FTA Report No. 0257

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Foil Ferry Preliminary Design Report

PREPARED BY

Foil Ferry, LLC
(Glosten, Inc. and Bieker Boats, LLC)

On behalf of Kitsap County Public Transportation Benefit Area Authority (Kitsap Transit)

SEPTEMBER 2023

U.S. Department of Transportation
Federal Transit Administration

COVER PHOTO

Courtesy of of Glosten, Inc.

DISCLAIMER

Foil Ferry Preliminary Design Report

SEPTEMBER 2023

FTA Report No. 0257

PREPARED BY

Douglas C. Zangre, Matthew A. Lankowski,
Lisa N. Renehan, Sean P. Ritchie, Dalton C. Bergan,
Paul G. Bieker, Eric E. Jolly

Foil Ferry, LLC (Glosten, Inc. and Bieker Boats, LLC)
1201 Western Avenue, Suite 200
Seattle, WA 98101

On behalf of Kitsap County Public Transportation
Benefit Area Authority (Kitsap Transit)

SPONSORED BY

Federal Transit Administration
Office of Research, Demonstration and Innovation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

AVAILABLE ONLINE

https://www.transit.dot.gov/about/research-innovation

Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE September 2023	2. REPORT TYPE Final Report	3. DATES COVERED May 2021 - July 2023

4. TITLE AND SUBTITLE Foil Ferry Preliminary Design Report	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Douglas C. Zangre, Matthew A. Lankowski, Lisa N. Renehan, Sean P. Ritchie, Dalton C. Bergan, Paul G. Bieker, Eric E. Jolly	5d. PROGRAM NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES) Foil Ferry, LLC (Glosten, Inc. and Bieker Boats, LLC) 1201 Western Avenue, Suite 200 Seattle, WA 98101 Kitsap County Public Transportation Benefit Area Authority (Kitsap Transit)	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration Office of Research, Demonstration and Innovation 1200 New Jersey Avenue, SE, Washington, DC 20590	10. SPONSOR/MONITOR'S ACRONYM(S) FTA 11. SPONSOR/MONITOR'S REPORT NUMBER(S) FTA Report No. 0257

12 . DISTRIBUTION/AVAILABILITY STATEMENT
Available from: National Technical Information Service (NTIS), Springfield, VA 22161; (703) 605-6000, Fax (703) 605-6900, email [orders@ntis.gov]; Distribution Code TRI-30

13. SUPPLEMENTARY NOTES NOTES [www.transit.dot.gov/research-innovation/fta-reports-and-publications] [https://www.transit.dot.gov/about/research-innovation] [https://doi.org/10.21949/1527670] Suggested citation: Foil Ferry Preliminary Design Report. Washington, D.C.: United States Department of Transportation, 2023. https://doi.org/10.21949/1527670.

14. ABSTRACT
Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC, have completed the preliminary design of Foil Ferry, a 150-passenger all-electric fast ferry. This effort was funded through the Federal Transit Administration's Accelerated Innovative Mobility (AIM) initiative. The preliminary design is targeted to the Bremerton—Seattle route in Washington currently served by Kitsap Transit diesel-powered fast ferries. The objectives of the Foil Ferry Preliminary Design, for which this report serves as the primary deliverable to FTA, were to advance the Foil Ferry design, reduce technical risks, develop emissions and performance predictions, and develop operating and capital cost estimates. The Preliminary Design validates the Foil Ferry concept for the route identified in AIM cooperative agreement Task 4, the *Route Economic Viability Study*, showing Foil Ferry to have dramatic environmental benefits and reduced operating costs compared to conventional diesel-powered fast ferries.

Construction of Foil Ferry is estimated to cost $14.1 million, plus $1.0 million for owner construction management and oversight. The first hull will also require the design to be advanced from the preliminary level to the functional level ($2.3 million), a prototype program ($0.8 million), and shoreside infrastructure design and construction ($3.2 million). All-in operating costs are estimated to be $1.3 million per year including energy, crew, and maintenance costs (including battery replacement every eight years), which is 35% less than conventional fast ferries. The next steps to progress the Foil Ferry program include: (1) build a scaled prototype vessel to mitigate design and schedule risks prior to construction of first-production Foil Ferry, and (2) develop a functional design package with sufficient detail for fabricators to bid on construction.

15. SUBJECT TERMS
Foil Ferry, fast ferry, hydrofoil, battery, electric, Seattle, Bremerton, Kitsap Transit, Glosten, Bieker, efficiency, maritime, emission reduction, GHG reduction, CO_2 reduction

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	Unlimited	62	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acknowledgments

This project was funded through the Federal Transit Administration's (FTA) Accelerating Innovative Mobility (AIM) program as part of the FTA's Research, Development, Demonstration and Deployment program authority. Additional project funding and/or in-kind support were provided by project partners Glosten and Bieker Boats dba Foil Ferry, LLC; DNV; Washington Maritime Blue; Port of Anacortes; Port of Bellingham; Port of Skagit; and Tacoma Power.

Kitsap Transit thanks the following Joint Innovation Project (JIP) members who contributed greatly to this project and for their dedication and support throughout the effort:

- Matthew Lankowski, Lisa Renehan, Kenneth Lane, Douglas Zangre, Sean Ritchie, and Dalton Bergan of Glosten; and Paul Bieker and Eric Jolley of Bieker Boats, for using their extensive expertise as naval architects in leading the development of all elements of the foil ferry design, including advancing the design from their original concept to preliminary design.
- DNV's Maritime and Energy Systems team of consultants, who brought their technical and business model development skills to the JIP and led the overarching project technical analysis and reporting.
- Jennifer States, Devon Thorsell, Joshua Berger, and Cassidy Fisher of Washington Maritime Blue, for JIP program management, development, and primary outreach led by the regional cluster organization.
- IP full team members and development partners for their project guidance and support, including Rob Fix and Don Goldberg of Port of Bellingham; Patsy Martin, Sara Young, and Linda Tyler of Port of Skagit; Daniel Worra of Port of Anacortes; and Cam LeHouillier of Tacoma Power.

Kitsap Transit also acknowledges and greatly appreciates Accelerating Innovative Mobility (AIM) Program Technical Assistance and all the JIP program supporters, including:

- Justin John, Transportation Program Specialist and FTA Program Manager, who provided invaluable project guidance and support.
- Alvaro Villagran, Colin Murphy, and Manali Sheth of the Shared-Use Mobility Center (SUMC), the public-interest organization that partnered with FTA to support multimodal transportation systems that work for all.
- Economic Development Alliance of Skagit County (EDASC), for providing meeting space, outreach, publicity, and technical guidance.
- Puget Sound Regional Council, for providing data that supported the Route Economic Viability Study.
- Puget Sound Energy, which brought technical expertise to support the foil ferry infrastructure plan development.

Abstract

Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC, have completed the preliminary design of Foil Ferry, a 150-passenger all-electric fast ferry. The preliminary design effort was funded through the Federal Transit Administration's Accelerated Innovative Mobility (AIM) initiative. The design is targeted to a Bremerton–Seattle route in Washington currently served by diesel-powered fast ferries. The objectives of the Foil Ferry Preliminary Design, for which this report serves as the primary deliverable to FTA, were to advance the Foil Ferry design, reduce technical risks, develop emissions and performance predictions, and develop operating and capital cost estimates. The Preliminary Design validates the Foil Ferry concept for the route identified in AIM cooperative agreement Task 4, the *Route Economic Viability Study* [2], showing Foil Ferry to have dramatic environmental benefits and reduced operating costs compared to conventional diesel-powered fast ferries.

Construction of Foil Ferry is estimated to cost $14.1 million, plus $1.0 million for owner construction management and oversight. The first hull will also require the design to be advanced from the preliminary level to the functional level ($2.3 million), a prototype program ($0.8 million), and shoreside infrastructure design and construction ($3.2 million). All-in operating costs are estimated to be $1.3 million per year including energy, crew, and maintenance costs (including battery replacement every eight years), which is 35% less than conventional fast ferries.

The next steps to progress the Foil Ferry program include:

1. Build a scaled prototype vessel to mitigate design and schedule risks prior to construction of first-production Foil Ferry.
2. Develop a functional design package with sufficient detail for fabricators to bid on construction.

This report was conducted in furtherance of the Federal Transit Administration (FTA) Accelerating Innovative Mobility (AIM) program with the goal of supporting innovation throughout the transit industry by promoting forward-thinking approaches to improving transit system design, service, and financing. The opinions and conclusions expressed or implied in this report are solely those of the researchers who performed the research on behalf of Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC, and on behalf of Kitsap Transit. This report does not have the force and effect of law and is not meant to bind the public in any way.

Executive Summary

Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC, have completed the preliminary design of Foil Ferry, a 150-passenger all-electric fast ferry. The preliminary design effort was funded through the Federal Transit Administration's Accelerated Innovative Mobility (AIM) initiative. The design is targeted to a Bremerton–Seattle route in Washington currently served by diesel-powered fast ferries. The objectives of the Foil Ferry Preliminary Design, for which this report serves as the primary deliverable to FTA, were to advance the Foil Ferry design, reduce technical risks, develop emissions and performance predictions, and develop operating and capital cost estimates.

Findings and Conclusions

The Preliminary Design validates the Foil Ferry concept for the route identified in AIM cooperative agreement Task 4, the *Route Economic Viability Study* [2], showing Foil Ferry to have dramatic environmental benefits and reduced operating costs compared to conventional diesel-powered fast ferries.

Construction of Foil Ferry is estimated to cost $14.1 million, plus $1.0 million for owner construction management and oversight. The first hull will also require the design to be advanced from the preliminary level to the functional level ($2.3 million), a prototype program ($0.8 million), and shoreside infrastructure design and construction ($3.2 million). All-in operating costs are estimated to be $1.3 million per year including energy, crew, and maintenance costs (including battery replacement every eight years), which is 35% less than conventional fast ferries.

The next steps to progress the Foil Ferry program include:

1. Build a scaled prototype vessel to mitigate design and schedule risks prior to construction of first-production Foil Ferry.
2. Develop a functional design package with sufficient detail for fabricators to bid on construction.

Benefits

Foil Ferry provides benefits in numerous areas, including safety, environmental sustainability, efficiency, and economic competitiveness.

Foil Ferry requires less than one-third the energy of conventional fast ferries. Its lightweight composite design and hydrofoil technology deliver efficiency gains that allow the vessel to be battery powered for commercially viable distances. The Foil Ferry design described herein is adapted to the Bremerton–Seattle fast ferry route. The vessel can complete each crossing in 32 minutes and a round trip on a single battery charge. Because it is an all-electric vessel, Foil Ferry emits no greenhouse gases or pollutants. Foil Ferry generates much less noise than an internal combustion powered craft and offers reduced motions relative to non-foiling hulls, providing passengers with a more comfortable ride.

Foil Ferry produces negligible waves as the hulls fly above the water's surface. This wake reduction compared to traditional vessels is important for protecting sensitive shorelines such as those along Rich Passage, Washington, which makes up a significant portion of the Bremerton–Seattle route.

Foil Ferry incorporates systems to ensure it is at least as safe and reliable as conventional fast ferries. The pilothouse is optimized for situational awareness, including a novel automated object detection system borrowed from the autonomous vessel market that improves outcomes and reduces the risk of collisions. In the event of a strike with an object such as a log while foilborne, a collision absorption system ensures that the vessel comes to a safe and controlled stop.

Project Information

This research project was conducted by Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC. For more information, contact FTA Project Manager Justin John at 202-366-2823, justin.john@dot.gov. All research reports can be found at https://www.transit.dot.gov/about/research-innovation.

Section 1

Introduction

Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC, have completed the preliminary design of Foil Ferry, a 150-passenger all-electric fast ferry. The preliminary design effort was funded through the Federal Transit Administration's Accelerated Innovative Mobility initiative. A rendering of the Foil Ferry design is shown in Figure 4-1.

Foil Ferry requires less than one-third of the energy of conventional fast ferries. Its lightweight composite design and hydrofoil technology deliver efficiency gains that allow the vessel to be battery powered for commercially viable distances. The Foil Ferry design described herein is adapted to the Bremerton–Seattle fast ferry route. The vessel can complete each crossing in 32 minutes and a round trip on a single battery charge.

Because it is an all-electric vessel, Foil Ferry emits no greenhouse gases or pollutants. The vessel generates much less noise than an internal combustion powered craft and offers reduced motions relative to non-foiling hulls, providing passengers a more comfortable ride. It is typical for passengers who normally experience seasickness to have no such symptoms on a hydrofoiling vessel.

Foil Ferry produces negligible waves as the hulls fly above the water's surface. This wake reduction compared to traditional vessels is important for protecting sensitive shorelines such as those along Rich Passage, Washington, which makes up a significant portion of the Bremerton–Seattle route.

The risk of collisions with debris or marine mammals is not unique to hydrofoiling vessels; however, Foil Ferry incorporates systems to ensure it is at least as safe and reliable as conventional fast ferries. The pilothouse is optimized for situational awareness, including a novel automated object detection system borrowed from the autonomous vessel market that improves outcomes and reduces the risk of collisions. In the event of a strike while foilborne, a collision absorption system ensures that the vessel comes to a safe and controlled stop and is quickly on its way again.

Construction of Foil Ferry is estimated to cost $14.1 million, plus $1.0 million for owner construction management and oversight. The first hull will also require the design to be advanced from the preliminary level to the functional level ($2.3 million), a prototype program ($0.8 million), and shoreside infrastructure design and construction ($3.2 million). All-in operating costs are estimated to be $1.3 million per year including energy, crew, and maintenance costs (including battery replacement every eight years), which is less than conventional fast ferries.

The next steps to progress the Foil Ferry program include:

1. Build a scaled prototype vessel to mitigate design and schedule risks prior to construction of first-production Foil Ferry.
2. Develop a functional design package with sufficient detail for fabricators to bid on construction.

Section 2 Vessel Mission Requirements

Mission Description

The Foil Ferry is designed to provide zero-emission, fast, safe, and affordable passenger transportation to the maritime community. It leverages private sector hydrofoil design innovations, lightweight composite construction, and advanced battery technology to serve and connect communities.

A specific operating profile was defined for the design described in this report, with unique parameters and assumptions including route length, schedule, passenger demand, environmental and operating conditions, and shoreside charging infrastructure. These unique parameters were carefully balanced with the principle of providing excellent value to a wide range of operations and environments.

Zero-Emission Transportation

Foil Ferry will reduce waterborne passenger transportation's negative impacts on the environment and local communities by reducing overall energy consumption and eliminating stack emissions.

High-speed ferries provide numerous economic benefits to the regions they connect. Unfortunately, conventional high-speed ferries also consume substantial fuel and emit large amounts of carbon dioxide (CO_2) and other pollutants. Even the most efficient modern conventional catamarans, such as Kitsap Transit's 118-passenger *Rich Passage 1* (RP1) class fast ferries, require an enormous amount of power (2,400 kW) to overcome the drag of the hull as it passes through the water and generates waves. Battery systems are considerably less energy-dense than fossil fuels, making them infeasible as the power source for such vessels.

