Design
EBDG Elliott Bay Design Group
EMD Electro-Motive Diesel
EOS Engineers Operating Station
EPA Environmental Protection Agency
FEA Finite Element Analysis
FPP Fixed Pitch Propeller
GDS Galley Design and Sales
GE General Electric
GPS Global Positioning System
LNG Liquefied Natural Gas
MARIN Marine Research Institute Netherlands
MCR Maximum Continuous Rating
MDD Marine Design Dynamics
MVZ Main Vertical Zone
NCE Noise Control Engineering
NVIC Navigation and Vessel Inspection Circular
PDI Preliminary Design Investigation
Rhino Rhinoceros 3D Modeling Software
SCR Selective Catalytic Reduction
SIF Staten Island Ferry
SLM Service Life Margin
SWBS Ship Work Breakdown Structure
USCG United States Coast Guard
VSP Voith Schneider Propeller

INTRODUCTION

Travel between Staten Island and Manhattan has been provided by ferry services since the 18th century and became an official municipal service in 1905. Staten Island is the southernmost of New York City’s five boroughs and is the only borough which is not connected via the New York City Subway system. Staten Island Ferries transit across the upper bay of New York Harbor (Figure 1) between the St. George Terminal on Staten Island and the Whitehall Terminal on Manhattan Island. The 5.2 mile route is operated 24 hours a day, every day of the year and serves over 22 million passengers annually. On a typical weekday, five boats make 109 trips, carrying approximately 70,000 passengers.
The current Staten Island Ferry (SIF) fleet consists of three classes of vessels, the AUSTEN, BARBERI, and MOLINARI Classes, and the M/V JOHN F. KENNEDY (KENNEDY). See Table 1 for the particulars of the current fleet of vessels.

### Table 1: Current Staten Island Ferry Fleet

<table>
<thead>
<tr>
<th>Vessel Class</th>
<th>No. of Vessels</th>
<th>First Built</th>
<th>LOA (feet)</th>
<th>Beam (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUSTEN</td>
<td>2</td>
<td>1986</td>
<td>207</td>
<td>40</td>
</tr>
<tr>
<td>KENNEDY</td>
<td>1</td>
<td>1965</td>
<td>297</td>
<td>70</td>
</tr>
<tr>
<td>BARBERI</td>
<td>2</td>
<td>1981</td>
<td>310</td>
<td>70</td>
</tr>
<tr>
<td>MOLINARI</td>
<td>3</td>
<td>2004</td>
<td>310</td>
<td>70</td>
</tr>
</tbody>
</table>

While SIF originally provided automobile service it has since been discontinued. Of the large vessels in the SIF fleet, the three MOLINARI Class ferries and the KENNEDY have the capability of accommodating vehicles, while the two BARBERI Class ferries do not. The ferries currently provide passenger-only service, with bicycles allowed to be walked on via the lower bridge to the Main Deck.

### GENERAL INFORMATION

The Staten Island Ferries are double-ended vessels which operate consistently in the same orientation with respect to their routes. As a result, the ends are labeled as the New York end and the Staten Island end. The New York end is assumed to be the forward end for standard naval architecture purposes, and port and starboard notations are referred to following that orientation. However, because both ends will act as both bow and stern, concepts of forward and aft for a double-ended vessel can be confusing. Thus, the directions referred to in this report will primarily be referenced as towards midships or towards the ends.

### FLEET ANALYSIS

In 2009 Elliott Bay Design Group (EBDG) was part of a team led by KPFF Consulting Engineers, engaged by SIF to perform a preliminary design investigation study. The goal of the study was to determine the best course of action for the Staten Island Ferry fleet to meet the demands to be placed on the system in the next several decades. Fleet ridership is expected to increase continually into the foreseeable future as both recreational activities on Staten Island and commuter traffic into the city are expected to continue to grow. Included in this study was an analysis of the existing fleet of vessels.

Options assessed in the fleet analysis included whether to renew the existing BARBERI and AUSTEN Class vessels to extend their service life, to design new large or new small vessels to expand the fleet capacity or replace existing vessels, and whether to augment overnight service with a high speed vessel. Multiple combinations of these concepts and their integration into the existing fleet were evaluated based on factors including operating costs, capital costs, and a qualitative score representing reliability, safety and security, maintainability, environmental stewardship, passenger experience, and fleet complexity. The primary recommendation resulting from this study was to build three new large ferries and retire three existing large ferries, namely the KENNEDY and the two BARBERI Class vessels.

Each vessel in the current fleet operates on a 30 minute one-way, one-hour round-trip schedule; with up to four vessels operating during peak rush hour periods. It is important to note that to remain on schedule the ferry must depart on time from the terminal on each end of the route.

Although passenger loads are variable throughout the day, several aspects of the system operation are fixed. Primarily, the terminal ramps are of a set width and provide a fixed capacity for loading and unloading passengers. While a typical run during rush hours can reach loads of approximately 2,500 passengers, this number is expected to increase in the coming years. As passenger loads increase, the loading and unloading time spent at the terminal will also increase, leaving less of the remaining hour of the schedule available for actually making the transit. The current fleet has a typical cruising speed of approximately 15.4 knots, with a little margin left over to make up time in the event of any delays. Part of the options for updating the existing fleet involved addressing this potential future schedule shortcoming via increasing the power and speed of the existing fleet.
In a separate study commissioned by SIF and performed by George G. Sharp, the option of converting the MOLINARI Class from conventional propeller driven propulsion to propulsion via Voith Schneider Propeller (VSP) units to improve maneuverability was considered. The BARBERI Class and AUSTEN Class vessels are driven by VSP units and provide a high degree of maneuverability appreciated by the captains within the SIF fleet. The study was done to determine the practicality of gaining similar maneuverability characteristics on the MOLINARI Class. Based on model testing of the concept design of this modification, including bare hull resistance testing and self-propelled testing using VSP propeller models, the modification proved not to be feasible. The added power required as a result of the modifications to maintain the desired operating speeds did not allow for sufficient operating margins with the presently installed engine power.

Evaluation of the recommendations provided by these two studies led to the decision to procure new large passenger only ferries to allow for replacement of the aging vessels within the fleet.

CONCEPT DESIGN STUDY
As part of the KPFF led Preliminary Design Investigation (PDI) EBDG prepared concept design studies for each of the vessel options to assist with the assessment of ridership, operation and acquisition aspects of each potential fleet combination. The following highlights the attributes of the new large ferry concept design included in the recommendation from the PDI.

