

# THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

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## Ferries For The Chesapeake, San Francisco Bay and New York Area; New Paradigms From New Technologies

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Perhaps the best and certainly the oldest reminder of the advantages of design for environment and mission is the diversity of dog breeds. Developed to serve the multiple purposes of guard, working and escort dog, the Boxer is a strong, boisterous, active dog with a very positive personality. To provide the necessary speed, dexterity and jumping ability, the Boxer needed to be a substantial dog of great power. The Nova Scotia Duck Tolling Retriever is not only suited for the Canadian Maritime climate, but also is specifically adapted for Nova Scotia hunting practices and waterfowl species. (Coldwell, 1999). The Half-Tide Spaniel, characterized by smaller ears and bigger feet than the true Water Spaniel, is perfectly adapted for leaving black dog hair on an orange couch. This unusual hybrid breed exemplifies the value of serendipity when a haphazard design process leads to a successful outcome.

### ABSTRACT

*Innovative technologies for ferries, their propulsion, their intermodal interface and their construction offer opportunities for improved service, reduced cost, reduced environmental impact and better passenger connections. However, the complexity of a modern urban ferry system requires careful and broad analysis throughout the entire system to develop an optimized integrated system at minimum financial and environmental cost.*

### INTRODUCTION

*"Horses for courses"*

*Old English saying*

The goal of all engineering efforts is optimized systems. In a few rare cases, engineers are presented with a sufficiently "blank sheet" to allow wide and fundamental choices in design. These cases represent the greatest challenges in engineering.

New ferry systems represent just such a challenge because they require a holistic approach to the entire system, from detailed vessel design to ticketing policies. The choices made in each of these areas also have potential to affect all of the other areas. Pricing policies can, for example, reduce the need for faster craft and thereby have a profound effect on ship design.

First, what paradigm has changed because of new technology? The most obvious is that vessel speed capability has increased. The other change is not really

technological; in some area, traffic congestion has increased to the point that the freeways and especially the bridges built to substitute for the earlier ferry systems are at capacity.

Currently, there are a number of individual or systematic efforts to establish such new ferry services throughout North America. In San Francisco, the Water Transit Authority, (WTA), was created by the California State Legislature (1999) to establish an integrated ferry system in San Francisco. In the Chesapeake, a new system has been proposed to link Crisfield, Maryland, and the Virginia shore. New York City is host to an ever-increasing fleet of ferries connecting the New Jersey suburbs and the city. A system was proposed to link Washington DC with the Virginia suburbs along the Potomac, and a system connecting Toronto and Rochester, NY began recently. Each new ferry system has different goals, environment and constraints, so each represents a unique and challenging optimization problem

The one overriding issue the authors came to understand during the development of this paper is the diversity of options, their complex interaction and thus the need for very careful and detailed analysis of every option and their interactions. There is also a strong question of what exactly is desired by the owner or the public. In comments to an earlier paper by the authors, McKesson (2002) notes that a ferry system can be designed to make the most profit, to have the least environmental impact, or to most reduce congestion, but not all three, so the engineer has an important role in presenting the alternatives to the decision makers (often the public).

Any comprehensive modern ferry system encompasses many disciplines and complex interactions of systems. Unlike most new ships, a whole new system has very few “givens” or existing interfaces to fit into. There are also competing measures of effectiveness, so there is no simple optimizing function analogous to required freight rate. For example, the first question a ferry designer must answer is whether water transport is justified at all.

The systems mentioned represent the two main types of ferry systems, systems that bridge a substantial water barrier or systems that parallel other modes. The proposed Crisfield and new Toronto systems are traditional roles for ferries, they save substantial mileage over alternative routes; the Crisfield ferry would save about 120 miles on a trip from Richmond, Virginia to Salisbury, Maryland, and the savings on a Toronto to New York City trip would be about 169 miles. Other exiting systems in this category are those crossing Long Island Sound at New London and Bridgeport, CT. In addition, both systems carry cars and trucks as well as passengers and both systems have as at least a partial goal the economic revitalization of one or both ends of their routes. The Toronto system is further distinguished from the Crisfield system in that it is quite a long water run and requires substantial speed to be time competitive with the land route via the Niagara Falls. The Toronto route is largely enabled by a fast craft. The Crisfield route was formerly the site of a ferry and is only about 24 water miles. To compete time wise with a land route only requires a passage less than about 90 minutes, giving a relatively leisurely boat speed of about 16 to 18 knots. Because foot passengers do not use these two systems for daily commuting, they also have relatively simple (but vital) interfaces with the rest of the transportation modes required to get a rider to and from the terminal at both ends.

The San Francisco, Potomac and New York systems are more complex because they are intended to parallel and compete with existing modes of transport. In urban areas with un-bridged water barriers this competition is moot. Traditionally a ferry is in a pretty strong competitive position because it is usually the only alternative to swimming. However, new commuter ferries have lots of competition from other modes. Both

New York City and San Francisco have rail transit tunnels and numerous highway bridges or tunnels spanning all the major arms of water. Washington DC has freeways paralleling the river and numerous bridges as well as a light rail/subway system and conventional rail ties into the Virginia and Maryland suburbs (one of which essentially parallels the Potomac as well). Water is very sticky stuff, and the small fast ferries most desirable for maximum regional mobility are inherently inefficient. It is easy to show that rail or road transportation is far more efficient when the infrastructure already covers the intended routes.

Despite these resources, urban areas with water barriers are finding ferry transportation increasingly attractive. Some of this is arguably due to the lack of will to manage the bridges and tunnels efficiently. Reserving a bridge lane exclusively for buses on the Bay Bridge in San Francisco (like that in some of the tunnels in New York) would provide more seat-miles than even a large ferry system could provide. However, such a measure may not be politically possible – the opposition to even HOV-3 lanes in many areas has been substantial. Even the installation of suitably ferocious animal statuary, despite its success in other areas (Kulash, et al, 1992), is probably inadequate to improve traffic flow. More extensive use of buses is also difficult in areas with extensive suburbanization – either the bus routes are excessively long and tortuous, or spaces must be found for numerous “park and ride” sites. Providing more fixed infrastructure, such as bridges and tunnels, or even rail car seats is terribly expensive and possibly environmentally impossible. Thus the reality, even though it may be partly imposed by poor transportation planning, is that a body of water with a bridge above it and a tunnel below has once again become a very real barrier to mobility.

Whether a ferry service is the best way to improve mobility across the water barrier is an issue bound in politics and economics: Those who benefit from a public work should pay for it; and those who pay for it should benefit, at least indirectly. This is especially important for modern urban ferries, as ferry (or other mass transit) systems are frequently publicly subsidized. Thus, in some areas non-riders subsidize riders through bridge tolls or taxes. Minimizing the level of subsidy increases even more the need for optimized solutions. However, even if full farebox cost recovery is possible, non-riders “pay” through environmental impacts, loss of waterfront and effects on growth. Even if a free, perfectly benign transport system could be invented, it would reduce the disincentives to growth caused by difficult commutes.

A ferry system is also an intermodal system: There are tradeoffs between waterborne and landborne portions of the overall system, as well as interfaces between existing land systems and new ones that require overall system optimization.

On the other hand, modern urban ferries that parallel bridge and tunnel crossings have some unique features, which lead to opportunities for unique design solutions:

- Routes are very short by normal ship standards
- Variation between minimum and maximum load is relatively small
- Extensive support can be made available at a terminal.
- Vessels operate mainly at a single speed and load conditions do not vary greatly.
- Vessels can be optimized for a particular route.
- Most ferry runs are reasonably sheltered from waves, so seakeeping is not of great concern.
- Property in general, but especially waterfront property, is vastly more precious than in many other areas.
- The public is often sensitive to environmental issues.

### **PASSENGER CAPACITY AND VESSEL SIZE**

*“For who hath despised the day of small things”*

*Zechariah 4:10*

There is an important difference between ferries and other urban transport systems. Classic urban transport theory holds that though many small vehicles are often more convenient than a few large ones, if the vehicle can be filled, the largest possible vehicle is always best (Vuchic, 1981). Put simply, this is because personnel costs and the costs of, and access to, right-of-way (rails, tunnels, streets, freeway lanes, etc.) are not strongly connected to vehicle size, but to vehicle numbers. Large numbers of small vehicles use considerable right-of-way length because of the requirement to allow headway between them, and additional provisions to allow moving vehicles to pass stopped ones. (This is, of course, the basic problem of automobile traffic.) Thus overall passenger productivity of the system, both with respect to cost and with respect to passenger capacity always rises with vehicle size.

This effect is not nearly as powerful for waterborne craft. First, there is no right-of-way infrastructure, and within fairly broad limits, watercraft can wander about freely. Second, Coast Guard guidelines link crewing requirements to number of passengers per craft. The guidelines provide for a Master plus one hand for each deck, plus one more hand for varying numbers of passengers over 149. A 299-passenger ferry will require a minimum of three total crew on board, (if all 299 passengers are on one deck) whereas a 149 passenger craft will only require two total crew.

Third, the distinction between a small passenger vessel and a ship is based on exceeding 100 gross tons, which is internal volume “admeasured” in a very specific way. The natural point at which a vessel might exceed 100 gross tons is near the size of most practical ferries, and

operating a typical urban passenger only ferry larger than 100 gross tons is probably economically unrealistic.

Though it is possible to use various aspects of the customary US admeasurement rules to advantage so as to make quite a large vessel less than 100 gross tons, there are costs, increases in weight, and distortions in design required to achieve this in large craft. The typical strategy is to exclude the superstructure of the vessel by use of tonnage openings and minimize the admeasured volume of the hull by excessively deep frames. (Volume outboard of the inner faces of the frames can be excluded under certain conditions.) This adds weight and cost due to the frames and frequently requires increased shell thickness to allow greater frame spacing. Experienced designers of small ships remark that tonnage concerns can add anywhere from 15% to 25% to the total weight of hull structure. This also favors designs that have relatively large superstructures as compared to their hulls, which gives advantage to catamarans. (However, the Coast Guard accepted comments for a proposed change in the basic tonnage breaks scheme in 1998, with the intent of using international conventions that do not have the peculiarities of the US system. Substantial changes in tonnage that will eliminate the distortions required may be seen.)

Fourth, there is a significant step function in Coast Guard vessel safety criteria at 49 and much more so at 149 passengers. The latter is the break between subchapter T and subchapter K of 46 CFR. “T-Boats” are more or less boats, whereas “K-Boats” are in many respects ships, at least with respect to most engineering systems. Probably even more important is structural fire protection. Subchapter K requires that vessel structure offers fire resistance “equivalent to steel” and imposes complex regulations on fire protection subdivisions. These latter requirements limit use of materials, the sizes of spaces, interconnections between them for mechanical systems (especially HVAC), and often require substantial insulation on fire resistance boundaries. This is especially important for high-speed craft or other craft, which have to be light, because composite (GRP) construction is virtually forbidden and aluminum structure has to be insulated from fire effects, since it loses strength at relatively low temperatures. This latter requirement not only adds cost, but weight. Some of the weight advantage of light alloy construction is lost due to the additional insulation it requires: a weight penalty as high as one and one half pounds per square foot is common. Since high strength low alloy steel superstructure might run only three pounds per square foot heavier than a comparable aluminum structure, half the weight advantage of aluminum is lost.

And fifth, turn-around time at the terminal can have a very strong affect on actual trip time. For relatively short routes, shaving a few minutes off the loading and unloading time can be as effective as increasing speed by several knots. This can more than make up for the fuel

efficiency advantage associated with larger vessels. The result is that a smaller ferry with quick turn-around, operating at a lower speed, might deliver the same service as a larger ferry going faster, but with less fuel burned per passenger-mile.

