SNAME Maritime Economics Panel (O-36) (And Friends)

Ferry Workshop

"There's no charge -
It's worth more for my moose to see your family,
Than it is for your family to see my moose"

"Bert & I", Marshall Dodge

Chris Barry, P.E.

The opinions expressed are those of the author, and do not necessarily represent official policy of the United States Coast Guard

Thank you all for taking your valuable time and coming to this workshop. I hope that we can all get something out of it.

My job here is to present a quick overview of a wide variety of issues to begin the interchange process, so I'll try to tread lightly on each.

There is an annual conference of government small craft users, the Multi Agency Craft Conference, held every year at the Little Creek VA amphibious warfare center. You can see lots of fast boats, big engines, night vision goggles, camouflage and all that sort of stuff there.

One topic of interest for users of high speed craft operators is shock absorbing seats, so that boat crews can operate fast in waves without injuries. At one conference, I was examining such a seat and the owner of the firm, also a person of *gravitas* like myself, having what a naval architect would call a high displacement length ratio, commented that the seat unfortunately was designed for Navy SEALs, not Coast Guard walruses.

The point of this story for today's presentation is:

"The Time Has Come, the Walrus Said, To Talk of Many Things"

- Speed
- Tonnage
- Design Options
  - Hull Design
  - Propulsion Systems
- Optimization
- Rules
- Alternative Energy
- Ferry Construction Productivity Improvement
- Finance

An effective ferry system requires doing a lot of things right and making the right decisions, based on the needs and goals of the overall system.

One fast vessel designer, Chris McKesson, responding to a paper on San Francisco ferries by Paul Kamen, Bryan Duffty and myself, commented that a ferry system can be designed to minimize air pollution, minimize congestion, or minimize cost, but not all three at once; so part of the political process in setting up a public ferry system is to determine goals.

Engineers can't help with that, but it is important to understand some basic engineering to get to the goals you want once you decide what they are.

I'm going to talk about some choices and a bit about how they effect these system choices.

Determine Optimum Speed

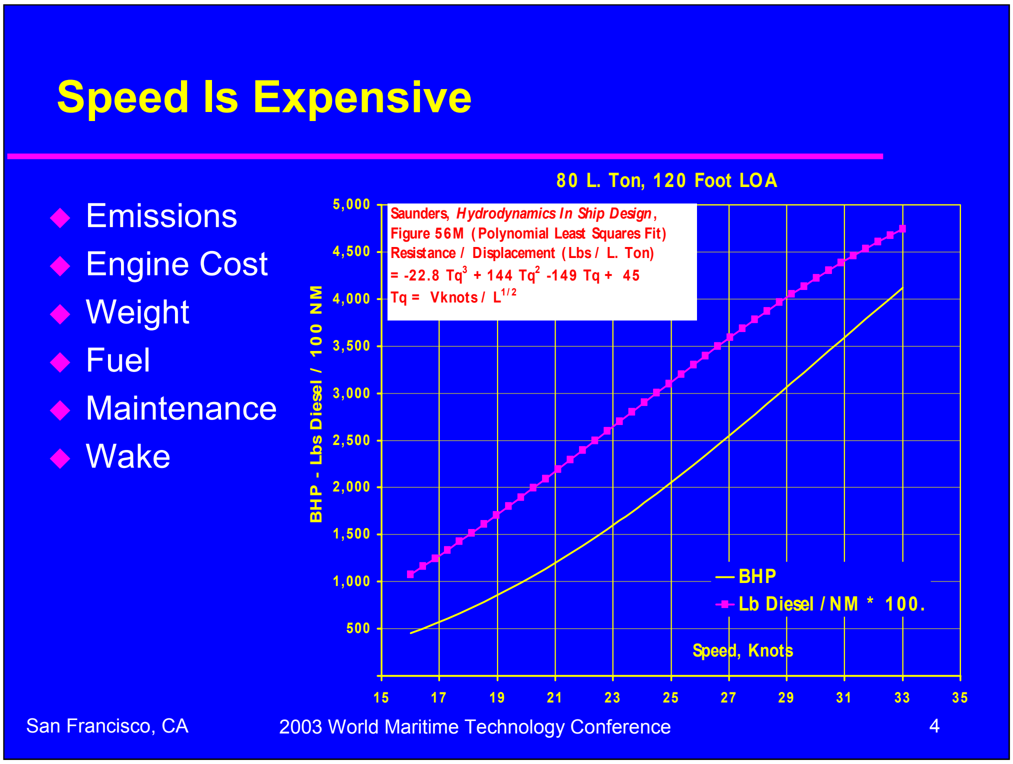
- High Speed Is Expensive
  - Energy / Emissions
- Cost/Speed Tradeoff Critical
  - Very Dependent on Route, User
  - Competition From Other Modes
  - Consider/Reduce Load, Maneuver, Low Wake Times
  - Simulate Commuter Decisions
    - Will More Smaller, Slower Boats Reduce Trip Time ?
- Best Role For Technology Is Reducing Cost of Speed
- Check Speed/Motion Tradeoff
  - Are Higher Speeds Reliable In All Weather?

Determining the operating speed of a system is a critical decision. This is the passenger only fast ferry running in Seattle, which made its last runs recently. Washington ferries found out, the hard way, that passengers, at least on this run, were unwilling to pay a premium for speed, especially when concerns of load times, schedule and wake tended to increase the real trip time.

Speed is expensive. The need for speed is very dependent on the user and route, and competition from other modes, such as BART, in the Bay Area. For example a Berkeley to SF route, you can beat BART at 18 knots for the best possible BART time and 12 knots for the worst. How much faster do you need to go?

It is also important to realize that the actual time the passenger spends on the ferry depends on time to load, unload, tie up, maneuver, go through low wake zones and so on. It may be more effective to attack these delays than increase speed. More doors are probably less expensive than more engines. Finally, the passenger is interested in total trip time, which includes getting to the terminal and waiting for a boat, so better landside connections might do more to increase ridership than fast boats. Also, in general a passenger will arrive at the terminal early enough to miss a ferry less than 5% of the time, which means they might be waiting for a boat a long time if there are few departures and the time they take to get to the terminal is highly variable due to traffic or unreliable connections.

As far as technology, I like to see it reduce the cost of speed, rather than just going faster. Finally, we have to remember that motions in waves can severely restrict speed, and make our decisions based on how often we can go fast.