Foil Ferry requires less than half the power (1,000 kW) to travel over water compared to a conventional high-speed ferry of similar capacity. It incorporates hydrofoils that lift the hull out of the water, drastically reducing wetted surface and wave-making drag. This drag reduction significantly reduces Foil Ferry's power requirements, enabling it to operate on 100% battery power over significant distances.

Foil Ferry's only emissions are those generated by the power plants that power the electrical grid from which it draws electricity. Table 2-1 compares estimated emissions of the 150-passenger Foil Ferry with the 118-passenger RP1 class fast ferries currently operating on the route, based on the 2020 energy mix of Bremerton, WA, electricity utility Puget Sound Energy (PSE). During the 40-year life of the ferry, the emissions inherent to the electrical grid will continue to decrease as renewable energy sources increase in response to the Clean Energy Transformation Act, which commits Washington energy supply to be free of greenhouse gases by 2045. When Foil Ferry's charging energy is generated wholly from renewable sources, there will be zero air emissions; all air emissions will have been reduced by 100%.

Table 2-1 *Round-trip Well-to-Wake Emissions Comparison (2020 PSE Grid)*

	RP1 Class Fast Ferry	Foil Ferry	% Increase (Reduction)
Energy Source	Diesel Fuel	Electrical Grid (PSE)	
Passenger Capacity	118	150	27%
Energy Consumed [1]	4,895 kW-hr	1,059 kW-hr	(78%)
CO_2 Emissions [1]	1,606 kg	418 kg	(74%)
PM2.5 Emissions [1]	0.38 kg	0.05 kg	(87%)
PM10 Emissions [1]	0.41 kg	0.03 kg	(92%)
NO_x Emissions [1]	23.54 kg	0.32 kg	(99%)

Vessel Speed

Foil Ferry has a takeoff speed of 20 knots and is optimized for a cruising speed of 30 knots. Cruising speeds greater than 30 knots are achievable but would increase energy consumption and likely increase the number of required crew, so limiting the speed is recommended while carrying passengers. Cruising speeds less than 30 knots would increase commuting times beyond estimated public acceptance. The operator has the flexibility to slow down to 23 knots while foilborne to improve navigational safety in confined areas.

Route

Kitsap Transit’s Bremerton–Seattle fast ferry route was selected for the preliminary design [2]. This decision was based on the high route ridership, moderate range, existence of key infrastructure, and the opportunity to demonstrate Foil Ferry's low-wake properties on a route with multiple boats in operation. The route is shown in Figure 2-1.

Figure 2-1 *Foil Ferry design route*

Source: Kitsap Transit

The Bremerton–Seattle route is 13.7 nautical miles long. Foil Ferry will make the crossing in 32 minutes, including takeoff, approach, and maneuvering at both ends. It is designed to recharge on the Bremerton end of the route only.

Terminals

Bremerton

Kitsap Transit's Bremerton passenger-only ferry service operates from the Bremerton Transportation Center using foil-assisted diesel-powered catamarans *Rich Passage 1* (RP1), *Reliance*, and *Lady Swift*. Foil Ferry will operate using the same berths as the RP1-class vessels (i.e., Berths 3 and 4 on A-float). The dock is a floating dock and has 1.37 m freeboard.

Shoreside charging capability will be added to this pier. Adequate capacity exists in the circuit running nearest to the dock, so no major rework is necessary. The following equipment will be added:

- A transformer, to reduce the circuit voltage
- A power conversion system, to convert AC to DC power
- A duct bank and conduit, to run the line from the circuit to the pier
- (Optional) An energy storage system (ESS), to reduce peak power demand
- A charging station, to connect the shore power to the vessel

The charging station will be automated to provide safe, efficient hookup of the shore power to the vessel. The Foil Ferry cabin top is outfitted with charging rails that accommodate a pantograph charging system. This technology is typical in bus depots and has been recently commercialized for marine vessels. Because the Bremerton Transportation Center is on a floating pier, the charging solution is not affected by tidal fluctuations. Pantograph charging systems offer a cost-effective, maintainable, and reliable solution for this scenario. The piers may also require minor modifications such as new or modified fenders or cleats.

Seattle

Kitsap Transit's Bremerton passenger-only ferry service currently operates from Pier 54 in downtown Seattle. The dock is a floating dock and has 0.76 m freeboard.

Kitsap Transit is evaluating options for an additional downtown Seattle landing site to support ongoing operations and growth of its regional passenger-only ferry service.

Port Orchard

When not in use, Kitsap Transit's existing vessels moor along the east breakwater at Port Orchard marina. The dock is a floating dock with approximately 0.30 m freeboard.

Ridership

The first production Foil Ferry will slot into Kitsap Transit's existing operations to demonstrate its commercial viability. To size the energy storage system, it is assumed the vessel will operate eight round trips per day, 257 days per year, which corresponds to weekday-only service minus four holidays. Adding weekend service is feasible but would reduce the useful life of the energy storage system compared to the baseline assumed in this design.

Weekday service ridership data from Kitsap Transit's RP1 class vessels from May 2019 through March 2020 show that the average passenger load is 56%, and only 12% of trips are at full load [3]. Foil Ferry ridership is assumed to match these pre-pandemic levels.

Operating Environment

The vessel is designed to operate on partially protected waters (lakes, bays, and sounds), which is appropriate for the selected route as well as most other routes suited for passenger-only ferry service. Foil Ferry can operate at cruising speed in Sea State 3 with significant waves heights up to 1.07 m. This is the 99th percentile significant wave height on the route. The 99th percentile wind speed is 27 knots.

Foil Ferry service will not be restricted any further than the existing passenger-only ferry service in Puget Sound. The motions experienced by passengers aboard Foil Ferry will be reduced compared to conventional catamarans because the vessel rides above the waves.

Section 3 Regulatory Requirements

U.S. Coast Guard

Foil Ferry will be U.S.-flagged and inspected by the U.S. Coast Guard (USCG). It is designed to meet 46 CFR Subchapter T, Small Passenger Vessels [4]. As required by Subchapter T, portions of Subchapters S (Stability), F (Mechanical), and J (Electrical) apply.

Additionally, the vessel meets CG-ENG-Policy Letter No. 02-19 [5], which applies to this vessel due to the inclusion of lithium-ion batteries. This policy letter incorporates the requirements of ASTM F3353-19 [6].

Outreach and discussions with USCG have begun and will continue through the final design to account for regulatory gray areas, since this will be the first composite battery electric passenger vessel in the United States.

DNV

The structural design of the vessel complies with the DNV Rules for Classification of High Speed and Light Craft (DNV-RU-HSLC) [7].

Tonnage

The vessel admeasures less than 100 gross register tons (GRT), as required to be certified under 46 CFR Subchapter T. It includes tonnage openings in the deckhouse so that the entire passenger area may be exempt from tonnage.

Federal Transit Administration

Federally funded procurements of ferry vessels are subject to additional requirements, updated each fiscal year (FY) in FTA's Certifications and Assurances and Master Agreement. This preliminary design incorporates the possibility of these additional requirements such that final design will comply if such funding sources are used.

FTA-funded procurements of ferry vessels are subject to additional requirements, including but not limited to those listed in Table 3-1. Table 3-1 also provides commentary on how these requirements relate to this preliminary design.

Table 3-1 *Requirements for FTA-Funded Ferry Procurements*

FTA Requirement	Preliminary Design
Buy America Requirements: 49 U.S.C. § 5323(j)	The vessel is designed such that at least 70% of all components by cost that can be, are sourced domestically. The cost estimate (Section 5) is based on meeting Buy America Requirements.
Pre-Award and Post-Delivery Review: 49 U.S.C. § 5323(m)	
Bidder Specification Requirement: 49 U.S.C. § 5323(m)	
Disadvantaged Business Enterprise (DBE) Requirements: 49 CFR Part 26	Vessel design allows for each of these requirements to be met.
Use of Federally Assisted Property: FTA C 5010.1E, Chapter IV	
Minimum Useful Life of Federally Assisted Property: FTA C 5010.1E, Chapter IV	
Transit Asset Management: 49 CFR Part 625	
Americans with Disabilities Act (ADA): 49 CFR Part 38, Subpart H and Part 39, Subpart E	These regulations being reserved, the vessel is designed according to the ADA Guidelines for Passenger Vessels [8].
Limitation on Certain Rolling Stock Procurements: 49 U.S.C. § 5323(u)	The vessel is designed such that at least 70% of all components by cost that can be, are sourced domestically. The cost estimate (Section 5) is based on meeting Buy America Requirements.

Section 4 Preliminary Design Description

General Arrangement

Foil Ferry principal characteristics are listed in Table 4-1. Exterior renderings are shown in Figures 4-1, 4-2, 4-3, and 4-4. For more details, refer to the General Arrangement drawing [9] provided in Appendix A.

Table 4-1 *Principal Characteristics*

Length Overall	27.5 m	90.2 ft
Breadth (Hull)	7.6 m	24.9 ft
Breadth (Main Foil)	10.8 m	35.6 ft
Draft (Hull)	0.94 m	3.1 ft
Draft (Foils, Displacement)	3.7 m	12.1 ft
Draft (Foils, Flying)	1.7 m	5.6 ft
Displacement, Lightship	46.8 tonnes	46.1 long tons
Displacement, Fully Loaded	60.7 tonnes	59.7 long tons
Passengers	150 passengers	
Battery Capacity	1,500 kW-hr	
Propulsion	2 x 500 kW pod drives	
Speed, Takeoff	~20 knots	
Speed, Cruise	30 knots	
Speed, Maximum	35 knots	
Design Range	30 nautical miles	

Figure 4-1 *Isometric view (fore)*

Figure 4-2 *Isometric view (aft)*

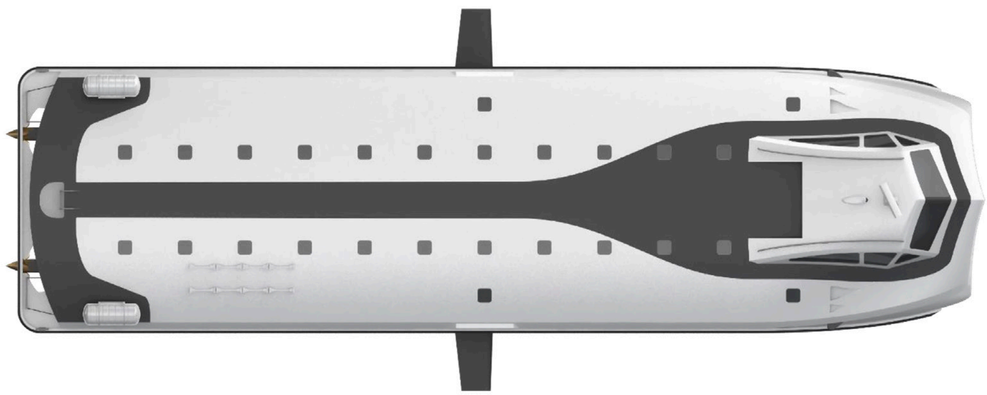

Figure 4-3 *Plan view*

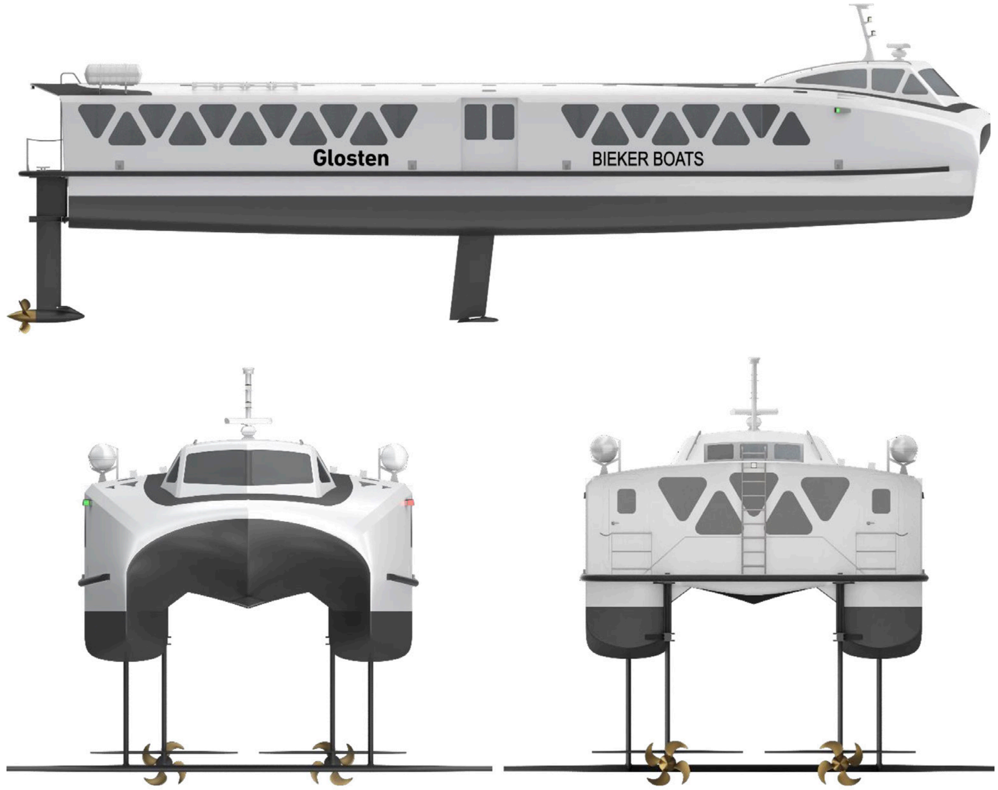

Figure 4-4 *Profile, fore, and aft views (top, left, and right)*

Crewing and Bridge Layout

Foil Ferry will operate with three crew members, which is typical for a single-deck boat of this size and speed. The crew consists of one licensed master, one licensed mate, and one deckhand.

The vessel has a compact modern pilothouse with seats for two operators. Both operators have access to all critical flight controls and monitoring systems. Eight monitors are arranged as shown in Figure 4-5. The flight control system display is front and center. Flight controls include control mode selection (auto/manual) and indication of current heading, roll, pitch, rudder angle, propeller RPM, flight control surface angle, and ride height. Joystick controls are integral to the helm chair arms for rudder control, and full flight surface control when flight control mode is set to manual. The throttle is located between the two helm chairs.