CONCEPT ARRANGEMENTS
The initial arrangements for the new large ferry were strongly driven by the overall look and feel of the current fleet of vessels, as well as the parameters of the terminals, as shown in Figure 2. The shape of the Main Deck ends is set by the dimensions of the terminals, and the terminal loading ramps set the approximate heights for the lowest two passenger decks at the ends.

![Figure 2: Concept Outboard Profile](image)

The vessel length overall was increased slightly relative to the BARBERI and MOLINARI Class vessels to maximize internal space, with the intent of minimizing the effect on operations. Within the available envelope of the vessel interior space the primary goal was to fit as many seats as possible on the three passenger decks (the Main Deck, Saloon Deck, and Bridge Deck). Additionally, it was desired that the Main and Saloon Decks be at the same elevation as the terminal loading ramps, similar to the MOLINARI Class and KENNEDY vessels which carry vehicles. Replicating a feature from the KENNEDY, direct and unimpeded walkways from the loading ramps into the passenger spaces were identified as a means for minimizing loading times by providing passengers direct access into the vessel without bunching around the exterior doors. See Figure 3 for the preliminary concept arrangements of the Main and Saloon Decks.

The fourth deck, the Hurricane Deck, is to be crew only; with both pilot houses and a house top space for ventilation and various machinery such as the emergency generator.

Additionally, stair towers were decided to be located at the ends of the vessels. Partly this was necessitated by the engine uptakes which needed to be located near midships, but mainly the intent was to accommodate passengers loading and unloading to and from the Bridge Deck, and also to assist in meeting the fire protection and refuge requirements of USCG Subchapter H (Reference [1]) and NVIC 9-97 (Reference [2]).

The current vessels in the fleet do not have separate stair towers, which required special regulatory approval. For simplicity, it was decided that this design should feature fully separated and protected stair towers in order to comply with Reference [1]. The addition of the dedicated stair towers was a major reason for the 10 foot length increase over the existing fleet.

![Figure 3: Concept Passenger Deck Arrangements](image)
PROPULSION CONFIGURATION STUDY

During the concept design phase a propulsion configuration study was performed for the new large and small ferry designs being developed. The propulsion study looked at seven unique propulsion system design options. The propulsion study was performed using input from SIF to ensure that emphasis was placed on the correct aspects of the propulsion system arrangement and operations. Attributes of the propulsion system were selected and weighted in accordance with the priorities of SIF operations. These attributes included maneuverability, reliability, maintainability, capital costs, life cycle cost, and efficiency.

The seven propulsion systems evaluated were:

- Diesel-mechanical with one VSP at each end
- Diesel-mechanical with two VSPs at each end
- Diesel-mechanical with one controllable pitch propeller (CPP) at each end
- Diesel-mechanical with two controllable pitch azimuth thrusters at each end
- Diesel-electric with one fixed pitch propeller (FPP) at each end
- Diesel-electric with two fixed pitch azimuth thrusters at each end
- Hybrid propulsion with VSPs

The results of the study indicated that the configurations with four total propellers were the most reliable because of their high degree of redundancy. However, the VSP and azimuth options were nearly as reliable because the vessel would still be able to operate if one propulsion unit were to fail. For maneuverability, the VSP options scored highest. Fuel use was the strongest driver for life cycle costs and emissions, and the diesel-mechanical options rated highest, with controllable pitch propellers first, followed by the azimuth thrusters, and VSPs slightly below those. Finally, the VSP options were deemed the most maintainable, based on SIF’s experience and expertise with the VSP driven vessels in their current fleet. The VSP options were followed by the diesel-electric with FPP option, and then all others, including the CPP and azimuth thrusters last, as they had the least similarity to the existing vessels in the fleet.

The final results of the propulsion configuration study indicated that either the two or four VSP unit diesel-mechanical options were the best choices for the Staten Island Ferry fleet, and were nearly equal in overall ranking. The option with four independently driven VSPs provided the best overall reliability, while the two VSP option had better maintainability and was less expensive over the full life-cycle of the vessel.

PROPULSION ARRANGEMENT

The concept design was completed based on the four unit option because it had received a slightly higher score and the heights of the smaller units proved easier to fit within the available depth and draft of the hull during initial development of the hullform. Because of commonality of EMD engines within the SIF fleet, four EMD model 8V-710 diesel engines rated at 2,000 BHP each were selected as being adequate to power the vessel to a similar speed as the rest of the fleet (8,000 BHP total, closest to the BARBERI Class). See Figure 4 for the original propulsion arrangement concept featuring four diesel engines and four VSP units. A shaft alley was included in the design to minimize the number of watertight bulkhead penetrations, and to provide an easy walkway from the engine room to the propulsion rooms.

Figure 4: Concept Propulsion Arrangement

STRUCTURAL CONCEPT DESIGN

The structural arrangement concept for the new large ferry design was developed assuming a steel hull transversely framed with 24 inch frame spacing. The original concept was to have large web frames every 20 feet, with longitudinal girders running between the web frames to support the ordinary frames. For structural continuity and racking strength the superstructure would be supported by web frames in line with the hull web frames, with superstructure decks stiffened longitudinally between frames. The basic midship scantlings were calculated against the ABS Rules for Building and Classing Steel Vessels for Service on Rivers and Intracoastal Waterways (Reference [3]).

PARAMETRIC WEIGHT ESTIMATE

Once the overall hull dimensions, concept superstructure arrangements, and propulsion configuration options were roughly settled, a parametric weight estimate was performed to estimate the vessel’s light ship weight.

The light ship weight estimate was performed based on the U.S. Navy’s Ship Work Breakdown System (SWBS), which divides the vessel into structure, propulsion, electrical, electronics, auxiliary, and outfit groupings. The various vessel parameters were used to estimate the weight of each SWBS group based on known weights from a database of similar vessels. Finally, margins were applied in accordance with Table II of the Margin Management and Procedures for U.S. Navy Small Craft [4] commensurate with the concept design phase of a vessel. See Figure 5 for a summary of the initial parametric weight estimate.
CONCEPT LINES PLANS

Based on the propulsion configuration study and weight estimate, an initial hullform was developed for the four VSP option. The most important factor defining the hullform was placement of the VSPs, which need a flat mounting plane. For the concept design, mounting planes were placed such that the VSP units were at the farthest longitudinal location possible while still maintaining a fine half angle of entrance and remaining within the envelope of the superstructure and stair towers. This was an important consideration to ensure the VSP unit housing would fit within the hull while providing a pathway for removal.

Further constraining the placement of the VSPs was available height for the engines and their maximum inclination. This determined the shaft angle which was fixed because straight-line shafts were preferred to keep the overall shaft layout simple and maximize efficiency.

