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# 50 YEARS OF DOUBLE-ENDED FERRY DESIGN

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## SUMMARY

The author's company, Elliott Bay Design Group (EBDG) and its predecessors have been designing double-ended ferries, ranging in length from 100' to 460', since 1953. Over that time the company has tried many different space arrangements, hull forms, propulsion types and structural designs. This paper provides a brief review of that design history and illustrates how that knowledge is applied to new ferry projects. The unique challenges of a double-ended ferry are presented, such as hull shape to optimize propulsion efficiency and vehicle deck layout to handle a variety of vehicle types while providing safe passenger flow and sufficient allowance for mechanical systems, lifesaving equipment and crew access. Choices for propulsion arrangements are presented against route considerations. A discussion on cost estimation at early stages of the design using historical data is included. Finally, some thoughts on the future of double-ended ferry design, including novel hull forms and basic vessel arrangements, will be presented.

## INTRODUCTION

"Legally, a ferry is the continuation or prolongation of a highway over a navigable stream." [1] This quote is from the first Transactions of the Society of Naval Architects and Marine Engineers (SNAME), published in 1893. Given the impact of ferries upon society, it should come as no surprise that they have been a topic of interest to many naval architects for many years. The Pacific Northwest region of the United States contains a mix of islands, rivers, peninsulas and lakes. Salt water and fresh water transportation routes have been a critical part of the economic development of the region beginning with the native peoples and continuing today. Since the arrival of the first settlers in the 1850's, power-driven ferries have been a common sight, linking the various communities through the movement of goods and people. With the advent of the automobile, a new type of vessel evolved. No longer was a sharp ended, narrow vessel that would lie broadside to a pier appropriate. The routes and vehicles pushed vessel design towards a configuration with a broad deck area for handling autos and symmetrical ends for ease in loading and unloading. Thus, the first double-ended car ferries began to appear in the 1930's. Many of these early vessels were brought up to Puget Sound from the San Francisco Bay Area, as newer larger vessels were introduced to meet the Bay Area's growing population.

In 1931 a new naval architecture firm was created when W. C. Nickum and his two sons, Bill and George, created W. C. Nickum and Sons. Their first significant contract for car ferry work was the rebuilding and repowering of several San Francisco Bay ferries that were relocated to Puget Sound after World War II. Their first complete design was the EVERGREEN STATE class for Washington State Ferries (WSF) in 1953.

At approximately the same time, another new naval architecture firm was established by Philip F. Spaulding, one of whose first contracts was to design the double-ended ferry CROWN CITY for Coronado Island in San Diego, California. The two firms competed fiercely for ferry design contracts, one often performing the detail engineering for a shipyard building to the other firm's plans. In 1972 the two firms decided that working together made more sense, so they merged to create Nickum and Spaulding Associates. The firm continued with a variety of ferry projects until a major slump hit the commercial marine industry in the 1980's. With no vessels to design or build, the Puget Sound area experienced a loss of shipyards and design talent. The assets of Nickum and Spaulding were purchased from the principals, George Nickum and Phil Spaulding, in 1987. Established as Elliott Bay Design Group, the firm has continued to build upon a history of ferry design.

The purpose of this paper is to share some observations and data gained from 50 years of designing double-ended ferries. Some of the issues apply in general to other types of Ro-Ro or Ro-Pax vessels, but the major focus will be on the unique challenges of a vessel that is essentially symmetric about centerline and about midships. The discussion is organized to parallel a typical design evolution.

## OWNER'S REQUIREMENTS

The design of a double-ended ferry, as with most vessels, begins with a consideration of the owner's requirements. As history has shown us, there is a wide range of choices that can result in delivering goods and passengers across bodies of water. What is a double-ended ferry and why choose this configuration? For the purpose of this paper, a double-ended ferry is one where vehicles are loaded on and off both ends of the vessel *and* the direction of travel switches so the bow becomes the stern. Most operators choose this configuration because that is what they currently have in their fleet and they are familiar with it. For some, such as the BC Ferry Corporation that has a mix of double-ended and single-ended vessels, it is because they believe the double-ended configuration offers advantages. These may be greater economy, improved safety or better acceptance by the client. Where there is a choice, it begins with looking at the route.

### Routes and Operating Speeds

The greatest argument for a double-ended ferry is when the route is short such as a river crossing. The time to maneuver the vessel so it can back in to the dock becomes a significant portion of the overall time between departures. The maneuvering time also consumes additional fuel and imposes the risk, however small, of any maneuver going awry. Clearly, as the route gets longer the contribution of maneuvering to the overall schedule diminishes. However, the operator will always need to shift his thinking and reactions as to how the vessel handles – a vessel backing down handles differently than a vessel going ahead. For the operator of the double-ended ferry, his vessel configuration is always the same allowing the mariner to concentrate on the external effects of wind, tide and current.

Other factors that might influence an operator to select a double-ended configuration are the surrounding vessel traffic and the number of vessels on the route. When weaving through shipping, the double-ended ferry, with its propulsion at each end, has excellent stopping power. It also has superior maneuverability, especially if using an azimuthing or cycloidal propulsion system. The ability to go directly into a slip and not having to pirouette in the shipping channel is also critical to safety. This is especially true when the ferry berth is subject to high cross currents, such as the Guemes Island route. The ferry we designed for that service has azimuthing drives at opposite 'corners' of the hull. Hence, the vessel can readily "crab" across the channel despite 2 to 3 knots of current.

**Terminal Facilities**

The majority of double-ended ferries we have designed have rounded ends. This configuration has developed to suit the typical terminal configuration in the Pacific Northwest where a set of wing walls serve to guide the ferry into the end of the berth. A ramp is then lowered to rest on the end of the vehicle deck and mooring lines are used to connect the ferry to the ramp. To keep the ferry in the slip, the engines are typically engaged, allowing the ship to push against the wing walls and keep aligned with the slip by maneuvering the outboard rudder. There are also sets of dolphins located to keep the ferry from pivoting excessively due to either current or wind forces. The ramp may be supported either by an overhead bridge structure, or by a combination of buoyant chamber and cables. If the latter, the deck overhang and hull cut-away must accommodate the dock.

The tidal range in the Seattle area is approximately 16' for a spring tide. Like any ferry, the designers of double-ended ferries need to evaluate the clearances required to fit the ends of the ferry under the ramps for a range of tides and vessel loadings. To accommodate the angle of the ramp, and to prevent long vehicles from 'high centering' on the ramp at the extreme condition of high tide and minimum operating condition (maximum freeboard), we typically slope the end of the vehicle deck. At the other extreme (low-tide and full-load condition), we consider the ramp slope and reduced clearances for tall trucks entering the vessel. In either case the change in trim of the vessel as heavy vehicles are loaded should be considered in the smaller ferries. This concern results in shaping the hulls with fuller ends as the vessel gets smaller.

Another owner's requirement that should be considered is the separation of passengers and vehicles during loading and unloading operations. In the larger vessels carrying upwards of 1000 passengers, separation is imperative to control the loading and unloading times. Of course, for safety reasons it is always desirable to keep foot passengers and cars apart, but most small vessels operate from small terminals and hence it is harder to justify the expense of a separate overhead loading bridge, especially if the ferry operates in an area of high tidal ranges. The maximum slope for a passenger walkway is 1:12 with a 5' level landing every 30' according to the disability regulations in the United States [2]. This makes an effective slope of 1:14, suggesting that a 10' tidal range would require a 140' ramp and landing system just to handle the tides.

If foot passengers are loaded over the vehicle deck, they should be directed to a stairway or elevator as soon as possible to get them up to the passenger spaces. This can have a major impact on the design of the vehicle deck and consequently the whole vessel.