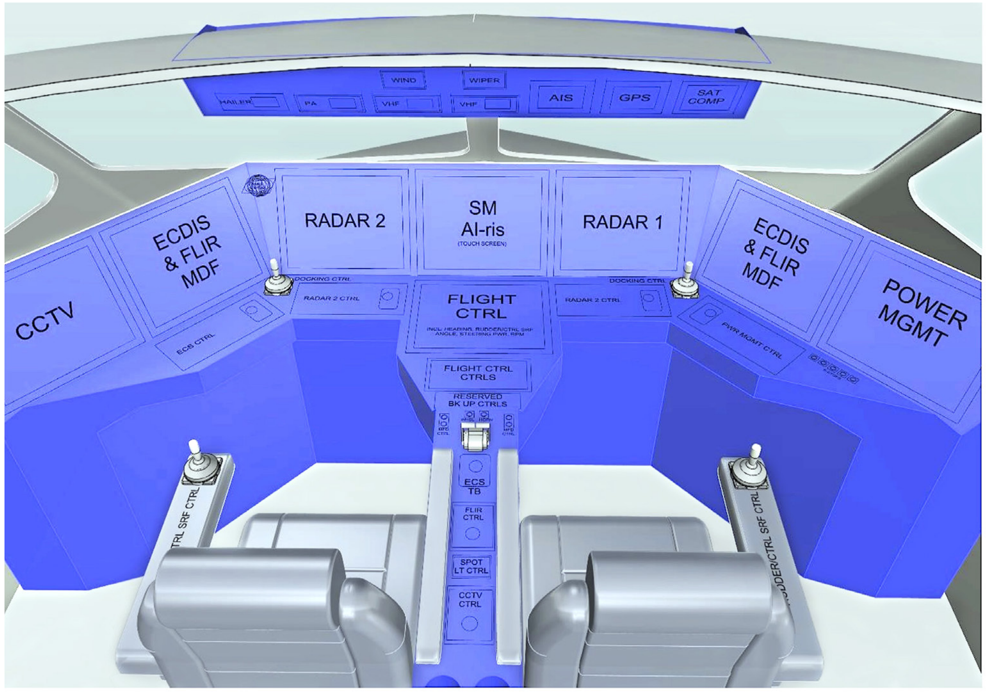

Figure 4-5 *Pilothouse arrangement*

Above the flight control display is the Sea Machines AI-ris system, a system for enhanced situational awareness and collision avoidance (more details in the Object Detection System section below). Radars flank the AI-ris and further outboard are the ECDIS and FLIR multi-functional displays (MFD). Outboard of those are the closed-circuit television (to port) for docking and power management system (to starboard). VHF, PA, loud hailer, GPS, and automatic identification system (AIS) are in the overhead. Ancillary items such as electrical switches are located out of the way on the side bulkhead.

Passenger Cabin

Passengers will board using the side doors on either port or starboard. A shoreside ramp, necessary to bridge the gap between the vessel and the pier, will land between the open doors.

Foil Ferry has seating for 150 passengers and stowage for 15 bicycles. Passenger seats are fitted with high backs and across-the-lap seat belts. Bicycles are secured to racks just inside the loading doors.

The main deck arrangement is shown in Figure 4-6.

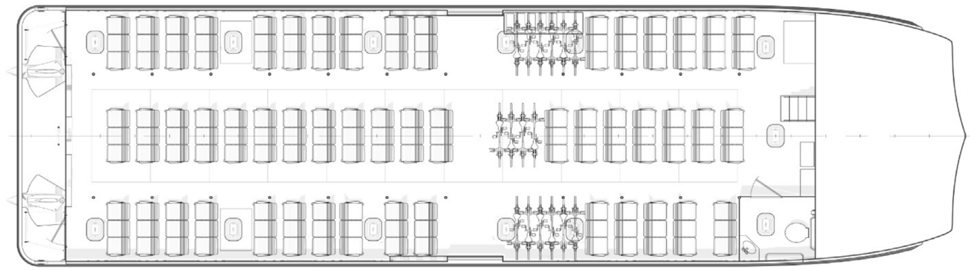

Figure 4-6 *Main deck arrangement*

The passenger cabin includes space for maneuvering wheelchairs and three designated wheelchair securing spaces. One wheelchair-accessible restroom is in the forward starboard corner of the passenger space. Doors at the aft end of the cabin are crew use only for maintenance and mooring. Access to the pilothouse is through the crew-only door at the forward end of the passenger space.

Structural Design

The hull, superstructure, and hydrofoils will be constructed of carbon fiber reinforced polymer. Carbon fiber structures are considerably lighter than aluminum for the same strength. The established lightweight construction methods used in aerospace and high-performance yacht industries are essential to the feasibility of efficient foiling craft.

Hull and superstructure scantlings were designed according to DNV Rules for High Speed and Light Craft (DNV HSLC) [7]. Foil Ferry will not be classed; however, 46 CFR Subchapter T requires that the structure be built to a recognized standard, and DNV HSLC is the most appropriate for this vessel. Vertical design acceleration, which is a major input to structural design loads, was calculated using the HSLC rules. Load scenarios considered in the structural design include sea pressure, bottom slamming, wet deck slamming, pitch slamming, bow impact pressure, and twin hull bending.

The hull and superstructure will be built in molds using epoxy resin infusion at room temperature. Hydrofoils and struts will utilize a combination of pre-impregnated carbon composites cured in an autoclave and resin infused carbon/epoxy laminates cured at room temperature.

Weight and Stability

A preliminary design level weight estimate was developed using estimated, calculated, and vendor-provided weights. The vessel’s lightship weight, inclusive of margin, is estimated to be 46.8 tonnes. At a full passenger load, the weight is approximately 60.7 tonnes. Table 4-2 provides more information.

Table 4-2 *Weight Estimate Summary*

PRELIMINARY WEIGHT ESTIMATE – SUMMARY						
SWBS* No.	**Group Description**	**Margin** %	**Weight** kg	**Margin** kg	**LCG†** m +fwd Fr 0	**VCG‡** m +ABL
100	Hull Structure	8%	9,737	779	12.67	2.03
200	Propulsion Plant	9%	15,820	1,424	9.22	0.51
300	Electric Plant	12%	4,849	582	11.46	1.38
400	Command and Surveillance	12%	305	37	21.75	4.19
500	Auxiliary Systems	12%	6,899	828	9.88	0.79
600	Outfit and Furnishings	12%	4,477	537	12.17	1.78
	Lightship (without margins)		**42,088**		**10.79**	**1.17**
	Design and Build Weight Margin	9.95%	4,186		10.79	1.16
	Contract Mods. Weight Margin	1.25%	526		10.79	1.17
	Design and Build VCG Margin	10.00%				0.12
	Contract Mods. VCG Margin	0.75%				0.01
	Design and Build LCG Margin	0.50%			+/- 0.13	
	Lightship (with margins)		**46,800**		**10.79**	**1.29**
	Max Operating Load (with margins)		**60,689**		**10.72**	**1.60**
	153 People		12,839		9.70	2.74
	15 Bikes		200		13.60	2.43
	Water		750		22.50	1.05
	Miscellaneous		100		13.00	2.75

**Ship Work Breakdown Structure, †Longitudinal Center of Gravity, ‡Vertical Center of Gravity*

Intact and damage stability calculations were carried out over the full range of displacements. The vessel meets the stability criteria set by USCG for small passenger vessels operating on partially protected waters (within 20 nautical miles of the mouth of a harbor of safe refuge, as determined by USCG).

Hull Form

Foil Ferry is designed in a catamaran configuration, which allows for sufficient deck area, improved stability, and less resistance than a monohull vessel of a similar capacity and speed.

The Foil Ferry hull form evolved during preliminary design to reduce the hydrodynamic drag during takeoff and the aerodynamic drag while foiling. The demihulls have round bilges, flat sides, nearly vertical stems, and a noticeable amount of rocker. Where possible, surfaces are kept flat or constant cross-section to simplify tooling and reduce cost. Hull lines are shown in Figure 4-7. The hull is further characterized by the following dimensionless parameters:

- Length to breadth (demihull) ratio: 13.7
- Block coefficient: 0.67
- Maximum section coefficient: 0.92
- Prismatic coefficient: 0.73

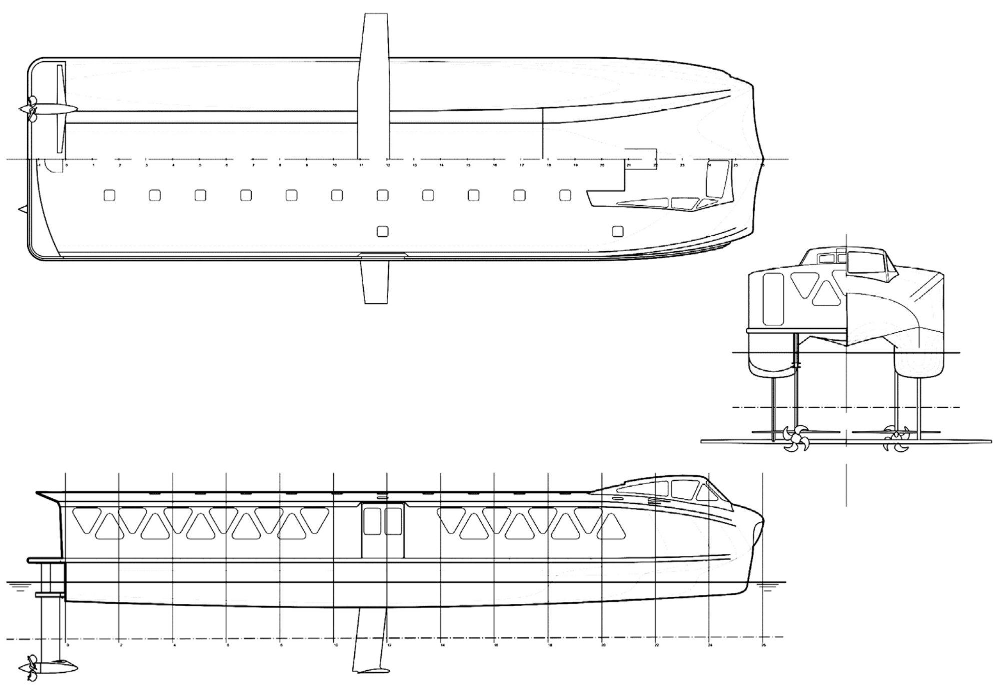

Figure 4-7 *Hull lines*

Hydrofoils

Foil Ferry features fully submerged hydrofoils that produce hydrodynamic lift and raise the hull above the water surface. The foils are in a conventional longitudinal configuration, meaning that the forward main foil supports most of the vessel weight. The aft foils are split laterally into two steerable outboard units with propulsion pods. Foil geometry is shown in Figure 4-8.

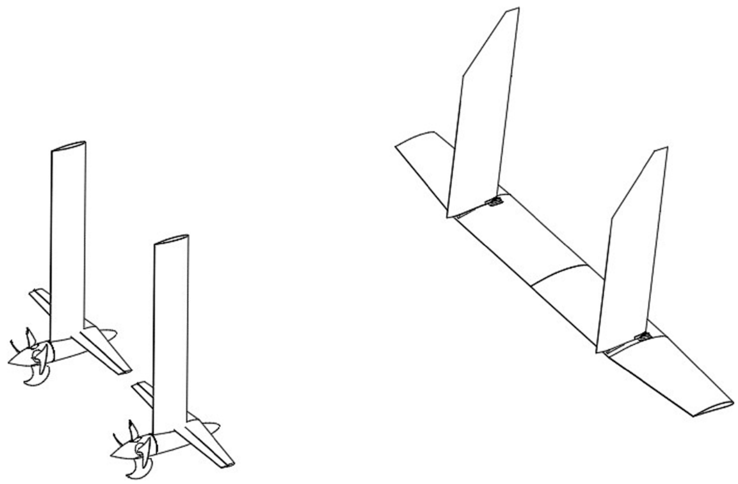

Figure 4-8 *Foil configuration*

Hydrofoil Design

The foils are designed for maximum efficiency at cruising speed. The foil section was designed considering the onset of cavitation over the full foil loading and speed envelope. Initial foil sizing was performed using a vortex lattice method to calculate the flow field. Then, Reynolds Averaged Navier-Stokes (RANS) computational fluid dynamics (CFD) was used to calculate the lift and drag of the foil system, including the downwash effect of the main foil on the aft foils.

Foil efficiency is highly sensitive to aspect ratio. By extending the main foil tips outboard of the hull breadth, the design recognized a 15% increase in performance compared to limiting the foil span to the hull breadth.

Collision Absorption System

Hydrofoiling ferries have a long history that includes many successful commercial applications. However, the risk of colliding with objects in the water such as logs (deadheads) remains a primary concern to vessel operators.

Foil Ferry has a patented collision absorption system that allows the vessel to come to a safe, controlled stop in the event of a strike with a large object while foilborne, mitigating the risk of injury to passengers and damage to the vessel.

The system can be reset via pushbutton control so the vessel can quickly be underway again.

The risk of collision is reduced by a computer vision and artificial intelligence object detection system (described in the Object Detection System section below).

Flight Control System

The flight control system maintains Foil Ferry at a constant attitude (roll, pitch, yaw) and altitude (height above water). The flight control system configuration is illustrated in Figure 4-9.

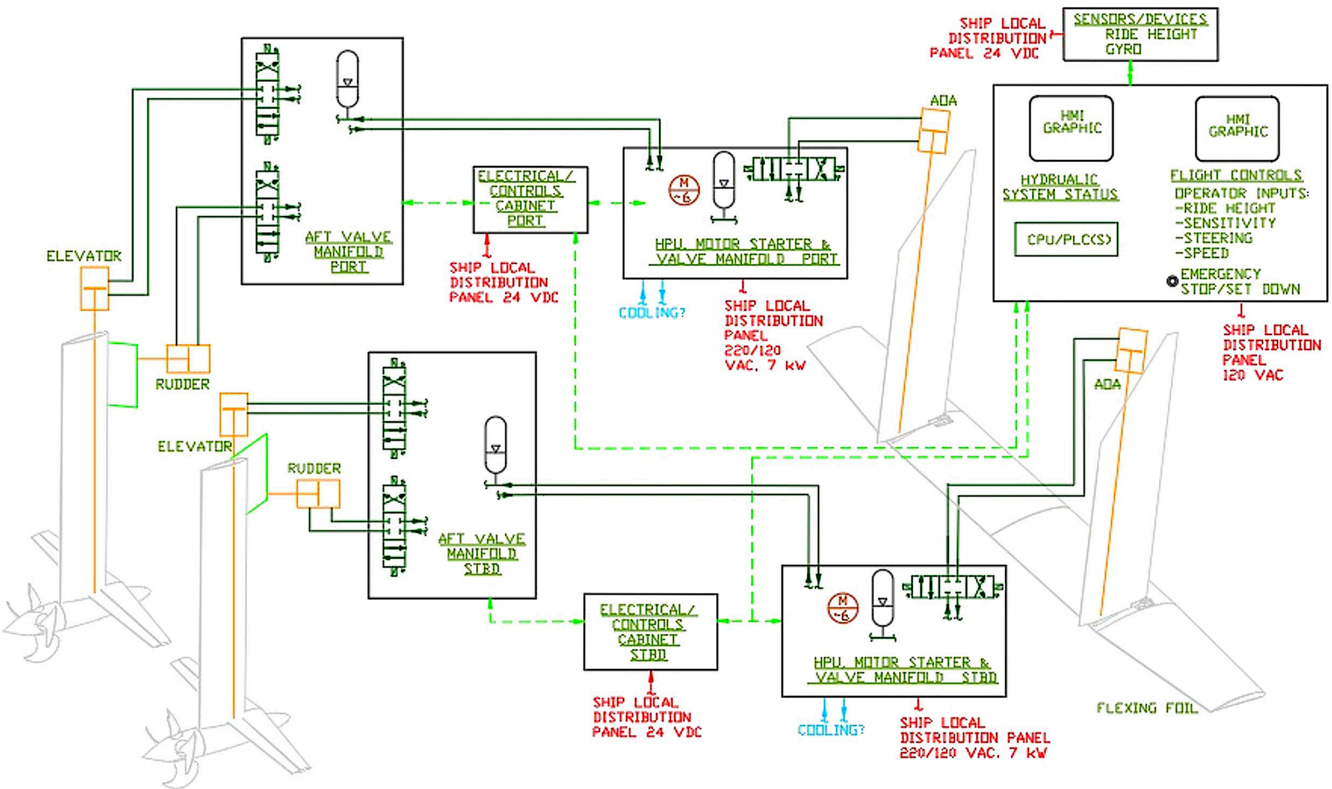

Figure 4-9 *Flight control system one-line diagram*

The primary sensors are an array of inertial measurement units (IMUs) and ride height sensors. The IMUs are combination gyroscopes and accelerometers that precisely sense changes in rotation and motion at sample rates of 100 Hz or more. The flight control system analyzes the data from the IMUs to determine the correct control surface adjustments to counteract changes in motion. Small control adjustments are conducted multiple times per second to maintain steady flight.