The initial hullform featured hard double chines near midship to keep construction of the hull as simple as possible while still maintaining adequate width throughout the engine room. Displacement for the concept hullform was developed such that the estimated light and fully loaded drafts and freeboards for the vessel would be similar to all existing vessels in the fleet to ensure proper alignment with the terminal. Figure 6 shows the initial hullform developed in the concept design study.

OUTLINE SPECIFICATION

Many parts of the concept design do not appear directly on the drawings or calculations. To provide a more complete view of the design, a set of outline specifications was developed during the concept design phase. The specifications covered the regulatory requirements for the vessels, such as the specific ABS rules and class notations. Additionally, the specifications discussed the interior arrangement concepts for seating and fixture arrangements similar to those installed on the other vessels in the fleet. The heating and ventilation system was also addressed, including the intentional lack of air conditioning as the current vessels are naturally ventilated.

DESIGN PHASE TRANSITION

The concept design report was finalized and submitted to SIF in November of 2010. As mentioned above, the design investigation related to reconfiguring the MOLINARI Class with VSP units, while running in parallel, was concluded in 2012. Also in 2012, SIF issued a request for proposals (RFP) for vessel design and construction support of new vessels which included options for the design of new ferries, the modification of the MOLINARI Class design or a combination.

Concurrent with the RFP solicitation and award process, a value engineering study was done on the new large ferry concept design in 2013, and in 2014 SIF applied for and was awarded federal funding from the Federal Transit Administration's Hurricane Sandy Resilience Program. These events contributed to ultimate selection by SIF to design and construct three new vessels based on the new large vessels. Further they also served to identify some attributes to be included in the contract design.

CONTRACT DESIGN PHASE

In 2014, EBDG was awarded the contract to design the new large vessels. Concurrent with this award, SIF also awarded a contract to The Glosten Associates as its Owner's Representative to provide review and oversight on behalf of SIF throughout the project.
At the outset of the contract design effort, the team of SIF, Glosten, and EBDG met regularly to review, test the vessel parameters established by the concept design, update parameters based on the concept design value engineering study and the resiliency grant, and to establish the baseline set of requirements for this vessel.

The team paid significant attention to the operational aspects of the existing SIF fleet. All departments of SIF were included in these discussions to ensure the best attributes were carried forward into the new design, and that opportunities for improvements were identified for the new vessels. Fundamental criteria for the final vessel design were established, these were:

- **Capacity** for 4,500 passengers.
- **Minimum 2,500 Seats.**
- **Direct and unobstructed loading and unloading paths.**
- **ABS Classed.**
- **Minimum transit speed of 15.6 knots.** Investigate and increase transit speed to provide additional passenger loading time at each terminal over existing vessels, with ability to make up lost time via a sprint speed.
- **Exceptional maneuverability** able to deal with prevailing tidal currents, weather conditions, and vessel traffic in New York Harbor.
- **Operate in all weather conditions within the harbor.**
- **Weather-tight side loading doors on Main Deck.**
- **Operate with one generator down for maintenance.**
- **Diesel mechanical driveline, able to maintain schedule with one engine off-line.**
- **Robust interior outfit, capable of surviving high passenger traffic with a minimum of maintenance.**
- **Enhanced crew accommodations.**
- **ADA compliant passenger spaces [5].**
- **EPA Tier 4 compliant engines.**

**ROUTE TIMING ANALYSIS**

As has been noted, maintaining schedule is extremely important to the operation of the SIF fleet and incorporating the best attributes of the existing vessel arrangements will simplify passenger loading. Ridership will increase, however, vessel and terminal arrangements will remain fixed. To accommodate for increased loading and unloading times, shorter transit times will be required.

To determine a design speed that would allow for one extra minute of load and unload time at the terminals at (from eight to nine minutes), SIF requested an assessment of the existing vessel schedules. To accomplish this analysis, two data sets were used. SIF made available a set of GPS data collected by AECOM under a separate contract related to each run of the BARBERI between May and August 2011. In addition, data for the tidal and river currents in the upper bay of New York Harbor over this same period were obtained. These two sets of data were used to evaluate the average transit speed, the average acceleration when approaching and departing each terminal, and the average passenger loading time. A model of the operating profile was then developed from these statistics.

Based on the results of the study a design speed of 16.3 knots was selected, and a goal of having a sprint speed above 17 knots set. The intent was that the new vessels would be able to maintain a typical schedule as ridership increases. In addition, the vessels will be well suited to maintain schedules during periods of high traffic on the route and in cases of any unanticipated delays.

**PROPELLATION SYSTEM CONFIGURATION UPDATE**

One of the first subjects addressed in the contract design phase was the propulsion system configuration. Several options and configurations were reviewed and reviewed. Propulsion system attributes were reviewed as well. Significant to this review was the question of the final VSP configuration. The concept design propulsion configuration study had shown that the two-unit and four-unit options were nearly equal based on the weightings given in the propulsion configuration study. The four-unit option was considered favorable for the reliability provided by redundancy. However, because SIF has ultimately experienced a high degree of overall reliability with VSP units and a two-unit configuration would be similar to that found on the BARBERI Class; the two-unit option was reconsidered. A review of lifecycle costs of both options, including capital, acquisition, and maintenance costs, showed that the two-unit option was less expensive overall. Although the addition of a combining gear added some complexity, the two-unit option was desirable to SIF operations and maintenance teams. Ultimately the two VSP unit option was selected.

The major issue with the two-unit configuration was the height of the VSP units themselves and the clear height above them required to perform standard maintenance. Propulsion power required remains unchanged whether driven by two or four units. Thus, with double the power being supplied to a single unit, the required blade length and mechanical height increased significantly while the depth of the vessel remain firmly fixed because of terminal interface requirements. Changes to the arrangements had to be made in order to fit the larger Voith 36R6 ECS/285-2 units. First, the hullform had to be modified to reduce depth in way of the VSP units such that the blades remained above baseline in normal operation. Secondly, a significant amount of extra height needed to be provided under the passenger stairs for the required maintenance clearances for the units. To accomplish this, the stair towers on the Main Deck were shifted towards the end of the vessel as far as possible. Figure 7 shows a profile view which illustrates the height constraints of the two VSP units, and how the stair towers were adjusted to work with them.
The major impact from the switch to two VSP units was to update the hull form. Because the blades of the larger units are significantly longer, the bottom of the hull in way of the VSP unit had to be raised to suit. In turn, the available displaced volume near the ends went down significantly. To compensate for the loss of volume at the ends the midship section had to increase accordingly, which had the benefit of increasing the available space in the engine room. Additionally, the switch was made to a round bilge to improve the hull efficiency and to help add volume lost by the switch to the shallower depth at the ends to fit the VSP units. Figure 8 shows the updated lines plan for the configuration with two VSP units.