**Vehicle Sizes and Mix**

Like any ferry that carries vehicles, the choice of what types of vehicles the vessel should handle is of major importance. At one time in the absence of an official standard, our company based the design on the 1965 Plymouth Fury III sedan owned by one of the principals. In the United States we have seen a trend to larger and heavier vehicles, both for passenger vehicles and freight vehicles. Ferries that were constructed in the 1950's, such as the EVERGREEN STATE with overhead clearances of 13' [3], are no longer suitable for highway standard vehicles. Many of our clients, such as Washington State Ferries, design around their own standard automotive equivalent unit (AEQ) [*Figure 1*], so they can establish the capacity of their vessels in a standard

| Standard Automobile | WSF | AMHS |
|---|---|---|
| Length | 18.5 | 17.66 |
| Width | 6.5 | 6.5 |
| Clear height | 7.5 | 10 |
| Distance between fenders | 0.5 | 2.33 |
| Nominal distance between vehicle sides | 2 | 3.5 |
| Weight | 5550 | 8000 |
| Axle Loads, Auto | 2775 | 4000 |
| Axle Loads, Truck | 32,000<br>(per AASHTO std) | 19,000 |

*Figure 1: Automotive Equivalent Units*

manner. Given the curved ends on double-ended ferries, the size of vehicle can have a critical impact on allowances for vehicle maneuvering, especially if there are multiple vehicle decks with interconnecting ramps.

**Number of Passengers**

By virtue of the double-end, passengers will enter the vessel from one end and exit from the other. In between they may need various amenities, such as seating areas, dining spaces, food service areas, restrooms, play areas or open deck areas. It is easy for the inexperienced passenger to get turned around, since the shape is symmetric, so the designer should provide visual clues to orient the visitor and direct them through the vessel. It was once the practice in Washington State on April 1$^{st}$ (April Fool's Day) to swap the ends of the vessel. Even seasoned passengers, used to finding 'their spot' on the vessel, would get fooled by the simple switch in the ends. Alas, in these days of properly-operated ferries, such whimsy is no longer permitted.

Because passengers must flow through the vessel, the arrangement of spaces to handle seasonal changes in the passenger loading can be more difficult. During periods of low ridership, it is advantageous for the operator to close off areas, thus minimizing the maintenance and improving the crew's ability to monitor the passengers. Especially in this age of security concerns, the question of where passengers can congregate merits vigorous discussion with the operator. In the Pacific Northwest, given the generally short runs and open ends on the vehicle decks, most operators permit passengers to remain in their vehicles. This has the potential of creating a passenger hazard should a fire occur on the car deck necessitating the evacuation of passengers.  The benefit of having them remain in their vehicles should they choose is the reduction of delays in unloading due to folks straggling back to their cars.

**ARRANGEMENTS**

The creation of the arrangements is at the heart of any passenger vessel design.  There are 1,000 ways to arrange the ship.  900 of those are awful, 90 of them are acceptable and only ten are really good.  The art of vessel design is the art of compromise.  The selection of a double-ended configuration merely presents some new challenges.  Some basic characteristics for various ferries designed by my firm are given below [*Figure 2*].

| Vessel Name | LOA (ft) | LBP (ft) | LWL (ft) | Beam (ft) | Beam at DWL (ft) | Depth of Hull at Side (ft) | Design Draft (ft) | Block Coefficient | Prismatic Coefficient | Midships Coefficient | Design Speed (kts) | Design Displacement (LT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DANIEL MATHENY V | 63.00 | | 59.50 | 32.67 | 32.67 | 4.00 | 2.00 | | | | | |
| WHATCOM CHIEF | 99.83 | | 88.00 | 44.13 | | 10.66 | 6.00 | | | | | 192.0 |
| COLUMBIAN PRINCESS | 120.00 | | | 42.00 | | 17.00 | 4.50 | | | | 9.0 | 233.9 |
| EAGLE | 120.00 | 108.00 | 116.00 | 46.00 | 36.67 | 12.08 | 7.00 | 0.38 | 0.55 | 0.68 | 10.0 | 302.0 |
| HERON | 120.00 | | 116.00 | 46.00 | 36.67 | 12.00 | 7.00 | 0.38 | 0.55 | 0.68 | 10.0 | |
| GUEMES | 124.00 | 100.00 | 100.00 | 46.00 | 30.79 | 9.50 | 5.00 | 0.68 | 0.74 | 0.91 | | 303.4 |
| HIYU | 162.00 | 149.00 | 149.42 | 63.08 | 42.50 | 17.00 | 10.00 | | | | 10.0 | 480.0 |
| Whatcom County New Ferry | 175.00 | 165.00 | 165.00 | 50.00 | 41.68 | 11.75 | 6.00 | 0.49 | 0.60 | 0.83 | 10.0 | 582.0 |
| CHRISTINE ANDERSON | 213.00 | 195.00 | 195.00 | 66.00 | | 16.50 | 10.00 | 0.31 | 0.55 | 0.57 | 11.4 | 881.0 |
| STEILACOOM II | 216.00 | 189.00 | 198.33 | 68.00 | 53.50 | 16.50 | 10.00 | 0.33 | 0.53 | 0.60 | 11.4 | 996.1 |
| PATRICK DENNIS | 225.00 | 202.17 | 217.00 | 62.00 | 49.33 | 16.50 | 10.00 | 0.35 | | | | 1,077.0 |
| CROWN CITY | 242.13 | 230.00 | 230.00 | 65.10 | | 17.25 | 11.50 | | | | 13.0 | 995.0 |
| ISLAND HOME | 254.66 | 224.00 | 238.66 | 84.00 | 64.00 | 17.50 | 10.50 | 0.43 | 0.53 | 0.81 | 14.0 | 1,823.0 |
| TILLICUM | 310.00 | 287.00 | 285.50 | 73.17 | 53.50 | 23.50 | 15.50 | | | | 14.0 | |
| Cross-Sound (7603) | 328.00 | 294.00 | 317.50 | 78.67 | 62.83 | 24.00 | 16.50 | 0.32 | 0.55 | 0.59 | 18.5 | 2,972.7 |
| WSF 130 Car | 342.00 | 319.50 | 336.00 | 83.17 | 69.34 | 27.02 | 17.48 | 0.32 | 0.51 | 0.63 | 17.0 | 3,995.3 |
| HYAK | 382.17 | 357.00 | 357.00 | 73.17 | 58.33 | 24.25 | 16.50 | 0.29 | 0.53 | 0.55 | 20.0 | 2,880.0 |
| SPOKANE | 440.00 | 418.00 | 436.00 | 87.00 | 63.00 | 24.75 | 17.00 | 0.33 | 0.60 | 0.54 | 20.0 | 4,336.0 |
| QUEEN OF ALBERNI | 457.00 | 417.33 | 436.00 | 88.83 | 71.58 | 26.00 | 17.50 | 0.35 | 0.54 | 0.64 | 19.0 | 5,458.6 |

*Figure 2: Hull Form Table*

**Vehicle Deck**

The arrangement of the vehicle deck dictates the principal dimensions of the vessel and the vertical access footprint. The shape about midships is symmetric while the shape of the ends is dictated by the terminal and the width of the vehicle loading ramps. The beam amidships is dictated by the number of car lanes (and the width of those car lanes), the width of the casing or casings, the need for a clear access path for passengers to get from their vehicles to the stairs or elevators, and the allowance for structure at the sides. Between midships and the ends the maximum beam may be carried for some distance before it curves in to meet the ends.