Each of these topics is a complex one, and numerous papers have been written on each of them, so the authors won't belabor them too much further. However, in very rough terms of the impact of these issues on cost, it is worth remarking that one of the authors designed and built a 25-knot, 49-passenger aluminum ferry in 1992 for \$160,000, or \$3,265 per passenger. The same shipyard had previously built a number of 149 passenger ferries in the same speed range for less than \$750,000 each, adjusted to current dollars (\$5,000 per passenger). However, recent larger fast passenger catamarans have cost \$10,000 to \$20,000 per passenger or more. Though not this entire cost differential is due to size, much of it is. Ferry planners are urged to evaluate very carefully the impact of vessel size and passenger capacity on cost, especially as regards to exceeding 149 passengers.

## ECONOMICS

*"Money is the mother's milk of politics"*

Opposition to a ferry system primarily stems from economic and environmental concerns. First the economic: The main economic concern is that some small group will be subsidized by other, "more deserving" groups.

Since ferries are frequently more expensive (even with farebox subsidy) than other modes, this is sometime cast as poor bus and car riders paying for wealthy ferry riders. However, buses and other land modes are also subsidized, perhaps even more. Automobile drivers who "pay" the subsidies in the form of gas taxes and bridge tolls can be particularly aggrieved, but they should realize that there is a structure of subsidies on automobile travel so pervasive as to be invisible (Litman 1999). In the Bay Area, transit subsidies also come from sales taxes, which are regressive in their effect, so the claim that the poor are bearing an unfair load has some credence. A ferry system must therefore have, and be shown to have, benefits that flow to non-riders, including those who don't use transit or even commute long distances at all.

It is relatively easy to perform this type of analysis for automobile traffic. The current ferry system operating between Marin County and San Francisco is the equivalent of one bridge lane, and is certainly less expensive. Studies by Shrank and Lomax (2001) place the annualized cost of traffic congestion at \$2,805,000,000 in the Bay Area in 1998 for 58,855,000 daily vehicle miles traveled and \$3,055,000,000 in 1999 for 59,750,000 daily vehicle miles traveled with a negligible change in available lane miles. The difference

in cost divided by the difference in daily vehicle miles suggests that the incremental value of taking a vehicle off the road each day for a mile is \$294 per year. If every 1.5 ferry riders takes a car off the road every day, for the round trip from Berkeley to San Francisco ferry transport is worth about \$1.78 per mile of the sea distance between terminals just to reduce traffic congestion. (Appendix A)

Essentially, by subsidizing a ferry system from bridge tolls (as is proposed in San Francisco), that part of the subsidy is quite "clean"; bridge users are paying other people not to get in their way as they cross, by providing them an alternative. In fact, a simple analysis of a Berkeley-San Francisco ferry suggests that riders could be paid five dollars per trip instead of being charged at all and drivers would still net a benefit.

It is worth discussing "induced demand" here, as it is an important concept for evaluating the beneficial effect of expenditure on transit. This concept suggests that building transit corridors (freeways, bridges, ferry routes) is, in the long run, hopeless. The existence of a convenient corridor will induce decisions to use it as opposed to not traveling at all, until the new corridor is as choked as the old ones. Therefore any and all improvements in transit should be opposed. In the case of ferries, this suggests that instead of reducing traffic congestion, ferries will just induce more people to drive who would not have traveled at all. Therefore, a ferry system cannot reduce congestion or any of its effects in the long run. However the validity of induced demand, and its magnitude, has been questioned recently (Cervero, 2003). A substantial part of induced demand is presumed due to construction along a new corridor, and concepts such as ferries that do not provide such opportunities may not be subject to this effect. However, the most important issue is that new corridor construction and increased demand may not be cause and effect, but rather joint effects of a third cause, essentially general trends to growth in an area. Clearly, the opposite is not true; providing good transportation in economically disadvantaged areas does not always make them grow. Travel is strongly linked to employment and transit expenditures, and congestion, are probably most strongly linked to employment growth, increased household incomes, and the growth of two-worker families (Crane and Chapman, 2003).

For a comparison with other transit modes, the question is even simpler, because there is a direct comparison between the costs of service. Valley Transportation Authority (McGregor, 2001) submitted a proposal for a Regional Express Bus Improvement Plan with a cost per rider of \$6.90. In fiscal 2001, farebox recovery was 13%, (sales tax provided 53.6%). The bus subsidy for this proposed service is thus on the order of \$6.00 per passenger. As another item of comparison, a new articulated bus has a peak capacity (225% of seated capacity) of 145 passengers, costs \$500,000 and has an average system wide speed of 14 (statute) miles per hour.

A “bare bones” 149 passenger ferry could probably match this speed for the price, with all passengers seated. (However, manning costs would be higher: Coast Guard regulations require an operator and a deckhand for this size craft.)

Current ferry subsidies in the San Francisco Bay Area range from \$6.33 for the Larkspur ferry to \$1.09 (1997) for the Alameda/Oakland ferry, with rates per passenger mile of \$1.15 (Alameda / Harbor Bay, 1998) to \$0.16 (Vallejo, 1998). New York ferries, with the exception of the Staten Island ferry, are only subsidized through preferred access to Port Authority facilities. These subsidies are at reasonable, or even bargain levels both based on parity to other transit systems and by evaluation of the value of decreased congestion. (Note also that this is based on sea miles, not replaced land miles.) If a ferry service is feasible at these levels of subsidy, it is politically acceptable on an economic equity basis.

Ferries can also be used as a tool to develop the political will to manage bridges more sensibly. For example, initiation of a ferry service with capacity equivalent to one bridge lane has been proposed as a rationale for converting one lane of the Bay Bridge to bus and HOV only. While this would not directly reduce congestion for single-occupancy vehicles, it would significantly improve bus mobility and increase the incentive to carpool.

For the poor, retired persons, or others who rarely use transit but still pay sales taxes, the question is whether the increased economic activity associated with a ferry benefits them, either by affording them jobs or by allowing others increased income, which can then be taxed to support their benefits. It may be true that a ferry will increase the productivity of workers using it, but it would probably be difficult to prove.

However, if ferries are built and maintained in the area using them, this would clearly provide local blue-collar employment. It is difficult to estimate this effect accurately without knowing how many ferries and routes will be eventually needed but a simple calculation is possible. In the case of San Francisco, the complete system cost capital cost is estimated at about \$400 million. The cost represents about half land construction and the other half shipbuilding with a small part landside vehicle cost (feeder buses). The land construction portion is clearly substantial labor, and a substantial job base, but these authors will leave that part to others to estimate. The marine portion would be about 222 million dollars (WTA, 2002). A typical shipyard worker building small aluminum vessels generates about \$100,000 to 150,000 of final vessel price per year, comprising his wages, profit and overhead, and the value of the materials he installs. The 222 million dollars thus represents 1,500 man-years of direct labor, 150 new jobs for a ten-year system build out. These jobs are also positions directly “hanging steel”. The factor used assumes that engineering, purchasing and administrative jobs are overhead, so there

would be another 30 to 50 “white collar” jobs, and other ongoing jobs to maintain the fleet, both trade and administrative. With economic multipliers on the order of 2.5 or so, a ferry system could be responsible for five hundred new jobs for ten years.

Of course, the question is whether this is new activity or activity shifted from some other sector, and thus no net gains. Clearly, there would be some substitution effect; construction of freeway or rail right of way would result in many jobs, but it is unlikely that it would be feasible to begin new bus, railcar or automobile manufacture, and much of the cost of right of way is land, which is probably zero sum with regard to jobs. The additional fuel used by cars idling in traffic is also a dead loss to the area. Vessel financing, farebox recovery and possibly federal grants also leverage the cost of ferry construction.

Ferry construction might be a lever to other marine activities. Large yacht construction (yachts over 80 feet are considered “super yachts”) is very similar to ferry construction in terms of materials and most processes and at least one notable US ferry builder is also a world-renowned super yacht builder. Such yachts are generally built to the Maritime Coastguard Act (MCA) 500 (International) gross ton limit for registration under a British Commonwealth flag. This means that they are essentially small passenger vessels under SOLAS and most of the regulatory requirements for them are similar to those for small ferries. In addition, if the US tonnage rules change, US owned super yachts (58% of the total currently) might be built for the US flag as small passenger vessels instead. Since the world order book for such yachts is years deep and expanding by 8% or more per year, this could well result in even more new jobs for an area.

For a system operating at a lower subsidy level with higher ticket prices, novel means of deflecting political opposition due to the perception of elitism have been proposed. One plan suggests giving bicycle riders deep discounts or even free passage, analogous to the free passage over toll bridges now offered to carpools during commute hours (Ebb, 2001).

On balance, it seems clear that some level of ferry activity, even at a reasonable level of subsidy is justified, and that especially if some ferry construction is undertaken in the area served, most sectors can economically benefit from a ferry system and should be willing to support it politically.

## ENVIRONMENTAL ISSUES

*“It’s not easy being green”*

*Kermit the Frog*

The main potential environmental impacts of ferries are air pollution due to engine emissions, wake, water pollution from bottom paint and ship discharge systems, loss of waterfront, noise, and effects on growth,

particularly locally to the terminal. There are also minor potential effects from industrial activities to maintain the vessels, but these can be mitigated by current practices. It is important to note that the effects (except for wake) may not be entirely, or even mostly, due to the vessel itself. The intermodal connections may cause environmental impacts as well, especially if large numbers of automobiles are involved. It is in the mitigation of environmental effects that new technology and other systems have the most potential to make a ferry system the best possible ecological choice.

First, it is important to remember that minimizing or even evaluating environmental impacts is rarely as simple as it seems. A good example is use of “biodiesel”, which is derived from plant oils, usually soybeans. This fuel is said to reduce particulates, and other adverse effects of conventional fossil fuels. It also reduces greenhouse gases in that it recycles carbon through plants rather than releasing it from deep in the earth. However, though biodiesel is often derived from “used” oils, these oils are not really waste. They are currently being recycled for other uses such as cosmetics, paints and animal feeds, so diversion of this stream to fuel will require replacement to fulfill current needs.

Extensive use of biodiesel will require increased farming of oil seed crops, which has environmental impacts of its own, most notably increased water pollution. Though soybeans are nitrogen fixing, they still require phosphate fertilizers, which run off and increase nutrient loads in rivers and estuaries. The increased mass of agricultural waste (soybean, traditionally, is plowed under to add nitrogen for a successive non-legume crop) may also produce greenhouse effects: Rotting vegetation produces methane, which has twenty times the greenhouse effect of carbon dioxide. Economic input (money for fuels going to farmers instead of foreign oil producers) may also have environmental effects. Extensive use of biodiesel may require further remediation measures, such as collection and utilization of agricultural waste, growing filtering species such as switchgrass in agricultural runoff areas or artificial aeration of rivers or estuaries. Each of these technologies has impacts and opportunities as well: Switchgrass has been proposed as a feedstock for other biological fuels (Blankenship, 2001).

Air quality issues are an important part of the environmental impact of ferries. There have been four major reports on the impact of ferries on air pollution. The first report by Long (1999) oversimplified the analysis, “spun” some data, neglected critical information and thus greatly overestimated the relative air pollution produced by ferries as opposed to automobiles and buses. Sweeney (2000) has offered a rebutting analysis that suggests ferry transit produces less air pollution than auto traffic, though perhaps slightly more than bus traffic. The WTA (2002) has done an Environmental Impact Report (EIR) of its own, and CALSTART (2002) has analyzed

three routes in San Francisco and provides a very thorough and substantive report. Corbett, et al (Corbett, 2003) have done an analysis of the impact of ferries on New York City air quality.

