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INLAND TOWBOATS
The Next Generation

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CONTENTS

INTRODUCTION ... 3
BIRTH OF Z-DRIVE ON THE INLAND WATERWAYS... 4
THEORY/DISCUSSION... 6
Z-drive Efficiency... 6
Propeller Design, Efficiency & Vibration ... 6
Steering & Manuverability ... 8
Pollution... 9
Drivetrain Effeciency... 9
Capital Investment and Maintenance... 9
Fuel Savings... 10
RESULTS ... 12
CONCLUSION... 14
ACKNOWLEDGEMENTS... 16

EXECUTIVE SUMMARY

Inland towboats on all the inland waterways and Gulf Coast have traditionally been built using main engines connected to reduction gearboxes connected to long drive shafts passing through the towboat hull to a propeller held in place by a large support strut and large rudders in front and behind the propeller. This paper explores the possibility and recent applications of azimuthing stern drives (ASD's, commonly known as z-drives). The advantages of using z-drives on inland towboats are decreased installation time, increased fuel efficiency, increased trip time efficiency, decreased major maintenance downtime, and higher customer satisfaction. Savings in fuel and trip time from ten to thirty percent will be shown in both theory and actual towboat operation in the body of this paper. Results included herein show an average of 28% fuel savings and 11% trip time savings for a set of controlled experiments with unit tows.

INTRODUCTION

The first generation of inland towing vessels from the Civil War to World War I used wooden hull boats with steam engines. The next generation of inland vessels after World War I used steel hulls and steam engines. And the third generation began with the use of used diesel engines from World War II naval landing craft. Since the 1940's, there have been many advances in electronics, diesel engine design and construction, crew comforts, and safety. But the new construction towboat of today is basically a variation of the 1940's design: a steel hull with one, two, or three diesel engines connected to reduction gear boxes driving horizontal shafts to large propellers with steering controlled by rudders in front and behind the propellers. There may be a steel shroud surrounding the propeller and attached to the hull called a Kort Nozzle, which helps direct the flow of water into and out of the propeller and increases the amount of thrust. There may be one, two, three, or four decks. Some may have an elevator-like pilothouse. However there has been no real advancement in propulsion systems since the 1950's. There needs to be the type of change that occurred from steam engines to diesel engines - a new generation - to justify the present construction cost of an inland towboat.

This type of change could occur with the use of available technology, primarily propulsion units known as "Z-Drives", to produce the next generation of inland towing vessel. A z-drive is a single unit that incorporates the propeller (which may or may not be in a kort nozzle), drive shaft, reduction gears, clutches, and turning machinery to turn the propeller (and nozzle if attached) 360º.