We have learned that car ferries have increased in beam over time. Part of this is due to larger vehicles, and part is due to a greater awareness of the need for emergency egress. One factor that should be appreciated is that wider vehicle lanes speed the loading of vehicles. We have observed that ferries in the summer time suffer from a combination of more vehicle traffic and persons who are on vacation and not experienced at driving on and off ferries. Their timidity can greatly impact the ferry schedule and cause discontent among passengers and crew. Wider lanes simply help the traffic flow. Similarly, we have found that if you put a pillar, stanchion or protrusion along the vehicle lanes, drivers will strike them with their vehicles, no matter how much black and yellow striping is used.

Accommodations for passengers are either on the main deck, typical of smaller ferries, or above the main deck. We have contemplated the idea of having the passenger deck located below the vehicle deck for reasons of fire safety, since flame and heat rise, but the disadvantages of such an arrangement seem to outweigh any advantages. To move the passengers up a deck requires stairs and at least one elevator in larger vessels. These items are located either in a casing between vehicle lanes or at the side of vessels. Of the ferry designs we have prepared, having a casing generally makes more sense than trying to route items out to the vessel's side.

The casing contains stairs, elevators, air intake, machinery exhaust and access to spaces below deck. The governing dimension is typically the elevator width plus required structure. Casing widths have increased over time. The most recent vessel designs have a casing width of 7' compared to 4' on the EVERGREEN STATE built in 1959, which was not equipped with elevators.

We have designed vessels with one casing on centerline, with one casing offset to one side, and with two casing lines placed about the centerline. In general, for car ferries up to approximately 40-car capacity, it makes sense to keep the passenger cabin on the main deck and locate it to one side. For vessels of 40- to 80-car capacity, having one casing with vehicle lanes on either side is preferred, with the passenger cabin located above the vehicle deck. For vessels with a capacity of 100 cars or larger, two casings provide better structural arrangements and improved passenger flow from the vehicles up to the passenger deck.

In 2003 EBDG teamed with The Glosten Associates and Jensen Maritime Associates to design a new 130-car ferry for Washington State. As one of our tasks we prepared a Deck Arrangements Study that looked at ten different configurations for the vehicle parking, passenger access routes, crew access routes and uptakes. The owner's requirements called for handling trucks down the center lanes with a clear height of 16' and two deck levels outboard to handle automobiles of up to 7.5' height. The upper vehicle levels were connected to the main deck via fixed ramps, as is the practice in Washington State. Considerable time was spent to determine the best slopes for those ramps and the ability of vehicles on the main deck to maneuver around the ramps. A maximum acceptable slope of 12 degrees was selected for the ramps. The space under the ramps was used for stowage of the rescue boats, deck lockers, crew shelter and anchor winch.

## HULL FORM

As stated previously, the double-ended hull configuration is typically chosen to eliminate the need to turn the vessel around. However, the author believes that the double-hull configuration has some other advantages. These include low resistance, low directional stability (hence quick handling) and protection from side damage.

The typical ferry we have designed has a V hull amidships with a narrow, flat of bottom at baseline. The side shell flares outboard with one or two knuckles between the heavy guard at the deck edge and the bottom. Typically, the waterline beam is 80% of the maximum beam. This shape provides excellent reserve buoyancy for damage stability and adds waterplane area as the vessel heels, thus improving intact stability. Where there is a draft limit, we increase the width of the flat of bottom. Shown below is the body plan [*Figure 3*] for the 77.62m ferry that EBDG delivered in 2007.

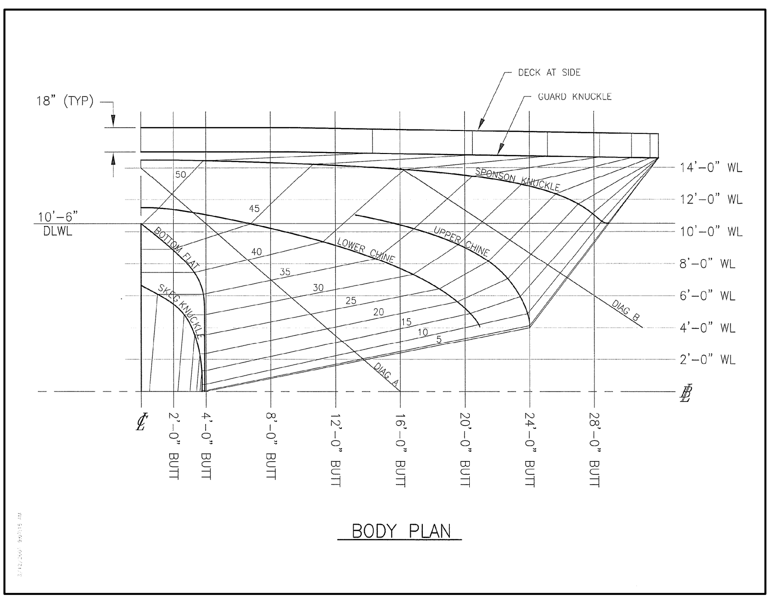


*Figure 3: Body Plan for M/V ISLAND HOME*

At the ends the waterline shape typically narrows to a fine entrance. Because the waterline beam decreases more quickly than the beam at deck, the effect is to create substantial sponsons. These are located sufficiently far above the bow wave to avoid increased wetted surface as the bow wave increases with speed. The shape of these sponsons also needs to consider wave slamming in rough weather, so a compromise is sometimes required between calm water resistance and speed in waves. The lower part of the hull at the ends is fitted with a skeg to support the shaftline (with traditional shafting on centerline) and to support the hull in dry dock. The skeg shape and volume are critical to the shape of the bow wave, hence we carefully consider the section area shape, including skegs. The graph [*Figure 4*] shows the normalized section area curves for a number of the vessel designs with which we have been involved.

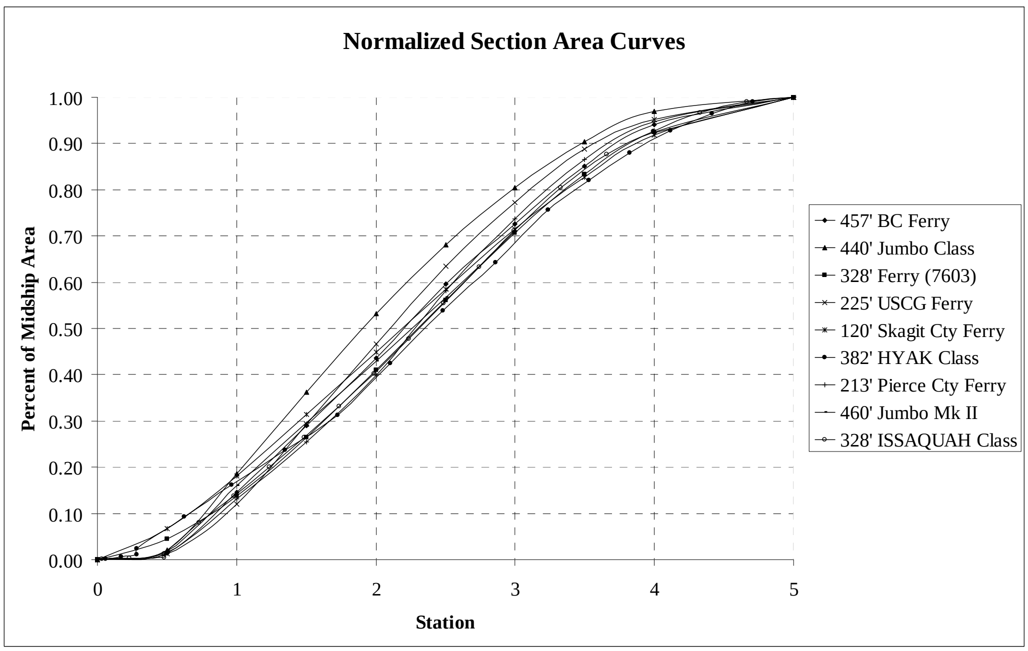


*Figure 4: Normalized section area curves for various ferries.*

Most of the ferries operate at a Taylor Speed Length ratio of between 0.9 and 1.0 with the average at 0.925. Comparing model test data within this range [*Figure 5*], we can see a significant variation in residuary resistance data. The solid line represents the resistance curve for the C Class ferries operated by the BC Ferry Corporation, clearly one of the most efficient hulls we have designed. Recently, BC Ferries have been developing a new class of large double-ended ferries based on the C class hull shape, a testament to the low resistance of the hull, as it will be used on a 20 plus nautical mile route where fuel efficiency is critical.