The WTA EIR and CALSTART studies suggest that given substantial additional, but feasible, controls to eliminate pollutants, ferries can improve or nearly equal air quality compared to automobiles for most routes. (The longest, fastest route is the most problematic in the CALSTART study, and is not shown to have lower emissions.) The best technology proposed is EPA Tier 2 (off-road engine requirements beginning in 2007) with the use of Selective Catalytic Reduction (SCR) of NO<sub>x</sub> and catalyst filters for diesel particulates. SCR uses ammonia or urea over a catalyst bed to reduce NO<sub>x</sub> to nitrogen and oxygen. Though these technologies are commercially available and in use for stationary engines, and have been demonstrated on large marine diesels and European ferries, they will require on-board reagent storage and increased space and weight claim for the systems, and of course, increased capital and operating cost.

The Corbett study is more pessimistic, suggesting that ferries will require more reduction than is possible with currently available technology to compete with autos or other modes on an air quality basis in New York City.

All of these studies have many assumptions that can be questioned, (though the magnitude of the numbers is sobering and a call to action). They include significant loads from the landside emissions associated with travel to and from the terminals, which are based on assumptions on mode of travel and distance to the terminal. Induced demand is presumed to reduce the beneficial effect of getting riders out of cars, and the magnitude of the effect is subject to substantial question. The studies also use a fairly high level of vessel speed in some cases, which might not be appropriate for future service. The pollution potential of comparative modes of transport are also worth questioning; the studies are mainly based on the presumed 2007 automobile fleet.

The CALSTART study also includes numerous suggestions for improving the air quality impact of ferry systems, and it is worth noting that many of them address the most obvious issue: The amount of pollution a ferry produces doesn’t change with passenger load, so filling the ferry is the best option for reducing pollution per passenger mile – the CALSTART study assumes 15% to 33% daily occupancy. One important issue is to fill the boat on the back haul. An empty car doesn’t make a return voyage, but an empty ferry might. In some areas, the smaller number of reverse commuters is more likely to travel alone, as they have less traffic to contend with, so getting them out of their cars has a proportionately larger effect on air quality. Thus strategies to increase the use of ferries for the reverse commute such as preferential pricing might benefit air quality. Other suggestions include actions to reduce the air quality impact of travel to and from the terminal.

The WTA EIR also addresses energy use. Energy use is also effectively a proxy for greenhouse gas emissions, since most fuels emit carbon dioxide pretty much proportionately to their energy content. The CALSTART report addresses CO<sub>2</sub> emissions directly. The WTA EIR estimates that ferries require 4,360 BTU/Passenger mile vice 4,342 for the auto/rail/bus combination that would result from no additional ferries. This is pretty much a push considering the imprecision of the basic assumptions, and it is easy to see that some changes may radically improve the energy efficiency of ferries, and thus lower their greenhouse gas impact. The CALSTART report finds that Tier 2 engines alone, or in combination with technologies that do not lower engine temperatures to control NO<sub>x</sub> formation (such as SCR) provide the most reduction of CO<sub>2</sub>. Thus there is even a trade-off between greenhouse effect and the adverse effects of the other pollutants. Ferries on some routes are better from a viewpoint of global warming.

Dredging is another environmental impact, and in some harbors, the disposal of dredge spoils is a significant problem, because they are polluted with heavy metals or other toxic materials. Here the key is to design boats and select sites for minimal dredging.

Anti-fouling paints, and to a much lesser extent topside paints also have environmental impacts. Low VOC paints are rapidly being developed that provide good protection and appearance without air quality issues, and aluminum can be left bare. Applied thin films also provide excellent cosmetics and protection at relatively low labor costs. The Coast Guard is no longer painting their 41-foot utility boat topsides, and the production 47-foot motor lifeboat topsides were never painted. Instead, a glass bead finish process has been developed to provide an acceptable appearance with the requirement for cosmetic painting. Tributyl tin bearing anti-fouling paints are being phased out and are being replaced by non-toxic low surface energy slick coatings. These paints self clean by the effect of the boat's motion through the water. These coatings require that the boat be relatively fast and operated frequently, which is certainly an acceptable requirement for a ferry.

A certain amount of waterfront loss is inevitable for a ferry terminal, but this too can be minimized. Likewise, good strategies for effective intermodal connections can minimize local effects, and the whole point of a ferry is to minimize regional effects. One strategy for minimizing perceived waterfront loss is to use mainly floating terminals. The Sea Bus system in Vancouver's Burrard Inlet uses entirely floating facilities made of concrete, though in this case to deal with a 17-foot tidal range. However, the terminals are expected to have at least a 50-year life, Case (1981). Terminals in sensitive areas could also be placed well away from shore, connected by floating or cable suspended walkways.

An even more interesting (though perhaps extreme) possibility for mitigating the impact of both terminals and

wake is a revival of the oldest ferry technology: The terminal itself could move out to the ferry by hauling itself on an underwater cable.

Even accurately evaluating, much less minimizing, environmental impact requires careful evaluation, with great potential for surprises and surprising opportunities for improvements. Good science is important and flawed environmental science is harmful in a similar fashion to medical quackery; both delay appropriate treatment and allow the patient to be harmed meanwhile. Regardless of any possible flaws in the pessimistic studies, though, it has had an effect of bringing the marine industry to "flank bell" with regard to alternative propulsion and other measures to minimize air pollution, so it is not a total loss. For example, Ecosound has in production a system comprising a special wet exhaust system with a water separator. The water is subsequently filtered and the HC and particulates are removed (Fulk, 2001). A ferry system may also be an opportunity for encouraging other changes in transit preferences based on pricing or terminal parking policies.

A properly planned ferry system can be an ecologically effective, and may give important opportunities for environmental improvements beyond just ferries.

## WAKE AND WASH

*"I leave a white and turbid wake"*

*Starbuck, Moby Dick*

Wake wash is another environmental issue that requires careful evaluation. Most of the major impacts (literally) of wake wash have been seen in Europe, where a fast ferry might be a 100 meter long vessel with several hundred passengers and a couple of hundred cars and trucks, doing 36 knots. This is a very different creature than most of the commonly proposed commuter ferries, but large fast auto carrying ferries might have significant issues with wake. The wake sensitivity of an area also varies along the routes. Blume (2001) has discussed the work of the International Navigation Association's (PIANC) Working Group 41 to develop guidelines for managing wake wash and notes that wash is highly dependent on channel conditions and their interaction with vessel characteristics and speed. Slower vessels can also produce large wakes depending on the channel depth. Effective management of wash requires an understanding of how wash creates risk in a specific site for property damage, to persons on the shoreline, and to the environment. The working group therefore is developing guidelines for a careful, site specific, risk based evaluation process for wash effects rather than generic standards.

## 80 L. Ton, 120 Foot LOA

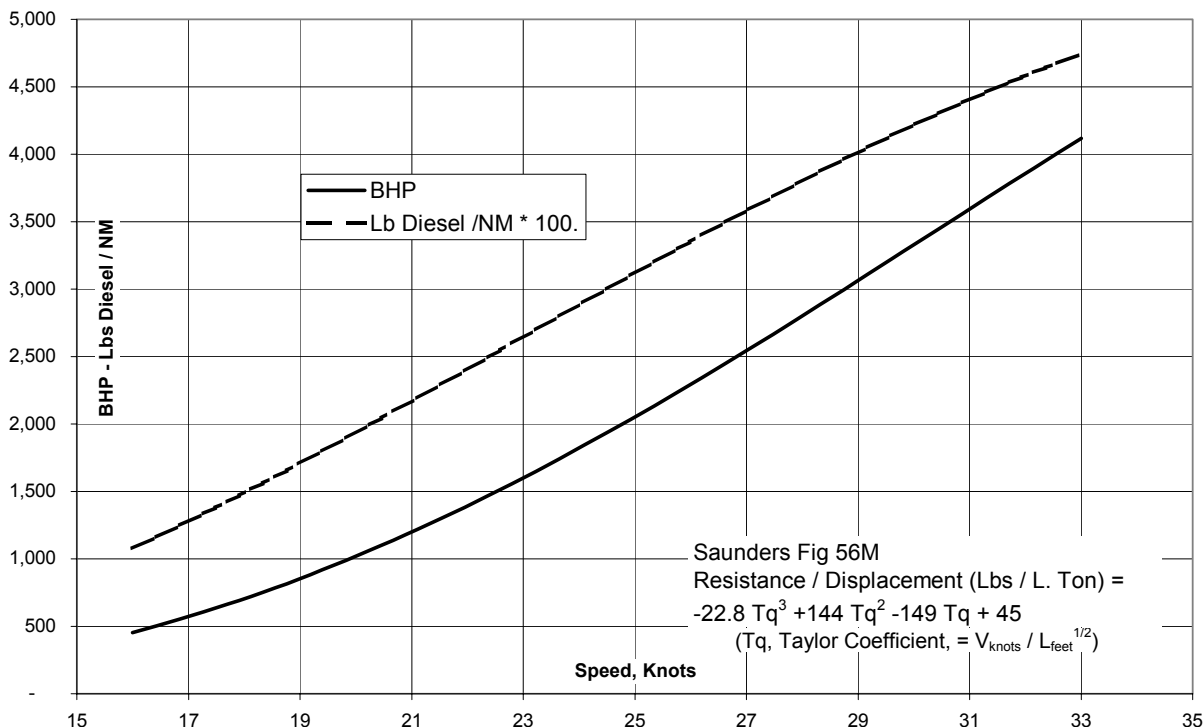


Figure 1

## ATTRACTING RIDERS

*"If you build it, they will come"*

*Field of Dreams*

Unfortunately, this is not really true. A ferry system must offer a higher level of service, as considered by enough riders to make the system viable, than other modes. Level of service is the overall measure of all service factors that affect users and includes speed, price, amenities, convenience and comfort, both on the vehicle itself and in the terminals. The perceived level of service, and what factors make it up also varies strongly from rider to rider according to both practical and emotional needs.

Speed beyond about sixteen knots or so increases costs rapidly for waterborne transit in typical ferry size ranges, so the lowest acceptable speed will almost always be the least expensive (and have the least environmental effects, and so on). Figure 1 is a more or less generic calculation of reasonably good speed and power for a nominal 120 foot, 80-ton ferry based on a fit to a plot in Saunders (1957). Power required increases as the cube of speed, and the fuel use as the square of speed. However, if the overall trip time for a ferry is much larger than that for competitive modes, it will be a perceived reduction in level of service and may affect ridership.

However passengers do not want fast boats, they might want fast trips, and their trip begins at home and ends at work. There is also some question about how

much they want them, and that varies from service to service. Passengers did not care enough for fast trips to keep the Seattle area passenger ferry running. (Figure 2) This ferry carried passengers only at higher speed, but at a cost premium compared to the larger, slower car and passenger ferries. There was insufficient ridership to support this premium speed service. On the other hand, the additional speed of some of the New York City services seems to be well enough valued that they are run at a profit.

Simple calculations can compare ferry routes to the land alternatives. Note that trip time must also consider various delays. The delay is the time spent waiting for the ferry, getting aboard, waiting for it to untie and maneuver at low speed and similar events on the arrival side. Assume the competing mode is BART, from downtown Berkeley to Embarcadero: With a five-minute delay, a 19-knot ferry beats BART even if the rider happens to step into a BART platform just as the train opens its doors, and if the rider arrives on the platform to see a train accelerating away, a 19-knot ferry is competitive even with a twenty-minute delay. Assume the competing mode is auto, vanpool or bus travel based on mean speed from Shrank and Lomax (2001). A Vallejo / Marin commute shows a competitive speed range of 22 to 28 knots and a competitive speed of 30 to 38 knots is required for a Vallejo to San Francisco route, depending on delay. In each case, the role of reducing the delay in reducing the required speed is substantial, so efforts to reduce loading



Figure 2

time, maneuver time, and connection time may be more profitable than efforts to increase speed. Again, the Sea Bus is an excellent example of a system where loading and maneuver times were carefully minimized, achieving an amazing 40 second loading period for 400 passengers. (This system is also very highly optimized to its intermodal connection and the reference is highly recommended in general for ferry planners.)