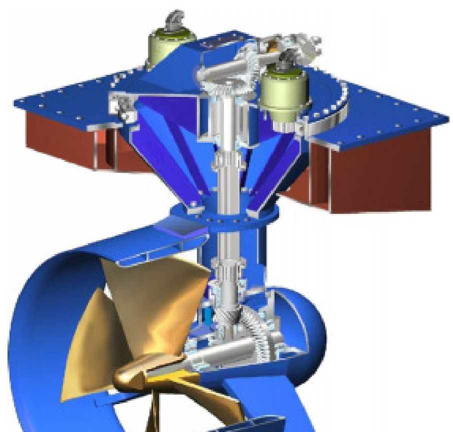


Diagram of Z-Drive Unit

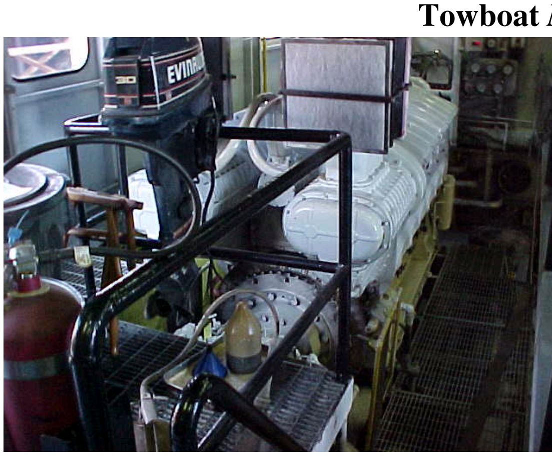
The use of z-drive propulsion units on inland towboats has never been taken seriously due to concerns about initial cost, maintenance, and durability. Z-Drive units have been used for many years on ocean going and harbor tugs. Z-Drive based designs for U.S. harbor tugs and coastwise towing vessels has gained popularity in the U.S. since the passage of the Oil Pollution Act of 1990. OPA 90 created a need for ship assist boats with greater maneuverability and stronger pull/thrust than traditional design ship assist tugs. Typically, two z-drive tugs can be used for ship docking instead of four conventional powered tugs.

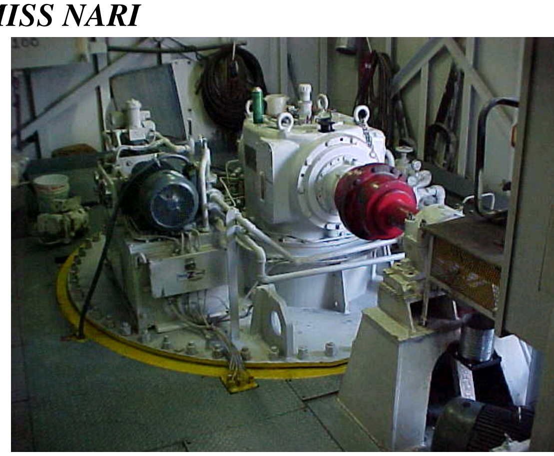
BIRTH OF Z-DRIVE ON THE INLAND WATERWAYS

The original inland towboat to use z-drives was the *M/V MISS NARI*. According to the 2006 Inland River Record, the *MISS NARI* was originally named the *DELTA CITIES* and built for Lake Tankers as a twin-screw conventional towboat in 1951 by St. Louis Shipbuilding, St. Louis, MO, 142.9 feet long by 43 feet wide. It was part of a fully-integrated tow complete with "wings" that were attached to the trail barge to extend alongside the towboat. The boat burned on Sept. 13, 1970 after colliding with the Port Arthur Bridge in Port Arthur, Texas. The boat changed hands several times but nothing was done to it until Compass Marine purchased it in 1980 and changed the name to the *MISS NARI*.

The boat was rebuilt with Niigata z-drives and diesel engines, and went back into service in 1982. The boat was used for dry cargo towing for some time and was last used for moving passenger barges. The Niigata engines were replaced with EMD 12-645E2 engines in 1990. The boat was used on nearly every river on the inland waterways and some on the Gulf Intracoastal Waterway. The z-drive units reportly had no major failure since installation. There was some replacement of housing gaskets and propeller maintenance in addition to the scheduled maintenance. Although the z-drive units can be serviced without the use of a drydock, the boat was docked several times to perform maintenance on the units.

Towboat *MISS NARI*





Niigata ZP-3A thrusters are rated at 1500 hp at 900 rpm. 75” diameter (1905 mm) propellers are running in KORT nozzles. For the harsh Mississippi River environment to which these thrusters are exposed, original NiAl Bz propellers were replaced with Stainless Steel propellers cast by Columbia Propellers. Spare Stainless Steel propellers were carried on the towboat with an improved and heavier design from Bollinger Shipyard, New Orleans, LA. Weight of z-drives is 11 tons each. Mr. Conrad serviced the Z-drives himself. Thrusters were equipped with only one steering motor driving a steering worm gear. Steering speed is 3 rpm.

The power transmission line consisted of a Niigata built, foot mounted, wet multiple disc clutch coupled to the EMD engine flywheel through a Haley Marine Gear flex coupling. Thereafter, an approximately 15 meter 6” solid steel shafting runs uphill approximately 10 meters and then levels to the Z-drives another 5 meters. All bearings (and there were many) are oil lubricated and all u-joints were grease lubricated.