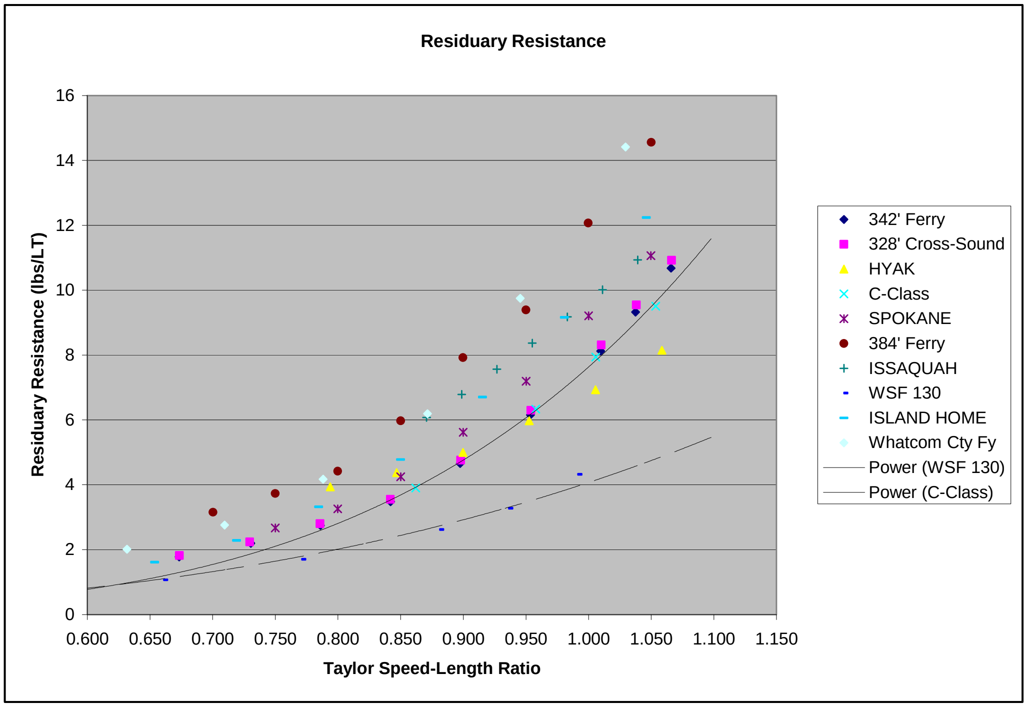


*Figure 5: Residuary Resistance Curves for Various Ferries*

During the design of the 130-car ferry for Washington State, the design team retained FRIENDSHIP Systems GmbH of Potsdam, Germany to investigate CFD optimization of the hull. Their hull form produced some improvements as shown by the dashed line in the chart, but it was a molded shape with compound curvature and hence more difficult to construct.

## STRUCTURE

Most double-ended ferries operate in relatively sheltered routes, so wave-induced bending and longitudinal strength are generally not governing factors. Where we have designed a ferry for an exposed route, such as the 457' C Class for BC Ferries, we used a 14' design wave, which is conservative even for the Straits of Georgia. For the 80m ISLAND HOME ferry, which can see rough winter conditions, the design wave was 2.08m, while on Puget Sound the 130-car ferry was designed for an extreme wave height of 13.3'.

The structural system for a double-ended ferry must accomplish three major things: 1) handle the vehicle wheel loads, accounting for fatigue due to a design life of 40 to 60 years, 2) provide sufficient racking strength to support the passenger decks, and 3) have a logical module so that the vehicle deck framing works with the seat pitch in the passenger cabin to ensure that window mullions don't obstruct the passenger view. The chart shows the various framing dimensions we have used [*Figure 6*].

| Vessel Name | Frame Spacing (in.) | Main Deck Plating (#/sq ft) |
|---|---|---|
| EAGLE | 24 | 17.85 |
| GUEMES | 24 | 20.4 C |
| HIYU | 24 H | 12.9 |
| PATRICK DENNIS | 24 | 20.4 C |
| TILLICUM | 27 H | 12.3 |
| HYAK | 27 H | 12.8 |
| SPOKANE | 28 | |
| QUEEN OF COQUITLAM | 28.5 H | 15.3 |
| CHRISTINE ANDERSON | 36 H | 15.3 C |
| QUEEN OF ALBERNI | 28.5 H | 15.3 |
| STEILACOOM II | 36 H | 15.6 C |
| Whatcom County New Ferry | 30 H | 15.3 C |
| WSF 130-Car | 27 H | 15.6 C |
| ISLAND HOME | 28 H | 20.4 |
| H = half frames IWO truck lanes<br>C = Corten steel (ASTM A572), yield = 46,800 psi | | |

*Figure 6: Basic Vehicle Deck Structure*

## WEIGHTS AND STABILITY

One of the challenges in any vessel design project is to estimate the weight of the vessel, especially at an early stage of the design.

### Weight Estimation

When we examine some of the data we see that there is relatively good correlation for early parametric estimating for this class of ferries. [*Figure 7*] The data point furthest away from the regression line is the 130-car ferry for Washington State. Based on data for the Jumbo Mark II ferry, a 140.20m class and this 39.62m design, their vessels are heavier than we have traditionally seen, perhaps due to additional passenger decks.

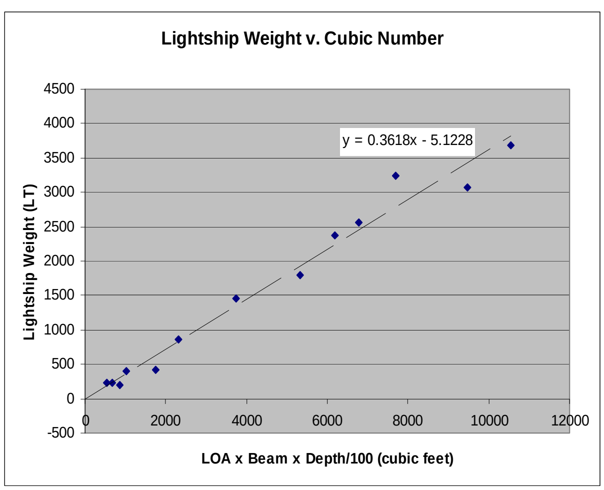


*Figure 7: Vessel Lightship Weight*

When we examine VCG against hull depth, we see two groups of data [*Figure 8].* The left-hand cluster represents those smaller ferries with their passenger accommodations on the main deck, while the right hand group represents the larger ferries that typically have full length superstructure and one or more upper passenger decks.