An array of ride height (altitude) sensors determines the vessel's height above the water's surface. The sensors average the height of the water over several wave periods; therefore, the feedback loop is slower than the IMU sensors.

The flight control system must be single fault tolerant, such that the failure of any device (controller, sensors, actuator, etc.) is detectable and does not negatively impact the ability of the flight control system to maintain steady flight or safely set down the vessel. A scaled prototype is recommended to validate the performance of each failure mode (described further in Section 6). The main foil control rod is normally under compression so that loss of hydraulic power lowers the vessel off the foils.

Control inputs from the pilot alter the rate of altitude change, roll angle, and rudder angle. The flight control system continuously adjusts the control surfaces to match the vessel attitude with the desired input. Actuation of the control surfaces is accomplished using a system of hydraulic actuators operating at a maximum of 200 bar (2,900 psi) pressure. Hydraulic accumulators are located near each of the primary foil actuators (one near each main foil strut and one near each demihull transom). These accumulators provide local energy storage in the hydraulic system and thereby reduce the instantaneous power requirements from the hydraulic power units.

Control Authority

The vessel's dynamic stability has been evaluated with respect to pitch, roll, and yaw. Roll authority, or how much roll moment the foils produce at a given speed prior to stall or cavitation, has been assessed for speeds between 18 and 35 knots. This is a major factor in determining the span of the main foil. Calculations show that the foil system as designed has sufficient roll authority to counter the heeling moment produced by a 27-knot crosswind at takeoff speed. Winds in excess will require a course into the wind or downwind during takeoff.

Propulsion

Podded Propulsors

Foil Ferry is powered by two 500-kW electric podded motor assemblies, one on each of the aft strut/foil assemblies. Each pod contains two 250-kW motors contained within a hydrodynamically faired pod driving one propeller. Electric podded propulsors are the preferred solution for Foil Ferry due to the simplicity of passive cooling and the lack of a mechanical drivetrain through the foil struts. Several propulsion vendors are currently developing podded propulsors in the size range suitable for the vessel.

Passive motor cooling minimizes pod diameter and thus drag. Most marine electric motors have jacket water cooling, making them too large to enclose in a pod. Passive heat rejection is used on small recreational pod drives, but as the power of a pod increases, the exposed area does not increase proportionally, so passive heat rejection is a governing factor in pod design.

Alternative propulsor arrangements feasible with existing off-the-shelf components were also evaluated, including more pods of smaller size or an L- or T-drive configuration. In this arrangement, electric motors above the waterline transmit power to a submerged propeller via mechanical drivelines. Podded propulsors are preferred for simplicity and reduced drag.

Vessel Operating Load Profile

The propulsion system must be able to provide sufficient thrust to satisfy the vessel's schedule under the worst-case conditions (i.e., a full load of passengers and adverse weather conditions). However, assuming every trip is in these severe conditions would result in unrealistic battery size requirements for adequate battery life. An assumed vessel operating load profile was used to inform propulsion and battery sizing calculations using average loading conditions (the average number of passengers carried per trip and normal weather).

Due to commute patterns, it is common for passenger-only ferries to be nearly full in one direction of travel and nearly empty in the other. Based on the ridership patterns observed on Kitsap Transit's RP1 class vessels (Section 2), it was assumed that 85% of all trips were at 50% passenger load. The remaining 15% were assumed to be full load. Of the full load trips, 7% were combined with a strong headwind (27 knots, Section 2). All other trips were assumed to have a median headwind of 8 knots.

Powering Calculations

Vessel resistance was estimated over a range of speeds using a combination of CFD, first principles, and empirical calculations. Propulsive efficiency was estimated by selecting propeller characteristics and calculating open water performance using a regression from systematic propeller series data. Propulsion motor power and torque were computed at each speed, and the propeller was checked against cavitation criteria.

While foilborne at 30 knots, Foil Ferry requires 821 kW electrical power for propulsion at 50% load. In the full-load condition with a 27-knot headwind, required power is 950 kW. Required power for takeoff at full load and headwind was calculated to be 823 kW. Two 500 kW podded propulsors are sufficient to power the vessel at cruise speed at all expected operating conditions.

Electric Plant and Distribution

The electrical plant is divided between port and starboard demihulls with many of the systems mirrored, providing inherent redundancy. A direct current (DC) grid solution with inverters for necessary house loads is the preferred solution for efficiency and weight reduction. The electrical system configuration is shown in Figure 4-10.

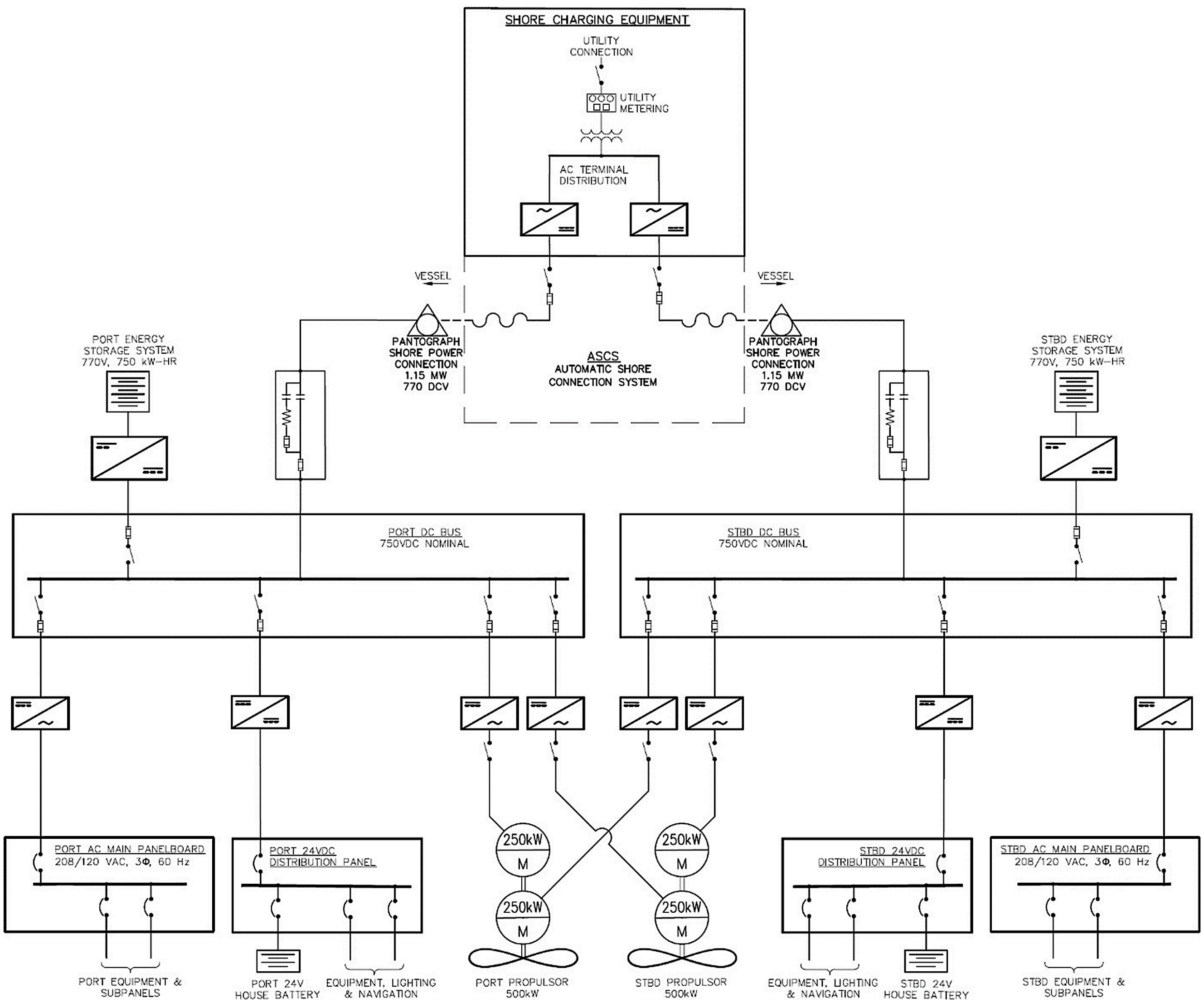

Figure 4-10 *Electrical one-line diagram*

Two independent power supplies charge the port and starboard energy storage systems through an automated shore connection system. Segregating the power system port and starboard reduces system complexity by eliminating short circuit protection requirements between the two buses. Each propulsor pod contains two motors, with one motor powered by each of the separate buses. This arrangement balances loads between the energy storage systems and increases system redundancy without adding equipment.

Energy Storage System

The energy storage system (ESS) uses lithium-ion based batteries. The ESS is divided into two battery rooms within each demihull. The battery room compartments are symmetrical, located forward and aft of the main struts.

Battery capacity is selected for 30 nautical-mile (nm) round trips, 2,000 trips each year, with a total service life of eight years. After each 30-nm trip, the ESS is assumed to recharge in 24 minutes under average loading conditions (the typical number of passengers on each transit and typical weather) and 28 minutes under maximum design loading (a full complement of passengers and significant headwind). The selected ESS energy capacity is 1.5 megawatt hours (MWh) with a maximum charge rate of 2.3 MW.

Various lithium-ion battery chemistries were explored. Within each chemistry type, there is a wide range of battery performance. High power density batteries are designed to charge and discharge quickly but are less energy dense. Conversely, high energy density batteries are designed to hold the maximum energy but cannot be charged and discharged as quickly.

High power density batteries were selected to minimize the recharge time. High energy density batteries can increase range by approximately 40% but are limited to about 50% of the charge rate of the selected batteries. The battery selection was limited to currently available marine approved products. Additional marine approved batteries with improved performance are expected to be available by the end of 2022.

Ship Mechanical Systems

Heating, Ventilation, and Air Conditioning

The passenger cabin is heated using lightweight electric resistance unit heaters distributed throughout the cabin. Ventilation is controlled by opening overhead hatches and the aft doors. Combination heat pump air conditioners can be used in lieu of the unit heaters when necessitated by the operating climate. The pilothouse has a rooftop air conditioner and heating is via a defrost unit and a single unit heater.

The battery rooms are fitted with independent mechanical ventilation to maintain the required six air changes per hour. Air conditioning units are installed in each space to control the temperature and humidity within the limits of the ESS. Condensers are air cooled and located on the vessel's exterior at the aft end of the house.

Bilge and Fire Main

Each demihull is fitted with a combination bilge/fire pump. A suction manifold allows for dewatering of each compartment and cross-connects to the opposite hull. Either pump can be used to charge the two fire hose stations located in the passenger cabin, such that hoses can easily reach all parts of the vessel.

Potable Water and Holding Tank

An ADA compliant head is located in the forward passenger cabin, furnished with a single lavatory and water closet. An on-demand water heater provides warm water to a low-flow lavatory sink. Independent potable water and holding tanks are located below decks with fill and pump-out deck connections forward.

Object Detection System

The vessel is equipped with an automated object detection system for an additional layer of situational awareness. The system specified is the Sea Machines AI-ris,[1] which uses an optical camera replicating human vision and machine learning to automatically detect and identify objects in the water, alerting the operator to their presence. This is one of several such systems recently developed due to advancements of fully autonomous marine vehicle capability.

The system consists of an optical camera (with infrared capability to be integrated at a future date); a touchscreen display that integrates and overlays optical, AIS, and radar data; and a processing unit that uses a neural network to classify detected objects and report their position and relative heading to the operator. The system will help the operator detect logs, marine mammals, and other objects that should be avoided.

[1] https://sea-machines.com/ai-ris/

Figure 4-11 *Sea Machines AI-ris optical sensor and display*

Source: https://sea- machines.com/ai-powered-vessel-vision/

Section 5

Cost Estimate

An engineering cost estimate was developed for deployment of Foil Ferry Hull #1. Annual operating expenses were also estimated. Tables 5-1 and 5-2 summarize these costs.

Table 5-1 *Estimated Foil Ferry Capital Costs (in 1000s, 2022$)*

Total Capital Costs	21,436
Vessel Design and Production Support*	2,345
Prototype Program*	750
Shoreside Permitting/Design/Construction*	3,200
Vessel Construction	14,141
000 Shipyard Engineering & Services	1,183
100 Structure	4,322
200 Propulsion	2,462
300 Electric Plant	1,043
400 Command and Surveillance	492
500 Auxiliary Systems	3,366
600 Outfit & Furnishings	908
Builder's Risk Insurance	138
Builder's Cost Financing	227
Vessel Construction Management	1,000

**Subsequent hulls for this route would not require these items*

Table 5-2 *Estimated Foil Ferry Annual Operating Costs (in 1000s, 2022$)*

Total Annual Operating Costs	1,336
Energy	262
Ferry Maintenance*	240
Shoreside Infrastructure Maintenance†	70
Crewing	764

**Includes periodic vessel battery replacement cost, assuming eight trips/day, 257 days/year*

†Includes periodic shoreside battery replacement cost, assuming eight trips/day, 257 days/year

Capital Cost Estimate

Capital cost estimates for each major item in Table 5-1 are described below. All costs are in 2022 U.S. dollars.

Vessel Design and Production Support

The design must be advanced to the level that shipyards can build it and bid on it with a high degree of certainty. Because the vessel must adhere to tighter tolerances than conventional vessels, a level of production design support is also anticipated. The estimated combined cost of functional design and production support is $2.345 million. Section 6 provides more details.