The waiting time depends on three factors; the time between ferries, schedule reliability and the probable variance in connection time to the ferry terminal. This last factor is more important than the actual time itself. Riders will generally, (though unconsciously), regard the probable time of arrival at the terminal as that which is within two standard deviations of the average. Informal surveys of transit times involving the difficult Washington DC Beltway by one of the authors suggest that there, the two deviation commute is within five minutes even for very long times. If this variance is typical, a ferry rider will time the connection to wait five minutes or less. If the variation is larger, riders will allow more time for delays getting to the terminal, and thus wait longer. However, the wait is also limited to the maximum time between ferries. This tends to favor more, smaller vessels, leaving frequently, so surveys of connection time variance are an important part of planning a system. This is also true for land modes, but the overwhelming economy of high capacity vehicles for land modes makes such a course of action very unfavorable, (Vuchic 1981).

It is also important to realize that the difference between frequent departures and fast trips is sometimes not adequately distinguished in passenger surveys. There is some evidence that time of trip is much less important than time waiting at quayside for a boat. Though fast boats allow frequent trips, so do many small ones.

A commute ferry has another issue affecting optimum speed: vessel productivity. Though all ship designs have to trade cost of speed versus rate of goods moved, there is about a two hour or so band of time each day, each way, during which there is substantial passenger demand. The ferry has to be fast enough to make as many trips as

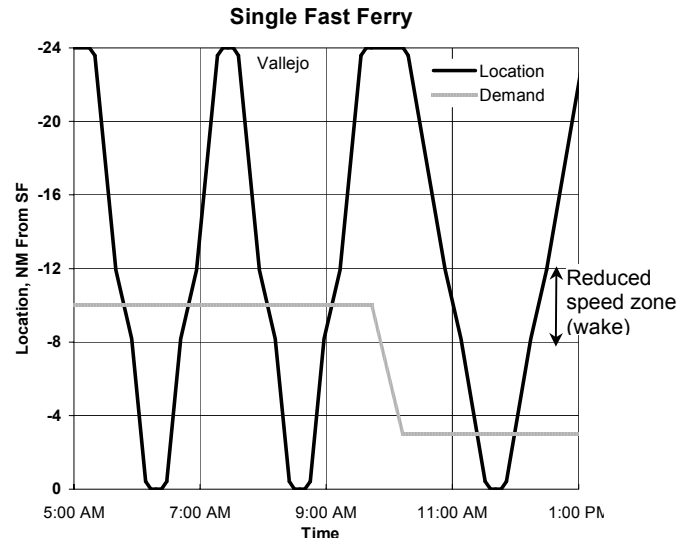


Figure 3

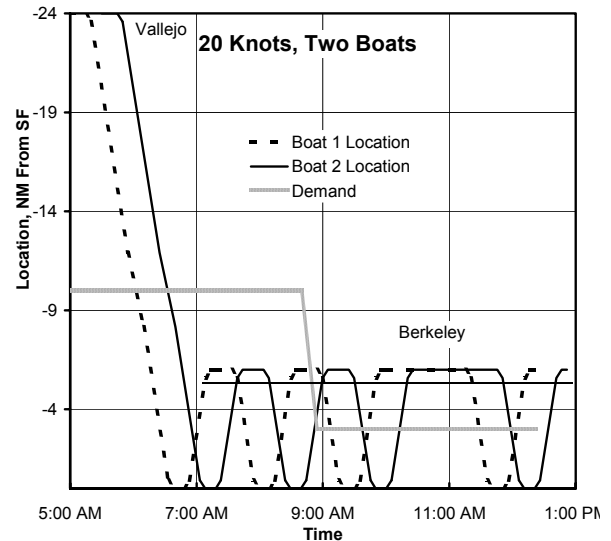


Figure 4

possible during the rush. If a run is fairly long, this requires substantial speed. Figure 3 shows the location of a ferry running between Vallejo, California and San Francisco as a function of time of day, over a passenger arrival time demand curve. Note that in order to make two trips in the rush hour, a fairly high speed is required. Later in the day, the boat can “slow steam” to save fuel when the demand for fast trips is reduced (a simple strategy which might substantially affect the results of the environmental studies). Figure 4 shows an alternative strategy: two slower, smaller boats leave at different times, thereby supporting the travel demand, but in each case, after a single trip to San Francisco, they go onto a short run. This kind of strategy might reduce the demand for speed in an integrated system such as San Francisco. Note also that the Potomac River Jet was intended to

spend mid day on short runs in the immediate Washington DC area.

A long haul ferry is not as subject to daily vagaries of load, so the productivity question is less demanding, though the relatively small size and demanding nature of the goods hauled (cargo containers don't need toilets or snack bars) means that crew cost of a long haul ferry can be fairly high, so that higher speeds may be more profitable. Long haul ferries generally have seasonal and weekly variations to contend with, though.

The convenience of a ferry system will always be a significant liability. Very few riders live next to a terminal, so there will always be at least one transfer between modes for a ferry trip. Good intermodal connections are thus critical to successful ferry systems. A rule of thumb is that each transfer deters fifty percent of users. It is difficult to imagine many riders tolerating more than one additional transfer between home and arrival at the terminal. It is important to approach this systematically as well: The authorizing legislation enables the WTA to operate buses as necessary to provide connections and the design of this support service will be as vital as any other component of the overall system. However, the authors feel that this element is so critical that new, innovative measures are required in addition.

Cost is another element of level of service. The ticket price for the Berkeley – Embarcadero center BART trip is \$2.75 one way, which would probably be difficult to match in a ferry without substantial subsidy, so other aspects of level of service as perceived by the riders will have to be higher.

Comfort is another element of level of service, and is an advantage of ferries, especially in the relatively benign sea states in inshore estuaries. Note here that as long as tonnage limits aren't pressed too hard, length is an advantage for watercraft and relatively inexpensive, perhaps even producing substantial resistance reduction. This reduces both first cost, (steel is generally cheaper than engines) and operating cost, through reduced fuel use and engine maintenance (just overhaul cost on a diesel for a fast military patrol craft can add as much 50 dollars to each hour of operation). This means that space and especially open deck space is relatively inexpensive.

Thus, ferries can be long and spacious, and few vessels would be small enough to cause seasickness for most riders. Noise and vibration can generally be better controlled on a boat than on other modes. There are some issues to be careful of though: Some people are very sensitive to diesel odors, which may occur on open decks in following winds. (Buses often also smell, but don't usually have open decks.) Arrangements also require thought; recent British Columbia fast ferries were widely criticized for a seating arrangement based on groups of four, which tended to leave inadequate seating when used by smaller groups.

Ferries also can offer amenities unfeasible on other modes, (including, of course, a pleasant boat ride) again

because of space, and because of open deck areas. Even if food service is not provided aboard, most ferries can allow people to bring food, can enable snack service at or near the terminal, and can provide space and quiet to consume food. Restrooms are required on ferries, and on the Seattle ferries are very important for riders preparing for work. It is said that the hair dryer outlets consume more power than main propulsion in the morning. Spacious interiors are beneficial for some persons with disabilities, and open deck space (and benign weather) can allow riders to bring bicycles or companion animals, which are important issues for some riders. (Disabled persons, cyclists and even dog owners can be substantial advocacy groups in some areas.) Amenities also extend to terminal design and features including security and comfort features as well as the opportunity to buy a latte.

The key problem is to determine those features that contribute to a high enough level of service to attract sufficient patrons, which may produce surprises. For example, some ferry riders prefer a slower ride as it allows enough time to read the paper or finish a snack. (There is a legend that the lengths of *New Yorker* articles are optimized for the Long Island Railroad commute into Manhattan.) One way that this can be determined *a priori* is to conduct extensive surveys, and the WTA is engaged in this now. However, in addition to the cautions normal for surveys, Hockberger (2001) offers some cautions specifically to ferry planners, most notably that responses to polls aren't commitments and aren't based on real world experience by those polled. The authors would like to offer an additional amplification on one of Hockberger's comments: Ferry travel is perceived as fun and pleasant, especially by its enthusiasts and those not using it every day, but for most travelers, transport of any kind is a means to an end, a "pain in the rear" to quote exactly, in the long run. Travelers eventually decide on modes based more on disutility, negative factors, than positive ones. Ferries have some probable disutilities, including cost, the inconvenience of connections and probably time. Planners need to work on minimizing negatives and to account for this sort of "honeymoon effect" in their polls.

The authors would like to suggest actual experiments with real ferry riders to investigate true effects of delays, speed and so on. A group of riders could easily be offered reduced fares to participate in various types of experiments, especially involving intermodal connections, and then be interviewed in focus groups. Experimental psychologists are very good at devising means of deceiving subjects to get to the truth in these sorts of studies.

## INTERMODAL CONNECTIONS

*“Getting there is half the fun”*

*Old ad slogan for rail travel*

As many sources have pointed out, most recently Hockberger, (1996), a ferry is part of a chain of transport. The profound effect of both delays and the disincentives of transfers mean that ferry planners must make intermodal connections a key focal point.

If cars are carried aboard, much of the problems of intermodal connections are eliminated, but even long haul ferries often have passengers that don't bring cars, so there needs to be good transit connections at each end. The operators of the proposed Crisfield ferry would be wise to keep in mind the importance of providing some transit within the Crisfield area to connect arriving passengers with summer homes, resorts or the other tourist facilities that are envisioned to be part of the area's revitalization. Cabs or jitneys (small privately operated passenger buses, usually now minivans), a “character” area shuttle, and a rental car outlet might be as vital as the boat itself, and would be an important draw for short-term visitors. (Note that Martha's Vineyard and Nantucket both have such systems running during the summer using school buses, and Whitbey Island has a free shuttle system running the length of the island.) In addition such systems often have passengers that arrive in their cars, but park them instead of boarding them, so access to adequate, secure, convenient parking is important.

Fortunately, ferries also provide a unique feature that simplifies intermodal issues, especially for urban ferries. A ferry terminal is a destination that splits a transport system into two parts, one on each side of the water.

The intermodal connections are two each “many to one” systems, and are orders of magnitude less complex than a “many to many” general urban system. The most obvious effect of this is to increase radically the feasibility of paratransit, especially carpools. A carpool or a public paratransit system (like the ubiquitous Supershuttle airport jitneys) is only feasible if the users share either a destination or an origin. Thus carpools generally are workplace based with members of each pool living somewhat near each other but having a nearly common destination. A ferry terminal is such a common destination, and people with quite different final destinations (especially if ferries depart the same terminal for different end ports) can easily carpool together. All that is required is that the ferry operators facilitate carpooling by strategies as simple as rideshare boards, or preferential parking. Often, two income earners (in a family) are going to different destinations, only one requiring ferry service. This allows “kiss and ride” carpools which do not even require any parking at the terminal. The success of single destination paratransit systems like Supershuttle suggests that such jitney services would be economically feasible for a ferry as well, and at lower rates, since vans could be reliably filled

every day and commuters could be charged by the month. (Such a system operates now between Annapolis, Maryland and several federal agency headquarters in Washington, DC.) Again, it would be relatively easy for a ferry operator to facilitate such systems. At the destination terminal, company sponsored paratransit is effective as well, and terminal pickup vans have been running for decades in conjunction with many public transit systems. Again, a ferry operator can facilitate such connections very easily by dedicated access lanes.