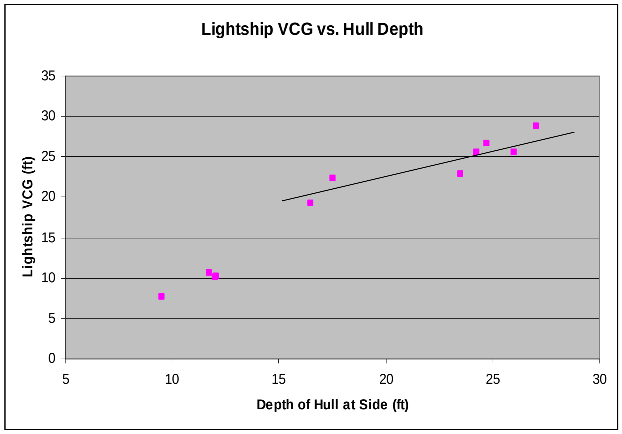


*Figure 8: VCG in Proportion to Hull Depth*

In addition to the lightship estimate, we also need to plan for weight growth over the life of the vessel. Given modern coatings, we can reasonably expect a life of 60 years for a modern ferry, knowing that a mid-life repower will likely be required. Ferries are more likely to be phased out for economic reasons, rather than technical obsolescence. This can take the form of growth in ridership requiring a larger vessel or replacement of the ferry crossing with a bridge. All vessels gain weight over their lifespan. A study by Washington State as part of their 130-car design project, showed an increase of approximately 0.1% per year. We strongly recommend that the initial design provide for this weight growth through the inclusion of a service life margin. To this the designer may wish to add a vehicle load margin to account for increased vehicle loads.

### Intact Stability

As mentioned earlier, the V hull form typically used for double-ended ferries provides increased waterplane area as the vessel heels and a reserve in righting energy. Consequently, there is usually little need to consider the use of weight saving techniques, such as aluminum structure. The exception to this is situations where the vessel has some strict draft limits, such as the 254' ferry we designed for the run from Woods Hole to Martha's Vineyard in Massachusetts. There was an owner's requirement to limit the draft to 10.5' in the full-load condition including a service life margin of 3" of draft or 73.16 metric tons, which equates to 5%.

### Damage Stability

The V form of the ferry hull also provides protection to the vessel from side damage. In the 56 years that Washington State has run their ferry system, there has never been a serious collision involving a ferry resulting in loss of life. In fact, the greatest collision risk comes from other ferries [4] as they represent some 90% of the commercial traffic on Puget Sound. There have been numerous groundings and allisions, the latter usually involving the ferry landing. Looking north to British Columbia, however, we do have an example of a collision on August 2, 1970 near Active Pass between a double-ended ferry and the Soviet freighter SERGEY YESENIN. The ferry was struck amidships, but due to the heavy guard strake and the hull flare, the damage was limited to the superstructure above the car deck. The watertight integrity of the hull was not breached. In groundings, however, the V hull form can present a hazard due to the loss of waterplane area on a falling tide.

The author remembers an occasion when the ferry WALLA WALLA grounded at the entrance to Eagle Harbour on a high tide. There was significant concern whether she would heel towards the shallow water as the tide receded or tip over into the deep water with consequently greater damage. Fortunately, the mud held her fast and she refloated on the next high tide without damage.

To protect against loss from flooding, due either to grounding or to collision, ferries are typically designed to a two-compartment standard of subdivision, required for US vessels over 200' in length. The graph [*Figure 9*] shows a typical floodable length, this one for a 255' ferry with engine room amidships and reduction gears placed outboard in each end to minimize the length of heavy propeller shafting. While the vessel is designed for a maximum operating draft of 10.5', the subdivision calculations were taken at 11' to provide a margin for future weight growth beyond the 5% allowed as a service life margin.

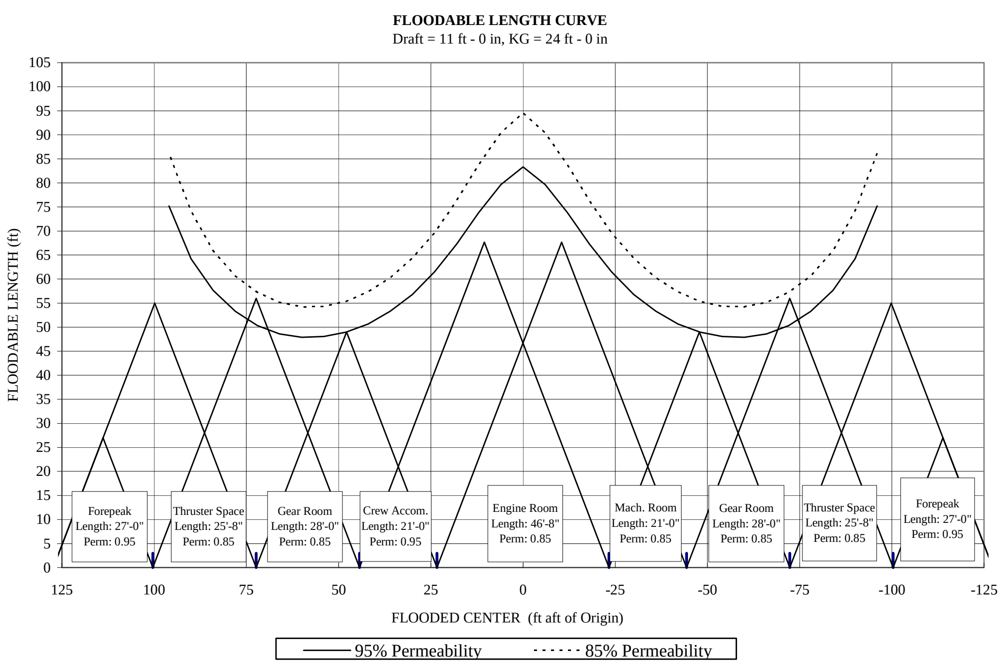


*Figure 9: M/V ISLAND HOME, Floodable Length Curve*

## FIRE PROTECTION

As in any passenger vessel, fire protection is a key part of the design challenge. It could be argued that fire protection is especially critical for vehicle ferries, by virtue of their transportation of truck and cars. A review of Washington State's safety record shows that, while fires on the vehicle deck have occurred [4], they have been infrequent and readily dealt with by the vessel's crew. A more serious fire on a double-ended ferry was one that occurred in British Columbia on May 12, 2003 when a fuel line ruptured in the engine room of the QUEEN OF SURREY. Passengers were safe on the upper passenger decks, but the heat was intense enough to buckle the main deck.

As part of designing the 130-car ferry for Washington State, we took an in-depth look at the effects of a fire originating in a truck on the vehicle deck. Our subcontractor, Rolf Jensen & Associates, used a flame and smoke modeling system to evaluate the thermal flux due to a very conservative maximum heat release rate (MHRR) of 80 megawatts (mW). Most design references for tunnels or car parks only consider a 30 mW MHRR value. This ferry's embarkation scenario is to muster the passengers on an upper passenger deck. There are four stairways from this refuge area to the four embarkation stations on the main deck. The criteria for success in the fire analysis was to safely disembark all passengers through at least two of the stairways within 60 minutes without exposing them to high heat (greater than 60 degrees C) or dense smoke (visibility of less than 5m). The vessel was assumed to have all of its active fire suppression systems, including the vehicle deck deluge system, to be disabled. The passenger flow during evacuation used a three dimensional network model developed by Rolf Jensen & Associates [5] and modified to reflect IMO MSC/Circular 1033.

The results of the fire analysis confirmed that the vessel arrangements provided a safe evacuation route for the passengers. It also demonstrated that having the ends of the ferry open and with large side openings, allowed the heat and smoke to dissipate to some extent [*Figure 10*].

