Propeller Driven, Recreational Marine Drive Designs: Learning from the Past with an Eye to the Future

An RBBI White Paper

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Abstract: *This paper focuses on technical issues, reviews the status of aging existing outboard and stern drive designs, identifies several emerging technologies and some unsuccessful efforts in the past. Related technologies with possible impact on future designs are briefly discussed (shift-pitch props, two-speed transmissions and composite gear cases) and the drive development process is discussed.*

Our earlier paper, "U.S. Commercialization of Innovative, Propeller Driven, Recreational Marine Drive Designs.[1]" focused on market dynamics surrounding attempts to launch U.S. built new high volume production drive designs. We refer you to it for a discussion of those issues.

*Please see "*Drivetrain Comparisons*"* [2] *by Bill Walker for an excellent discussion of current dominant drive designs (inboard, outboard, stern drives and water jets).*

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For copies of "U.S. Commercialization of Innovative, Propeller Driven, Recreational Marine Drive Designs" (our earlier paper covering market dynamics surrounding the introduction of high production volume U.S. built drive designs), and information about our new product development services, see our Polson Enterprises web site :

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Existing Designs Are Showing Their Age

Over the years, marine drives evolved from paddles to sails to inboards to outboards and then to stern drives. In the 1990's stern drives and outboards matured and reached the "end of the line" in development. For example, MerCruiser's stern drive debuted in 1961 [3]. In addition to normal product support improvements, the drive has been though several iterations. These iterations are sometimes referred to as being "squeezed." The process is similar to squeezing juice from an orange. The first squeeze (iteration) results in lots of orange juice, but each successive squeeze is more difficult and results in less juice.

Early MerCruiser iterations focused on performance improvements. Midway though the life cycle they focused on broadening the application to higher horsepower gas engines, diesel engines, twin props, surface props, racing and other applications (Bravo One, Bravo Two, Bravo Three, Blackhawk, Bravo One XR, Bravo One XZ). As the drive matured, iterations focused on cost reduction, model year changes, product support (reducing warranty issues, increasing service intervals, meeting EPA emission regulations, adapting the drive to the latest GM engines), manufacturing issues (bar codes, recyclable packaging), accessories (Blacktrac two-speed transmission, shift-pitch props, oil reservoir bottles, branded lubricants) and increased use of the capabilities of today's ECMs, Electronic Control Modules, (optimizing EFI, diagnostic tools, SmartCraft Gauges).

Outboards have also stalled at design dating back to the early 1960's. Although there have been tremendous improvements in engine efficiency, emission reductions, maximum horsepower and reliability, the basic outboard drive design has not changed in almost 40 years.

Mercury received an Innovation Award at Boating Week 2000, not for their drives, but for their SmartCraft Gauges!!! This is a sign of very mature designs.

As outboard and stern drive designs matured, major manufacturers, small firms, academic researchers, government labs and independent inventors began to develop new designs in an attempt to create the next evolutionary step. So far, none have succeeded. In addition to the recreational marine drive market, several designs also hope to capture portions of the commercial work and fishing boat market and the market for larger marine drives (mega-yachts, maritime vessels, passenger vessels, fast ferries, military patrol boats, tugs, bulk carriers and cargo vessels).

Others Have Tried in the Past

Recreational marine drives is a very tough market, even for revolutionary designs from well-known manufacturers and especially for die cast drives. Several significant drive designs have failed to be launched or failed in their struggle for market share.

- Kiekhaefer Aeromarine's K-Drive (1974)
- 1981 Kiekhaefer design
- U.S. Marine's L-Drive (1980's)
- Yamaha's Hydradrive (1990's)

Continued

In 1961 Carl Kiekhaefer (founder of Mercury Marine) sold Mercury to Brunswick. He resigned from Brunswick in 1970 and formed Kiekhaefer Aeromarine with his son Fred. In March of 1974 he showed a "Next Generation" stern drive at the Miami International Boat Show. The patented drive [4] received rave reviews [5] for its innovative trunion trim system and independently steerable lower leg, but was never produced due to the tremendous investment required. In his normal boisterous demeanor, he said the drive would capture 1/3 of the stern drive market. His target of obtaining 1/3 market share for a superior drive produced by a major manufacturer (both John Deere and Chrysler showed interest) backed by his name is an indication of how difficult market share is to capture in this industry.

Later on (1981), Kiekhaefer patented [6] a drive that did not have a u-joint, trimmed through the hull, had a near 45-degree drive shaft angle down to the prop and the steering system rotated the gear case about the vertical centerline of the prop. The drive, loosely based on a 1970 OMC patent [7] by Charlie Strang the inventor of the stern drive, was never mass-produced.