Prototype Program

The prototype, as described in Section 6, will be built and tested to mitigate design and schedule risks, reducing overall program cost and schedule of the full-scale vessel detailed design and construction phases. This program cost is estimated at $750,000.

Shoreside Infrastructure

The estimated price range for shoreside infrastructure, including permitting, design, and construction, and based on the required electrical power to the dock as described in Section 6, is $2.5–$3.2 million. This includes a 1,000-kW-hr battery energy storage system (BESS), which reduces electrical demand charges, saving about $200,000 in energy costs per year. Without the BESS, the shoreside infrastructure costs are reduced to $2.0–$2.5 million.

Electricity costs are refunded by Puget Sound Energy (PSE) in full for the first five years of operation, up to the amount of PSE-owned infrastructure upgrades required to run power from the closest landside circuit to the pier. The total cost of PSE-owned infrastructure is estimated to be in the $50,000–$75,000 range.

A more detailed shoreside infrastructure cost estimate was developed by DNV.

Vessel Construction

The cost of building the vessel is largely driven by supplier equipment and material costs. A detailed estimate was developed with input from shipyards and composite structure manufacturers. Appendix B provides a detailed cost breakdown in standard Ship Work Breakdown Structure (SWBS) form. The estimated vessel construction cost is $14.1 million.

Vessel Construction Management

Oversight of construction is a normal and important part of new vessel acquisition. The owner contracts with professionals to ensure adherence to the construction contract, to assist in negotiation of changes to the contract, and to be a technical liaison between the owner and the shipyard. The construction management estimate for this project is $1.0 million.

Operating Cost Estimate

Annual operating cost estimates for each major item in Table 5-2 are described below. All costs are in 2022 U.S. dollars.

Cost of Energy

Electricity consumed by Foil Ferry and associated costs are summarized in Table 5-3. The PSE rate table for Primary General Service [10] was used based on PSE guidance. A 1,000-kW-hr shoreside energy storage system was selected to reduce maximum grid demand from 2,473 to 820 kW, based on preliminary work by DNV.

Table 5-3 *PSE Rate Schedule, Foil Ferry Power Requirements, and Annual Cost Estimate*

PSE RATE SCHEDULE		
Basic Charge	$358.11	per month
Demand Charge, Oct–Mar	$12.55	per kW
Demand Charge, Apr–Sep	$8.57	per kW
Total Electricity Charge	0.070532	per kW-hr
Reactive Power Charge	$0.00112	per kVAR-hr
ENERGY STORAGE SYSTEM CHARACTERISTICS		
ESS Size	1,000	kW-hr
Grid Demand	820	kW

FOIL FERRY POWER REQUIREMENTS		
Charging Demand	2,300	kW
Ferry Energy per Trip	900	kW-hr
Charging Efficiency	85%	
Energy per Trip	1,059	kW-hr
Trips/Day	8	
Energy/Day	8,471	kW-hr
Operating Days / Year	257	
Energy/Year	2,176,941	kW-hr
Energy/Month	181,412	kW-hr

TOTAL ELECTRICITY COST		
Basic Charge	$358	per month
Demand Charge, Oct–Mar	$10,291	per month
Demand Charge, Apr–Sep	$7,027	per month
Electricity Charge	$12,795	per month
Reactive Power Charge	$0	assume PF=1
Monthly Total, Oct–Mar	$23,444	per month
Monthly Total, Apr–Sep	$20,181	per month
ANNUAL TOTAL	**$261,752**	**per year**

In comparison, the existing RP1 class vessels consumed 187,000 gallons of diesel per vessel-year in 2021, for a cost of $433,000 per vessel-year (two vessels in the three-vessel fleet operate at any given time). The average price of diesel for Kitsap Transit in 2021 was $2.32/gallon, but diesel prices are highly volatile.

As of March 11, 2022, diesel costs Kitsap Transit $5.08/gallon. At these current electricity and diesel prices, the annualized energy cost savings of Foil Ferry compared to a RP1 class vessel is $700,000. Figure 5-1 shows the annual energy cost savings at current electricity prices and varying diesel prices. The energy savings are in addition to the ability to carry 27% more passengers.

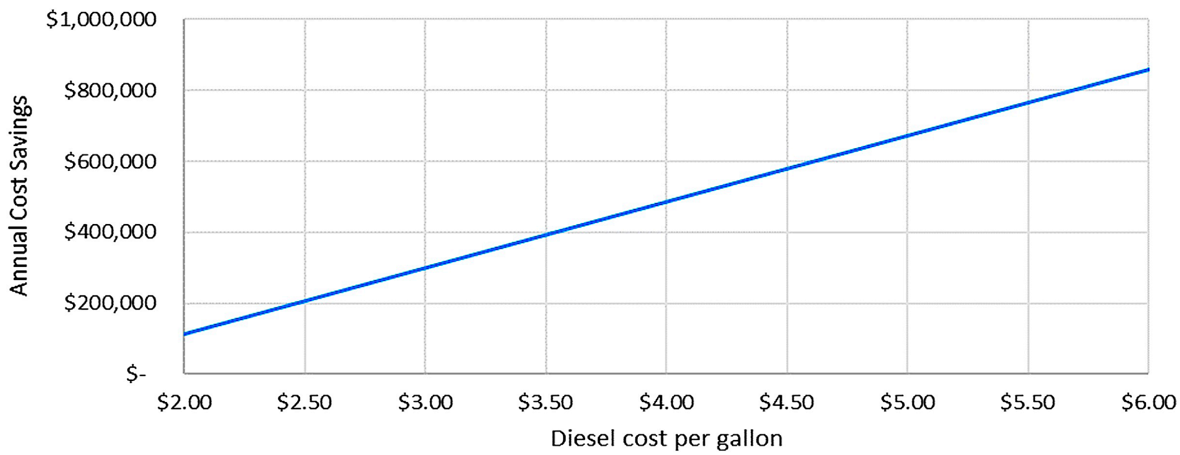

Figure 5-1 *Diesel price versus annual operating cost savings, 150-pax Foil Ferry and 118-pax RP1 class*

Furthermore, electricity prices are significantly more predictable than diesel prices. Figure 5-2 shows the cost of energy output by an all-electric fast ferry versus a geared diesel fast ferry using national average inflation-adjusted diesel and electricity prices over the past two decades.

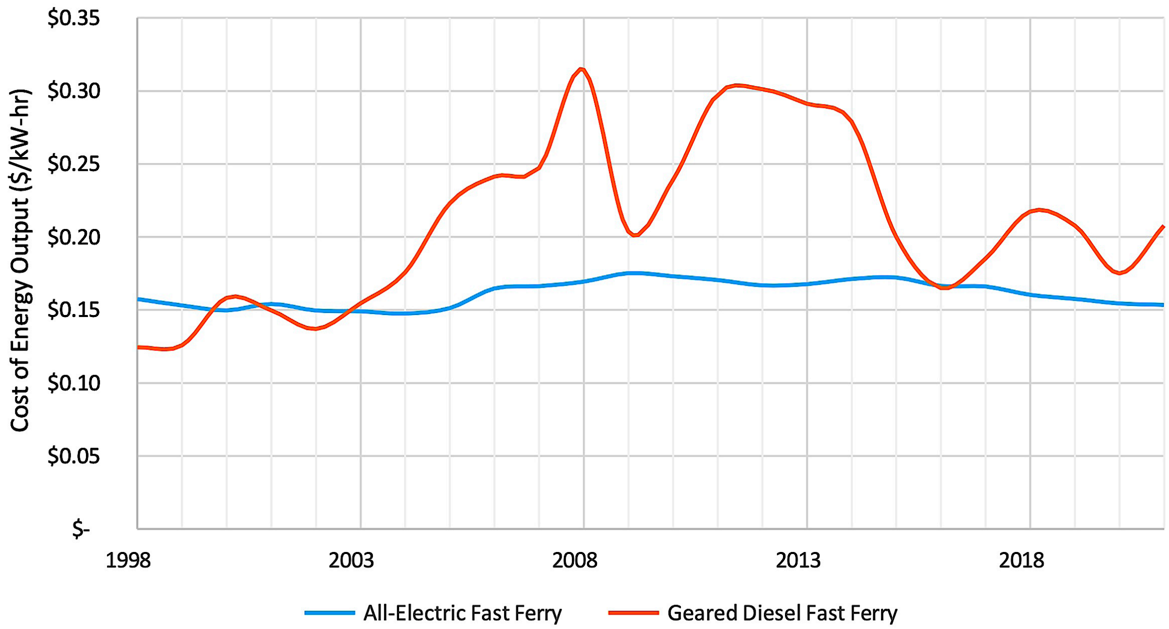

Figure 5-2 *Cost of energy output using inflation-adjusted diesel and electricity prices, 1998–2021 (in 2021 USD)*

Maintenance

Maintenance of the vessel and shoreside infrastructure will be similar to Kitsap Transit's existing fleet apart from the following:

- Electric passively cooled motors reduce maintenance compared to existing diesel-powered vessels.
- A retraction system for the aft foil struts allowing for the propulsor to be lifted out the water is employed.
- Most inspections of the ESS are on an annual basis and may be performed by a qualified in- house employee or subcontracted to the battery supplier.
- Vessel battery replacement after eight years should be planned for (assuming eight round trips/day, 257 days/year), but battery life monitoring may result in extended longevity.
- Hydraulic systems for foil controls should be comparable to other marine hydraulic systems. A titanium leading edge plate to the foil strut mitigates incidental flotsam strikes.

The maintenance cost of Foil Ferry is estimated to be $106,000 per year. Batteries have a finite life and must be replaced intermittently. Foil Ferry has been designed for an eight-year battery life, and the cost of batteries is currently $1.075 million (an average cost of $134,000 per year spread out over eight years). Incorporating this periodic battery replacement cost results in an annual operating cost of $240,000 per year.

Maintenance of the shoreside charging infrastructure, including periodic replacement of the BESS, is estimated at $70,000 per year.

Crewing

Crewing requirements are identical to Kitsap Transit's existing RP1 class ferries, with three crew on the vessel and additional support staff as needed. The average crewing cost per ferry is approximately $760,000 per year.

Section 6

Recommended Further Work

Prototype Vessel Construction

Testing a scaled prototype of Foil Ferry will mitigate design and schedule risks of the next design phase, as well as construction of the first production vessel. The primary objectives of the prototype project are as follows:

1. Validate control system operation.
2. Validate collision absorption system operation.
3. Provide platform for flight control system refinement and design development.
4. Validate design assumptions of structural loading, powering, and controls for full-scale production units.
5. Reduce commissioning time of first production vessel.

A prototype scale tradeoff study was performed to evaluate the costs and benefits of scales ranging from 1:12 to 1:3 (vessel lengths of 2.5 m to 9 m). The scales were evaluated based on total program cost, program duration, and ability to reduce program risk. A 1:5 scale prototype is recommended as the most cost-effective size to meet the primary prototype objectives.

Functional Design

This preliminary design has validated the Foil Ferry concept, reduced technical risks, and developed a cost estimate. A functional design phase will pick up where the preliminary design effort left off. A plans, specifications, and estimate (PS&E) package will be developed to the functional design level of detail. This will allow shipyards to bid on construction of the vessel with a high level of certainty (minimizing risk to the shipyard), reduce the amount of engineering required during construction, and promote adherence to the weight-sensitive design intent. In this phase, detailed analysis including Finite Element Analysis (FEA), computational fluid dynamics (CFD), and traditional calculations will be accomplished. Regulatory review will be required for many of the drawings and analyses. The following plans, specifications, and estimates will be developed:

Reports

- Basis of Design Report
- Functional Design Report
- Technical Specifications
- Design Weight Estimate
- Speed and Power Analysis
- Electrical Power Load Analysis

- Seakeeping Performance Report
- Regulatory Body Communications and Correspondence
- Intact and Damage Stability Report

Drawings

- General Arrangement Drawing
- Hull Lines Drawing
- Hull and Superstructures Drawings
- Tonnage Drawing
- Foundations Drawings
- Appendage and Control Surfaces
- Main and Rear Hydrofoil Assembly Drawings
- Insulation Drawing
- Propulsion System Drawing
- Docking Plan
- Anchoring and Mooring Drawing
- Electrical System One-Line Diagram
- Shore Power Diagram
- Pilothouse Console Arrangement
- Steering and Flight Control System Diagram
- Lighting Plan – Interior and Exterior
- Auxiliary Systems Drawings
  - HVAC Systems
  - Collision Absorption System
  - Fire Main System
  - Bilge System
  - Potable Water System
  - Hydraulic Systems
  - Sewage System
  - Battery Cooling System
  - Battery Exhaust System
- Window, Door, and Hatch Schedule
- Standard Penetration Details

Appendix A General Arrangement

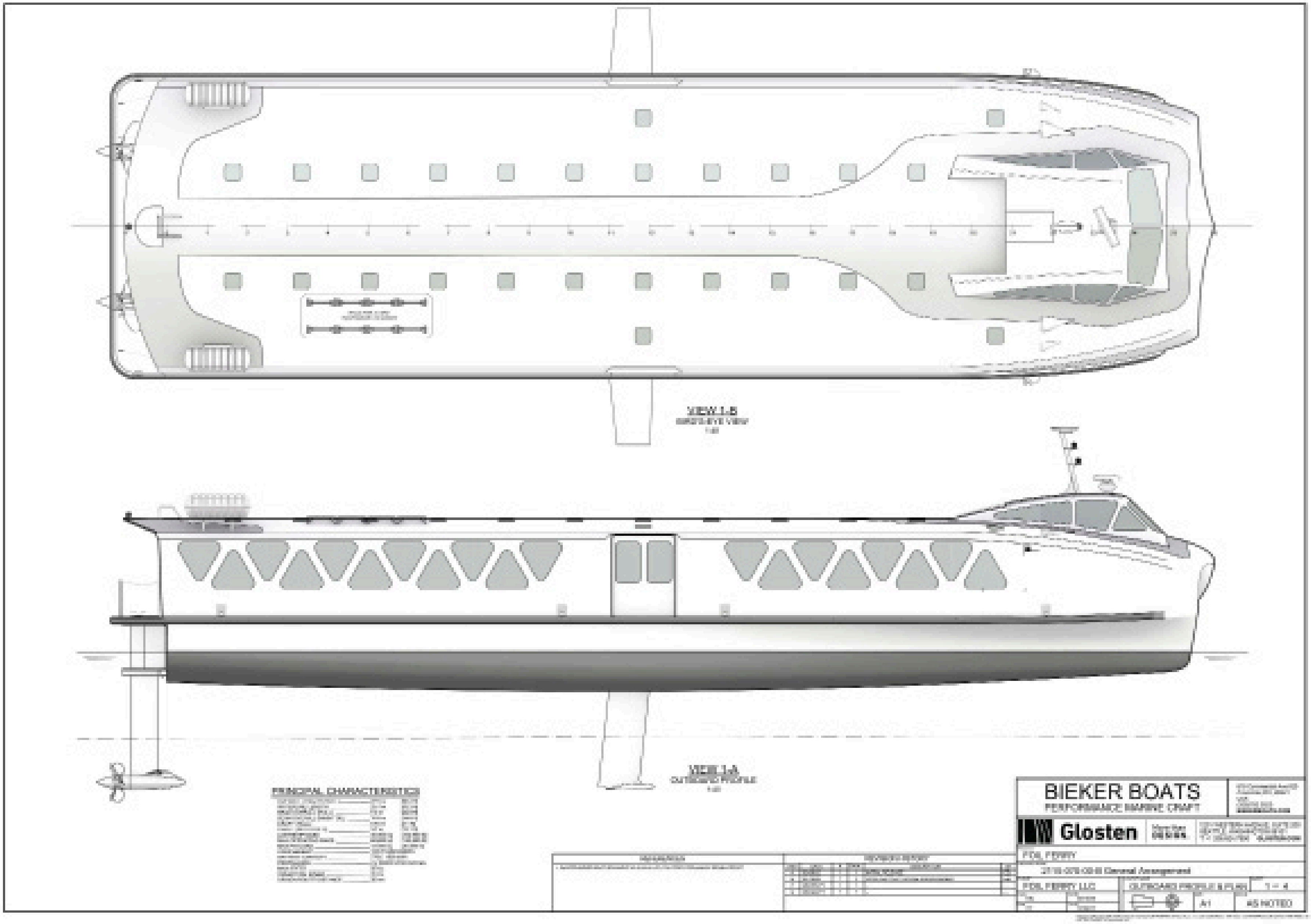

Figure A-1 *General Arrangement View 1-A and 1-B, outboard profile and birds-eye view*