SPEED AND POWER
A round of speed and powering estimates were performed for the vessel's updated propulsion configuration and hull form. The program HydroComp NavCad 2012 was used to perform a parametric resistance estimate based on available data sets. Factors addressed included appendage and air drag, wind and waves, and shallow water effects to account for the 50 foot average water depth within New York Harbor.

The speed and powering estimates were performed based on several parametric data sets, and attempts were made to align the results with model test data from another double-ended ferry. However, the variation in speed and powering estimates between the various methods used was high, largely because of the fact that the various data sets are based on conventional, single-ended, monohull vessels.

However, a clear result became apparent despite the variation amongst the different estimate methods. First and foremost was that the vessel would likely require more power than previously planned to meet the higher design speed of 16.3 knots. Thus it was decided that the larger and more powerful EMD 12V-710 engines would be used.

ARRANGEMENT UPDATES
During the meetings with Staten Island, members from all aspects of SIF operations were included in the discussions. The following are the key design changes from the concept arrangement which fully refined the design to a level suitable for release as a bid package to shipyards.

Machinery Arrangement
Once the propulsion configuration was decided upon, the machinery arrangement could begin to be settled in place. This proved somewhat difficult because the engines would need to meet EPA Tier 4 emissions requirements at the time of construction, but the Selective Catalytic Reduction (SCR) system required for this had not yet been finalized by EMD. The design team considered both GE and EMD engines as each was finalizing their EPA Tier 4 engines in this power range. Ultimately the EPA Tier 4 version of the EMD 12V-710 engine was selected at a power rating of 2,500 HP at 750 RPM.

Concurrent with vessel design, EMD was finalizing the design and seeking regulatory approval for their SCR system. Throughout the design process EMD provided updates to the design team with changes in the SCR design and their best estimates for certification. For a brief period early in the design the possibility of requiring an upper engine room level on Main Deck for housing the SCRs was considered. This proved to not be necessary as the SCRs were reconfigured for installation forward of the engine and their size reduced. The overall machinery arrangement improved as a result.

The engines, accessory racks, and SCRs were placed in the center of the engine room and positions were adjusted as the design progressed. Some additional factors affecting the final engine placement included size and configuration of the torsional couplings, and fluid coupling selection by Voith Schneider. Figure 9 shows the final engine room arrangement, including placement of the main engines and accessory racks, and the generators, boilers, and marine sanitation device.
Ship Service and Emergency Generators

Marine Design Dynamics (MDD) was part of the EBDG design team and performed the electrical system design for the vessel. MDD worked to develop a full electrical loads analysis, switchboard layout, and electrical distribution system for the design. For operational redundancy, SIF required that typical operating scenarios could be satisfied by a single ship service generator, and if in the case that a generator was down for maintenance, a third generator was available as a backup. This double redundancy proved to be a challenge that would impact the selected VSP configuration.

The then current VSP 36R6 ECR/285-2 units required off unit electrically driven pumps to provide hydraulic power to the units. These pumps have a very large electrical load of up to 125 kW per VSP. These high loads drove the single generator size requirement upward such that Tier 4 generators would be required. Several possibilities were considered related to shaft generators and taking advantage of power takeoff from the combining gear, but these were all very complex. The design team presented this issue to Voith Schneider, who agreed to provide a version of the VSP units with integrated mechanically driven hydraulic pumps. Using this configuration, the electrical generators required were limited to 425 kW, which remain under current EPA Tier 3 requirements, and satisfy the redundancy requirements given by SIF. A 400 kW emergency diesel generator is required and is placed in the Hurricane Deck house.

Engineers Operating Station

The Engineers Operating Station (EOS) is located to the port of the main engines. This fire and sound insulated space contains the switchboard, control station, a small office and snack room, and licensed and unlicensed crew lockers and heads. In conjunction with the EOS, a stair tower leading up from the engine room to the Main Deck and the Hurricane Deck for access by the crew was fit within the uptakes. The generators and boilers were located to starboard of the main engines.

The EOS was modeled in detail in Rhinoceros 3D modeling software, version 5 (Rhino), including all furniture and electronics. A 3D view of the EOS arrangement is shown in Figure 10. The arrangement went through several design iterations with review by the SIF operations staff to ensure an efficient layout for the engineering crew. The control electronics were modeled and arranged on the console in order to ensure there was adequate space for all items and to verify console dimensions. The nearby structure and ventilation ducts were also modeled to confirm satisfactory clearance.

Hold Layout and Floodable Length

Initially the concept for the hold arrangement had focused on a shaft alley to minimize the number of shaft seals required at watertight bulkheads, especially considering the twin shafts of the four VSP unit design. However, switching to the two VSP unit option meant there would be only one main drive shaft per end. Furthermore, space constraints within the engine room for the engines, accessory racks, and SCRs forced the combining gears to be located in the adjacent spaces. Thus for the updated propulsion arrangement it became clear that the shaft alley
concept was providing minimal benefit, while making floodable length issues with the hull somewhat difficult. Instead, an auxiliary machinery room was placed on either side of the engine room to house the combining gears, as well as elevator equipment, fuel and water tanks, various auxiliary pumps and piping systems, and the fire protection system.

Figure 11 shows the final hold layout of the vessel, with an auxiliary machinery room, void space, propulsion room, and bow void on each end of the vessel. Floodable length curves for this hold arrangement and at a subdivision draft of 13 feet 6 inches confirmed the validity of the design.

![Hold Arrangement Plan](Image 38x474 to 293x605)

**Figure 11: Hold Arrangement Plan**

Stair Towers
The shift to the two VSP units pushed the stair towers towards the ends of the vessel by a few feet to provide overhead clearance above the VSP unit for maintenance. Additionally, this allowed for a flat landing to be added to the stair tower, which provided a suitable area to add an access and maintenance hatch for servicing the VSP unit.

However, SIF expressed a strong desire to maximize the walking length for passengers boarding the vessel, so the exterior doors to the stair tower were desired to be placed as far from the ends as possible. This created a bit of a struggle for fitting the original stair tower fire doors on the Main Deck. To solve the problem, a larger and more uniform stair tower was created, with major transverse fire protection bulkheads being added at the full extent of the passenger space Main Vertical Zone (MVZ) lengths, with automatic sliding fire doors. This maintained a clear path of entrance with a long visual extent on the Main Deck and Saloon Deck, while also allowing passengers to move towards centerline to access the stairs up to the Bridge Deck. The final profile view of the passenger stair tower is shown in Figure 12.