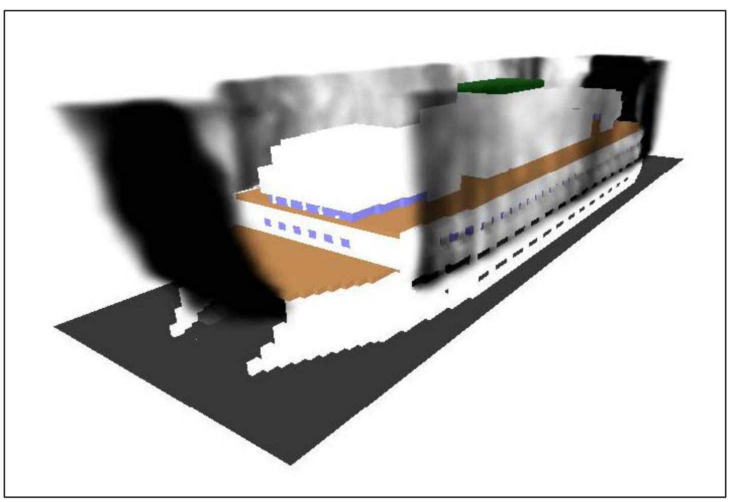

*Figure 10: Smoke Modeling for 130-Car Ferry*

The author believes that through the use of such tools for fire protection and passenger flow analysis, we can both improve the safety of ferries and avoid overly prescriptive regulations.

**PROPULSION**

The double-ended ferry lends itself to a wide variety of propulsion configurations. Historically, these have ranged from steam-driven, side paddlewheels to a cable ferry powered by horses on a treadmill. In more recent times, we have seen the diesel engine become the dominant power source with a variety of means of putting the power into the water. The table below [*Figure 11*] shows some of the basic choices we have used in our projects.

| Vessel Name | Geared Diesel w/FPP | Geared Diesel w/CPP | Diesel w/Azimuthing or Cycloidal Drive | Diesel-Electric | Cable | Route |
|---|---|---|---|---|---|---|
| DANIEL MATHENY V | | | | | X | River |
| WHATCOM CHIEF | X | | | | | Short |
| COLUMBIAN PRINCESS | | | X | | | River |
| EAGLE | X | | | | | Short |
| HERON | X | | | | | Short |
| GUEMES | | | X | | | Short |
| HIYU | | | | X | | Medium |
| Whatcom County New Ferry | | | | X | | Short |
| CHRISTINE ANDERSON | X | | | | | Medium |
| STEILACOOM II | | X | | | | Medium |
| PATRICK DENNIS | | | | X | | Short |
| CROWN CITY | | | | X | | Short |
| ISLAND HOME | | X | | | | Medium |
| TILLICUM | | | | X | | Medium |
| CROSS-SOUND (7603) | | | | X | | Medium |
| WSF 130 Car | | X | | | | Medium |
| HYAK | | | | X | | Medium |
| SPOKANE | | | | X | | Medium |
| QUEEN OF COQUITLAM | | X | | | | Long |
| QUEEN OF ALBERNI | | X | | | | Long |

*Figure 11: Propulsion System Alternatives*

Clearly, there is no preferred approach that works for every ferry. As designers, we look for the machinery configuration that meets the owner's performance requirements with the best balance between reliability, maintainability, fuel efficiency and operability. This search typically takes the form of a propulsion study where we work with the owner to establish weighting criteria for the various aspects of the propulsion system. Typically, an owner will have strong opinions on what equipment and what configuration works well for his operation.

One of our roles as the designer is to introduce other ideas we have seen and educate the owner on the pros and cons of different choices. Recently, we worked with Whatcom County on the design of a ferry to replace one we had designed for them 40 years ago. The demand for improved service meant that the new vessel would be significantly larger than the old boat. The older vessel would remain as the 'back-up' boat. The route is very short with strong currents, forcing the existing ferry to take an "S" shaped course and crab into the landings. One additional constraint was the shallow water at one of the landings – requiring that either the county dredge to accommodate a deeper, larger ferry, or that we design a larger boat with a shallow draft. The latter was chosen, since dredging would be an ongoing maintenance expense with potential environmental concerns.

After looking at various options of azimuthing drives, and propellers in tunnels with high lift rudders, we selected cycloidal propulsion as providing the best choice. The higher capital cost and lower propulsive efficiency were more than offset by the elimination of dredging and the short run. We tested the hull at a model basin in British Columbia to confirm the resistance predictions from Voith. The owner also had the opportunity to send one of his senior captains to North Carolina, which operates ferries of a similar size with the Voith propulsion, so he could confirm the ease of operation.

**CONSTRUCTION COST**

Among the first words from a client's mouth is the question of "How much will it cost?" Early stage estimation of construction costs is an essential part of any ferry project, especially when the client is a public agency with an extended process for obtaining funds. It should be noted that most ferry clients are established operators with a good grasp on the operating costs of their fleet. But in many cases it has been a decade or more since they last built a vessel. They must, therefore, rely heavily on the designer to help them create a realistic capital plan.

We have pursued two avenues for the estimation of construction costs. The first is to look at long baseline historic data with appropriate inflation factors. The other is to use near term data from a variety of ship construction projects and rationalize it in terms of fundamental vessel characteristics. This builds upon the basic work of Benford [6] and Watson and Gilfillian [7].

Using long baseline historic data, for vessels constructed over 40 years ago requires careful documentation of how the project was contracted, but can provide useful estimates. In the United States the Bureau of Labor Statistics can provide historic wage data for shipyards and the US Navy tracks materials cost data. The graph below [*Figure 12*] shows the changes for the marine industry relative to the consumer price index. As an example on how this can be used, Washington State issued a bid package for three 130-car, diesel-electric ferries (EBDG Job Number 7603 as shown earlier in Figure 2). The bid opening in 1977 produced a low bid of $58.9 million. Using material and labor cost data for shipyards, these same vessels would have a price of $45.7 million per vessel in 2003, or $8.56 of lightship weight. We estimated the cost of a new 130-car ferry using geared diesel propulsion in 2003, and our price for the first vessel was $50 million, or $8.93 (within 4%).