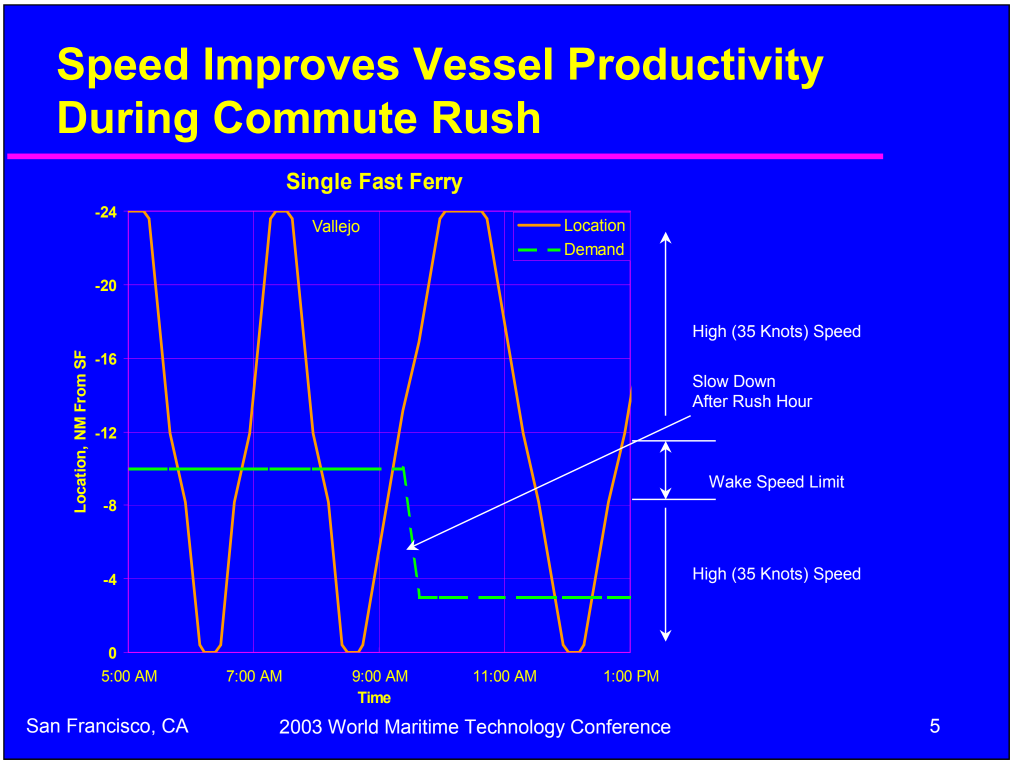
Again, speed is expensive. It increases emissions, engine and boat cost, weight (due to increased engine and fuel weight), fuel costs, and maintenance. The last item is often underestimated. A high performance 3,500 BHP diesel can cost as much as $65 per operating hour in periodic overhaul costs alone - a center section overhaul on such an engine can exceed $250,000.

Speed also may tend to increase wake.

This is a simple calculation for a nominal 80 ton, 120 foot ferry, based on a generic approximation of resistance for a wide range of hull types.

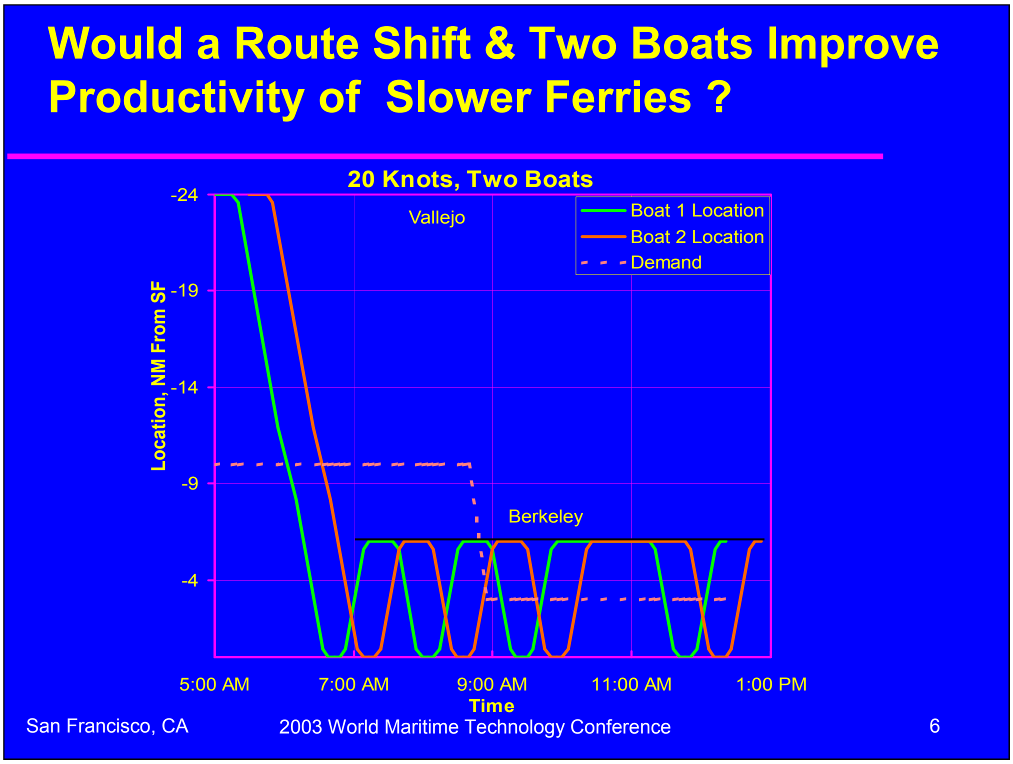
19 knots requires 851 horsepower, burning 1703 pounds of fuel to go 100 nautical miles, but 33 knots requires 4,117 horsepower and 4741 pounds of fuel for the same 100 nautical miles. It is also worth noting that the smaller engines would weigh around 6,000 pounds, and the larger ones, as much as 28,000. Since the higher speed will also require more robust structure, the faster boat will be heavier as well, so its power and fuel requirements will probably be more than shown here.

It is also worth noting that the method used to generate this chart is based on the ratio of speed to the square root of length, “Taylor’s Coefficient”. The point here is that in general, the longer and lighter a boat is, the easier it is to propel.