Since one environmental objection to ferries is the impact of parking and traffic at the terminal site, another obvious solution based on “many to one” is multiple remote “park and ride” (and ride) sites served by a dedicated bus feeder. This adds a transfer, which is a disincentive. The authors would like to introduce here the notion of the “strength or weakness” of a transfer. The deterrent effect of a transfer depends on how strong, or perceptible, it is and this deterrence can be minimized. After all, most people do not avoid changing modes to ride in an elevator, and some airports have light rail systems connecting terminals. Minimizing the adverse impact of a transfer can involve psychological means such as common color schemes and practical matters such as combined ticketing at the first mode and careful scheduling. If a park and ride bus always arrives at the ferry when it is ready to board, the wait to leave will not be perceived as inconvenient as arriving at an empty quay and waiting for the ferry. This is the case even if the real time between leaving the bus and the ferry departure is the same. Good thinking about the connection between bus and ferry, plus the ability of the operator to coordinate in real time between ferry and bus if needed may reduce the impact of the transfer, especially if terminal “mechanics”, such as ticket purchase, can be taken care of at the park and ride lot or aboard the bus. (Obviously, the bus could also serve foot passengers as part of the park and ride loop.)

The pain of transfers can also be reduced by technology. Studies performed by the WTA suggest that making them more predictable, through such techniques as real time information on schedules at stations and over the Web can mitigate the disincentive of intermodal connections, and such techniques are reasonably feasible with current technology. One scheme would be to connect the stops by low power radio and have them relay data to each other and to standard wireless devices used by riders nearby to display a countdown to bus arrival. The next time readers download a large document from the web; they might consider how such information can reduce somewhat the discomfort of a wait. It is possible that schedules could even be optimized in real time by such a system using software based on fuzzy logic.

A more radical option is to encourage the use of “light urban vehicles” as an intermodal system. LUVs are non-freeway worthy vehicles including bicycles, hybrid human/electric vehicles and small electric cars

(“neighborhood electric vehicles”; essentially fancy golf carts) to connect to the ferry. In 1998 a ruling was handed down by NHTSA allowing such vehicles on roads posted at speeds less than 35 mph at local option. In one such plan, the New York Power Authority, with the Long Island Railroad, is offering commuters a lease of Ford Think City electric vehicles, preferential parking with recharging facilities and a discount on the monthly ticket Sharke (2002). The schemes to encourage such vehicles are endless. Bicycles and single person hybrids are a no-brainer here – there is no reason not to allow bikes secure storage at a terminal or even aboard the boat, but planners need to ensure that terminals are bike-friendly, with traffic controls to make cyclists safe from other traffic. Required remote parking for non-preferred cars (not carpools or LUVs) and highly controlled “kiss and ride” lanes would go a long way toward this by reducing traffic at the terminal.

## NEW TECHNOLOGIES

*“These are the days of miracle and wonder”*

*Paul Simon, “The Boy in the Bubble”*

New developments often require more than just an effective technology to be viable. Automobiles requiring special fuels, for example cannot function without a wide spread infrastructure of stations offering this fuel, which in turn requires many automobiles using it, a sort of “chicken and egg” dilemma. The computer operating system wars provide a real world lesson in this. A ferry system provides an opportunity to demonstrate and nurture special technologies because it is relatively self-contained and limited in scope. A ferry system might well just be the initial catalyst for a more widely applicable technology, and therefore have effects far beyond just getting people to work. That said though, it is important to realize that a ferry operator has a fiduciary duty to provide cost effective service. If a ferry is used as a demonstrator for some new technology with wider benefits, those that benefit should pay, and the operator should be compensated specifically and explicitly by public sources (such as state general funds) through earmarked grants, for the impact of using the technology.

Computers themselves are a new technology that enables many others. Some Computer Aided Engineering gurus have called this the “Age of Customization”, because CAE/CAD/CAM enables an integrated environment that affords very rapid and thorough design, analysis, and prototyping at minimal cost. One group has developed a completely new rocket engine in less than a year using only a small team and desktop software. Specifically for high-speed craft, Home aircraft builders have used these techniques to build flight qualified (for experimental aircraft) gas turbine engines in their garages. Ulak, Akers, *et al* (2002), have recently implemented and validated methods for direct computer simulation of the

behavior of high-speed craft in waves, improving optimization and reducing risk. An engineer with a laptop and a modem can design and model a system in three dimensions, perform Finite Element Analysis, Computational Fluid Dynamics, and many other analyses on it and send the model to a rapid prototyping service. The next morning, a FedEx package will come with a precise model of the part in plastic. Meanwhile, another vendor can take the same model and part, investment cast it in stainless steel and finish machine it. One of the authors developed a simple system at a shipyard that used parametric hull and systems models integrated with speed and power and stability software. Within a week after receiving an order, a construction design for an aluminum workboat was complete and files to cut all the aluminum parts were sent on line to a distributor, who delivered them the next day. There is also much more understanding about “thinking about thinking” and software tools to aid in this. All of these techniques enable new solutions and customized designs at much lower cost and risk than ever before.

## ALTERNATIVE FUELS AND PROPULSION

*“Row, row, row your boat”*

*Traditional Round*

Ferry planners are investigating a number of alternative fuels and propulsion technologies. The authors would like to add something to this, keeping in mind the desirability of looking at a fuel through its entire cycle.

Gaseous fuels, especially natural gas (mainly methane) are especially attractive. It is relatively less polluting than other fuels, both with respect to trace materials like hydrocarbons and sulfur, but also with respect to carbon dioxide generation due to the higher ratio of hydrogen to carbon. Geological origin natural gas is also widely available (though not as cheap as it used to be).

Methane is also available from biological sources through anaerobic decomposition of non-food plant materials (and insect materials such as chitin, but this might not be practical). Most plant material is long chain sugar polymers, but these molecules can be broken into glucose (cattle are outstanding in this field) and then decomposed to methane by bacterial processes, which could be warmed by solar energy. Though this requires collection systems that might have adverse impacts, it would also reduce methane now entering the atmosphere from agricultural waste. Since methane is a very powerful greenhouse gas, this might be a net benefit, but again, the whole system needs to be accurately evaluated.

The main problem of methane is that it is very bulky and the systems (which have to be at the terminal) to compress it to pressures at which storage aboard becomes feasible are potentially noisy, expensive and require energy. The authors have conceptualized a straw man

149 passenger ferry running 18 knots on two 600 horsepower engines for a variety of issues. If fueled twice a day on methane, (at 8 round trips per day) it would need 242 cubic feet of cylinders at 150 atmospheres. This is twenty each eight-foot by one-foot cylinders. A comparable liquid fuel rate would be 337 gallons per day, fuelling once. (And note that liquid fuel storage can be discounted against tonnage by storing it in tanks with deep frames, whereas this isn't practical for cylinders - lightening holes in deep tonnage frames can't line up.) Is this volume of fuel storage practical? Good question.

Another problem with methane is that it doesn't work well in diesel engines. It doesn't ignite under pressure and has other drawbacks such as lack of injection pump lubricity. One solution to this is gas turbines, which are compact, powerful, and have relatively low emissions. Unfortunately, they also have relatively poor fuel economy and require substantial air intakes.

The Navy explored a solution to this in the '90s, and better yet, it also reduces NOx emissions. This is Steam Augmented Gas Turbine, SAGT. This system uses the hot exhaust to fire a boiler. The steam is then injected in the combustor where it is heated even more. This lowers the temperature in the turbine, which reduces the efficiency somewhat but also reduces the thermal load on the turbine blades, so they can be made of less exotic materials. However, picking up the waste heat in the gas turbine exhaust lowers the bottom end temperature of the cycle, which is much more effective in increasing thermal efficiency. The big gain is that mass flow through the turbine is increased without increasing compressor load, (which is parasitic on the system) or airflow. As a result, power produced in LM2500 turbines fitted with this technology was tripled and fuel consumption for typical DDG 51 service was reduced by almost 30%; Urbach (1994). There are numerous variants of this technology with various stages of intercooling and reheat, but it is worth exploring, especially since the lower limit of waste heat recovery temperature in conventional fuelled engines is based on the condensation temperature that would produce corrosive sulfur compounds. A methane fuel SAGT plant could "squeeze" its exhaust even harder for better efficiency. A ferry is an ideal platform for this technology as one drawback to SAGT aboard a warship is the weight of a reverse osmosis plant to produce the necessary injection water. A ferry would not need to carry this equipment - it could take on water as well as fuel. The technology of RO has also improved. One of the authors recently contacted vendors of such equipment and acceptable purity is now achievable in two pass rather than the three pass systems required a decade ago. One drawback to this system is that the steam produces a large visible plume, (which is a severe problem for a combatant). A ferry operator would have to be sure the public knew that the plume was steam, not smoke.

It is also worth noting in passing that more or less conventional steam is another candidate for gaseous fuels. Since a ferry can take on water frequently, it can use a once through system, exhausting steam to a direct contact condenser at very low temperatures. This also eliminates the steam engineer's least favorite device, the deaerating feed heater. Feedwater can be deaerated ashore, (possibly with solar heat) in a tower. The turbine can also be simplified. Radial inflow turbines are inexpensive, simple, very efficient at a single design point (though poor elsewhere), but a ferry runs at mostly constant power and speed. To add yet another choice, note that the Navy also has explored gas turbine heated steam either for additional shaft power or to run the first stage of air compression; Marron (1981). Again, on a ferry, this could be very simple as it would be once through.

Another gaseous fuel is hydrogen. This can be used in turbines, fuel cells, or if pure oxygen is also available, in a direct steam generator with water injection into the flame. Hydrogen is even worse for storage, (unless new technologies based on chemical storage or absorption proves feasible). The straw man ferry requires 34 cylinders. However hydrogen can be produced from solar energy and it is interesting to imagine a solar powered system to generate it just to see if it is at all even vaguely possible.

To just get a bound on the feasibility of some kind of solar power scheme, we explored solar heated magneto hydrodynamic (MHD) power. Though ultimately photovoltaics may be more efficient, the basic physics of MHD is easy to use to get an estimate. It is the same as any other heat engine, though instead of spinning a turbine, MHD works by passing a conductive fluid through a magnetic field. Most MHD systems use hot gases from burning fossil fuels, generally with an additive to increase conductivity. This means that they are essentially a bladeless gas turbine, but they still have to have a compressor and the resultant losses. However, a solar system can use boiling mercury instead, since it is highly conductive (thereby eliminating the need for super conducting magnets - MHD power density increases directly with fluid conductivity and with magnetic flux density squared).

Liquid mercury is pumped onto a porous heat-absorbing medium (graphite powder, for example) in a cavity illuminated by a reflector shining through a high temperature lens. The mercury boils and the hot vapor expands through a nozzle. The rapidly moving vapor passes through a magnetic field and electric current is generated in pickups on the nozzle walls. At the end of the nozzle a chamber with cooling coils condenses the mercury back to a fluid. This is just a steam engine with a funny turbine and can be readily analyzed, at least to a back of the envelope level, by classical thermodynamics, a mercury properties table and just a bit of magneto hydrodynamics. Something similar could be done with regular water steam turbines, but MHD (both as turbine

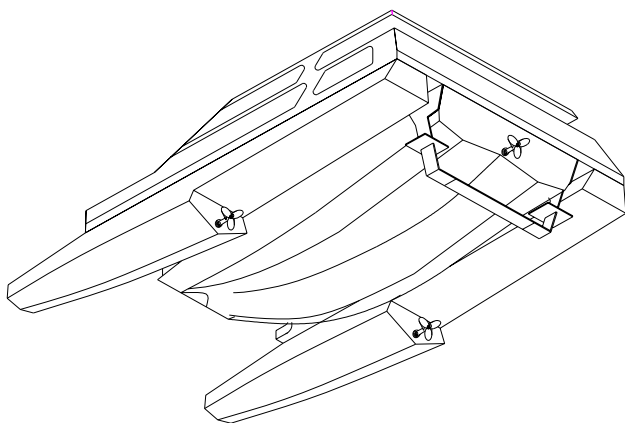


Figure 5

and as pump) allows a sealed system with no moving parts, (except a fan or water pump to cool the condenser) which is attractive.