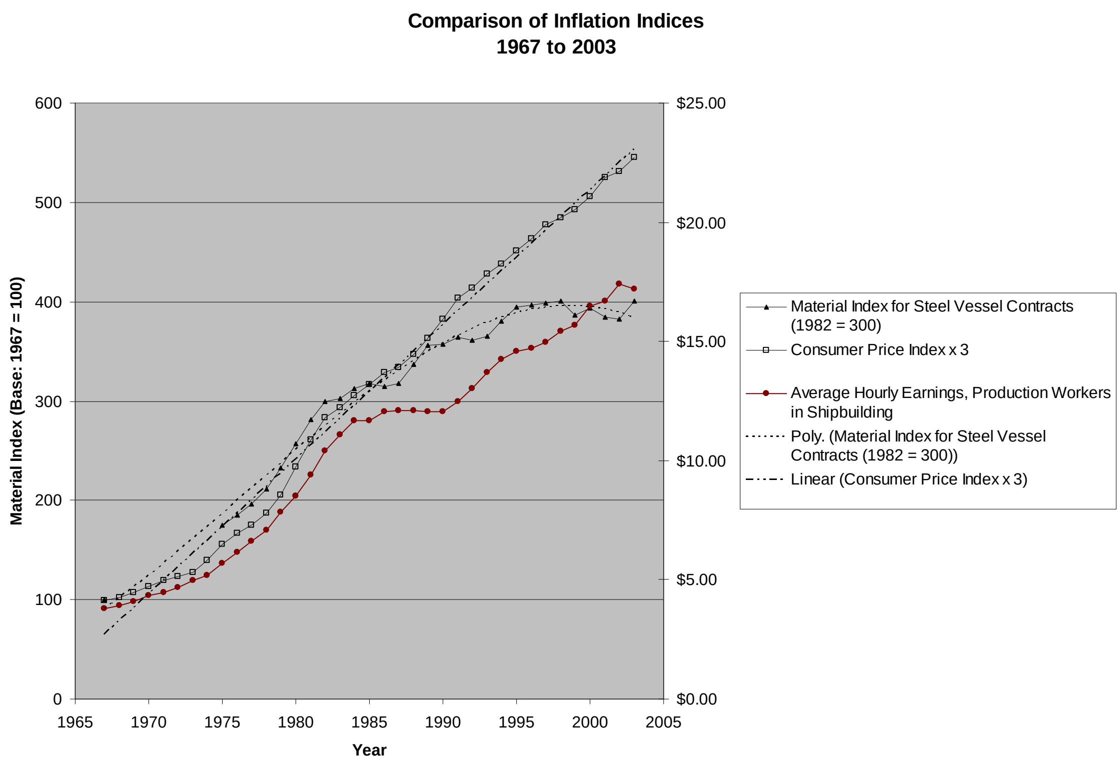


*Figure 12: Inflation Data for Vessel Construction*

The other approach uses recent cost for vessels that has been analyzed according to basic weight categories using a Ship Work Breakdown System (SWBS). In short, if we can estimate how much the electrical system weighs, we can estimate the material costs for purchasing the electrical equipment and labor hours for installing the materials. Since this approach relies on statistical data, we can apply standard deviations to the average numbers to arrive at a corresponding confidence factor that the cost will be below a calculated value. Using the same example of the Washington State 130-car ferry in 2003, we estimated a base cost, using SWBS data of $39 million for the first vessel, or $6.92. By applying standard deviations of data variance, we estimated that the vessels could be constructed for a cost of $46.5 million or less with a confidence of 68% and for $56.6 million or less with a 99% confidence factor. Given the sharp rise in materials and equipment prices since 2003, that confidence might be severely tested if the ships were to be bid today, hence, the need to continue to collect cost data for analysis.

## CONCLUSIONS

So, what has 50 years taught us? First is that there always will be opportunities to improve the art of double-ended ferry design. Within the past 10 years we have designed two 54-car ferries for Pierce County, Washington. From an exterior appearance they are similar but the arrangements for the most recent boat, M/V STEILACOOM II, which was delivered in January, 2007, show numerous changes [*Figures 13 – 15]*, including:

- Access paths for passengers with disabilities
- A controllable pitch propeller system rather than fixed pitch
- More vehicle clearance
- A larger passenger cabin
- Greater security for vital spaces such as the engine room and pilothouse
- These changes are in response to regulatory initiatives, ridership increases and performance improvements. We see change as the norm rather than the exception.

As designers of double-ended ferries, we are aided by the new tools of computational fluid dynamics and finite element analysis to create hulls that are more efficient, both hydro-dynamically and structurally. There are areas for innovation in the propulsion systems as we seek to reduce emissions and our consumption of fossil fuels. We can also make the ferries more secure from terror threats, a new reality that must be considered anytime vehicles and passengers are transported across the water. The fire analysis tools described above can help us design active and passive protection into the vessels.

Another fact that we need to recognize is that our clients, the ferry operators, will be seeing new challenges as populations grow, cars and trucks evolve, and yes, even as passengers change. In the U.S. we are re-examining the weight and size standards for passengers. Worldwide, people have gotten taller, heavier and, unfortunately, wider. The seats, lifejackets, stability standards and evacuation equipment may not be suitable for the passenger of the future. We know that the steel hulls can reasonably last for 50 years, but our regulations and designs must be refreshed far more often. The team at Elliott Bay Design Group looks forward to working with our peers to continue to improve double-ended ferries.