Propulsion control was remote to the towboat and included a conventional towboat steering handle with built in throttle for engine speed control. These controls were custom built by Niigatta to meet towboats controls to which captains were accustomed. Shipboard power is provided by two 75 kW, Detroit Diesel 6-71 engines driving Lima generators.

The *MISS NARI* moved barges on the Mississippi, Ohio and Missouri rivers for many years. According to the Owner, Eddie Conrad, the *MISS NARI* is a nameplate 3000 horsepower towboat but has proven itself to be equivalent to a 5000 horsepower conventional towboat.

In the spring of 2006, Bill Stegbauer of Southern Towing Company began discussions with Ed Shearer of Shearer & Assoc., Inc., (now The Shearer Group, Inc.) to design a new series of 3200 HP towboats using alternative propulsion concepts. After much discussion and investigation into various alternative propulsion devices, it was decided to pursue the possibility of a towboat equipped with Z-Drives. Shearer & Associates were contracted to design the new towboats and approached several manufacturers of Z-Drives to develop preliminary arrangement concepts.

In the fall of 2006, Southern Towing Company produced an informational paper on the possible use of azimuthing thruster drives (more commonly known as “z-drives”) for propulsion units on inland towboats. As a result of this research and other factors, Southern Towing Company built four 3,200 horsepower inland towboats starting in late September of 2007 and completing the project in the first week of September, 2009. The first new towboat has been in service since August, 2008. Each of the new towboats has been in service enough to compare their performance with the predictions made in the original informational paper.

THEORY/DISCUSSION

Z-drive Efficiency

Jeffboat Shipyard, Jeffersonville, IN and Aquamaster did a joint study and model test of a triple screw towboat at VBD facility in Duisburg, Germany. Although the test report is not dated, company sales data listed in the report infers the test was conducted during 1997. The model towboat was tested using the traditional propulsion system and then tested using a z-drive propulsion system. Each propulsion system was tested with a tow and without a tow. The conclusions of the study were: thrusting straight ahead was the same for both propulsion types; steering forces increased 50% to 70% using the z-drives; stopping forces increased 50% using the z-drives; and maneuverability increased 54% to 390% using the z-drives. These are significant increases in vessel efficiency since inland towboats do not go in straight lines for long distances. These types of efficiencies translate into less fuel used to make turns and bends, to enter locks, and to work around docks and fleets; to gain more miles per hour using the same amount or less fuel; and to decrease accidents due to greater stopping and handling ability. (A copy of this study can be provided upon request.)

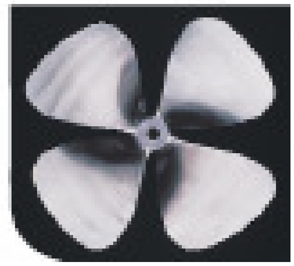
Propeller Design, Efficiency & Vibration

One of the items mentioned in STC's original paper was the use of skewed propellers. Skewed propellers are not generally used on inland towboats. They are typically found on ocean going and offshore vessels that normally spend all of their time thrusting forward. Although this type of propeller will greatly reduce or eliminate vibration in a vessel and provide greater thrust at the same speed as a conventional inland propeller, it will not thrust backwards or stop a towboat as well as a conventional inland propeller. Since inland towboats have to go in reverse almost as often as they go forward, the ability of a propeller to thrust in reverse as well as it thrusts forward is a necessity making the use of skewed propellers on a typical towboat unattractive.

Nonetheless, Southern Towing Company installed partially skewed propellers on several of its 3200-3600 horsepower towboats in 1994. When the first engineering studies were done for sizing the skewed propellers for the STC size boat and horsepower, the manufacturer predicted fuel consumption would decrease by 5%, vibration in the boat would decrease 67%, and the thrust would increase by 9%. These predictions were thought to be preposterous, but a gain of 3% fuel savings and increased thrust by 5% would be acceptable. The initial set of skewed propellers were put on a 3600 horsepower towboat towing various size dry bulk barges in a multitude of tow configurations on the Lower Mississippi River. The odd size tow configurations created a large amount of resistance to being moved through the water. This would normally create increased fuel consumption. However, fuel consumption decreased from 7% to 10%, vibration in the towboat dropped dramatically, and the thrust increased in excess of the predicted 9%.