The bottom line is that a mercury MHD plant running between 1390 F and 329 F would be able to achieve about 43% overall efficiency or a bit better. (These calculations are left to the reader and will appear in the quiz.) Based on standard figures for sun tracking reflectors at 38 degrees latitude, the raw solar input is about 3 MW hours per square meter of reflector per year, yielding about 1.3 MW hours per square meter per year. The same straw man ferry as above, counting losses due to electrolyzing water, compressing hydrogen, and a fuel cell aboard will require about 98 reflectors, each five meters in diameter. This would take up a collector field of about 2 acres, or the equivalent area of a parking lot for 270 cars.

Assuming each dish and an allocated portion of the compression and storage system is \$15,000, plus land and maintenance, gives energy cost equivalent to diesel fuel at a bit over \$3.00 per gallon. With still more shaky assumptions, the energy cost of a round trip ticket is about two dollars, roughly a dollar more than a diesel powered craft. Obviously this cost probably is wrong by a good deal, but it is unlikely to be less. Is this cost differential acceptable? Are there any adverse impacts to planting these solar dishes filled with mercury steam all over the parking lot? Should society subsidize ferry riders using solar energy directly? How much? Are the authors totally out in left field with these analyses? All good questions which are left to the reader as well, but it does suggest that there may be something to some kind of solar scheme in the long run, as well as its limits.

## HYBRID HYDROFOILS

*“Something old, something new, something borrowed...”*

*Traditional wedding superstition*

An obvious way to improve the viability of a ferry system is to improve the efficiency of the boat itself, especially if a high (hence costly) speed is required to be competitive with land modes. There are numerous

schemes to achieve this, and many depend on a combination of hydrofoils and planing lift. Hoppe and Migeotte (2001), for example, have been developing a series of systems comprising catamarans with hydrofoils between the hulls with substantial success, and several fast craft in service. The authors have developed a system, the stepped hybrid hydrofoil, which we initially thought was original until we sought a patent. We then found out it had been patented in a basic form in the '50s in Sweden, earlier versions may have seen military service in World War II and the Coast Guard even tested one in 1972-1975 as a high speed rescue boat (Williams, 1975). Now we have a mystery: Why don't we see them now? We now believe that there were critical issues creating difficulties for the early stepped hull hybrids and that this is why they are not now common, despite their obvious potential. We also believe that we have solutions for some of these problems, and present our suggestions.

A hybrid hydrofoil is a vehicle combining the dynamic lift of hydrofoils with a significant amount of lift from some other source, generally planing lift. The attraction of hybrid hydrofoils is the desire to meld the advantages of two technologies in an attempt to gain a synthesis that is better than either one alone. Partially hydrofoil supported hulls mix hydrofoil support and planing lift. The most obvious version of this concept is a planing hull with a hydrofoil more or less under the center of gravity. Karafiath (1974) studied this concept with a conventional patrol boat model and a hydrofoil. His studies showed large reductions in drag but also revealed that many configurations were unstable in pitch. The authors initially became involved with the hybrid concept when working on FMC's High Waterspeed Test Bed (HWSTB) for the US Marine Corps, which was a hybrid with an aft hydrofoil and a forward planing surface. The HWTB project is beyond the scope of this paper, but the concept worked. A half scale demonstrator representing a 66,000 lb. armored vehicle made 35 knots true speed.

Pitch instability is the chief issue in any hybrid hydrofoil and the variety of schemes are all various innovations to address this problem. Planing hybrid hydrofoils can exhibit dynamic pitch instabilities similar to porpoising. This phenomenon can be best understood for a nominal configuration with a single hydrofoil beneath the center of gravity of a planing hull. If such a configuration is slightly disturbed bow up from an equilibrium position, the lift on both the foil and the hull will increase. The hull accelerates upwards and the intersection of the water surface and the keel moves aft. This develops a bow down moment, but at a relatively slow rate. By the time the bow drops enough to reduce the excess lift, the vessel is well above the equilibrium position, and the keel/waterline intersection is well aft. It falls back down toward the equilibrium position bow down, as if it had tripped on its stern. Then, it carries through equilibrium, takes a deep dive and springs up again. This cycle repeats, each time growing more

severe. The only way that this motion can be damped is if the hull provides enough damping to prevent the increasing overshoot. Note that this is a smooth water instability and occurs with only a nominal initial disturbance.

The stepped hull concept is obvious from this discussion. The foil is at the extreme stern of the vehicle and a step is provided forward of the CG. The step confines the planing lift to the forward part of the hull so that the relative position of the center of gravity, the step and the foil control the proportioning of lift between hull and foil. Bow up pitch of the vehicle produces a strong bow down moment from the aft foil, directly proportional to pitch, that reduces the pitch much more rapidly than the movement of the center of planing lift. The step also means that the running attitude of the planing hull can be set at a trim producing optimum lift.

The authors developed simple programs, discussed in more detail in Barry and Duffy (1999), to predict the resistance of various hybrid configurations. They show that halving resistance is possible, but so is doubling it if the parameters are not correctly chosen. A stepped hull hybrid could be a very bad performer unless computer programs are available to optimize resistance.

When the bow of a stepped hybrid hull encounters a wave, it will initially rotate like a planing boat, but the rotation will increase the angle of attack of the aft foils, which lifts the vehicle bodily upwards from the rear and reduces pitch acceleration. The hull is therefore "anticipating" the oncoming wave and goes over it. This motion has to be carefully tuned to the anticipated wave environment for optimum performance, but it is clear that a properly designed stepped hybrid hydrofoil would have excellent motions, and methods such as those implemented by Akers (1999) can be extended to partial foil support. Since good seakeeping behavior is enhanced by high lift in the foil, good motions are associated with high lift efficiency, and the initial Swedish patent cites efficient seakeeping as an advantage of concept.

Unfortunately this doesn't address roll stability, which we discovered was a problem by experiment. The lightly loaded forward hull and fully submerged foils provide almost no roll restoring moment if the hull is optimized for low resistance. The answer to this is a catamaran forward hull.

We discovered another problem during the HWSTB program: A foil optimized for high speeds would stall without lifting at the relatively low takeoff speeds. We changed to "barn roof" foil sections, which resist stall to very high lift coefficients. These sections were unavailable prior to about 1970, and may be another critical issue for early hybrids.

Propulsion involves two other problems, especially for pure hydrofoils: Getting the force into the water often requires passing it through the struts which is costly in terms of money, appendage drag, complexity and efficiency. Unlike a pure hydrofoil, a hybrid can be

propelled by hull-mounted components. However, a hybrid also needs a propulsion system that will not overload the engine in the takeoff condition. This can be achieved by surface piercing drives forcibly ventilated by propulsion machinery exhaust or jet drives mounted in the forward planing hull and discharge at the step. Again these systems were unavailable to early hybrids.

A final problem is the practical issue of building the foils. Pure hydrofoils require exotic, expensive, stainless steel foils. The HWSTB had aluminum foils, but they required almost 24 hours of machining on a large five axis CNC mill, at frightening cost. A hybrid is slower and has larger foils at optimum. These foils can be made by casting high durometer polyurethane (roller blade wheel material) in a simple mold over a high strength low alloy steel welded core, so the foils themselves are affordable.

A ferry is a single speed vehicle, and the hybrid concept is well suited for this. A route requiring thirty to forty knots can be achieved at an acceptable level of cost and reliability with a hybrid. The stepped hybrid concept is much less dependent on size for speed and seakeeping than a conventional planing hull, so smaller, less expensive ferries are feasible. Our concept of a small passenger ferry is shown in Figure 5 above. Such a craft would be about 75,000 lb. full load and require only about 675 EHP to achieve 35 knots, so a pair of diesel engines in the 700 BHP range would be sufficient. Such comparisons are always suspect, but about 2000 BHP (total) would be required to propel a conventional monohull planing craft of the same weight to the same speed. A catamaran of the same weight with two 700 BHP engines would only be able to achieve 26 - 27 knots.

## SLENDER VESSELS

*You can't be too thin or too rich.*

It is worth pointing out that if you had said "fast commuter" at the turn of the 20<sup>th</sup> century, you would have been referring to a class of quite fast (20 knots or more) yachts used by wealthy individuals, not the public, for commuting to work. These yachts were characterized by very slender hulls by current standards (ten beams or more long). Since these vessels were generally steam-powered, they were also relatively low powered by current standards. This concept in vessel design might still be applicable to some routes today.

The authors did a quick design analysis that suggests that a 149-passenger ferry might be feasible with seating equivalent to interstate bus or first class airline spacing, in a 120 foot by 15-foot craft. The beam could actually be reduced further, but was chosen as the narrowest that fits the NPL High Speed Round Bilge Series (Bailey, 1976). This vessel would have acceptable intact and damage stability characteristics and requires power on the order of 1300 BHP to make about 25 knots. Such a vessel would

probably require some type of roll stabilization, but active fins are well proven for such craft, and considering the relatively high speeds, passive fins with stall resistant sections might be sufficient. Rudder roll stabilization, anti-roll tanks or even recent concepts using high-speed gyros might also be feasible. Such a vessel would not have enough deck area for moving around and for the extra amenities common on many new catamaran ferries, but this space might not be a significant factor for short runs. It is also worth noting that such relatively narrow vessels with bus-like seating are common in ferry service on rivers and in inland waters in Southeast Asia.

With multihulls, hulls of even greater slenderness are possible. The narrow hulls provide very low drag, especially in the high displacement-to-speed regime needed. They achieve the necessary deck area and stability by a variety of multiple hull configurations, including trimarans (with two small side hulls) or as many as four small hulls acting as “training wheels” (resulting in a pentamaran). Our straw man concept for Berkeley is a very slender hull catamaran. In this case, the low cost per installed horsepower at engine sizes based on land vehicle applications suggests two similar hulls. But for other sizes, where a single engine and driveline of higher power might be more economical than two smaller ones, asymmetrical multihulls (proas) have the potential to outperform the catamaran in terms of cost, resistance, and vessel motions.

## CONSTRUCTION TECHNOLOGY

*“Engineers and designers need to gain profound knowledge of the erection process and incorporate product design and process design producibility features into the detail design.”*

*W. Edwards Deming*

The final element of ferries is improvements in construction technology. CAD/CAM has had a major effect on shipbuilding, especially at small shipyards, which have been in the forefront of applying CAD/CAM to boat building. The important point of this change is that it enables a new enterprise to be competitive. In fact such enterprises, without established bad practices, will be far more agile in applying new technology and methods. Barry *et al* (1998) point out the importance of breaking old practices, re-engineering whole enterprises and applying lessons from other industries to small shipbuilding. A start up enterprise or an enterprise moving from repair to newbuilding can apply these techniques to start at a point old yards are finally achieving after years of “broken rice bowls”.