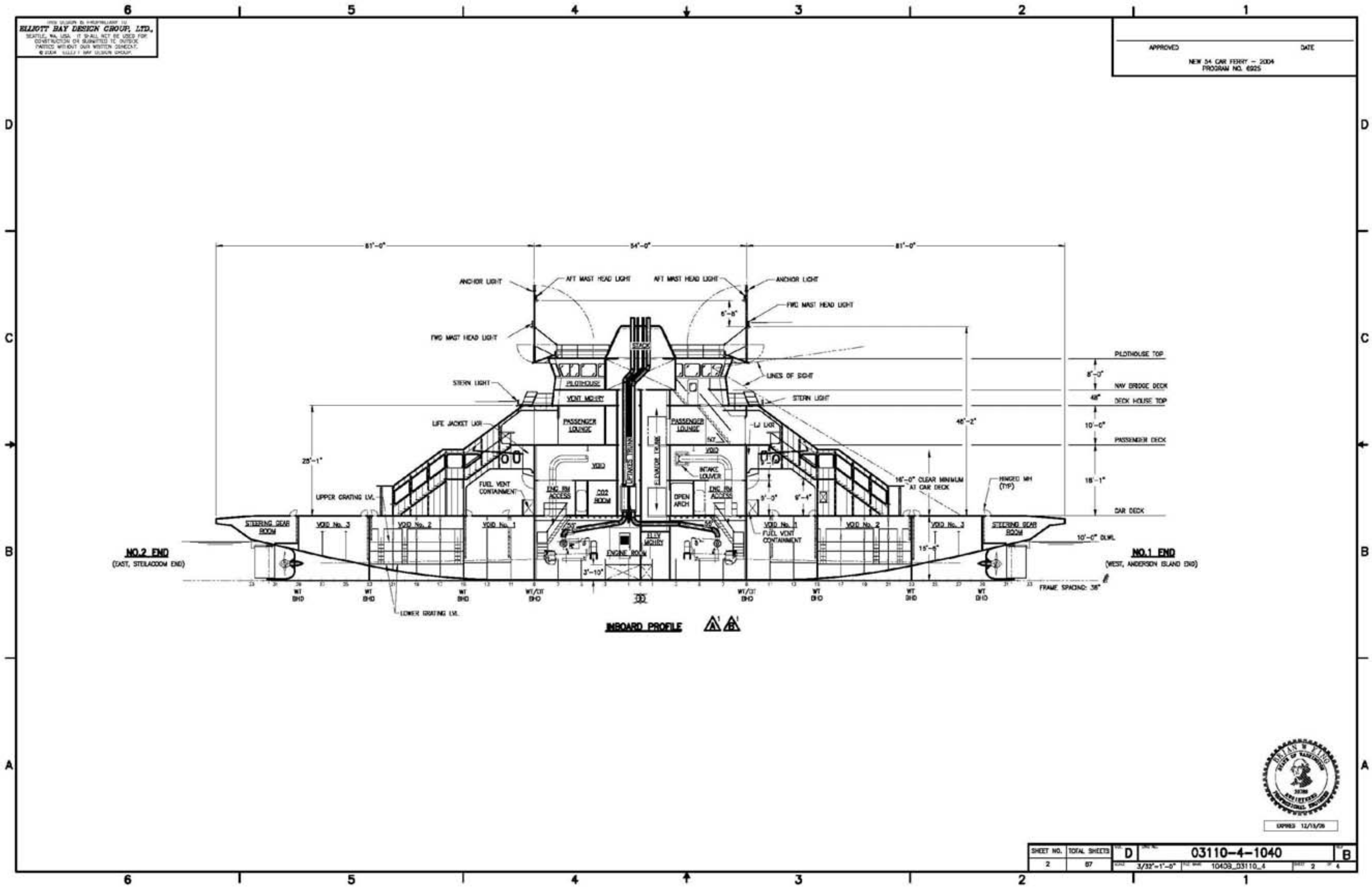


*Figure 13: Inboard Profile of M/V STEILACOOM II*

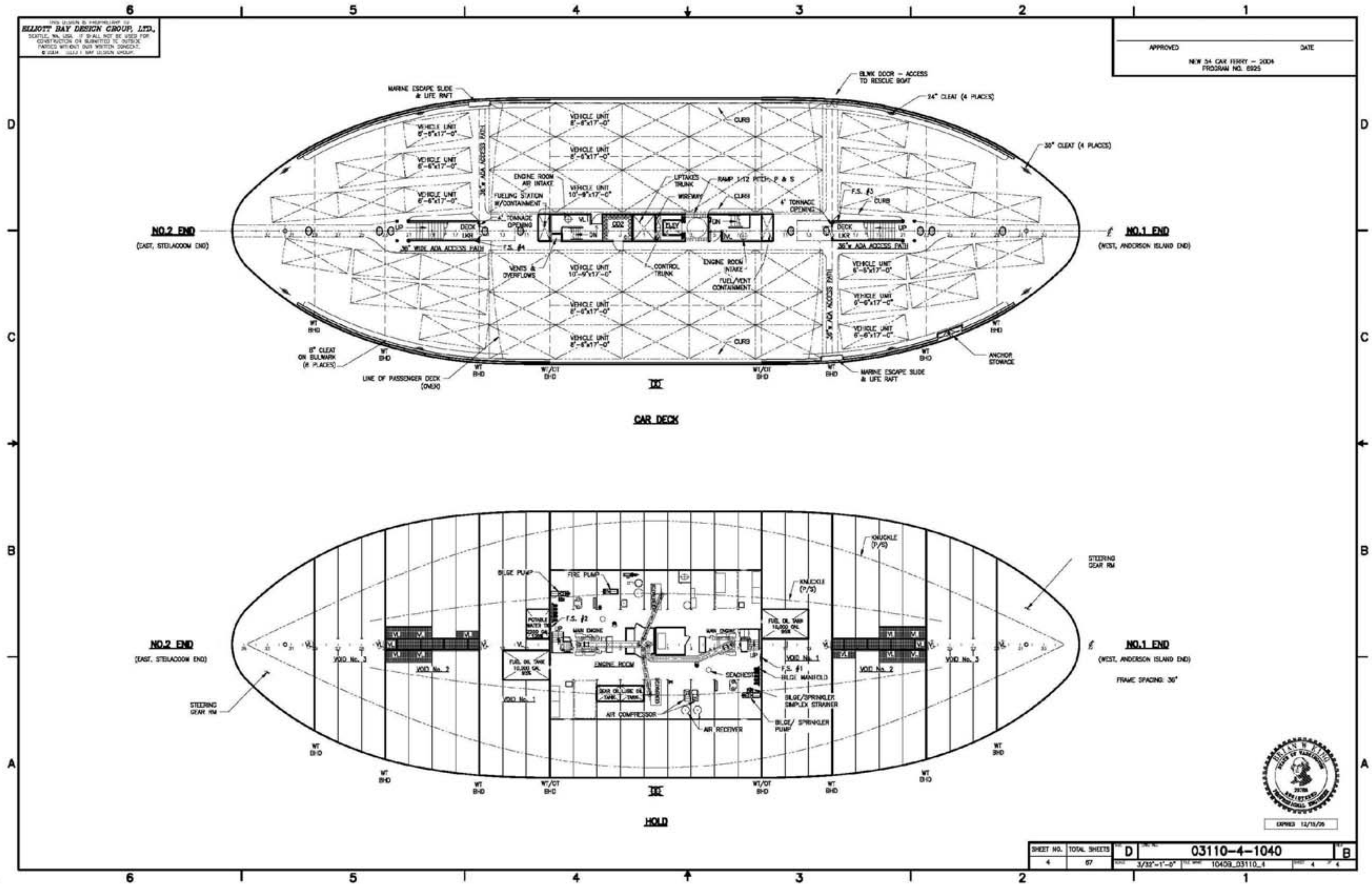


*Figure 14: Main Deck and Hold Arrangements for M/V STEILACOOM II*

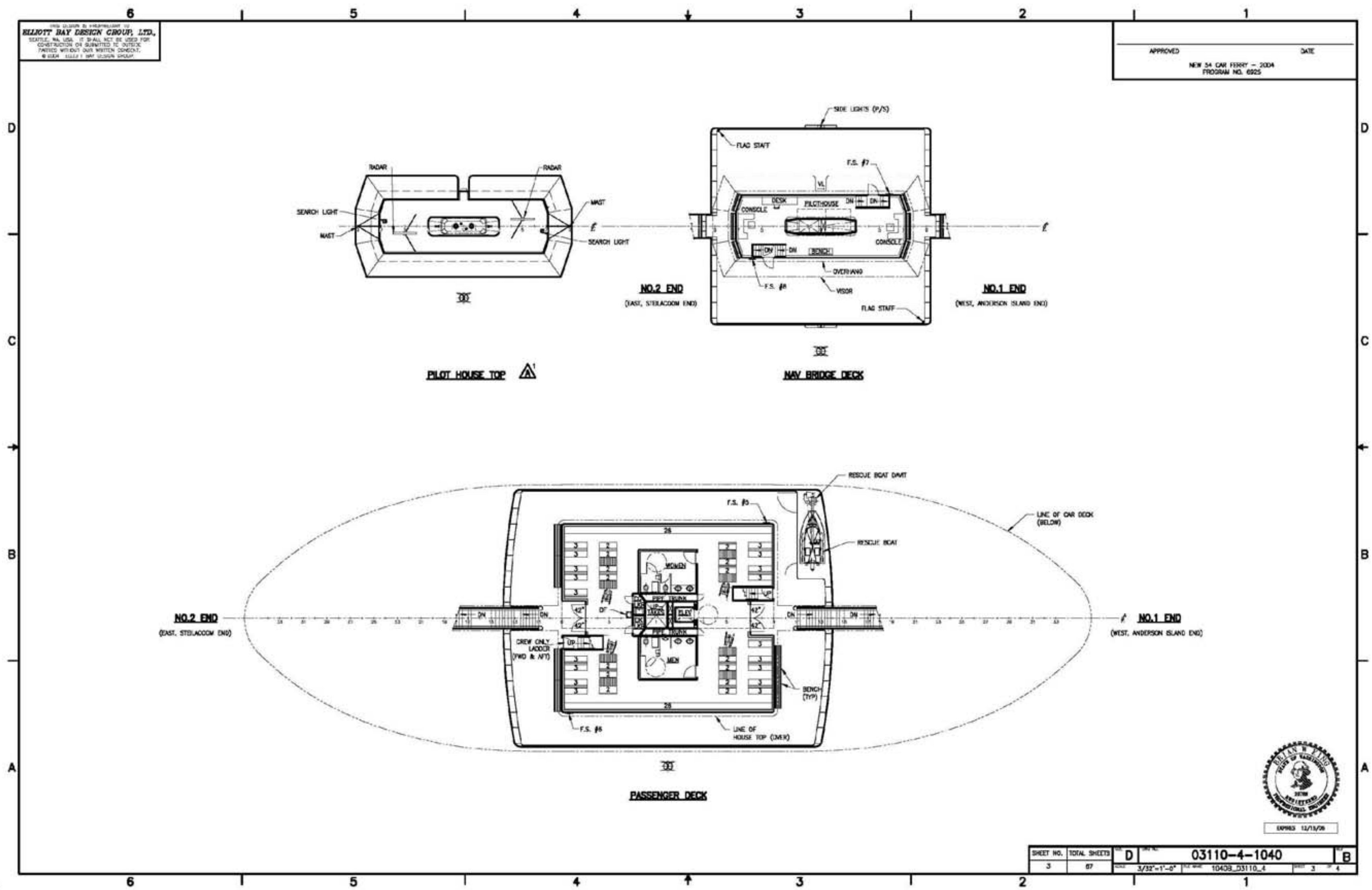


*Figure 15: Passenger Deck and Bridge Deck Arrangements for M/V STEILACOOM II*

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