The configuration of the stair towers also played a crucial role in meeting the requirements of Subchapter H [1]. The stair towers and open deck areas at the ends provide a significant portion of the safe refuge area on the vessel in case of an emergency, as well as providing a safe means of egress to the embarkation areas or other unaffected zones on the vessel.

![Stair Tower Profile View](Image 319x609 to 574x755)

**Figure 12: Stair Tower Profile View**

Safety and Evacuation
The Staten Island ferry fleet operates under a USCG approved Safety Assessment [6], which addresses the specifics of operating within New York Harbor. The route is short enough that the vessels are always within close proximity to a terminal. Furthermore, the amount of traffic in the harbor is such that there will always be vessels available for assistance within minutes, whether they are other ferries, USCG rescue vessels, or New York fire boats. In all cases there is at least a second Staten Island ferry waiting on standby. As such, the general plan in an emergency is to return to the nearest terminal if possible, otherwise passengers are to seek refuge on the vessel until they can transfer to another ferry.

Based on this, and on the applicable regulations, the passenger spaces on the vessel are divided into four major zones, all separated by full A-60 boundaries. The first division is the MVZ bulkhead at midships and the second is the Saloon Deck. In the event of an emergency in any one space, the unaffected MVZ plus the stair towers and ends of the vessel are capable of providing sufficient safe refuge for the full 4,500 passengers until they can be evacuated, with passage from one end to the other protected by the A-60 boundary of the Saloon Deck.

The resiliency grant directly added the requirement to include the side loading doors. The side doors are intended to provide further options for evacuation of passengers. Rescue vessels or other ferries can tie-up at either of the ends or along either side of the vessel. Furthermore the side loading doors also work to expand vessel docking capabilities.

Security Features
One of the major factors in the arrangement of the various passenger spaces are the security concerns associated with managing such large crowds of people. Particularly, a security crew needs to be able to sweep the vessel from end to end every time the vessel docks to ensure that everyone disembarks. To accomplish this, the passenger spaces were made as open as possible, with full visibility from side to side along most of the length of the spaces. A-60 window were added to the MVZ bulkheads to enhance visibility along the length of the vessel in the passenger spaces. In addition to being a security feature,
this provides a greater feeling of openness in the passenger spaces.

The exterior space on the Bridge Deck is fitted with lockable security gates to allow the ends of the vessel to be closed off during low traffic times to simplify security. Also, great care was taken to ensure there were no hiding spaces on the vessel and that all bulkheads and ceilings would be as smooth and tamper resistant as possible. Similarly, passenger seating will be open underneath and all of the fittings in the toilet spaces are selected based on experience with the other vessels in the fleet.

MDD, as part of their electrical and electronic systems design task, worked with SIF to develop a camera system layout and local area network on the vessel that has wireless capability to be tied into landside systems. A dedicated security equipment room is provided on the Hurricane Deck to handle all of the required equipment.

Crew Spaces
The crew spaces on the Bridge Deck above the passenger stair towers and beneath the pilot houses underwent several design iterations before reaching their final state. These spaces needed to include male and female locker rooms for both licensed and unlicensed crew members, as well as a crew space and break room, heads on both ends of the vessels, and electronics and fan rooms. Also, it was desired that the access to the pilot houses remain within the crew spaces. The final configuration features lengthwise hallways, with an athwartships passage connecting the two sides and providing the access for the stairs up to the pilot house, as shown in Figure 13.

Pilot House Arrangement
To design the pilot house arrangements and console layout a list of required bridge equipment was first developed from ABS, USCG, and client requirements. A preliminary selection of bridge equipment was made by which to estimate equipment sizes. The pilot house was then modeled in detail in Rhino with all of the equipment. Several iterations of the bridge and main console layout were created. SIF reviewed the models with their operations staff between each of the iterations and recommended changes to the design to improve its functionality for the crew.

The vessel will operate with a crew of four in the pilot house: a captain, a helmsman, a navigator, and a lookout. The final layout is shown in Figure 14. The primary concern with the arrangement was to place the VSP controls in a position which was comfortable to operate from both a sitting and standing position while also providing clear line of sight to the bow. The main consoles were moved aft from the forward windows in order to provide access for the lookout. An asymmetrical console design was chosen to both provide the captain more space and allow for new electronics to be added without modifying the existing consoles.

Modeling the pilot house in 3D proved to be an effective way to communicate the arrangement and allowed SIF to view the design in 3D from a viewpoint within the pilot house. This added realism led to specific equipment positioning improvements and modification of the window sizes on the forward end of the pilot house.

Anchor and Mooring Equipment
SIF strongly desired a full sized anchor, and a highly capable set of mooring equipment for the vessel. The capabilities of the new vessel were desired to be expanded compared to the existing fleet, especially with regard to resilience during storms.

An anchor sizing study was performed to determine a suitable anchor for holding the vessels in case of a loss of power in a significant storm event. Reference [4] requires anchors be sized for a minimum wind speed of 40 knots, and a current of one knot. However, the current from the Hudson River can reach almost three knots, so that value was used instead. The final anchor requirement was approximately 4,000 pounds.

A sizeable windlass is required to deploy and retrieve each anchor. It quickly became apparent that the only location the windlass would fit was on the Hurricane Deck, with the anchors stored in pockets on the exterior of the Main Deck. This
arrangement incorporates a hawse from the Saloon Deck to the Hurricane Deck, the length of which is sufficient to hold a section of chain attached to the anchor. A suitable length of wire rope attached to the top of the chain and stored on the windlass allowed for a chain locker to be avoided, while still providing adequate capability for anchoring the vessel within the depth of water in New York Harbor.

In normal docking at the passenger terminals the vessel fits up to the terminal ramp and the terminal mooring lines are connected with hooks to dedicated mooring eyes on the Main Deck ends. For mooring at the Staten Island maintenance docks, the mooring arrangement features a strong capstan at each end of the vessel, sized to allow for repositioning of the vessel at the dock in strong winds. The capstans are complemented by two double bitts and two chocks at each side bulwark for placing both bow/stern and spring lines. Also included are gates at each side of the vessel to allow for placement of gangways in any side mooring at the dock.

INTERIOR DESIGN
The overall interior arrangement of the passenger spaces was relatively fixed at the time of the concept design; with two open walkways along the length of the vessel for passenger flow, and all other areas providing rows of fixed seating except in way of the snack bar, elevators, or restrooms.

To improve passenger flow from the exterior through the stair towers and into the passenger spaces, SIF desired doors in the passenger areas which did not require ramps on either side of the sill. EBDG worked with a door manufacturer to develop specifications for sliding weathertight and fire doors to comply with ADA regulations. With a typical sliding door frame, the sill would need to be recessed into the deck to avoid the use of ramps. This can be difficult from a construction and maintenance perspective, so low-profile door sills which do not protrude more than one half inch above the height of the finished deck were developed in order to remain compliant with ADA requirements [5]. In addition, the doors were designed to be counter-balanced, bi-parting doors in order to open with less than five pounds of pull force, eliminating the need for powered door openers.