In addition to reducing the trip time for commuters, speed also increases the productivity of the boat and its crew. Especially for vessels in commute service, the ability to make two trips during a short rush hour may be more important than the increased cost of speed.

This plot is the location of a ferry starting at Vallejo and passing through an assumed restricted speed zone. It is able to make two round trips during the commute hour. Later in the day, it “slow steams” to provide service at lower fuel costs.



However, especially with more smaller craft and an integrated route system, we can see that it might be possible to get good productivity despite low speed. Here each boat runs to San Francisco once from Vallejo, then crosses back and forth on a shorter route from the East Bay, serving many more commuters at lower fuel costs.

This might or might not be a good idea, but these are the kinds of options available that might be worth looking at. It requires careful study, probably including computer simulation, to make the best choice.

It is worth remarking here, that all major US transportation areas maintain a computer transportation simulation system for evaluating the effects of changes in infrastructure on traffic flow. It would probably be wise to make use of this system as part of a ferry project evaluation.

Gross Register Tonnage (GRT)

http://www.uscg.mil/hq/msc/mtn.1.99.htm

- Ferries Now Must Be Less Than 100 “Standard” GRT
  - 100 GRT = 10,000 Ft^3 of “Enclosed Volume”
  - Various Ways of “Exempting” Space
    - “Open To Weather”, Deep Frames
    - Adds Steel Weight, Cost, Strongly Type Forming
- CG Has Proposed to Convert To (Int’l) Convention
  - 1999 Request For Comments: www.uscg.mil/hq/gm/regs/localnav/97-3198.htm
  - True Enclosed Volume (m^3): GRT = (0.2+0.02Log V) V
  - Breaks Will Be Increased: 100 GRT Becomes 1600 GRT ??
  - Rule Rewrite Is Very Complex - Affects Many Regulations
  - New Tonnage Rules Make Big Changes For Ferry Design

One interesting point about small passenger ferries is that they are defined as “admeasuring” 100 gross register tons. A “ton” in this sense is a measure of volume capable of generating revenue, and is 100 cubic feet under the current “Standard” system. The standard system is an old system and has numerous exemptions that have grown up over the years, for example, the space above the main deck of most ferries is exempted by a special door, that theoretically makes these spaces open to the weather, and hence exempt. There are other loopholes in this system, but in general, they are strongly type forming, driving ferry design to short, fat, high boats. As a result of this and the additional structure required to exempt some spaces, both first cost and operating cost tends to be higher than if the vessels were unconstrained by these rules.

Most countries had admeasurement systems that worked in different peculiar ways, so a convention was held to develop an international system that would be uniform, with few loopholes. This is called the convention system. It measures all of the volume inside the boat with very few exemptions and applies the equation here to it. Under this system 100 register tons is about 14,000 cubic feet. The Coast Guard asked for comments about admeasuring new boats under the convention system, and changing the breaks for various regulations to higher numbers, so that the limit for small passenger vessels might become 400, 800 or 1600 convention tons. This is a complex undertaking requiring several years, but when complete, it will change ferry design radically and even may affect system planning.

The websites for details of both tonnage systems (and the simplified system, mainly used for recreational boats) and the comment request are listed here, for those interested.

Hull Design

- Lots Of Choices - “*Horses for Courses*”
- Planing / Semiplaning Monohulls
- Catamarans/Wave Piercers
- Air Cushion
- Hydrofoils
- Hydrofoil Hybrids
  - Planing Hulls With Partial Hydrofoil Support
  - SWATH/HSYSWAS
- Wing In Ground Effect: WIG/PARWIG, Ekranoplan
  - More Like An Airplane - Similar Roles In Transport
  - Much Faster Than Surface Craft (150 Knots +)
  - Caspian Sea Monster: Soviet Airborne Battalion Ferry

There are a lot of choices for hull form for ferries. As the English say, it is a matter of horses for courses.

Besides various waterborne modes, one interesting possibility is “Wing In Ground effect” or “Power Augmented Ram Wing In Ground effect”. An air wing, flying close to the surface is substantially more efficient than at altitude, so it is possible to design rather peculiar looking, but very efficient, seaplanes that run only a few feet above the water surface. This is probably not useful for the short runs of a daily commuter ferry (unless Bay Area property becomes expensive enough to make commuting from Oregon cost effective), but it is an interesting, and perhaps ecologically friendly alternative to conventional air traffic, as these craft do not use valuable airport runways and are considerably more fuel efficient.

This is more than a wild idea. One effective use for such a device is ferrying an infantry battalion across the Caspian Sea, and the former Soviet Union had built a range of very large Ekranoplans, “Caspian Sea Monsters”, for exactly this purpose.

Planing / Semiplaning Monohulls

- Well Proven/Lowest Risk
  - Classic “NPL” Hull Very Efficient Up To 30 Knots
  - Limited Deck Area, Not Favored by Tonnage
- New Developments
  - Improved Hull Forms - Double Chine Types
- Shallow Draft
- Excellent at 20 - 30 Knots
- Poor Motions In Waves
  - Roll - May Require Stabilization
  - Pitch/Heave Acceleration
- Lowest First Cost
  - Can Be HSLA Steel or Aluminum

Planing and semi-planing single hulled boats are still a very good answer for many ferry runs.

I am particularly fond of the hull type with rounded bilges forward and a hard chine aft, such as the UK National Physical Laboratory in the classic “NPL” series. These are still among the most efficient hull forms up to about 30 knots or so and are still widely used for patrol boats throughout the world. Unfortunately, they are not treated well under the standard tonnage rules, so they tend to have limited deck area, which is a key for a ferry.

The double chine form has similar efficiencies as the NPL form at the higher end of the speed range, and perhaps better seakeeping.

Well designed monohulls can have shallow draft and most types are excellent at speeds up to about 20 to30 knots.

Unfortunately they can have poor motions, especially roll, which may require fin stabilizers or other systems. They also can have very bad pitch and heave motions in head seas.

Monohulls will generally have the lowest first cost, and they can be made in steel as well as aluminum, especially high strength, low alloy steels, which also can have improved corrosion resistance for only a few cents per pound additional cost over regular mild steel, and much less than half the cost of aluminum.