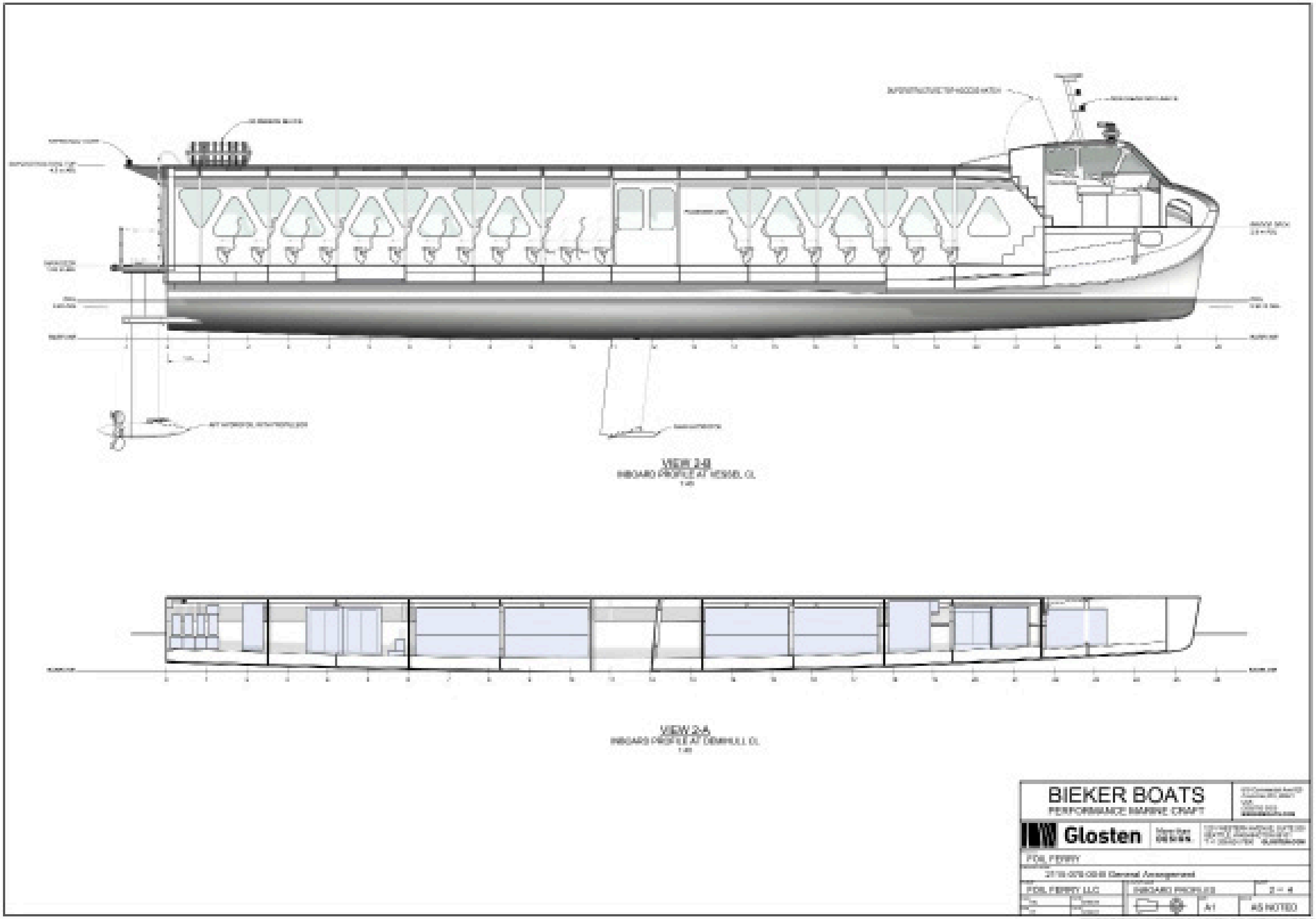

Figure A-2 *General Arrangement View 2-A and 2-B, inboard profiles*

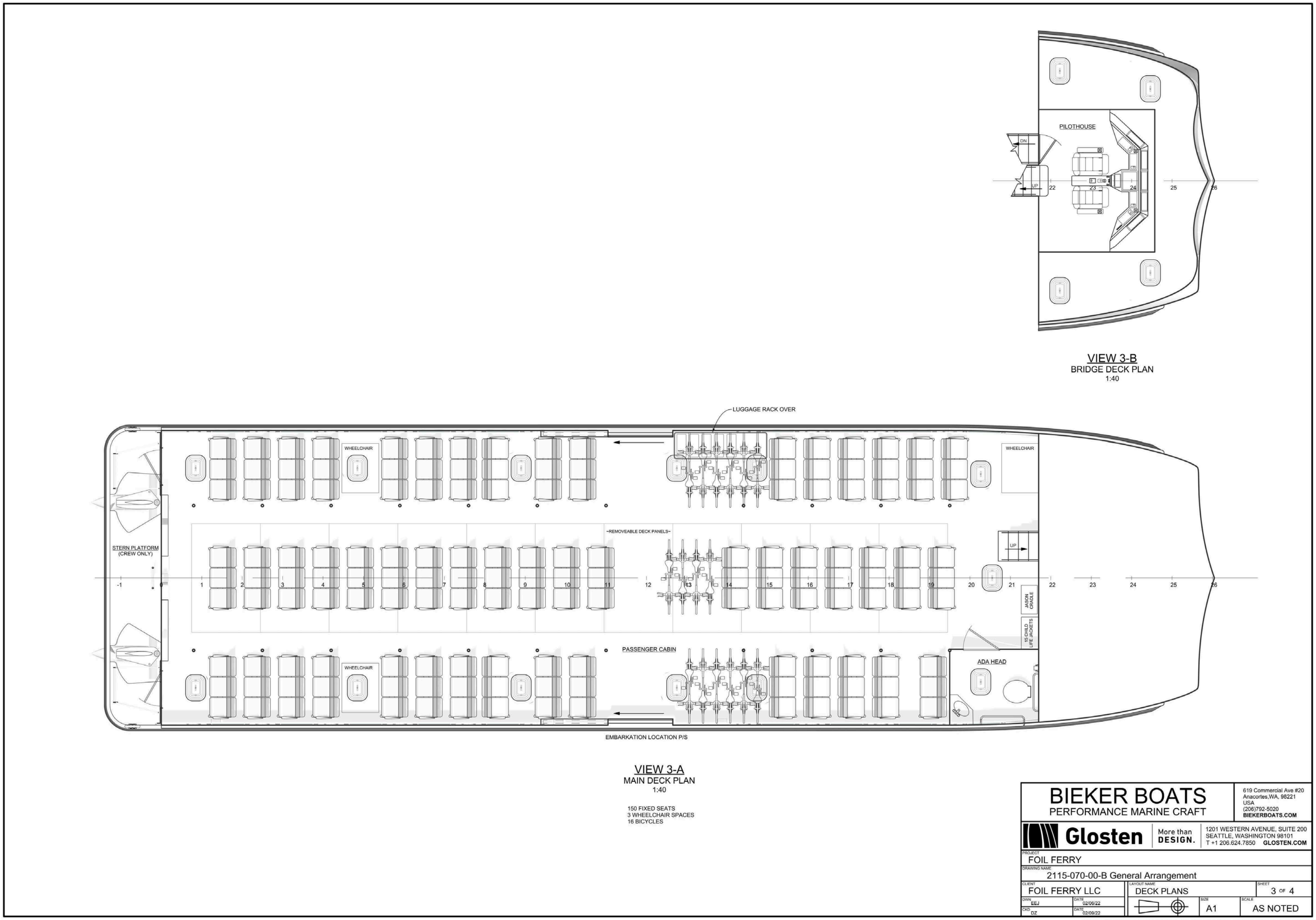

Figure A-3 *General Arrangement View 3-B and 3-A, bridge and main deck plans*

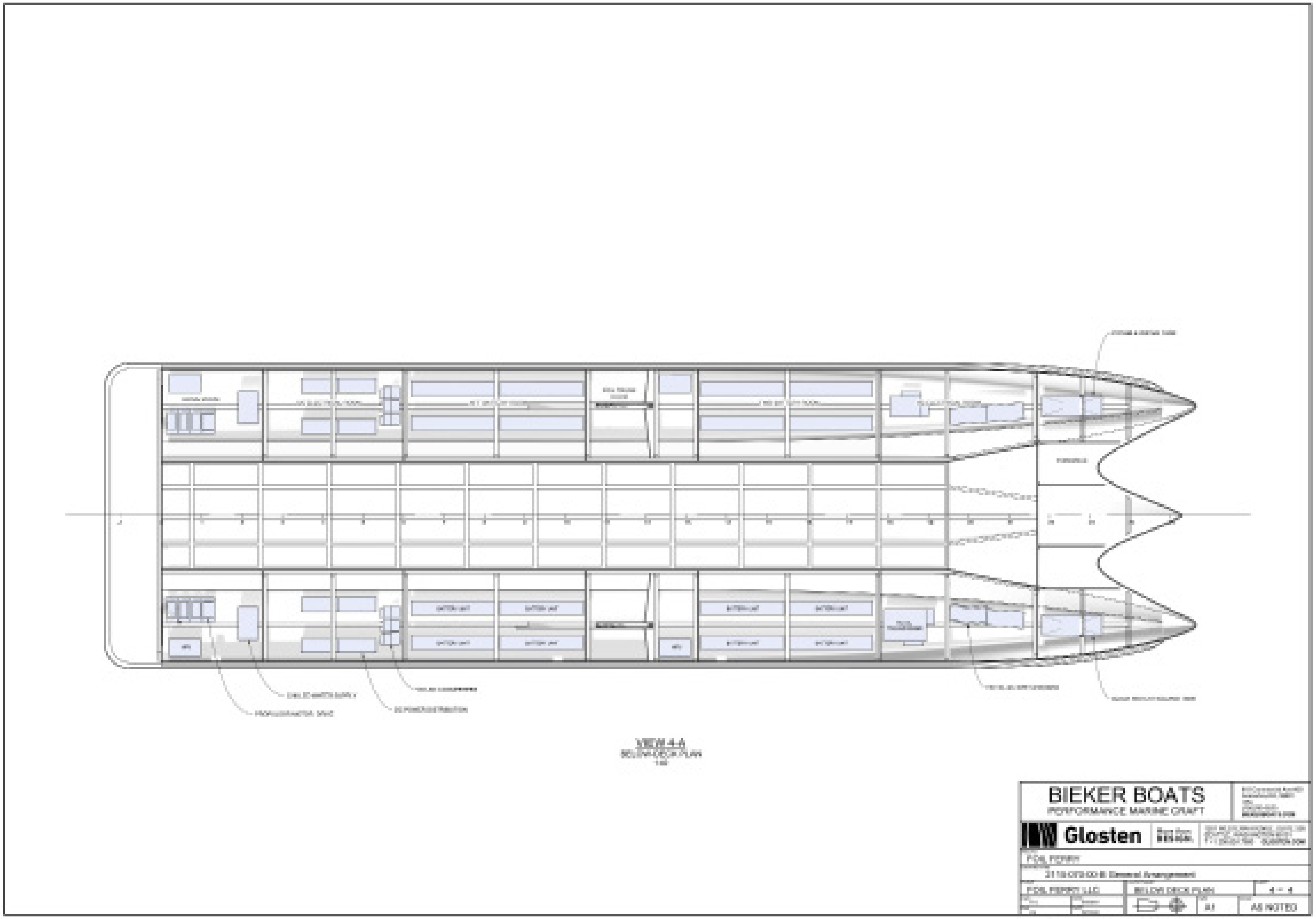

Figure A-4 *General Arrangement View 4-A , below-deck plan*

Appendix B Vessel Construction Cost Breakdown

FOIL FERRY – ENGINEER'S COST ESTIMATE				
SWBS NUMBER	**SWBS GROUP DESCRIPTION**	**LABOR (HOURS)**	**MATERIALS ($)**	**SUBTOTAL ($)**
000	Shipyard Engineering & Services	8,540	307,990	1,033,890
100	Structure	320	3,433,425	3,460,625
200	Propulsion	1,440	1,862,000	1,984,400
300	Electric Plant	2,880	619,300	864,100
400	Command and Surveillance	980	320,000	403,300
500	Auxiliary Systems	6,603	2,199,127	2,760,382
600	Outfit & Furnishings	5,388	323,008	780,988
	SUBTOTAL	**26,151**	**9,064,850**	**11,287,685**
	Hourly Labor Rate	$85		
	Material Markup (for shipping, receiving, taxes, storage)	15%		1,359,727
	Estimating Allowance (for unknowns)	10%		1,128,768
	CONSTRUCTION COST SUBTOTAL			13,776,181
	Builders Risk Insurance	1.0%		137,762
	COST SUBTOTAL			13,913,943
	Project Financing	3.0% APR	12 months	227,137
	TOTAL CONSTRUCTION COST ESTIMATE			$14,141,079

Appendix C Foil Ferry Wake Study Report

Glosten

BIEKER BOATS

Kitsap Transit
Connecting Communities

Federal Transit Administration

FOIL FERRY WAKE STUDY

3 MARCH 2023

GLOSTEN AND BIEKER BOATS LLC, DBA FOIL FERRY LLC

COVER IMAGE CREDIT: GLOSTEN

PREPARED FOR KITSAP TRANSIT & THE ACCELERATING INNOVATIVE MOBILITY CHALLENGE FTA GRANT PROGRAM WA-2021-016-00

REPORT 21021-000-02 REV(-)

DOUGLAS C. ZANGRE
STATE OF WASHINGTON
56426
REGISTERED PROFESSIONAL ENGINEER
Digitally Signed 03-Mar-2023

PREPARED	CHECKED	APPROVED
Digitally Signed 03-Mar-2023	Digitally Signed 03-Mar-2023	Digitally Signed 03-Mar-2023
Douglas C. Zangre, PE	Matthew A. Lankowski, PE	Justin M. Morgan, PE
NAVAL ARCHITECT	PROGRAM MANAGER	PRINCIPAL-IN-CHARGE

More than
DESIGN.