SIF also desired large windows with an opening section to improve air flow within the vessel. In order to achieve this function while maintaining a look similar to other SIF vessels, custom exterior windows were designed. The window design was developed for aluminum construction with steel fire clips in order to reduce the overall weight of the assemblies.

Directions in Design (DID) was part of the EBDG design team brought on to develop the full interior design package. At the outset of their task it was agreed to set the arrangement of the snack bar as an anchor point in the design. A basic requirement for the snack bar was that it be open to the passenger spaces while incorporating the best attributes of others in the SIF fleet. The snack bar aboard the KENNEDY was considered as the model arrangement. For fire load considerations and the elimination of the need to be able to isolate the snack bar with shutters, the classification of the snack bar was limited to that of a simple serving pantry, with no heating elements or open flames, and a potential fire load limited to meet the requirements of Reference [2].

DID worked with Galley Design and Sales (GDS) who were able to develop layout options that were appealing and facilitated the retail aspects of the snack bar operation. With the permission of SIF, GDS worked with the vendor that currently held the contract to operate the snack bars on the existing vessels. Through interviews and discussion, GDS was able to identify layout options that met SIF requirements and incorporated a suitable arrangement of shelves and counters to house all of the required equipment. Options were considered by SIF and the current arrangement was selected.

For the seating, the look and feel of the wood seating in the KENNEDY was preferred by the ridership of the Staten Island ferries. Wood seating was not an option for the vessel due to fire load considerations, but the seat profiles and wood look were given due consideration. The design team looked for and contacted several seating vendors, both traditional marine and non-marine. Three vendors were asked and they agreed to provide seating mockups with a similar look to the KENNEDY seating, but having the durability of the seating on the MOLINARI Class vessels. These mockups were placed in the SIF terminals to give the public a preview of potential seating options for the new vessels. These mockups were also used to finalize the specifications for the seating. The seats are to be of all metal fabrication to ensure they are completely non-flammable, have a maximum allowable weight per seat, and their fit and finish are to be durable and tamper resistant.

DID identified and presented ceiling options including all LED lighting for both passenger and crew spaces. To complete their design, they selected flooring and bulkhead finishes and colors. Several renderings were created based on the various combinations of seating, lighting, flooring, and finishes, in a variety of color schemes. These options were reviewed by SIF, and Figure 15 shows the selected option typical for the interior passenger spaces.

DID developed a full description drawing set that details the flooring, snack bar arrangements and equipment details, furniture schedules, including passenger and crew space fixtures, furnishings and accessories, ceiling and lighting fixtures and bulkhead finishes.
TERMINAL INTERFACE
The interface of the vessels with the St. George and Whitehall terminals is of utmost importance to the operation of the vessels. A terminal interface drawing was developed to ensure that each of the following aspects was adequate for the vessel design:

- Bow radius and deck plan shape
- Deck heights and loading ramp landing locations
- Hull freeboard and trim
- Drafts and the location of the peak skegs.
- Pilot house location, height, and visibility

A plan view of the two terminals showing all of the slips, and drawings of the loading ramps in plan and profile for both the St. George and Whitehall terminals were used as a background to compare the vessel design against. The loading conditions from the stability assessment, including maximum anticipated passenger trim, were used to determine the extreme range of freeboards and drafts for the vessel from beginning to end of service life. Finally, tidal data from as close to the terminals as possible was analyzed to determine the lowest and highest expected tides in which the vessels might reasonably be expected to operate.

The profile of the vessel was placed into the terminal in both the lowest freeboard condition with the lowest tide and in the highest freeboard condition with the highest tide. The loading ramps were verified to work with the vessel in all reasonable conditions. Some aspects, such as high water level in the harbor during a serious storm can exceed the range of the interface of the vessel to the terminal without adjustment via ballasting, but this is an extreme condition.

The locations of the pilot houses are important for visibility of the captains when docking, but if they are located too high or too close to the ends of the vessel they may interfere with awnings over the terminals. Every effort was made to ensure the pilot houses had adequate visibility of the ends of the vessels, while keeping them as low and set back from the ends of the vessel as possible. This was needed to ensure they had significant clearance from the awnings such that the captains would feel confident in approaching the terminal and not feel closed-in by the awnings overshadowing them. Using Rhino, several animations of the docking of the vessels were developed for the various pilot house options. These were used to select the final design location of the pilot houses to the satisfaction of the crew. The final arrangement features the pilot houses as low and far back as possible, with the fan rooms placed behind the pilot houses rather than as a half-height space below.

Finally, a bathymetric survey was performed for both of the terminals. Based on this, a bottom profile was created for the vessel at centerline, and sections were created for the vessel through the peak skeg, VSP unit, and midship section to ensure the vessels would not impact the bottom. The results of this survey show that the mud in the shallowest of the slips could pose some problem with the peak skegs. However, the profile of the BARBERI Class vessels was compared, and the peak skeg of the new vessel design is of the same depth but not as close to the ends as the peak skeg of the BARBERI Class, which operates satisfactorily. The surveyed depth in these slips may be a result of built up silt from propeller wash.

STRUCTURAL DESIGN
The design of the structure underwent a significant optimization effort early in the contract design phase. A spreadsheet was developed which calculated the required plate thickness and stiffener sizes for an array of stiffener spacings and web frame or girder distances, using a genetic algorithm type optimization routine. The resulting structure options were then assessed with regard to both material and labor costs.

Generally, narrower spacing requires thinner plating and smaller stiffeners which results in lower overall material costs (and lower structure weight). However, narrower spacing also results in more stiffeners overall and thus the welding and construction costs can increase. The results of the structure optimization were compared against various permutations of material and labor rates to ensure that the optimum values selected were truly optimum regardless of where the vessels would be constructed, or what the prices of steel would be when bidding took place.

The final structural optimization settled on a frame spacing of 24 inches through the hull and web frames every ten feet near midships and every eight feet near the ends which worked well with the bulkhead arrangement in the hull. The girders within the hull were located to best match the optimum stiffener length and align with the arrangement of the longitudinal bulkheads. Frame spacing in the hull remained at 24 inches. In the superstructure, the web frame spacing was set at 20 feet, and the longitudinal deck stiffeners were spaced at 21 inches. The relatively tight deck stiffener spacing was required to limit weld distortion on the thinner deck plate desired for weight savings. The structural midship section (Figure 16) shows the representative structure throughout the vessel.
A full structural model of the vessel was created in conjunction with the development of the entire suite of structural drawings. Rhino was used to model all major bulkheads, web frames, girders, and stiffeners on the vessel.