Catamarans

- Not Always the Best Solution
  - What is the “Equivalent Monohull”?
  - Higher Structural Weight Fraction
  - Higher Cost Than Monohulls
- Gives Deck Space/Stability Without Hull Beam
- Displacement Types - Long, Narrow Hulls
  - Very Efficient In Mid Range - No Hump Problems
  - May Have Reduced Wake
- Planing Types - Higher Speed Range
- Structural Issues - Nuisance Cracking Common
- Accelerations May Be A Problem

I find the broad acceptance of catamarans somewhat ironic, because my first job was at the San Francisco naval architecture firm Morris Guralnick Associates, which proposed a catamaran for the first Golden Gate ferries in the early 70’s. This was deemed too radical at the time.

Cats are generally the first choice for a ferry these days, but it is not always justified - cats are not magic with respect to resistance as it is often claimed, for example. A cat has a lower resistance than if the two hulls were squished sideways into one, but much more than if they were put end to end, so the statement that a cat is better than an equivalent monohull bears some questioning. Cats will have more weight of structure per passenger than a monohull, and generally higher cost per pound of structure. However, they have lots of deck area, which is a valuable feature for a ferry.

Cats come in two breeds, fast displacement types, with long, narrow hulls and planing types, with shorter, usually wider, hulls. Displacement cats are especially good for the mid range of speeds and can have reduced wake. Planing cats are for going fast, maybe above 30 knots or so.

The extended structure of a cat tends to give high loads, and nuisance cracking can be a problem – cat structure has to be very carefully designed.

The extended hulls also tend to damp rolling and make them very stable, but in certain wave conditions this can cause high accelerations and passenger discomfort - a boat may have to be optimized for wave conditions in design.

Catamaran Wave Piercer

- Catamaran Modified for Improved Motions
  - Several Different Designs Available
  - Hull Extension “Anticipates” Waves
  - *Hoverspeed Great Britain* Now Holds the Blue Ribband
- Reduced Hull Lift Improves Motion In Waves
  - *But*
  Also Reduces Hull Efficiency
- Must Be Tuned for the Required Sea State
- Bottoming Out / Bow Diving Can Be Problems
- Requires Longer Hulls Forward Of Passenger Space
- Structural Cracking Very Common

The answer for improved seakeeping for cats is the wave piercer. There are several different specific designs, but they all feature narrow, very sharp hulls extending well forward of the cross structure. These hull extensions encounter the waves ahead of the hull but react to them with less force, and often submerge entirely. This reduces the accelerations put on the passengers. That this is a successful concept is evidenced by the fact that the current holder of the “Blue Ribband”, for the fastest crossing of the Atlantic by a passenger vessel (once held by the *HMS Queen Elizabeth* and the *USS United States*) is now held by a wave piercer, *Hoverspeed Great Britain*, which won it on its delivery voyage.

However, the hulls are also less efficient at providing lift, so wave piercers probably will require more power.

The hull design also has to be tuned for the anticipated sea state.

In very severe waves the hulls may not provide enough lift lift fast enough, so the cross structure is struck by the waves, resulting in sudden accelerations and passenger discomfort.

Wave piercers have to have long (and thus expensive) hulls for their passenger load, and with the long hulls, extended structure, and occasional wave impacts, they can have structural cracking problems if not very carefully designed and built.

Air Cushion Vehicles
High Speed/Amphibious - Higher Cost

- HoverCraft - Has Fabric Cushion Seal All Around
    - Amphibian - May Be Valuable On Some Routes
- Surface Effect Ship (SES) - Actually a Planing or Displacement/ACV Hybrid - Not Amphibian
    - Less Fan Power But More Hull Drag, No Side Seals
    - Some Designs Require No Seals At All
- ACVs Still Have Wakes, Still Have Wave Drag
- Motions Can Be A Problem
    - Besides Normal Motions, ACVs Can “Cobblestone”
- Propulsion Systems Can Be Complex & Expensive
    - Especially For Amphibian Designs

Air cushion vehicles use a fan to produce an air cushion to lift the hulls. These also come in two basic flavors, HoverCraft and Surface Effect Ships. HoverCraft have a flexible fabric seal curtain all around the vehicle, which means that they can be amphibian, which may be important for some routes. They are used on the Dover / Calais route across the Channel for just this reason; the shallow beaches and range of tides puts the terminals at the water’s edge now, but a mile up the beach later the same day. Unfortunately the all around seal is expensive and air flows out all around, increasing required fan power.

An SES can be considered a hybrid of air cushion and catamaran. The air cushion is trapped between two side hulls which remain in the water. This reduces cost and fan power, but eliminates amphibian capability. Most SES’s have bow and stern seals but some have only bow seals or even none at all.

Regardless of type, though, ACVs still have wakes and wave drag. Even if the hull doesn’t contact the water, the fan blows a depression in the water, which makes waves, and tilts back the vehicle, so some cushion lift produces drag.

Motions can be a severe problem for ACVs because of the possibility of essentially bouncing on the air cushion, called cobblestoning, which can produce severe passenger discomfort, so ACVs often require ride control systems.

Propulsion can also be a problem, especially for amphibian ACVs.

A hydrofoil is a boat lifted by a wing below the surface. At high speeds, hydrofoils are the most efficient concept, with and much as 75% reduction in drag. Because most of the foil is submerged beneath the waves, hydrofoils can have very good motions in seas. Unfortunately, the foil is deep, and this can require deep channels to run in. The propulsion system somehow has to get power into the water down the foils struts, which can be a challenge.

Hydrofoils also come in two flavors, full submerged foils and partially submerged foils. Fully submerged foils need automatic ride control systems to maintain the right hull height above water and are the most efficient with best motions. Of course, failure of the automatic control system can result in the boat crashing into the surface. Partially submerged foils maintain height because the portions of the foils normally above water add lift if they enter the water, but they lose a bit in both efficiency and motions.

A problem for both types of foils is the actual foil construction itself. Such a relatively small (to reduce drag) appendage has to be very strong, and has to resist corrosion and cavitation, so they are made of very sophisticated stainless steel alloys, which are expensive and require lots of expensive machining and forming operations. The structure to support the foils and distribute the loads of the foils into the hull can also be complex and expensive.