There are any numbers of case histories of radical improvements to demonstrate the benefits of a holistic approach to shipbuilding. The author’s shipyard tripled profits in a single year with a simple CAD/CAM system well integrated into production and sales. Bender reduced

labor costs by 20% on the first Offshore Supply Vessel that was built with an integrated system that included outfit, over and above earlier improvements from automated CNC part cutting. The Coast Guard YARD built a run of small buoy tenders with substantial savings to the taxpayer with these techniques. (Mercier, 1997)

Eight keys to these radical improvements are critical:

- Process re-engineering systematically examines the needs and capabilities of all members of the organization, and looks for opportunities to change for improvement, not only in particular processes, but in the interaction of processes.
- The integrated product model is the central reservoir of information on the product. CAD enables construction of the product model, while process re-engineering develops the conventions of information in the product model. A product model must be in 3D and includes non-graphic data and usually links to other databases.
- Design for CAM is incorporating features to improve productivity, and modifying design to take advantage of Computer Aided Manufacturing. Process re-engineering develops these changes so that they meet the needs of production.
- Advanced outfitting/group technology is finishing whole components as early as possible, and classifying and organizing tasks by location and type of processes/problems to plan installation.
- A flexible standard product line is building products by using standardized systems, preferably with parameterized details and standard components and thus predictable work, cost and process content.
- Concurrent engineering is doing design simultaneously across disciplines and includes all aspects of production as well as the final product.
- Advanced workflow control is a variety of techniques to schedule, predict and control work packages, increasing productivity.
- Statistical process measurement and control is the measurement and application of statistics to the results of all the other processes and changes.

It is worth noting that most of these techniques were applied during the course of about a year in a small shipyard building aluminum boats, including small ferries. This shipyard (in a high wage area) had a book value of about \$1,000,000 and turned over \$12,500,000 in production the following year with a profit of about 10%, resulting in an annualized return on investment of better than 100% up from 30% the prior year. These systems work well. They are mainly process and people improvements, don’t require new equipment, and can be readily applied anywhere.

The importance of re-engineering and being willing to look at construction processes in a completely new way can’t be over emphasized. For example, Oetter *et al* (2001) have proposed a new technique for building small metal developable surface ships which might be

applicable to fast ferries. This system was actually invented by TQM focus groups of shipfitters, welders, riggers and designers and is intended to facilitate advanced outfitting, which is often difficult in small vessels because the blocks themselves are too small, components are late and the engineering effort is too costly. Gribskov (2002) also notes that distributed systems such as piping and cable, end up spanning conventional ship type modules in small vessels and create rework to either connect or install subsequent to block joining.

The proposed system is as follows:

- All parts are precut using standard Computer Aided Lofting/Numerically Controlled Cutting (CAL/NCC) techniques.
- The boat is subdivided into blocks, each comprising a major surface, i.e. the port bottom plate, the port side plate, etc. Some grand blocks are also designated, mainly the two bottom plates together, the entire hull below the deck and the entire hull.
- A jig is made of angles set up on jackstands for each surface. The angles run along selected rulings of each surface determined during the lofting process. Other jigs are built for the deck and other flat surfaces.
- Other small jigs can be developed as required for assemblies (such as edge stiffened webs) to be installed on the surface blocks.
- The developed plates are set on the ruling jig, and the longitudinal and transverse stiffeners are installed.
- Foundations and brackets for outfit that will be connected to that surface are installed.
- The welded out surface is blasted, primed and optionally finish painted.
- Outfit components are mounted on the surface blocks up to limits implied by the need to lift and tilt the block. Since most blocks run the length of the boat, distributed systems can be installed now as well.
- The bottom surfaces are joined to the form the first grand block and all machinery bearing on the bottom is installed as convenient. Appropriate parts of the bulkheads can be installed at this point and subsequently.
- The sides are joined to the bottom and appropriate outfit and bulkhead parts are installed.
- The pre-outfitted deck and deckhouses are installed

This system (which is non-proprietary) may be useful, but more important; it is an example of the type of thinking possible to radically improve small ship construction through re-engineering.

## SYSTEM TOPOLOGY

California Proposition 13, along with other tax and land use policies, provides a strong disincentive to residential mobility in the Bay Area. Two worker

families, rapid employment changes and other effects also contribute to job/home immobility, or “job sprawl” (Crane and Chapman, 2003) provide disincentives in all urban areas as well as California. This means people do not follow their jobs as might be the case in other eras, nor will they necessarily locate to minimize their commute, so that the commute pattern becomes increasingly chaotic with time. The currently proposed topology of many ferry systems is a network converging on “downtown”, which is appropriate for the traditional central business district commute pattern. This pattern will probably become less dominant over time, however and may represent an opportunity for a ferry system. There are other types of transport topologies including spoke and hub and tangent loops. (Since San Francisco is nearly central to the Bay Area, the current system might be considered an informal spoke and hub system as well.) Spoke and hub systems imply additional transfers and hence are probably not optimum for most riders, but may be a critical opportunity for a minority of riders. Ticketing policies and schedules can maximize these opportunities for those riders even without a specific spoke and hub system. Loop topologies add additional stops for some riders (and longer voyage times) but not necessarily transfers for all and can serve a wider variety of destinations. Higher speed vehicles may be justified for either loop or spoke and hub systems and future technologies may make them more feasible. However, one of the advantages of a ferry system is that the system topology can be changed from voyage to voyage, so the specific long-term topology is of only minor concern in the planning stages. Nonetheless, planners should be aware of the need and opportunity to modify topology in the future.

## POLITICS

*"The trouble with Democracy is that there are never enough weekday evenings"*

Environmental and economic issues are frequently politicized as regards ferry services. Ferries were once the darlings of the environmental community. The historical reasons for this are fairly clear: Ferries are an alternative to cars; ferries interface well with public transportation; ferries interface well with bicycles; and travel by ferry enforces a non-automotive mode for at least one of the land legs of every trip. Most important of all, ferries can be far more fuel-efficient and far less polluting than cars. This was especially true 30 years ago, when ferries were slower and cars were dirtier.

In the case of the San Francisco Water Transit Authority, initial proposals, or at least their public perception, called for a network of small high-speed ferries connecting some 26 terminals. Unfortunately fast requires lots of power. There is nothing inherently wrong

with putting vision out first and doing the science later, as a promotional strategy, but in this case it backfired badly. The hypothetical fast ferry network was a very large and easy target for environmentalists. Fast ferries with no required emission controls naturally stack up very poorly against busses with the newest and cleanest engines. An unfair comparison, but the rock was thrown anyway and the target was hit.

As the debate moves further into politics, we are driven, probably prematurely, to consider zero-emission options similar to the Australian Solar Sailor, or the new fuel cell powered design project now under way. These are very low speed designs, intended more as demonstrations than as practical solutions. Demonstrations are valuable and the authors applaud them, but their prominence distracts from more basic approaches to the same problems and may lead to unfortunate disappointments with the result of condemning the entire concept of ferries if they prove impractical. If we slow down enough, the required horsepower per seat is about the same as a moped going downhill with a tailwind. For example, by slowing down from 36 knots to 12 we can reduce power and emissions by about 96 per cent. Does it make sense to commit all our innovative technological resources to eliminating the last four percent of emissions?

Even though the authors have offered a particular high-speed technology, we believe ferry planners should emphasize the strong dependence of environmental impact and cost on speed, and be very careful to select the appropriate speed requirement for each route.

Another example of exotic technology over basic solutions is the approach to minimizing wake. If we read the press about the possible approaches to this problem, we find the discussion centers on wave-eating hull forms, air cushion vehicles and other new technologies. There are simpler solutions. Resistance can be roughly divided into two categories: frictional and wave making. Every hull design is a trade-off between the two. Wake waves a problem? Take the trade-off differently: Accept more frictional resistance and generate less wave-making resistance (or just go slower, or even just avoid the wrong speed for the channel).

It is encouraging to see that WTA is gradually backing away from what was perceived, especially by environmentalists, as a high-speed large ferry vision, and articulating a more varied system. However, one result of this initial perceived vision is the Sierra Club statewide position paper opposing ferries in or near waterfront parks. If this is taken seriously - and unfortunately it probably will be - there are going to be many prime ferry sites that will face unnecessarily contentious political struggles. This is currently the case along the Berkeley/Albany waterfront, where some factions of the City Council have all but succeeded in striking Berkeley off the WTA's map, despite overwhelming popular support for ferry service in Berkeley.

Local opposition at one end or the other of the route has scuttled other system proposals. Some proposed New York area systems have met fierce opposition from residents near terminal locations. After having paid enormous prices for homes in quaint shore side villages, homeowners understandably took a dim view of thousands of cars passing in and out each day. The operators of competing modes may also oppose ferry systems because they see a ferry system as "cherry picking" their best potential patrons. Of course, the recent demise of a system to carry gamblers from New York City to casinos in Connecticut (because it was unable to get a suitable landing facility) was solely based on technical issues, not political ones.

The point here is that an important early step in a ferry system is to carefully select and groom terminal locations, and to either make friends with enough stakeholders to ensure sufficient support, or to give up quickly, before substantial money is spent on studies.

It is also important to increase visibility of the marine technical issues at an early stage, thereby making sure that at least technical issues don't provide problems, or even cover for more subtle issues. We reemphasize that seemingly minute vessel design issues may have significant impact in overall system cost, environmental impact or feasibility: "Such slips sink ships" (Webster, 1973).

## LONG TERM TECHNOLOGIES - A FUTURE OUTSIDE THE BOX

*"In Theory, there is no difference between theory and practice. But in practice, there is."*

*Jan L.A. van der Snepsheut*

We have a reasonably clear idea of what the next generation of ferries will look like. But what comes after that? Some informed predictions:

### ***Asymmetric multihulls***

Humans seem to have an irrational aversion to asymmetric vehicles, but asymmetric solutions might offer some unexpected advantages, and should always be kept in mind. Consider the slender vessel / training wheel concepts with small amas discussed above: The single long hull is more easily driven at displacement speeds than a catamaran, has better seakeeping characteristics, and in some cases, there are potential savings in installation, operating, and maintenance costs because there is only one engine and driveline instead of two.

The problem with these configurations is the unexpected high drag of the relatively short amas. For optimum proportions, we are probably best guided by the "natural" solution presented by the Polynesian outrigger canoe. The ama is quite long, but very slender. The optimized proa can be thought of as a trimaran with both

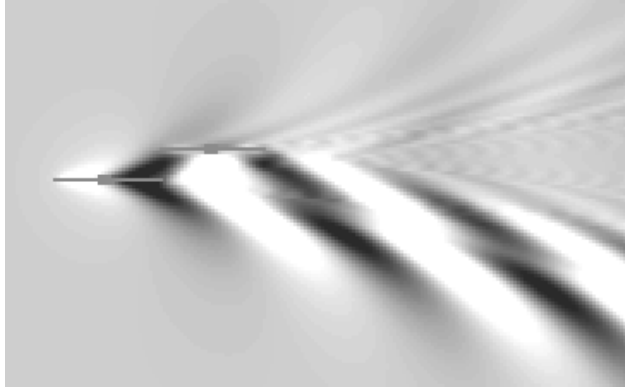


Figure 6

*A sample wake wave calculation from the Michlet program, showing an asymmetrical multihull configuration that leaves most of the wave energy on one side.*

amas placed end-to-end on one side, for greatly reduced wave making resistance.

Another contra-indication for the asymmetrical multihull is the fact that costs associated with one large engine are not always lower than costs for two small ones. Part of this is an artifact of the economy of scale available when using engines based on mass produced automotive or truck engines. Doubling horsepower in the 250-1,000 BHP range typically quadruples engine and gearset cost.

Future propulsion systems might not exhibit the same economy v. power relationship, however. Various systems based on electric drive or fuel cells might throw the balance back towards the proa.

Another possible benefit of asymmetrical multihulls is manipulation of the wake waves. It may be possible to build a vessel that leaves waves on only one side, Figure 6. (Tuck & Lazauskas, 1998). (This violates the answer to the classic trick question, "what happens if you tow a half-model down the middle of the tank?")

Applications for such a configuration are of course limited, but intriguing: Consider a large lake lined with waterfront properties, subject to wake damage. A circular ferry service, always circling the lake in the same direction, could benefit from an asymmetrical multihull that only makes significant wake waves on the offshore side. (There might have to be one boat for the clockwise route and one for counter-clockwise.)