FINITE ELEMENT ANALYSES
Finite element analysis (FEA) was used extensively to validate the structural arrangement from both a strength and vibration standpoint. The typical 3D shell element approach was followed. The FEA software used for the analysis was ANSYS Workbench.

The primary FEA was a global level analysis concerned with the racking resistance of the superstructure and Main Deck structure. The large open passenger spaces limited the number of structural bulkheads available to carry transverse loads due to racking. Despite this limitation, the required racking strength was developed through the use of major transverse web frames with section properties far in excess of ABS minimum local scantling requirements, and the use of the elevator and uptake space trunks as primary structural members. Special attention was also paid to the vertical integration of the racking structure throughout the superstructure and into the hull. Figure 17 shows a portion of the global FEA mesh for the racking analysis.

A number of local FEA models were run to validate the specific local structural arrangements of critical areas on the vessel. Specifically, local models were developed to analyze the major deck areas where deck machinery, including the anchor winch and capstan, are to be installed, the hull end structure exposed to docking impact, the slender peak skeg structural integration and dry docking interface, and the main passenger stairs including structure integrated into the stairs to facilitate VSP machinery maintenance and removal. Major equipment foundations for the main engines and combining gear and for the VSP units were also modeled and analyzed for strength and vibration characteristics. Figure 18 shows contours of stress in the VSP foundation when subjected to maximum design loading.

NOISE AND VIBRATION ANALYSES
Along with the strength of structure, the vibration response of the vessel is another important design consideration. Because of the typically limited damping present in welded steel structures, any local area of structure that has a resonant mode of vibration near one of the major excitation frequencies from the machinery installation can respond with damaging or uncomfortable levels of vibration.

To validate the structural arrangement from a vibration standpoint, both basic calculation and advanced analysis were used. For preliminary vibration checks of typical stiffened plate panels and girders, a spreadsheet based empirical formula calculation was used. More complicated structure was analyzed with three dimensional shell element models using ANSYS Workbench to perform modal and forced harmonic analysis that identified the resonant modes.

Atypical structures such as the pickle fork overhangs at the ends of the superstructure and the masts were checked and the structural arrangement was modified to shift the resonant modes well clear of the excitation from machinery. Main machinery foundations were analyzed for suitability using pre-stressed modal analysis to account for the sizable reaction loads during operation.

Along with structural damage, crew and passenger comfort are the main considerations when setting limits on vibration response. Additionally, noise levels in crew and passenger spaces are also a prime consideration for the comfort onboard the vessel. Close attention was paid to the crew and passenger space structure vibration and noise levels, with contractually required limits on both.
The baseline ABS minimum scantlings for the passenger decks were found to be inadequate from a vibration control standpoint. The stiffness was increased accordingly by using heavier section plate stiffeners and a revised girder arrangement. Noise Control Engineering, LLC (NCE) was retained to perform advanced noise and vibration analyses [7]. NCE identified multiple additional areas to improve the structural arrangement of the superstructure to control vibration. NCE also was able to recommend ventilation system silencing and sound insulation in critical areas to attain the desired contract noise limits around the vessel. This extra level of analysis validated the contract level design and will help to ensure a successful detail design and construction phase.

**WEIGHT ESTIMATE**
The structural Rhino model was used to develop the steel weight estimate. All other groups were developed based on itemized weights or estimated from the vessel drawings. The final weight estimate remained fairly consistent with the original parametric estimate, with a few noted exceptions discussed in further detail below. The design margins were updated throughout the process in accordance with Reference [4].

**Service Life Margin**
In addition to the light ship weight, a Service Life Margin (SLM) is applied to the various loading conditions to account for weight growth over the life of the vessel. At the outset of the design process an eight percent SLM was applied for the maximum load conditions and half of that value was used for the design load conditions. This preliminary SLM value included a three percent general margin and a larger five percent margin for the potential to convert the vessel to operate on Liquefied Natural Gas (LNG) fuel in the future should that ever become an available option.

**STABILITY ASSESSMENT**
The stability for this vessel is fairly straightforward. The vessel has a large beam which provides ample metacentric height. The passengers are a relatively light load compared to the light ship weight, despite their high center of gravity relative to the vessel and high possibility for passenger heeling moment.

However, despite the simplicity of the stability with regard to regulatory requirements, the trim of the vessel from passenger crowding at the ends is of significant concern with regard to docking and undocking at the terminals. Additional loading conditions were developed with the passengers distributed towards one end of the vessel to assess the impact to trim. To help deal with the trim of large passenger loads during extreme tide conditions, sizeable ballast tanks were added in the voids adjacent to the propulsion rooms. The final trimmed conditions were brought back into the terminal interface drawing to ensure the new design would work similar to the existing vessels in the fleet. Overall the new design fits between the envelope of the MOLINARI and BARBERI Class vessels with respect to docking.

**HULLFORM OPTIMIZATION**
Initial efforts made by EBDG to improve the efficiency of the hullform using CFD analysis focused on investigating changes to the ends to improve the pressure distribution on the hull. In addition, round bilges were added in place of hard chines throughout the mid-body. Overall, these initial hullform improvements resulted in a reduction in resistance of approximately eight percent.

Building upon these results, additional improvements were made by placing emphasis on maximizing the waterline length, reducing the half angle of entrance, and improving the overall wavemaking resistance of the hull. The second round of optimization resulted in a further reduction of deep-water hull resistance of approximately 12 percent.

**Shallow Water Effects**
New York Harbor has an average depth of approximately 50 feet. Given the design speed and the overall length of the vessel, additional considerations of hullform with respect to its performance in shallow water were required. Due to the additional complexities induced by shallow water analysis in CFD (due to the additional boundary conditions), the design team felt it best to begin shallow water analysis from a hullform initially improved for deep water conditions.

Initial shallow water analyses indicated that the fullness of the hull and minimal deadrise was causing suction and having detrimental impacts on vessel sinkage and trim. To counter these effects, the waterplane area at the ends was increased to increase the trim correcting moment, which did prove effective in reducing the sinkage and trim. However, the overall increase to resistance caused by the wider half angle of entrance at the bow had a net negative impact on resistance of the vessel in both deep and shallow water. A more effective approach to counteracting the effects of shallow water was to increase the deadrise, which had positive effects with respect to reducing the resistance caused by suction on the hull and vessel sinkage.