U.S. Marine's L-Drive, designed by David Jones, consisted of an outboard power head vertically mounted inside the hull near the transom. The engine powered a stern drive leg through the bottom of the boat and required hulls designed specifically for the drive. It featured a lightweight outboard engine, compact design, aesthetic installation, lower steering loads and received several designs awards including Design New's Excellence in Design Award [8]. The L-Drive was produced, but phased out in just a few years, even with the assistance of Brunswick which acquired U.S. Marine in 1986. Many L-Drives remain in the field and some are almost worshipped by their owners.

In the mid 1990's Yamaha released the patented Hydradrive [9], a hydraulic shifting stern drive. Its smooth hydraulic shifting eliminated "clunky" shifting problems previously associated with stern drives and the entire drive performed exceptionally well. Yamaha sold them at a heavy loss in an attempt to "buy market share", but the effort failed due to the strong presence and marketing actions of Mercury Marine/Brunswick. Some of which resulted in a Federal Court [10] anti-trust case years later.

Toyota showed a fairly conventional twin prop stern drive [11] in the late 1990's. The drive strongly resembles the earlier Yamaha drives (possibly a joint effort).

November 16th 2000, MerCruiser celebrated the production of the 2.5 millionth stern drive in Stillwater. New designs in this area would have to go against a very established presence.

Some Designs Are Still Trying

Several drives that have been around for years are re-entering the race with additional vigor. For instance, jet drives have received a great deal of attention in recent years, not only on PWCs and sport-jet applications, but also on larger fast moving vessels. Twin Disc's Arneson Surfacing Drive continues to "hang on" and appears to be gaining some ground. Ducted props/prop jets are getting some attention. Miniature stern drives (less than 100 horsepower) are being marketed in Japan and Europe. ZF (an inboard transmission firm) recently formed a new unit, ZF-Trimax, to market the Trimax surface drive.

Others Have Recently Entered Limited Production

Several new designs [12] have entered limited production:

- Air Drive, ventilated tunnel drive
- DBD Marine, surfacing drive from Australia
- LA. ME. Sea Rider, surfacing drive from Italy
- Lansing Marine Transom Drive, rear mounted shaft drive from the U.K.
- PowerVent, vented tunnel drive
- Pulse Drive, surfacing drive
- Seafury, surfacing drive from New Zealand (requires 45 degree transom)
- Simplicity, new inboard configuration

Some Concepts Have Not Reached Production

Several drives concepts appear in the recent literature, but have not appeared in production.

A. Split Drives

Several alternative designs feature a fixed upper unit (inboard engine or outboard power head) and a steerable lower leg. The L-Drive is discussed earlier, is an example. Volvo Penta patented one through the base of the hull [13] and Yamaha patented one on a horizontal disc behind the transom [14]. Several others are present in the patent literature.

B. The Inside Outboard Idea

When outboard powerheads moved from carburetors to fuel injection, they no longer have to operate with their crank vertical. New mounting configurations became possible. Among them, placing an outboard power head inside the boat with it's crank horizontally powering a stern drive [15]. The high power to weight ratios of outboards, emission advancements plus the upcoming availability of high horsepower four-stroke outboards (Yamaha's new 250 HP four-stoke) make this concept very attractive.

A recent patent [16] filed from South Africa describes a outboard power head (inside the boat) mounted to a conventional drive leg through a rotating transom disc (rotates parallel to the transom). The engine and drive leg rotate with the disc and are trimmed with respect to it by hydraulic cylinders. The design addresses the union between engine and drive. Stern drives [17] presented the first successful alternative to outboards by changing this union to a u-joint, gimbal housing and right angle drive in an effort to move the engine inside the boat, while still allowing steering, trim functions and thrust parallel to the keel. This drive proposes an evolutionary change in stern drives eliminating the right angle drive, u-joint and gimbal housing while maintaining steering, trim and horizontal prop thrust.

Other attempts are being made by several groups to capitalize on the use of these new powerful, clean outboard engines mounted inside the boat in various configurations.

C. A Peek Behind Closed Doors

Several efforts remain cloaked in secrecy, while glimpses of others can be viewed from a variety of sources. Brunswick's recent attempts at hydraulic drive [18] and a pump jet [19] can be seen in the patent literature. An Oct 1999 Volvo Penta patent [20] hinted of a composite gear case (continuous drive member removing close tolerance needs of conventional stern drive gear case) . They briefly exposed the XDP-Composite drive to the press in late 2000 [21] , but it remains in the shadows. The new drive would be anticipated to be much lighter in weight and offer significant improvements in corrosion resistance, as well as a drastic reduction in assembly time.