Foil Supported Hybrids
Up to 50% Reduction In Drag

- Planing/Hydrofoil Hybrids
  - RCS Not Usually Required
  - Better Performance Than Planing Hulls
  - Low Cost Than Full Hydrofoils
  - Monohull Designs
    - German / Swedish Stepped Hull, Kunitake, Rodriguez, Payne
  - Catamaran Designs
    - HYCAT (Calkins), Catfoil (Gee), Hysucat (Hoppe)
- Buoyancy/Hydrofoil Hybrids
  - HYSWAS, TechnoSuperliner
  - Submarine Hull(s) With Wings Supporting Upper Hull
  - Very Good Motions - RCS Required, Very Deep Draft

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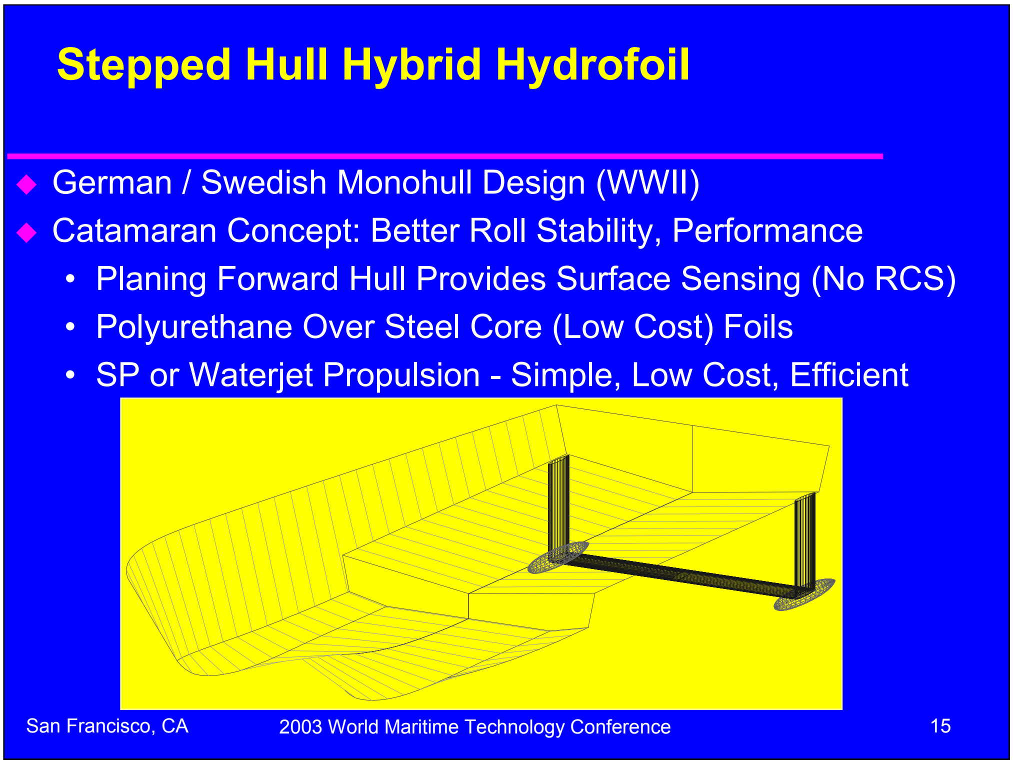
Once again, hybrids are a possibility. Planing / hydrofoil hybrids provide partial support for a planing hull with a hydrofoil. This usually eliminates the automatic ride control systems, or at least minimizes its complexity, because the planing hull acts to maintain height. The hydrofoil gives better performance than a simple planing hull alone, because the partial hydrofoil support is at greater efficiency, but the hybrid is considerably lower cost than a full hydrofoil. It is also appropriate to lower speeds, so it may be suited for routes that do not justify the speed of a hydrofoil. They also come in many different types – a whole subclass of the patent system is dedicated to planing hybrid hydrofoils. They can be either monohull or catamarans with different ratios of hydrofoil support and planing lift. The ferry builder Rodriguez runs monohull hybrids with very minimal supplementary hydrofoil lift, mainly to improve motions, but other concepts carry as much as 75% of the weight on the foils. There are many catamaran concepts with one or more hydrofoils running between the hulls. The Hoppe Hysucat has a main lift foil amidships and a trim foil aft. Quite a number of these are in service now, with some in service since the 80's.

Buoyancy / hydrofoil hybrids have one or more deeply submerged hulls with wings that lift the weight of the upper hull clear of the water. These designs have very good motions in waves, but often require automatic ride control systems. The large submerged hull also means that they have very deep draft.

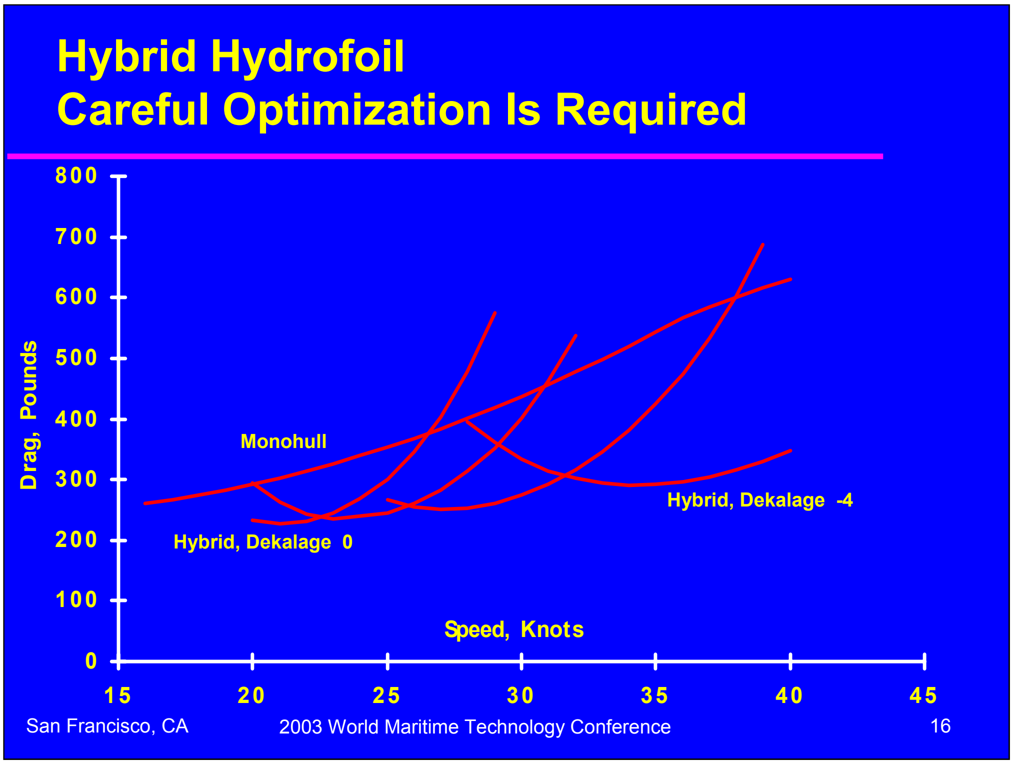


This is an illustration of a stepped hull hybrid hydrofoil concept by the Rev. Bryan Duffty and myself. The forward planing surface maintains height and the aft foils support the weight of the aft portion of the boat. If it encounters a wave, the forward section rises, causing the aft foils to increase angle of attack and thus their lift, which carries the whole boat over the wave.