Although the pilots on the test towboat loved the extra forward thrust, they had nothing but bad things to say about the reverse thrust and stopping power of the skewed wheels. STC worked with the manufacturer to "tune" the skewed propellers for better reverse performance but could never achieve the backing power of a normal inland towboat propeller. STC is still using the skewed propellers on towboats with unit tows but is using regular inland type propellers on the rest of its towboats.

Skewed Propeller



Traditional Towboat Propeller

Using skewed propellers in a z-drive eliminates the problem of poor reverse thrusting and stopping performance as the whole z-drive unit turns 180º to provide reverse thrust but the propeller itself is still thrusting forward relative to itself. (This performance was predicted by the Jeffboat/Aquamaster model test that showed a 50% increase in stopping force using the z-drive units.). Actual performance of the STC z-drive towboats showed that the stopping distance of a z-drive towboat with a tow was much shorter than a conventional towboat. Using a skewed propeller in a z-drive unit also increased thrust, which resulted in shorter trips and thus additional towing days of revenue over time.

All inland towboats will have some level of vibration throughout the boat due to propeller cavitation. Inland towboat propellers are a compromise between forward and reverse efficiencies. The skewed propeller maximizes the forward efficiencies, which eliminates vibration in the towboat caused by propeller cavitation. This will add to crew comfort and extend the wear on the drive train and propulsion unit due to little or no constant vibration. There have been towboats built where the crew quarters, galley, and pilothouse have been separated from the hull by resiliant mounts that dampen the vibration caused by normally operating propellers. This approach tries to solve a symptom of the vibration problem but does not solve the problem itself. Skewed propellers provide a solution to the actual problem. Performance of the STC z-drive towboats proves that the use of skewed propellers almost eliminated vibration caused by the propellers.

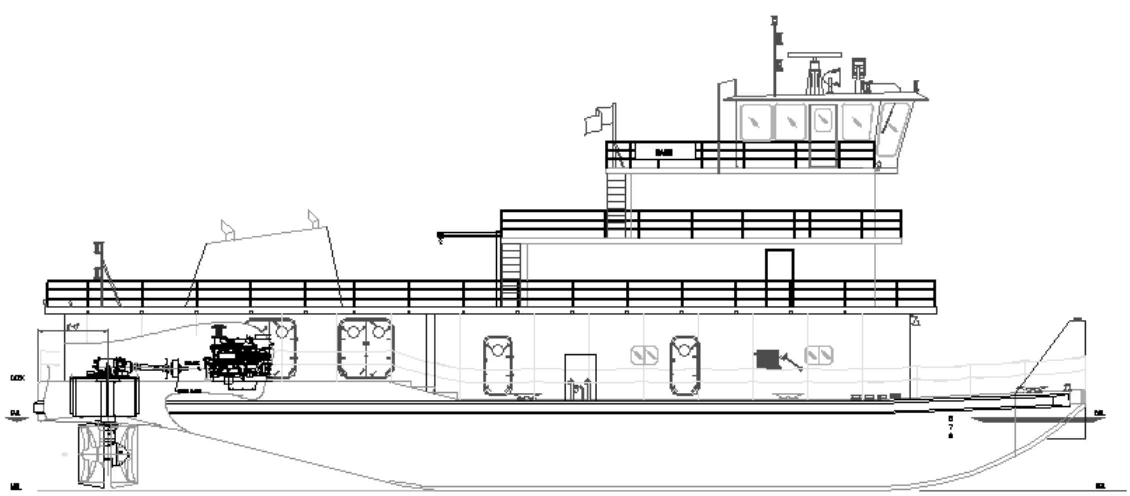
Z-Drive with Skewed Propeller

Steering & Manuverability

The traditional use of rear (steering) and/or forward (flanking) rudders on an inland towboat causes an increase in fuel consumption. When the rudders are used, they change the direction of the water flow produced by either the forward or reverse rotation of the propellers. The flow becomes a mixture of water slipping in the direction to which the rear of the rudder is pointing and a churning mass of water against the forward edge of the rudder. The change of flow creates a backpressure on the propeller. The backpressure on the propeller puts additional load on the engine, which increases its fuel consumption to keep the propeller turning at the set speed.