Drives behind closed doors can be anticipated to be based on developing technologies, materials, trends and regulations. Improvements can be anticipated in the areas of twin props [22], surfacing props, ducted props, hydraulic drives, tunnel hulls, through hull drives, smart drives (optimize performance, on-site diagnostics, self repairing), drives designed for use with emerging power sources, reduced emissions, automatic transmissions [23] , designs reducing propeller injuries and parasitic losses (gear train inefficiencies), improved engine to drive interface, designing for re-cycling, increased use of composites, active noise cancellation, fly by wire steering controls and modular construction.

Drive Specialization

Specialized products emerge in a mature industry. Drives may be designed and marketed to specific applications or regions. Drives are already being manufactured specifically for ski boats, hi-performance, racing and salt water applications. Some are even manufactured just for sale in California. Go-Devil [24] outboards are designed for very shallow water applications. Other segments that might support specialized drives include very economical boats, houseboats, bass boats, rescue/pursuit boats and emerging hull designs (catamarans and multi-hulls).

The Design Environment is Changing

Drive Applications are expanding. Certain drive types are dominant in specific market segments (outboards in bass boats), but things are changing. The constant thirst for speed of bass boats has Mercury and Stroker teaming up to install a Mercury Racing Scorpion 377 stern drive. [25] Stern drives are showing up in RIBS. Outboards are similarly trying to expand their sphere.

Increased access to high end 3-D CAD systems, hydrodynamic simulation packages and rapid prototyping systems are changing the manner in which drives are designed and tested.

Recent developments indicate the engine/power plant side is not as stable as it was once thought to be. Ficht, Oribital, four-strokes, EFI, DFI and other technologies have burst on the scene. Constant changes in the GM engine line, Toyota's debut of a ski engine, Bombardier's recent purchase of the OMC drives and Ficht technology [26] a preliminary announcement Yamaha and Ford are teaming up to build marine engines [27] (*denied by Ford*). Mercury Racing recently began testing a 320 HP turbine powered outboard. [28]. Battery power, fuel cells and hybrid power are making noise on the automotive front. Third world fuels, lower octane levels, MTBE and alternative fuels further complicate the matter.

The customer service environment is changing. Stingray boats offers a personalized web site [29] for each boat owner complete with access to online owners manuals and a parts list for their specific boat. They are in process of adding online service bulletins and service records. The bar is being raised. Full online support of marine drives is rapidly becoming a customer expectation.

IMTEC changes to Boating Week which then changes to Boat Building 2001. The title of the largest builder changes hands from Brunswick to Genmar with the purchase of the OMC boat lines. The design environment is definitely changing.

The Drive Design Process is Complex

Some, new to the industry, anticipate rapidly moving from successful prototypes to high volume production of new designs. Due to high tooling costs, warranty issues and other costs associated with making changes later, manufacturers put drive designs through a number of steps and tests before production. The list below is in no way inclusive, but does provide an indication of the time and funding required to design a drive.

- DFA (Design for Assembly)
- DFM (Design for Manufacturing)
- Tooling
- Cost reduction
- Styling
- Endurance tests
- Consumer acceptance testing
- Log strike tests
- Corrosion tests
- Anodic protection tests
- Vibration tests
- Intake design/tests
- Performance testing (speed)
- Hydrodynamic tests (drag, stability)
- Steering tests
- Engine Cold Start tests
- Engine Heat Soak tests
- Emissions tests
- Smoke tests
- Fuel system tests (fuel system fires)
- Fuel efficiency tests
- Servicing requirements are optimized
- Serviceability review
- Cooling system tests
- Shifting tests
- Weight reduction
- Water ingestion tests
- Propeller development and testing
- Sound level tests ("pass by" and "in the boat")
- Review of Operator, service manuals and decals
- Compliance with all SAE and ABYC [30] standards and recommended practices
- Fuel tests: Test with all anticipated fuels (octane levels, winter & summer gas, RFG [31] (Reformulated Gasoline), popular current additives, MTBE, etc., including long term seasonal engine storage
- Engine durability testing at all speed ranges to identify potential fuel and lubrication problems
- Trailered tests: Store for long periods on trailer to detect possible fuel and lube problems

Related Technologies

Vertical trim, two speed transmissions and shift-pitch props have been in the background for several years. Some new designs and third party devices incorporate these features.