To our surprise, when we sought a patent for this concept, we found that there was a Swedish World War II era patent on a monohull version and that such boats may actually have seen service in the German Navy during World War II.

The catamaran concept is an improvement on the basic monohull idea in that as the monohull lifts out, the narrow hull left in the water doesn't provide good roll stability unless efficiency is somewhat compromised. The catamaran concept retains well separated planing surfaces to control roll as it lifts.

Advantages of the basic hybrid concept here is that there is enough hull in the water to allow surface piercing or waterjet drives to be hull mounted, eliminating the problem of running power down the struts. The foils of a hybrid are also larger for the amount of lift they produce, because the boat is slower. This means that these vehicles can use composite foils consisting of a resilient plastic, such as polyurethane, cast over a simple steel core, which will be much less expensive. This is a well proven technology as it is widely used for now high speed rudders.



One important note about hybrids is that there are many variables in their design, and these variables must be carefully optimized.

This plot shows the resistance of a small stepped hybrid hydrofoil. The hybrid has substantially less resistance, reducing required horsepower by as much as half, compared to a similar planing boat, as long as the angle of the foil relative to the hull, (the dekalage), is properly selected, but it can have much more resistance with the wrong angle. Careful computer simulation is required for hybrid hydrofoil design.

The three main propulsion options are conventional submerged propellers (which may have advanced features for a cavitating environment), waterjets, or surface piercing propellers.

One key concept for any propulsor is that thrust is the mass, usually of water, accelerated, times the velocity change. However, the energy required is based on the mass times the velocity change squared and how efficiently the propulsor changes the velocity. This means the most efficient propulsion is achieved by accelerating the most mass through the smallest possible velocity change. Capturing lots of mass means either moving through the water fast or having a large area of the propulsor to capture the mass.

Cavitation is another concern. Heavily loaded propellers at high speed cause the water around the propeller to boil at normal temperatures. The cavities generated by this reduce efficiency and can damage the propeller, rudders or adjacent hull.

Conventional underwater propellers are the most common solution, and are generally the best option up to about thirty knots or so. They have good efficiency at lower speeds because they tend to have large loaded area, but as speeds rise, they have an increasing tendency to cavitate and the drag due to the shaft, struts and so on becomes quite significant.

Waterjets have very little appendage drag, but have small loaded areas. The internal pumps of waterjets are also quite efficient. This means that waterjets generally are best at high speeds where the inlet is able to capture lots of water and the elimination of appendage drag is important. However, the tend to be heavy, especially since they have a lot of internal entrained water, take a lot of internal space, and are costly.

Surface piercing propulsors are not as efficient at accelerating water as a conventional prop but can have very large diameters, so they get back the lost efficiency. They also don’t cavitate and have no appendage drag. They are relatively light and inexpensive, but the shafts, steering gear and associated equipment is exposed at the waterline aft of the vessel. Of course, amphibious vehicles generally have to have air props.

Power Options

- Diesels Are Well Proven, Cost Effective
  - Pollution Issues - Fuel Choices Limited (Cetane, Lubricity)
- Aircraft Derived / Industrial Gas Turbines
  - Light, High Power, Proven, Lower Emissions
  - High First Cost, High Fuel Cost, High Maintenance Cost
  - Multifuel - CNG, Other Alternative Fuels
- Future Alternatives (Back To the Future?)
  - Steam Assisted Gas Turbine (STAG - Bottoming Cycles)
  - Better Efficiency, Lower Temps: Less NOx, Lower Cost
  - Steam Turbine - Also Multifuel, Low Emissions
  - Fuel Cells, Stirling, Sail Assist, SCORE (Rotary Diesel)

The most common prime propulsion movers are diesel engines. They are quite fuel efficient, and reasonably priced. Note, though that the major market for diesels is trucks, so there are lots of engines produced in large quantities in the 300 to 700 horsepower range. Above this power range, fewer engines are made, so they tend to be much more expensive, even on a per horsepower basis, than in this range. Diesels tend to produce pollution in the form of particulates, PM, unburned hydrocarbons, HC and NOx, and in general reducing PM and HC, or increasing fuel efficiency increased NOx. Diesel fuel also has special requirements because it has to ignite and burn at the correct rate under pressure in the cylinder and lubricate the fuel injection system.

Gas turbines are either aircraft derived or industrial engines. They are lighter, but quite a bit more expensive than diesels. They can have substantially lower PM, HC and NOx emissions than diesels, but tend to have lower fuel efficiency, thus they produce more carbon dioxide per horsepower as well as costing more to run. However, gas turbines can run on virtually any fuel. Many industrial gas turbines are used as natural gas compressors because they can run on natural gas.

There are some interesting alternatives. Gas turbines have low efficiency because they have very hot exhausts, so this heat is wasted, but this heat can be used to make steam, which either runs a separate steam turbine or is injected into the gas turbine. The former is a common strategy in commercial power plants and can be very efficient. The latter is a bit less efficient, (though much more than a gas turbine alone) but can lower combustion temperatures, allowing use of less expensive materials for the turbines, and further suppressing NOx. Conventional steam is another option for ferries, because they can be rewatered from sources ashore. This avoids the equipment and maintenance required to maintain water quality normally carried on a steam ship. Steam also has low pollution and is multi-fuel, and nearly as efficient as diesels. Other future options include fuel cells, Stirling cycle engines, sail assist, and rotary diesels.