This is similar to the cruise control on a car. When a car on cruise control goes up a hill, the engine speeds up to keep the car moving at the set speed. When the engine speeds up, more fuel is used. The same thing is happening on an inland towboat whenever the steering or flanking rudders are used. Since the steering rudders are constantly in use, the engine is always using more fuel. There are no rudders on z-drive units which eliminates the additional fuel used when a towboat is steered.

With the traditional propeller and rudders system, a towboat tends to slow down as it is steered. This is due to the inefficiency of how the water is directed by a rudder as stated in the previous paragraph. The rudder movements cause reduced water flow into and out of the propellers and add frictional resistance to the boat moving through the water. The loss of speed decreases maneuverability and adds to the overall trip time of the tow. A z-drive system does not have this inefficiency as documented in the Jeffboat/Aquamaster study. Consequently, the towboat should not slow down when steering unless the pilot slows the engines for some reason. Actual performance of the STC z-drive towboats confirmed the prediction of no loss of speed or maneuverability when changing direction of the towboat.



Inland Towboat with Z-Drives in place of Traditional Propellers and Rudders

Pollution

With the passage of the Oil Pollution Act of 1990 (OPA 90), oil leak/spill penalties became much more onerous. All boat operators began to eliminate any potential sources of oil leaks. A frequent cause of an oil leak from normal wear or damage was the stern tube shaft bearing or the strut shaft bearing, both of which are oil-lubricated bearings. These leaks are to be reported as oil spills and result in fines from the U.S. Coast Guard.

All conventional drive inland towboats have a shaft seal where the drive shaft goes through the hull. Over time as the seal wears, water leaks into the boat. On some seals, a small quantity of leakage is required to keep the seal lubricated. This causes water to accumulate over time in the boat's bilge where it mixes with oil and other liquids from mechanical sources. The boat operator then has to keep the bilge or other voids pumped out until the boat can be removed from service for drydocking to repair the seal. In addition to the loss of revenue, the cost of drydocking, and the cost of replacing the seal, the oily water mixture has to be disposed of properly. Actual performance of the STC z-drive towboats proved there was no accumulation of oil or oily water mixtures in bilges or on the deck of the towboats. This eliminated a routine disposal cost of conventional towboats for these waste oil/oily mixtures and drydocking cost to replace the seals.

Drivetrain Effeciency

In response to OPA 90, non-oil lubricated shaft bearings were substituted for the oil lubricated shaft bearings which cured the oil leaks but created more resistance on the drive shaft. The increased resistance decreases the efficiency of these two main support drive shaft bearings. This increased dry bearing resistance increases the amount of horsepower required to turn the drive shaft, which uses more fuel. With a z-drive towboat, there would be no through the hull shaft seals. There are shaft seals on the z-drive unit itself. However, the z-drive shaft seals are double seals on the inside of the unit and, for additional protection, on the outside of the unit. There is almost no resistance to the propeller turning in a z-drive unit. On the Southern Towing Company z-drive towboats, a crescent wrench could be used on the input shaft to turn the propeller by hand.

Capital Investment and Maintenance

The old rule of thumb for the cost of new construction of a towboat with z-drive units is to add twenty-five to fifty percent to the construction cost of a traditional design. This rule of thumb comes from adding the cost of z-drive units to the total cost of a traditional towboat. This does not take into account the items that are eliminated from the construction cost of a traditional towboat. If a towboat is designed for z-drive units, there is no need for a main engine reduction gearbox, intermediate shaft, tail shaft, shaft couplings, shaft support bearings, stern tube and stern tube bearing, strut and strut bearing, propeller, steering rudder, flanking rudder(s), steering rudder tube and upper and lower bearings, flanking rudder tubes and upper and lower bearings, tiller arms, jockey bars, steering rudder hydraulic cylinder, flanking rudder hydraulic cylinder, hydraulic pipes and hoses running everywhere, steering pumps, and a hydraulic oil reservoir. The steering pumps are the largest consumer of electricity on the towboat. With the elimination of the steering pumps, smaller generator units can be used. Since there is no strut, stern tube, or reduction gearbox to install and align, many expensive man-hours are eliminated from the construction cost. Therefore, the cost of a new z-drive inland towboat will be approximately the same cost or at most ten to twelve percent more than the current construction cost of a new, conventional design, inland towboat (depending on which manufacturer of z-drive units is used). Actual construction cost of the STC z-drive towboats proved this assumption to be valid.