A. Vertical Trim

New designs need to consider the issue of vertical trim. Outboard jacks are widely available, but it is not currently possible to vertically adjust stern drive height "on-the-go". Stern drive trim systems pivot at the gimbal housing and cannot trim vertically. Builders mount stern drives at a height (sometimes called the "X- dimension") for best overall performance. However, as boat load, load distribution, fuel level, and water conditions change, so does the optimal "X-dimension".

Stern drive manufacturers provide spacer plates that can be installed in the middle of the drive leg. Installing spacer plates is a major operation and no similar option exists for shortening the drive. Spacer plates are normally used by boat builders in determining the optimum height for drives in new models.

Most stern drives are also limited in "down angle" (number of degree below zero the drive is able to trim). Down angle is used to generate bow lift. Third party manufacturers have created standoff boxes [32] to move the drive further behind the boat, thus increasing the leverage from the available down angle.

In the late 1990s at least two patents [33] were granted to mechanisms allowing the true vertical trim of stern drives.

B. Two-speed Transmissions / Shift Pitch Props

Some new drive designs promote increased performance due to reduced weight, drag or other features. We suggest these projects be aware of two concepts that might offer existing designs a new life, but have not yet reached the mainstream due to cost and reliability.

MerCruiser's Black Trac two-speed transmission [34] adapted to the engine bell housing in an effort to give more "zip" to stern drive boats. The units were especially effective in diesels and twin prop drives, but too expensive for widespread use. Several efforts of this nature can be found in the patent literature and occasionally in at least limited production [35]. Combined Engineering Concepts Ltd. of the UK announced a third party "in the leg" two-speed [36] for Volvo's duoprop stern drive in November 2000.

Land & Sea's Torque-Shift propeller [37] is basically a two-speed transmission for single prop stern drives. The propeller "shifts" from a low pitch at take-off to a larger pitch at midrange allowing much harder hole shots, quicker planning times and higher top speeds.

In addition to shift-pitch props, at least one firm is developing hydraulically shifted continuously variable recreational drive propellers [38] . This design allow the prop to reverse in pitch, removing the need for a reverse gear. Continuously variable pitch propellers offer even greater opportunities for performance improvements than shift-pitch props, but are currently very expensive.

The availability of an economical, builder installed, widely accepted two-speed transmission or shift-pitch prop for outboards and/or stern drives would make it more difficult for a new drive design to compete against the long-standing outboard and stern drive designs.

Technology Substitution

New drive designs preparing to fight for market share need to understand Technology Substitution [39,40], the study of one technology replacing another. Among the variables influencing early adoption rates are:

- The specific industry under study (some industries are more open to innovation)
- Return on investment needed in the industry
- Capital costs (new vs. old)
- Advantages (new vs. old)
- Cost savings & Tax Advantages (new vs. old)
- Anticipated Life of the Unit (new vs. old)
- Maintenance/Warranty costs (new vs. old)

New designs must offer very significant advantages in several of these areas, and have almost no disadvantages to be accepted by the market.

Parting Thoughts

These thoughts were composed for those considering trying to launch a new drive design.

1. Other competitive new designs are simultaneously trying to enter the market. This war may not only be fought against traditional inboards, outboards and stern drives. In addition to the many designs mentioned in this paper, several innovative water jet designs [41, 42] are also beginning to surface.

2. Several other drives, some with significant advantages and features have fought this war and lost.

3. New drive designs may have applications outside recreational boats: commercial work and fishing boats and larger craft (passenger vessels, fast ferries, military patrol boats, etc.). Some large vessel propulsion systems may move down to recreational applications.

4. The concept of "squeezing" new designs. Most new drive concepts are still at very early stages of development. Once placed in production, they will have much greater opportunity for further improvement than mature stern drive outboard designs. If a drive is marketable in its current state, it will become easier to sell as it evolves.

5. This is a very cyclical market. New boat sales swing rapidly with consumer confidence in the future economy. Many feel we are on the edge a downward swing in boating sales. Drive designs must be in it for the long haul, not just for the good times. Existing drive companies rely heavily on funds generated from the sale of service parts during times of economic downturn. New designs do not have this luxury as it takes many years to build up a substantial service parts business.

6. If a drive design appears to offer significant improvements over current designs, this opportunity must be weighed against technical, marketing, industry dynamics, intellectual property and economic factors when coming to decisions concerning further development, licensing and/or production.

7. Cable water skiing [43] (no boat involved) has jumped from Europe to the U.S.

8. Remember, this paper does NOT address the market dynamics issues surrounding attempts to manufacture high volume production drives. Please see reference #1 for those issues.

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Note: Some of the smaller firms and their web sites come and go. The links may not be current.

All Patents cited can be viewed by patent number at:
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