It is important to keep in mind, during implementation of a system, that there are numerous small improvements in boat design possible to reduce costs or improve performance.

Two interesting ones are stern flaps and combined plants.

Stern flaps are a simple way of reducing the resistance of medium to high speed boats, especially fast displacement craft, that was developed by the Navy. Flaps have been installed on Navy destroyers, frigates, and cruisers and Coast Guard patrol boats and large cutters. They can reduce drag by 8% to 12%, with comparable reductions in emissions. They work by modifying the flow around the stern, suppressing wake and the rooster tail seen on some fast craft. Though they are not a huge improvement, they are quite inexpensive, so the small investment is paid off quickly.

A ferry on a route that has substantial periods of low speed can benefit substantially from combined engines. The picture shows a British motor torpedo boat installation with a large turbine for attack mode and a much smaller diesel for cruising. This radically improves fuel economy, and reduces noise, emissions and maintenance costs because only the low powered small engine is running most of the time.

It is also worth noting the comparative power of the two engines. This remind us again of the tremendous increase in power required to go fast.

Because they tend to have short runs, some ferry routes may provide a opportunity to at least demonstrate and evaluate alternative energy schemes.

Solar power is sometimes proposed. It is important to realize that the key to solar energy is usually to minimize power per dollar, which may require different solutions for different situations, but there is some chance that this may work. In another paper, Paul Kamen, Bryan Duffty and I evaluated a system based on solar heated mercury vapor magneto hydrodynamics that might produce hydrogen at a cost equivalent to about $3/ gallon diesel fuel.

Photovoltaics are most often suggested, but they are expensive, have relatively low efficiency, because they only use photons above certain frequencies, and can have substantial hazardous material use in manufacturing.

Dish or trough engines, using various heat engines are actually perhaps a better choice. The dish or trough reflector concentrates heat so high thermodynamic efficiencies are feasible. Stirling cycle engines are often proposed, but the major problem here is that the best Stirling engines use helium as a working fluid, which requires sophisticated seals. Air engines are less efficient, but have much less sophisticated seals because air is easier to seal, and leakage is not a problem, so here is an example of a less efficient, but less exensive solution that might be better.

Dish or trough engines can run steam turbines as well. They often use an intermediate fluid to heat a boiler, but they can also use a micro turbine and a direct contact condenser, with water conditioning (the dearating feed tank) handled remotely for a bank of troughs or dishes.

Mercury vapor magneto hydrodynamics is a new concept that uses solar heated mercury vapor. The vapor, which is conductive, is expanded through a magnetic field. This generates electricity directly without moving parts. The mercury is cooled to a liquid and recycled in a sealed system.

Optimization is figuring out what the right things to do are, and then doing them right. The various dog breeds are all highly optimized for their tasks and environment, for example. It is very important for any system, but there are very wide options in a new ferry system, because the decisions can be made right, right from the start.

The process of vessel design has to feed back up to system design, and this is the role of synthesis studies and point designs. Vessel synthesis studies use computer tools to find optimized vessel characteristics for a given set of criterion, and can evaluate the cost and effectiveness impact of a wide variety desired vessel characteristics. Once such an optimized set of characteristics is determined, a point design can be done to verify that the characteristics are in fact feasible. This validation then serves to validate the specification of the vessel and determine the impact of vessel design on system design and vice versa.

One lesson from dog breeds is that “off the shelf” designs are rarely optimum for a new task and environment, and selection of an “off the shelf” design has its costs. I have a Nova Scotia Duck Tolling Retriever. It has the mild temperament and intelligence of a Lab or a Golden, but is much smaller, and better suited for a small yard. However, the “Nova Scotia” part is not so well suited for the milder winters of Maryland, resulting in lots of shedding. Custom designed dogs are not feasible in the short run, but custom designed boats are easy.

In fact, “off the shelf” is a significant source of risk, because it is more “often off the shelf” with just a “few minor changes”, which usually increase weight, hazarding speed and stability.

There is no real advantage to off the shelf either. Custom design of boats is a well established process, and there are so few ferries in the worlds that there is no real mass production to provide substantial cost savings. In addition, especially with computer tools, design cost is fast and only a small fraction of the total cost. For example, Kawasaki Heavy Industries is now developing complete custom tanker designs in only eight calendar days.

Coast Guard Subchapter T/K Regulations Control Most US Ferry Operations

- For Vessels Under 100 GRT
- 46 CFR Subchapter K
  - For More Than 149 Passengers (or 49 Overnight)
  - Intermediate Between T and Full H
  - Requires “Structure Equivalent to Steel”
    - Aluminum Requires Extensive Insulation
- 46 CFR Subchapter T
  - Less Than 149 Passengers or 49 Overnight
  - Simplified Rules In Many Areas of Construction
  - More Acceptance of Common Boat Practices
  - Fiberglass Construction Allowed

Passenger only ferries are generally small enough to be regulated under 46 CFR Subchapter T or K, depending on the number of passengers. T and K boats has to admeasure 100 gross tons or less.

Subchapter K is for more than 149 passengers or 49 overnight passengers. It is intermediate in requirements between the T-boat rules for smaller vessels and the rules for full sized passenger ships, Subchapter H. One important feature of K-boats is that they have substantial structural fire protection requirements, so that structure equivalent in fire resistance to steel is required. This essentially eliminates fiberglass construction altogether, and requires substantial insulation of aluminum structure, which increases cost and weight.

Subchapter T is for fewer than 149 passengers. This allows simplified “boat-like” standards in some areas of construction, including fiberglass construction.

IMO High Speed Craft Rules
New Alternative to T/K

- Many Areas Still Require Interpretation
- “Total Engineering Approach”
  - Includes Operations & Rescue, Not Just the Boat
- Applicable to High Speed Craft In Ferry Service
  - Recognizes “Aircraft Like” Operations and Weight
- New Issues
  - Requires Crashworthiness, Seat Belts, Training, Etc.
  - Allows Fiberglass with Appropriate Measures For Equivalent Safety For More Than 149 Passengers
- More Expensive In Service
  - Is It Worth It? Is It Really Safer?

The International Maritime Organization has developed an international system of rules for high speed craft, which can be used as an alternative to T or K.

This is a total engineering and systems approach to the vessel which includes all areas of design, construction and operation, including available resources for passenger rescue in the community and other system concerns. It recognizes the aircraft like operation and weight limits of fast craft. However, many more areas are open to interpretation.