The operation of the *M/V MISS NARI* with z-drive units since 1982 with maintenance costs no different than a traditional towboat proved that the z-drive unit could function on an inland towboat just as well as the traditional drive system. In fact lower long-term maintenance costs are possible since a towboat with z-drive units does not have all the normal maintenance problems and requirements found in the typical towboat's hydraulic steering gear, drive shafts and bearings, reverse reduction gearboxes, and rudders.

Fuel Savings

The Jeffboat/Aquamaster study demonstrated that a z-drive towboat would be safer and more efficient to operate since it can stop quicker, maneuver better, and make better time. The study also indicated that decreased fuel consumption could be expected from these efficiencies. The use of a skewed propeller would further contribute to increased thrusting power and decreased fuel consumption.

As pointed out in the proceeding paragraph, there are many efficiencies to be gained from the use of z-drive units on an inland towboat: better stopping power, decreased time making bends and turns, decreased time making locks, docks, and fleets, greater thrust, and decreased fuel consumption. These efficiencies can be quantified as percentages of decreased fuel usage to determine future reduced operating costs. If each one of the above items decreased fuel consumption over a year by one percent, the cumulative effect would be a five percent reduction in fuel cost and inland waterway user taxes paid during that year. This would be the lower end of the percentage range. If a towboat normally made five miles per hour going upriver with loads and the z-drive units provided an extra one mile per hour, the increase in efficiency is twenty percent, the trip time takes twenty percent less time, and the fuel used for the trip is reduced by twenty percent. Since the z-drive units do not cause the engine to speed up when steering or the tow to lose speed, fuel use is reduced by one to three percent. Using a skewed propeller instead of a traditional propeller is possible with z-drives, which reduces fuel consumption seven to ten percent.

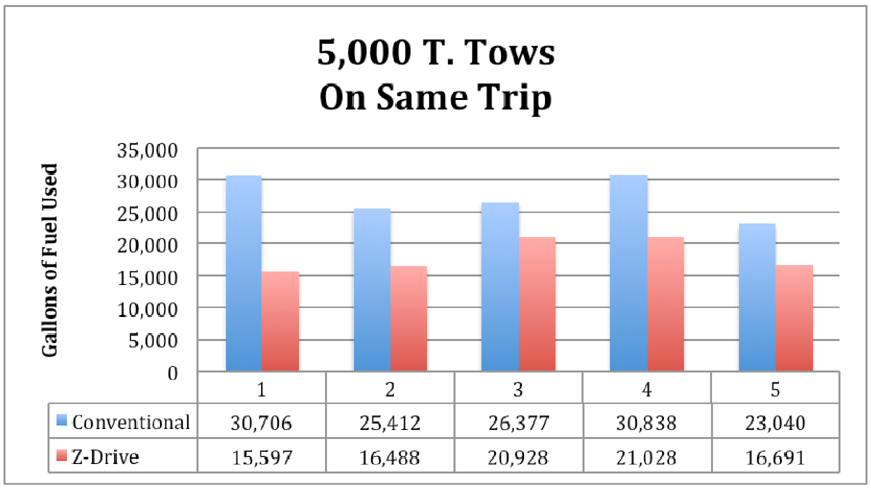
Adding these values together further show a possible reduction in fuel consumption of thirty-five percent during a year. However, there is no reason to believe statistically or with common sense these individual values are cumulative. If each value overlaps the next by half, then the reduction in fuel consumption would be seventeen and a half percent. These assumptions establish an expected range of five to seventeen percent fuel reduction during a year.