Table of Contents

List of Figures

Executive Summary

Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC, have completed the preliminary design of Foil Ferry, a 150-passenger all-electric fast ferry. The preliminary design effort was funded through the Federal Transit Administration's Accelerated Innovative Mobility initiative. The design is targeted to a Bremerton–Seattle route in Washington currently served by diesel- powered fast ferries. This report focuses on a subset of the preliminary design effort aimed at quantifying Foil Ferry's wake characteristics.

Objectives
The objective of this report is to quantify Foil Ferry's wake characteristics to determine whether Foil Ferry satisfies the Rich Passage, Washington, wake wash height criterion, as Foil Ferry's planned Bremerton–Seattle route passes through this waterway.

Findings and Conclusions
It was found that Foil Ferry satisfies the Rich Passage wake wash height criterion with considerable margin.

Benefits
Foil Ferry produces negligible waves as the hulls fly above the water's surface. This wake reduction compared to traditional vessels is important for protecting sensitive shorelines such as those along Rich Passage, which makes up a significant portion of the Bremerton–Seattle route.

Project Information
This research project was conducted by Glosten, Inc. and Bieker Boats, LLC, doing business as Foil Ferry, LLC. For more information, contact FTA Project Manager Justin John at 202-366-2823, justin.john@dot.gov. All research reports can be found at https://www.transit.dot.gov/about/research-innovation.

Abstract

Surface waves generated by ships and boats (wakes) can negatively impact environmentally sensitive shorelines. This phenomenon resulted in limited fast ferry traffic between the population centers of Seattle and Bremerton, until a comprehensive study was undertaken to develop a wake wash criterion that, if met, adequately limited erosion to the shorelines. Glosten, Inc. and Bieker Boats, LLC, have designed Foil Ferry, a high-speed, all-electric ferry that is fully supported by hydrofoils and produces much smaller wake than a similar sized conventional fast ferry. To quantify this wake reduction, Glosten performed a computational fluid dynamics (CFD) analysis to evaluate the wake generated by Foil Ferry. Calculations show that the vessel satisfies the Rich Passage wake criterion with considerable margin.

Introduction

Rich Passage is a narrow waterway in Washington between Bainbridge Island and the Kitsap Peninsula that makes up part of the route between Seattle and Bremerton (Figure 1).Washington State Ferries (WSF) introduced fast ferry service on the Bremerton–Seattle route in 1986. Vessels on the route were required to slow down through Rich Passage in the 1990s following reports of shoreline erosion and other damages caused by the ferries' wakes. The impact of vessel wakes on Rich Passage beaches have been studied since then [1], [2]. Kitsap Transit began service on the Bremerton–Seattle route in 2017 using a foil-assisted diesel-powered catamaran named *Rich Passage 1* (RP1) after the wake of that vessel was deemed acceptable [3]. Kitsap Transit's service was expanded to multiple vessels of the RP1 design in 2019.

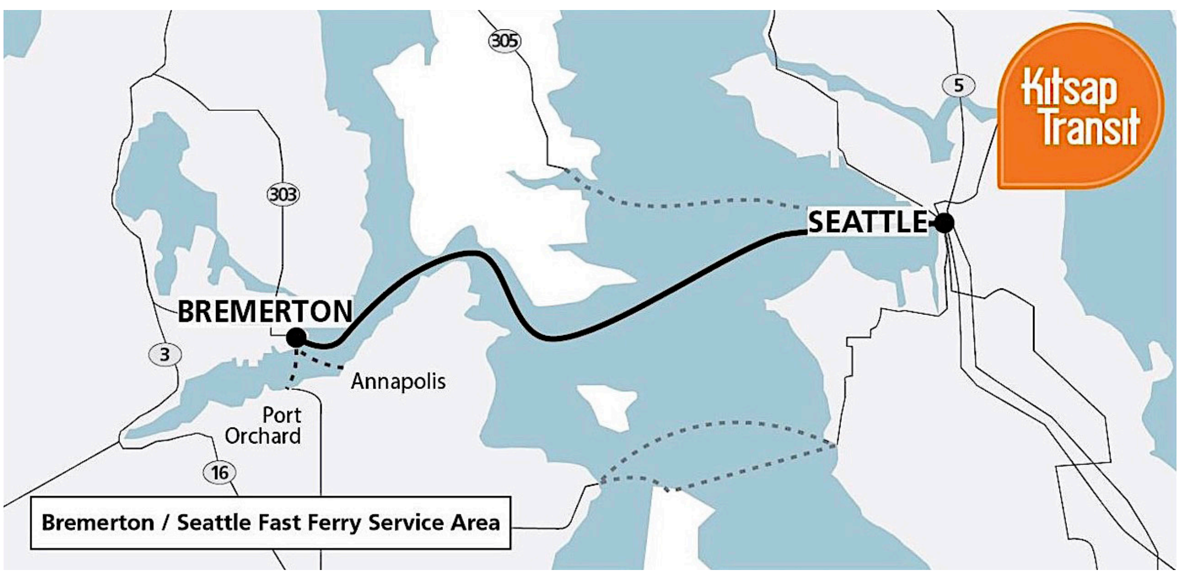

Figure 1 Bremerton–Seattle ferry route (image credit: Kitsap Transit)

Foil Ferry, designed by Glosten, Inc. and Bieker Boats, LLC, is designed to provide zero-emission, fast, safe, and affordable passenger transportation. The vessel leverages the proven technologies of ultra-efficient hydrofoils, lightweight carbon fiber construction, and energy-dense marine batteries to serve and connect communities. The preliminary design of a Foil Ferry specifically adapted to the Bremerton–Seattle route was completed in 2022. Figure 2 shows a rendering of the vessel design.

Figure 2 Foil Ferry

Wake Criterion

A passenger-only fast ferry wake criterion was developed specifically for Rich Passage based on cumulative research [2]. The wake criterion is specified as follows:

$$T_j \le 3.5: H_j \le 0.20$$
$$T_j > 3.5: H_j \le 1.16T^{-1.4}$$

Figure 3 Wake Criterion formula

where T_j is the j^{th} wave period in a wake train in seconds and H_j is the average wake height for waves at the corresponding j^{th} period of the wake in meters, measured at 300 meters from the sailing line. The previously used wake wash criterion was only concerned with the largest amplitude waves and was found to be inadequate for protecting the shorelines of Rich Passage. This newer criterion evaluates the full wake train spectrum, capturing that shoreline damage may occur from not just the largest waves in the wake train, but also smaller waves with longer periods.

The fast ferry RP1 was constructed by All American Marine in 2010. It was designed by New Zealand–based Teknicraft Design Ltd. under the guidance of the research program investigating the feasibility of restoring fast ferry service between Seattle and Bremerton [1].

To design the RP1 to meet the wake criterion, CFD techniques were validated by modeling two existing high-speed vessels and comparing CFD results with field measurements of those vessels' wakes [4]. The technique for calculating the far-field wave field was to calculate the near-field wave field using Reynolds-Averaged Navier Stokes (RANS) CFD and extrapolate the results to the far-field using Havelock sources. The results showed good near-field correlation with field measurements and reasonable far-field correlation.

The RP1 was designed with these CFD techniques and, after careful calibration of its hydrofoil angle of attack and interceptors through iterative in-situ field measurements and adjustments, it was shown to satisfy the wake criterion [1].

Methodology

The steady state flow field around Foil Ferry's hydrofoils was calculated using the RANS CFD software FINE/Marine by Numeca. The model includes only the geometry of the hydrofoils and struts; the hull and superstructure are omitted for simplicity since they do not contribute to vessel wake.

Modern computing power allowed for a computational domain large enough to capture the far- field wake field. Explicit modeling of the entire wake field eliminated the need to extrapolate the near-field wave field to the far-field using other techniques such as that used by Kandasamy et al. in 2009 [4].

The size of the computational domain was set to 2,000 m long by 700 m wide—far exceeding what was required for resistance and propulsion calculations. The domain vertical extents were set to 33 m below the waterline and 12 m above the waterline. Unlimited water depth was assumed. The mesh was refined in way of the free surface according to best practices for free surface capturing. Adaptive grid refinement was used with free surface capturing criteria to further refine the free surface during the simulation and accurately capture the wave train. Computations were carried out at full scale, maximum operating weight, and 30 knots boat speed. Results of the CFD simulations were used to quantify the height of the vessel wake and compare it to the Rich Passage criterion.

A separate simulation was run to determine the effect of shallow water on the wake wash 300 m from the sailing line. The boundary condition on the domain bottom surface was changed from external to slip wall, and the bottom surface was moved vertically upward to represent a constant water depth of 18.3 m (60.0 ft). At this water depth and at 30 knots boat speed, the wake produced by the vessel was characterized as supercritical because the depth Froude number was equal to 1.15. The domain width was increased from 700 m to 3,370 m to capture the increased breadth of the supercritical wake.

Discussion and Conclusions

Figure 4 displays the wave elevation calculated by CFD near the vessel. The wave amplitude of the deepest trough at the stern of the vessel is about 0.5 m and the amplitude of the largest peak is about 0.25 m. Figure 4 shows the calculated wave elevation over the entire CFD domain in deep water. The characteristic Kelvin wake pattern is visible, though the waves are of lesser magnitude and different character than conventional marine vessels. The wake waves are seen to decay as they propagate away from the vessel.

Figure 6 shows the calculated wave elevation over the entire CFD domain in water 18.3 m deep. The supercritical nature of the wake pattern is demonstrated by the disappearance of transverse waves and the wider angle between the diverging waves and the vessel path.