Some new issues it brings up are crashworthiness of the boat itself, use of seatbelts in some cases, and more extensive crew training. It does allow fiberglass construction within the constraints of providing equivalent safety through other systems.

It is probably more expensive to implement in service, and there is not really enough experience to demonstrate that it is really safer than the T and K rules.

Ferry Construction Productivity Improvement

- Shipyards Have Low Capital Costs, High R.O.I.
- CAD/CAM/CAE =Radical Increases In Productivity
  - Integrated CAD Model
  - Extensive CAM - New Production Techniques
    - Low Cost Automation
  - Highly Empowered, Skilled Workforce
  - Bender - 20%+ Labor Reduction Using Product Model
    - No Increases in Engineering Labor
- Other Process Improvement Techniques
  - Re-engineering (Deming, Juran)
  - Lean Manufacturing (Toyota Production System), 5 S

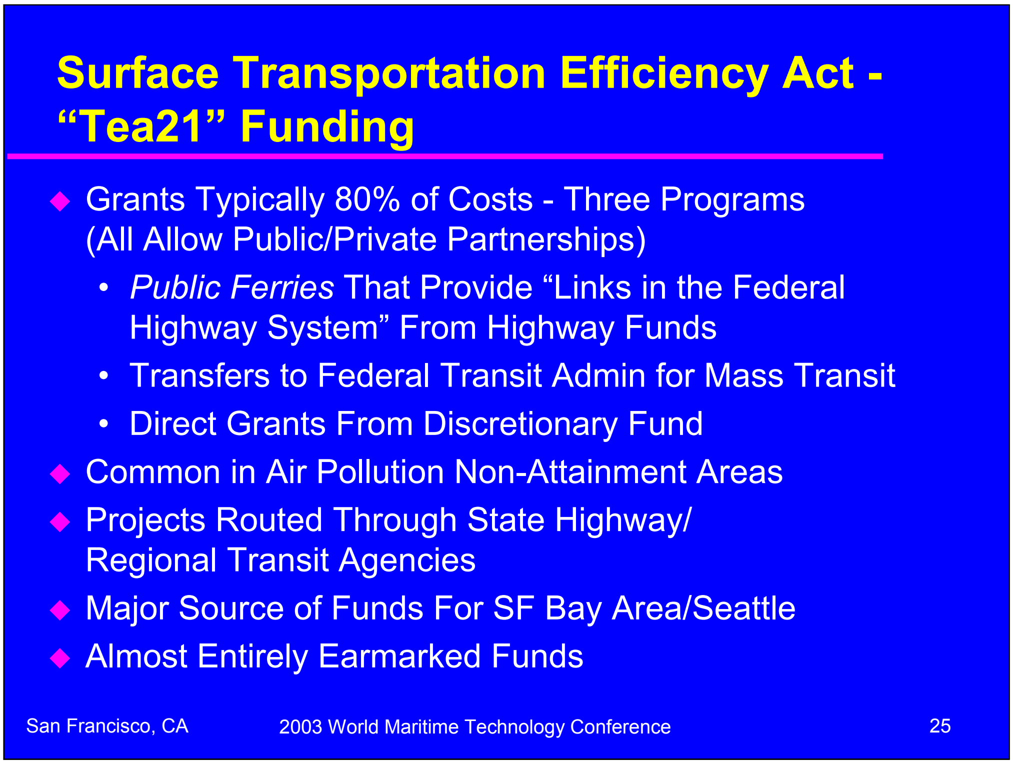
The construction of small ships is very much like building contracting, in that relatively limited capital improvements are required to establish a shipyard. In fact some small ships are built, essentially out of CAD/CAM "kits" by their owners outside of any real shipyard.

Computer Aided Design/… Manufacturing/… Engineering has greatly facilitated this process and radically improved productivity. Initially, productivity was greatly improved by eliminating hand lofting and cutting. The CAD data can be used directly by computer controlled cutting torches, but more improvements are possible. The key is re-engineering the whole construction process using an integrated 3D product model, a unified CAD database, which allows all sort of production improvement technology such as low cost automation, *Kan Ban*, advanced outfitting and all sorts of other improvements. Bender, in Mobile AL, has used just such an integrated product model and reduced labor by 20% on the first ship they used it on.

Another key is an empowered, skilled workforce, and the way to do this is decent wages and incentives such as employee stock ownership and profit share, as well as self-directed work teams (which are enabled by the information in the product model).

There are also many other improvements possible, many adapted from so-called "Lean manufacturing" and "5S" techniques, originally developed by Toyota. The quality gurus Deming and Duran have championed these techniques in many industries, and their employment in the Far East is one of the main reasons for high shipyard productivity there.

It is important to note that shipyards that employ these techniques are much more productive than those that don't. In terms of California ferries, this also means that it is possible to apply these techniques and build ferries and other vessels in California or even the Bay Area at a profit, in in the face of high wages and other costs, thereby providing local jobs.



The major source of funding for public ferries is what is now called TEA21 money, what used to be "Ice TEA". These are federal grants that provide money for essentially providing links in the existing federal high way system. They are transfers to the Federal Transit Administration, and direct grants from a discretionary fund.

They are frequently invoked based on air pollution non-attainment.

Many of the projects are routed through state highway or regional transit agencies.

In the past, this program has been a major source of funds for the San Francisco Bay area and Seattle.

However, the current legislative process has resulted in virtually all funds from TEA21 being earmarked for specific projects in Congress, so getting these funds is now a highly political process.

Other sources, mainly for non-public ferries or for shipyard improvement and technology development include the Title XI loan program. This program federally guarantees financing for ship acquisition and shipyard improvement, including guarantees for foreign sales. The current rules allow 87.5% funding for ferries. However, the associated fees are substantial, so it is not worth looking at for less than about $2M. Incidentally, it is worth noting that this program, is a guarantee program, not a grant or even a direct loan. In the long run, Title XI generally has operated at a profit for the government, though some losses have hit it hard in some years.

Other sources include MARITECH, which provides matching funds for shipyard technology improvement demonstrations, through the National Shipbuilding Research Program and the Small Business Innovative Research program, which provides seed money for a wide range of innovative technology, especially dual use military and civilian technology.

Thank you for you time and interest. Please feel free to contact me for any further information:

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