#### ***Surface-piercing propellers***

These will gradually supplant waterjets as the preferred propulsive device for fast ferries. Surface-piercing propellers are well suited for high speeds because they are generally not subject to cavitation damage, replacing the vapor bubbles with entrained air brought down with each rotation of each blade.

They are more efficient because they allow a larger "actuator area" without compromising navigation draft or shaft angle. Unlike fully submerged propellers, which are

almost always too small and turning too fast for best efficiency, surface-piercing propellers have almost no practical diameter limitation. Coupled with appropriately deep reduction ratios, larger slow-turning propellers leave less wasted energy in the slipstream than fully submerged propellers, and much less than waterjets.

Fixed surface-piercing installations can also be considerably less expensive than waterjets. But it will take time for the industry to leave the current orthodoxy of waterjets for fast ferry applications (Kamen, 1989, 1990). (Note however that two of the authors are former employees of Arneson Marine, manufacturer of a surface-piercing propulsion system.)

#### ***Wing in ground-effect***

Evolution is amazingly good at optimization, and useful analogies can often be made to biological systems. When looking for natural analogs to surface vessels, we find a total lack of any animal that travels any significant distance by planing along the surface of the water. Similarly, we find no hydrofoils in nature. What we do find - and we find them in abundance - are birds and even fish that fly just above the surface in ground effect. In nature it appears to be either wing-in-ground-effect or displacement mode, and nothing in between seems to have survived to tell the tale.

The theoretical explanation is simple: As a hydrofoil moves closer to the surface, the water becomes "soft." Upwash is reduced because there is a reduced low-pressure field to pull the flow up as it approaches the foil, and downwash increases for the same reason. The flow is increasingly asymmetrical fore and aft, induced drag increases, and performance of the foil degrades.

But as a wing operating in air moves closer to the water surface, the relatively "hard" boundary of the water imposes a plane of symmetry that significantly reduces induced drag, and performance improves.

So whenever we have to operate at high speed near the boundary between a dense fluid and a thin one, it makes much more sense to derive all our lift from the thin one.

What does this imply for fast ferries?

Water is sticky stuff. When efficiency and high speed both become the most important parameters, WIG designs will dominate.

However, because the economics of these vehicles will resemble those of airplanes, the obvious question is, "why not just use an airplane? Answer: The WIG ferry does not need to compete for airspace or runways, both of which are in very short supply (Ebb, 1990)

#### ***Personal amphibians***

Earlier in this paper we demonstrated that the economy of scale is relatively weak for ferries. Because of crewing requirements tied more-or-less linearly to the number of passengers, there is little savings in crew costs for large ferries over small ones.

However, crew cost v. number of passengers is a step function with some interesting characteristics. Below 149

passengers (assuming a single-deck configuration), there is no reduction from the crew of two, so crew costs increase as the inverse of the number of passengers.

But when the vessel becomes small enough to be passenger-operated, this cost suddenly drops to zero.

A number of "boat-pools" (like van-pools) have been operated at various times, and their popularity is likely to increase.

Private marinas, however, are seldom located at transit nodes or close enough to downtown employment centers. This suggests a role for the personal high-speed amphibious vehicle.

Two of the authors have developed a conceptual design for such a vehicle. Unlike previous attempts at consumer amphibians, this one is capable of moderately high speed when waterborne, and is easily retrofitted to a wide range of existing vehicles.

As pressure to achieve urban mobility increases with congestion, the market will almost certainly produce a viable high-speed personal amphibian.

#### ***Electronic ticketing and faster boarding***

Ferry system planners are beginning to realize that the time spent boarding or leaving the ferry does, in fact, "count" against trip time. For a typical urban route of six miles, a minute saved at the terminal is equivalent to increasing speed from 18 knots to 19. This is a speed increase that would require about a 17% increase in installed power, and an 11% increase in fuel consumption per trip. Big doors and wide gangways are cheaper.

One of the decisions facing the designer of a ferry system is the location of the "control point" for ticketing.

For fastest loading the control point should be on the pier, so that all passengers are "inside" the paid system and ready to board when the ferry arrives. The disadvantages of the on-shore control point are that boarding areas have to be larger, passengers have to wait in a restricted area, and passengers cannot take advantage of nearby commercial services while they wait.

Controlling at the gangway, however, slows down boarding and increases trip time.

Collecting tickets after boarding, railroad style, is subject to abuse and for large ferries, places unreasonable demands on the crew.

Electronic ticketing, a la the CalTrans "Fastrak" now in use at bridge tollbooths, is a fairly straightforward solution. Although the control point is at the gangway, the electronic debiting of the ticket has no effect on the speed of boarding.

#### ***Dual mode - a new paradigm for ground transit***

Despite the tireless efforts of transportation planners, environmentalists and politicians to get people out of their cars and into public transportation, the brutal reality is that the personal automobile is here to stay. This is not as bad as it might sound, however. Various versions of the "dual mode" scheme promise to combine the convenience of the car with the efficiency of the train.

In a dual mode transportation system, individuals own small private vehicles that they park at home. These can be electric, hybrid or engine-powered when they are operated autonomously by their owners on local roads. On the freeway, they enter a guideway system and are computer-controlled, powered (and recharged) by the guideway, and can link up into trains to minimize air resistance and maximize vehicle density. A good example of a dual mode prototype is the "RUF" system developed in Denmark (Jensen, 2000).

How does this affect ferry design?

The dual mode vehicles occupy less than one-quarter of the volume taken up by conventional cars. They are much more standardized with respect to size and shape. And best of all, they are designed to be controlled remotely when on a guideway, so it is not necessary for the passengers to drive them onto a ferry. This means that there is no need to provide clearance for the doors to open, and no need for standing headroom on the car decks. Fully automated and optimized loading and unloading of the vehicles will be extremely fast and efficient, irrespective of whether the cars are moving forwards or backwards.

Dual mode vehicles will stack into a ferry so efficiently that we believe it is safe to predict the return of the car ferry, even on urban routes that parallel existing bridges and tunnels. That is, if dual mode ever becomes a reality on land, dual mode adapted car ferries will follow.

Meanwhile, and more within the time frame of our own life expectancies, we will probably see an increasing tolerance of small electric scooters along with bicycles on urban ferries.

## **CONCLUSIONS**

*"God intended people to travel by ship"*

*Cedric Ridgely-Nevitt*

Ferry systems are economically and politically justified even with substantial subsidy, but system designers have a duty to make sure that the systems are as cost and environmentally effective as possible.

Passenger capacity (especially over 149 passengers) and speed need to be very carefully considered and justified. Both are expensive, and other approaches may be less expensive and more effective in attracting riders and protecting the environment.

Environmental issues need to be very carefully analyzed, looking through the whole lifecycle of and supply chain of a system. Simple answers can do more harm than good.

The intermodal portion of the system is at least as important as the marine portion and probably more so.

The construction of ferries in the region served is a worthwhile goal and is feasible, even in a high wage area by using both established and innovative techniques for modern shipbuilding.

There are numerous innovations, some silly, others worthwhile, and some appearing to be one while actually the other. The authors have thrown out a few and leave it to the readers to judge which category they fall in, but the point is that there are a lot of ideas out there and marine professionals need to contribute their own, and be open to those of others. However, it is important to understand which are for now and which are for later, and to avoid making too many promises.

Many ferry planners specify commercial off the shelf (COTS) vessels or proven parent craft. This is sometimes even required by law. Returning to the theme of the frontispiece, one of the authors chose a “Toller” as a companion animal, because its tolling behavior gives it a playful nature and it has the temperament and the intelligence of the retriever breeds, but because they often traditionally work from a canoe, they are much smaller than other retrievers – or a boxer, for that matter. However, the “Nova Scotia” part gives it a heavy double coat and furred webbed feet, both of which require substantial grooming effort. Changing the task or environment of a dog requires acceptance of compromises because dogs are not available other than COTS (or literally “proven parent”) with any real predictability. This is not the case for a boat and the science of naval architecture is sufficiently well advanced that a predictable, reliable ferry with the desired characteristics, and only those characteristics, is usually possible without requiring a “proven parent craft”. We also note that “slight” modifications of a proven parent have been seen to be a very good way to get into trouble, especially those that add weight to high speed craft. The parent was presumably optimized, and a modification by definition moves it off optimum, and perhaps even over the edge.

All naval architects are familiar with the design spiral, but in the case of a ferry, the ship design spiral is an inner loop in the system design spiral. We advise that, in the course of their studies, that planners do “ship synthesis studies” using automated systems such as that offered by Eisele and Gupta (2003) to optimize requirements, and to determine the cost and system effectiveness effects of speed, passenger capacity, required emissions equipment and so on well prior to announcing the speeds, ship types and so on. There is plenty of time for boat rides later. Following optimization, “validation” or “point” designs should be done to confirm that their requirements are achievable and to further validate costs and other possible impacts, trade-offs, or opportunities. This is a very important step in any acquisition process, and a valuable learning experience to scrub and clarify the requirements documents. This may even lead to changes in the overall mission. However, once the validation design shows, for example, that an aluminum catamaran with surface drives can meet the requirements, all that has been shown is that there is at least one way to skin that “cat”.

In this regard, we would also advise planners, when they specify vessel designs, to specify interface and other

requirements (as validated) but not to specify vessel solutions or designs. Leave that to the designers and shipyards and allow them to propose their best solutions, taking into account their processes, experience and skills. A shipyard or a designer may come up with a better way, or one as good but cheaper, and the only way to find out is give the offerors as much latitude as possible and just look at what comes in when proposals are due. At this point, and not earlier, artist’s conceptions and boat rides are appropriate.

The Society of Naval Architects and Marine Engineers needs to become much more prominent and visible in ferry design and overall system design issues, especially as regards the interaction of system design and vessel design. The position paper on ferries was an excellent start, but the fact that even the staff list of the WTA does not use the term “naval architect” suggests more visibility in this area may be needed. There are numerous other opportunities for both passenger and goods short run water transport that would provide both economic and environmental benefits, and SNAME needs to be a leading voice, ready to advise those interested in this opportunities.

Finally, individual marine professionals need to be alert to ferry system proposals at an early stage, especially those involving public funds, and to participate. It is our duty, both as engineers and as citizens to contribute our expertise in appropriate public forums.

*The views and opinions expressed are those of the authors and are not to be construed as official policy or reflecting the views of the U S Coast Guard or the Department of Homeland Security*

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**Appendix A – Subsidy Calculation**

Year	Data From Shrank & Lomax		
	1998	1999	Difference
Daily Freeway Vehicle Miles Traveled (VMT)	45,145,000	45,710,000	565,000
Daily Arterial Vehicle Miles Traveled (VMT)	13,710,000	13,995,000	285,000
Daily Sum, Vehicle Miles Traveled (VMT)	58,855,000	59,705,000	850,000
Annual Congestion Cost	\$2,805,000,000	\$3,055,000,000	\$250,000,000
<b>Annual Congestion Cost / Daily VMT</b>			<b>\$ 294.12</b>
Assumed Persons / Vehicle			1.5
Berkeley Ferry Round Trip Road Miles			26
VMT Reduction / Ferry Passenger			17
Round Trip Sea Miles For Ferry			12
Maximum Persons Carried Per Trip			149
Trips / Day / Vessel			4
Person Road Miles Carried / Day At Full Capacity			15,496
VMT Reduction At Full Capacity			10,331
Annual Savings At Full Capacity			\$ 3,038,431
Assumed Capacity			60%
<b>Annual Savings At Assumed Capacity Per Vessel</b>			<b>\$ 1,823,059</b>
Annual Savings / Regular Passenger			\$ 5,098
Commute Trips / Year (52 Weeks less Vacation & Holidays)			239
<b>Savings / Trip / Passenger</b>			<b>\$ 21</b>
<b>Savings / Sea Mile / Passenger</b>			<b>\$ 1.78</b>