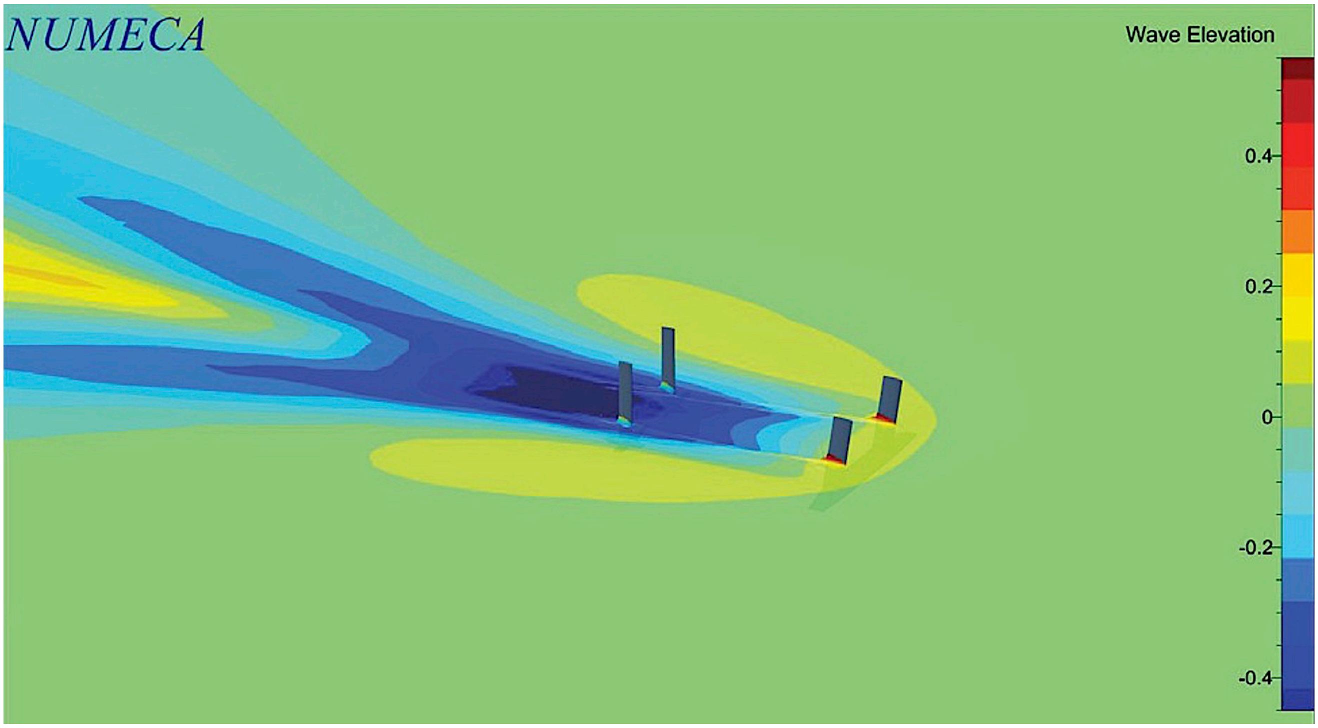

Figure 4 CFD-calculated wave elevation near the hydrofoils, in meters

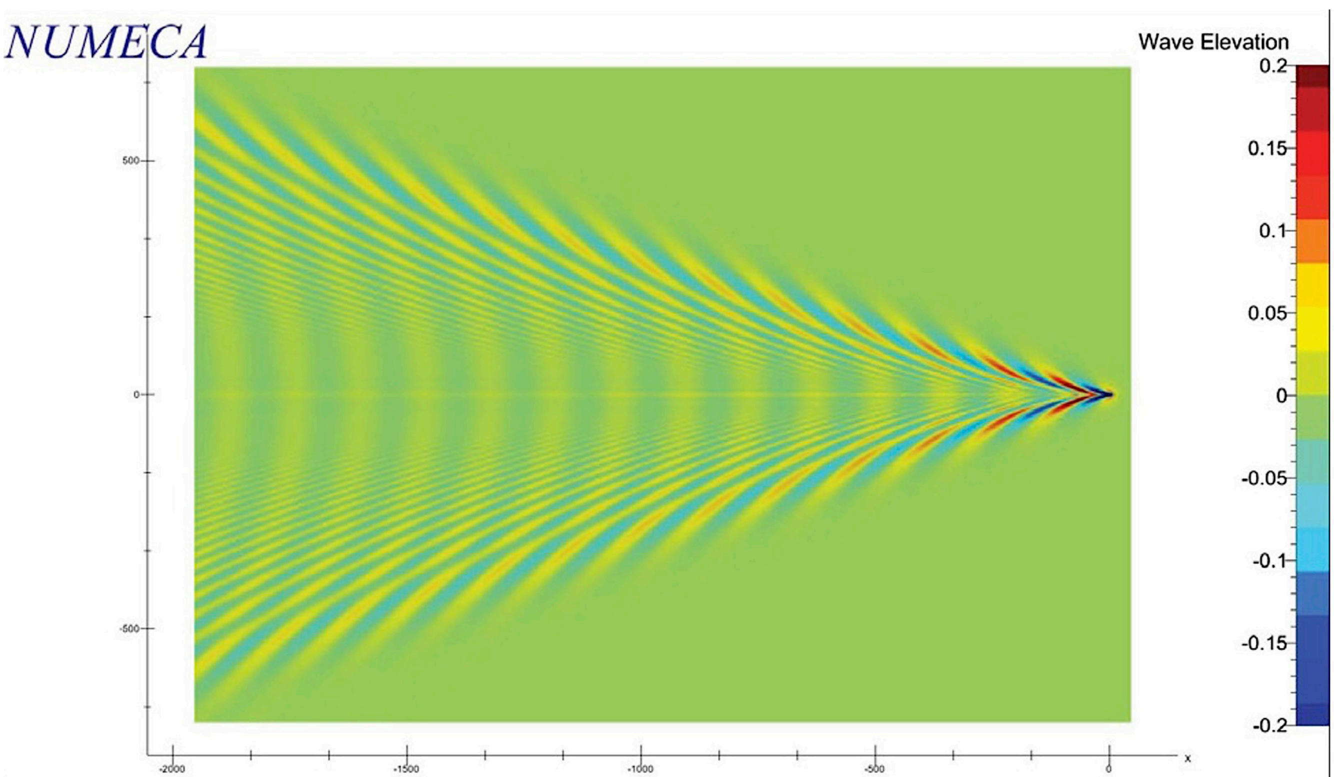

Figure 5 CFD-calculated wave elevation, entire domain, deep water, in meters

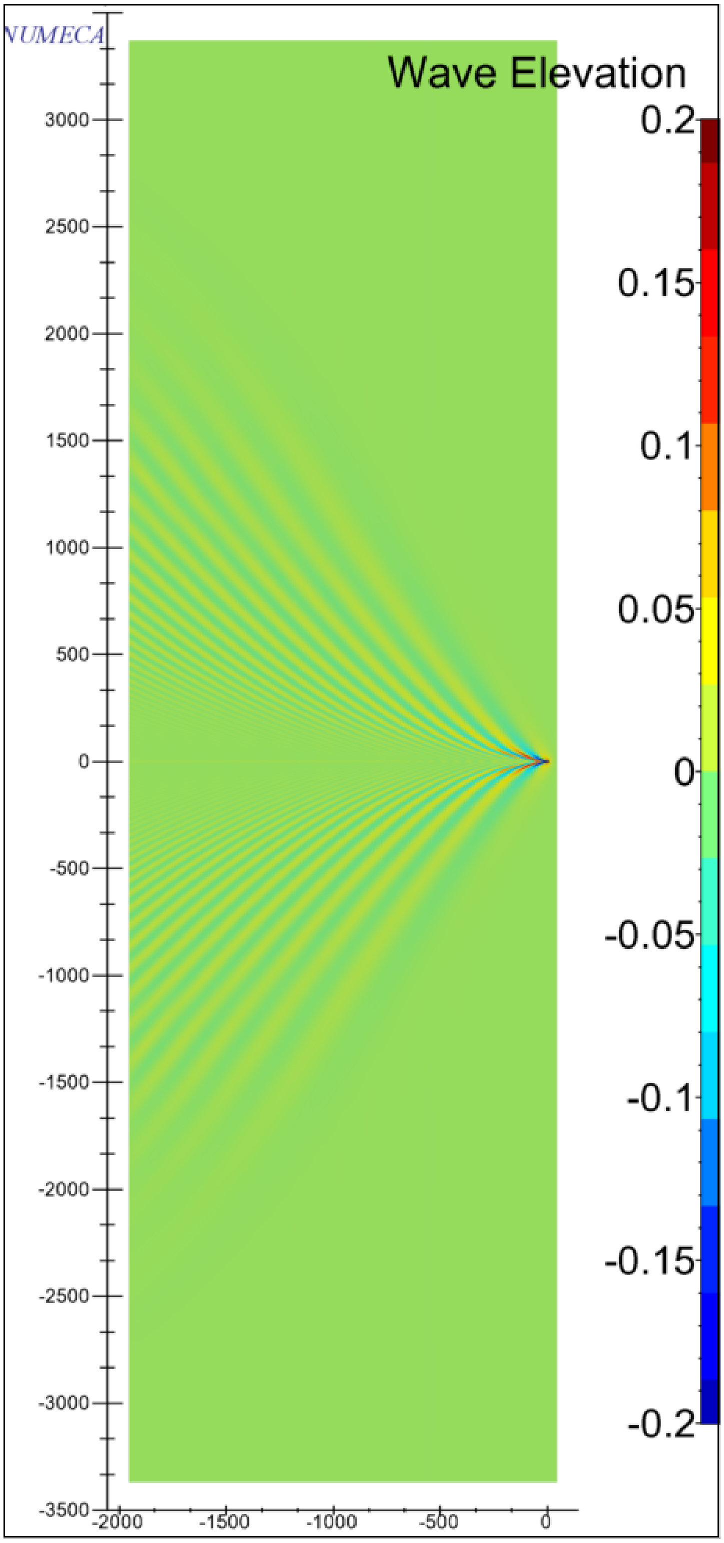

Figure 6 CFD-calculated wave elevation, entire domain, 18.3 m water depth

The wave elevation at 300 m from the sailing line was extracted from the CFD results. This wave profile, in spatial coordinates, represents the steady state wave train that moves with the speed of the vessel.

The wave profile was converted to a time series using an implicit time-stepping method. The wave time series shown in Figure 7 represents what a stationary wave buoy would experience from the passing wave train. The spectral density, which shows the power of the wave train at each frequency, is shown in Figure 8.

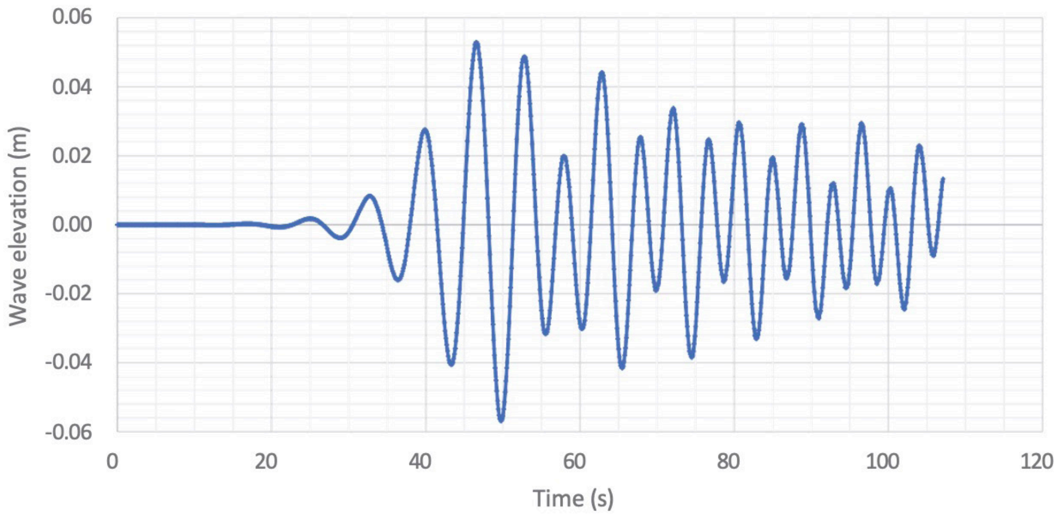

Figure 7 Time series wave elevation 300 m from the sailing line, deep water

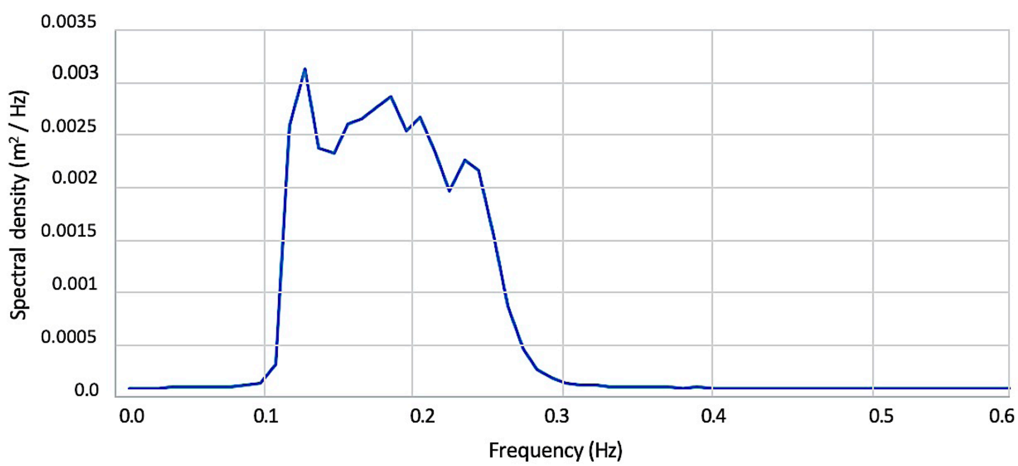

Figure 8 Spectral density for time series wave elevation, deep water

The average wave height and wave period wake spectrum for Foil Ferry at full passenger load and 30 knots measured 300 m from the sailing line is shown in Figure 8. Foil Ferry meets the Rich Passage wake energy criterion with considerable margin.

Figure 9 includes the plots of average wave height and period for RP1 taken from a study by Côté et al. [3]. The RP1 data came from field measurements rather than CFD. Field trial results are subject to variability due to imperfections in vessel heading and ambient environmental conditions.

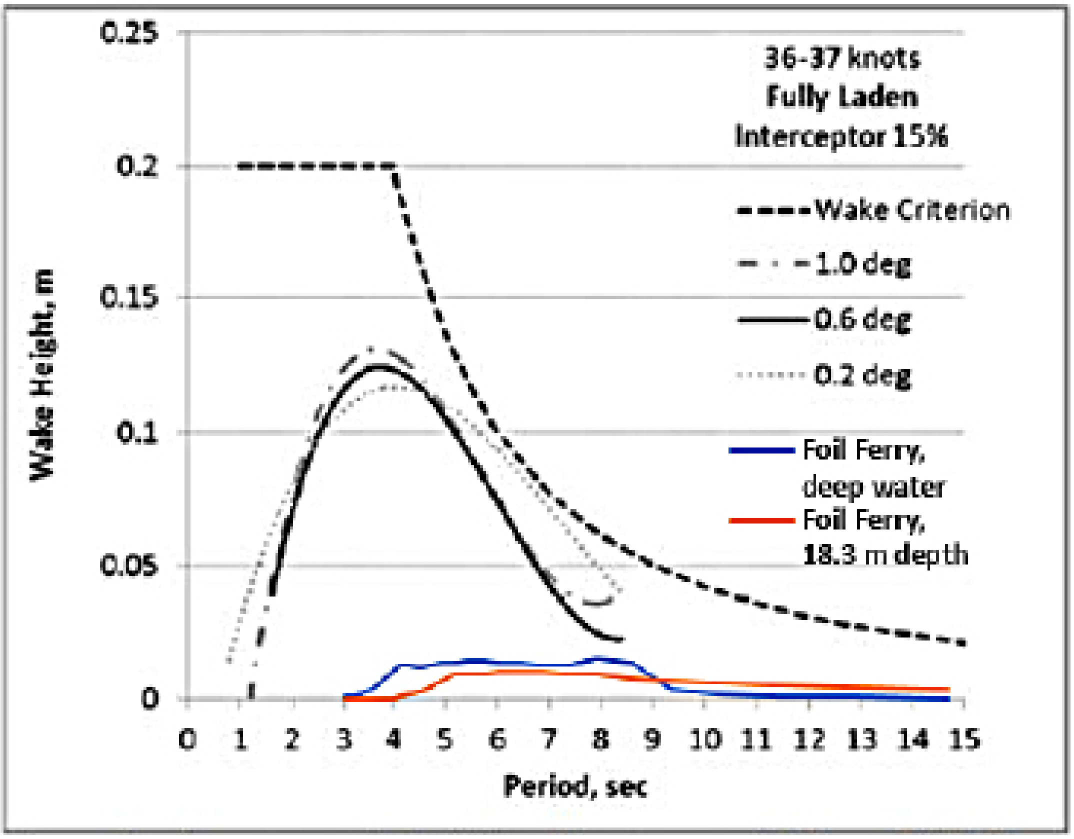

Figure 9 Wake results, Foil Ferry (blue & orange) compared with RP1 (black & gray); adapted from Côté et al. [3]

References

1. Golder Associates. *Wave Energy Evaluation of Passenger Only Ferries in Rich Passage.* 13 January 2013.

2. Osborne, P., Côté, J., MacDonald, N., and de Waal, N. *Full-scale Measurements and Impact Studies with High Speed Foil-assisted Catamarans in a Wake Sensitive Area*. FAST 2009.

3. Côté, J., Curtiss, G., and Osborne, P. *Rich Passage 1 Wake Validation and Shore Response Study*. ASCE Ports 2013.

4. Kandasamy, M., Ooi, S. K., Carrica, P., Stern, F., Campana, E. F., Peri, D., Osborne, P., Côté, J., Macdonald, N., and de Waal, N. *CFD Validation Studies for a High-Speed Foil-Assisted Semi-Planning Catamaran*. FAST 2009.

References

1. DNV. *Study on Infrastructure, Regulatory and Permitting, and Economic and Environmental Impact*, Rev. 0. 29 July 2022.
2. DNV. *Route Economic Viability Study*, Rev. 0. 21 July 2022.
3. Kitsap Transit. Fast Ferries Performance Indicators. Accessed 14 September 2021. https://www.kitsaptransit.com/fast-ferries-performance-indicators
4. U.S. Code of Federal Regulations. 46 CFR Subchapter T, Small Passenger Vessels. Accessed 22 March 2022.
5. U.S. Coast Guard. CG-ENG-Policy Letter No. 02-19, Design Guidance for Lithium-Ion Battery Installations Onboard Commercial Vessels. 2 October 2019.
6. ASTM International. ASTM F3353-19, Standard Guide for Shipboard Use of Lithium-Ion Batteries. Last Updated: 4 December 2019.
7. DNV. Rules for Classification of High Speed and Light Craft (DNV-RU-HSLC). October 2020.
8. U.S. Access Board. Proposed Passenger Vessels Accessibility Guidelines. 2013.
9. Glosten, Inc. and Bieker Boats, LLC. Foil Ferry General Arrangement, Drawing No. 2115-070-00.
10. Puget Sound Energy. Electric Summary Sheet No. S-10, Effective Date: 1 January 2022.

U.S. Department of Transportation
Federal Transit Administration

U.S. Department of Transportation
Federal Transit Administration
East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
https://www.transit.dot.gov/about/research-innovation