**Weight Reduction**
Despite all of the efforts to reduce impact of shallow water effects on the existing design it became apparent that reducing the displacement was the only option to improve performance as much as required. Reducing the displacement would reduce overall resistance and would allow for refinement of the bottom shape of the hull to reduce shallow water effects, which was hoped to allow the vessel to achieve the desired design speed. Thus, an effort was undertaken to identify several areas where weight could be significantly reduced.

As a first step, the overall weight estimate was updated to reflect the current state of the design. This allowed for refinements in the design margins from Reference [4] to be applied to the weight estimate. For example, the weights for the engines and VSP units are stated by their manufacturers. Using these data, the margins on these particular items were reduced to only two percent. Further, the structural definition and 3D model of the
vessel had been developed to a point where structural weight estimates could be refined in several areas. As an example of the refinement of the structural weight estimate, accurate measurement of bulkhead areas to include window and door cutouts could be made where they had previously been neglected or only roughly estimated.

Next, the thickness of the superstructure deck plating was reviewed and reduced by narrowing the frame spacing on the decks from 21 to 16 inches, providing a significant weight reduction, and the thickness of the Main Deck was reduced as well. The reduced stiffener spacing served to satisfy ABS Rule requirements and will help to control distortion during assembly.

Additional weight savings were achieved by altering the black and grey water system design by changing from sewage treatment using a traditional marine sanitation device to an advanced bioreactor waste water treatment system, lowering on board water requirements.

The final issue addressed was the SLM included in the various design conditions. Contributing to this decision was the small historical weight growth in SIF vessels as confirmed by a deadweight survey of the M/V ANDREW J. BARBERI. This survey identified up to a three percent growth in light ship weight over the 34-year lifespan of the vessel. The vessels are always well maintained and only necessary modifications are made. Further, the SIF maintenance facility is located immediately adjacent to the St. George terminal. Consequently the vessels do not carry an abundance of stores and spares aboard and accumulation of weight on board over their lifetimes has been kept to a minimum. The final SLM used for the maximum load conditions was taken as five percent of the light ship weight, reflecting the minimal weight growth anticipated for normal operations while still allowing some margin for a potential future LNG conversion.

Overall, the design load displacement was reduced by approximately 270 long tons. To incorporate this reduction, and reduce the shallow effects and overall hull resistance, the deadrise angle of the flat portion of the bottom of the hull was increased. This weight reduction effort and hullform change showed via CFD analysis that the vessel would likely achieve the desired design and sprint speeds.

**Final Optimization and Model Testing**

To confirm these results, Marine Research Institute Netherlands (MARIN) was selected to perform the final optimization and model testing. MARIN was asked to perform a hullform optimization study to improve resistance, and then to manufacture and test a scale model of the vessel including appendages to confirm predicted bare hull resistance. Further, MARIN was to conduct self-propelled testing in conjunction with Voith Schneider using scaled VSP models to confirm design and maximum speeds of the vessel given the main engine horsepower to be installed.

Their optimization efforts netted another significant improvement to the baseline resistance of the hull. This was done by increasing the bilge radius throughout the midbody, and reducing the prismatic coefficient via slightly increasing the midship section area. There was initial concern that the increase in the midship section area and subsequent reduction in deadrise could increase the shallow water effects. However, initial results from MARIN’s CFD analysis indicated that even with a slight increase in shallow water effects as a percentage of the total resistance, the combination of the increase in the bilge radius and slight reduction in deadrise would provide an overall net reduction to the vessel resistance in shallow water.

During the optimization process, care was taken to minimize impact of the modification of the bilge radius on the structural arrangement of the vessel. This was important in order to avoid adding too much weight because of an increase in the size of the bilge brackets, and to avoid the bilge radius crossing over the location of the outboard-most longitudinal girder. A 3D view of the final optimized hullform is shown in Figure 19.

![Figure 19: Final Hullform](image)

Finally, with the hullform settled, the model was constructed and the test was performed in December of 2015. The model testing included self-propelled still water resistance testing, maneuvering, and seakeeping studies. The resistance testing indicated that the vessel would likely be able to achieve speeds acceptably higher than required. The self-propelled model test results predict a design speed of 16.7 knots at 85 percent of the maximum continuous rating (MCR) of the installed power, and a maximum speed of 17.3 knots at 100 percent MCR. Figure 20 shows the model running in shallow water at a speed equivalent to 17 knots full-scale.
Maneuvering tests and seakeeping tests were performed by MARIN as well. The free-running, self-propelled maneuvering tests were done both with and without the peak skegs. The maneuvering tests provided strong results indicating that the peak skegs prevented steering overshoot while not adversely affecting steering response. Overall handling of the vessel in the zigzag maneuvers proved to be better with the skegs installed. Finally, seakeeping tests indicated that vessel accelerations would be well within most comfort standards, even in the event of some of the largest waves seen just outside of the entrance to New York Harbor.

FINAL DESIGN AND BID PACKAGE
Once the model testing was completed and the hullform confirmed, the final contract design drawings were completed and sent to ABS for design review. Concurrent with finalizing the design, as Owner’s Representative, Glosten provided an independent review of the design. Specifications were completed and ABS comments were incorporated as part of the final bid package. The final bid package was submitted following completion and assembly of the drawings and specification.

CONCLUSIONS
The final design features capacity for the full 4,500 passengers, and seating for approximately 2,550 persons. Passenger and crew spaces, including the pilot houses and EOS, have been arranged with the vessel operations in mind. To facilitate current and future scheduling demands, the hullform has been optimized and test predictions indicate that the design speed of 16.3 knots will be met and a sprint speed of over 17 knots will be available. The VSP units will provide a high degree of maneuverability in a manner similar to existing vessels in the fleet.

The main engines will be EPA Tier 4 compliant. Ship service generators will be small enough to remain within Tier 3 requirements, while allowing for typical operation of a single generator while underway with at least one on standby if the third is undergoing maintenance. The vessel has endurance capabilities to allow for a full week of operation prior to refueling or offloading sewage. Maintenance access for the main engines, generators, and VSP units has been thought out, with convenient lifting rails and access hatches located accordingly. Other attributes include anchoring capabilities, mooring equipment and arrangements customized to SIF operations, four rescue boats and vessel side loading doors.

The vessel design has incorporated the Owner’s requirements. The ability for the EBDG design team, including DID and MDD to work with SIF and Glosten as the Owner’s Representative in a cooperative manner throughout the process was essential and welcomed. This has been a challenging and rewarding project and we are proud to be a part of the next generation Staten Island Ferries to serve in New York Harbor.

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[9] United States Coast Guard, Equivalent Alternatives to 46 CFR Subchapter H Requirements, NVIC 8-93, CH-1, November 10, 2005.