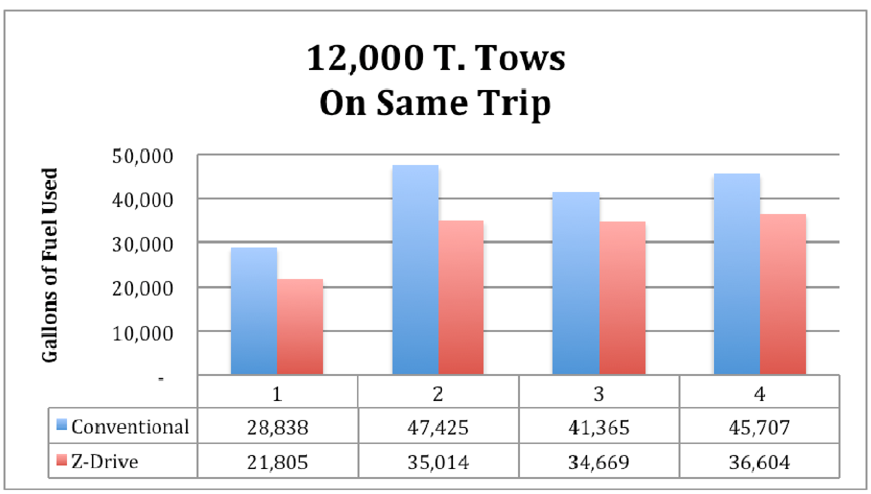
The fuel consumed by three 3200 horsepower conventional towboats was averaged over a four and a half year period. This produced an average yearly fuel consumption of approximately 731,677 gallons per boat. During this period, the price of fuel averaged a yearly increase of thirty percent. In 2002, the average price of midstream delivered diesel fuel was \$0.803 per gallon. For the first six months of 2006, the average price of midstream delivered diesel fuel was \$2.01. If there were a five percent reduction in the fuel consumption of the same horsepower towboat during the next year, using the \$2.01 average fuel price (plus \$0.224 inland waterways fuel tax), fuel cost would be reduced by \$81,729 per boat. If there were a ten percent reduction, fuel cost would be reduced by \$163,458 per boat. If there were a fifteen percent reduction, fuel cost would be reduced by \$245,185 per boat.

As fuel prices and taxes have increased in recent years, the dollar amount of these reductions have also increased, and they will continue to grow as future fuel prices and taxes increase. These are significant numbers, which can make up the difference of the new construction cost over a short time.

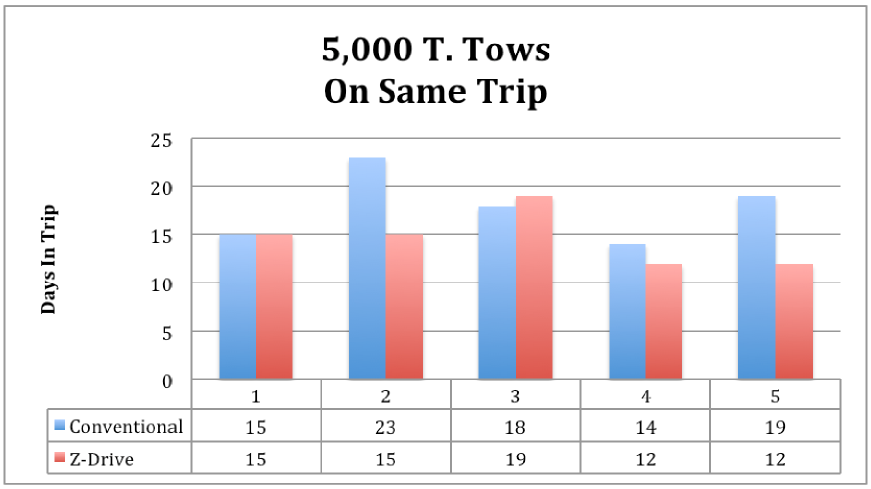
RESULTS

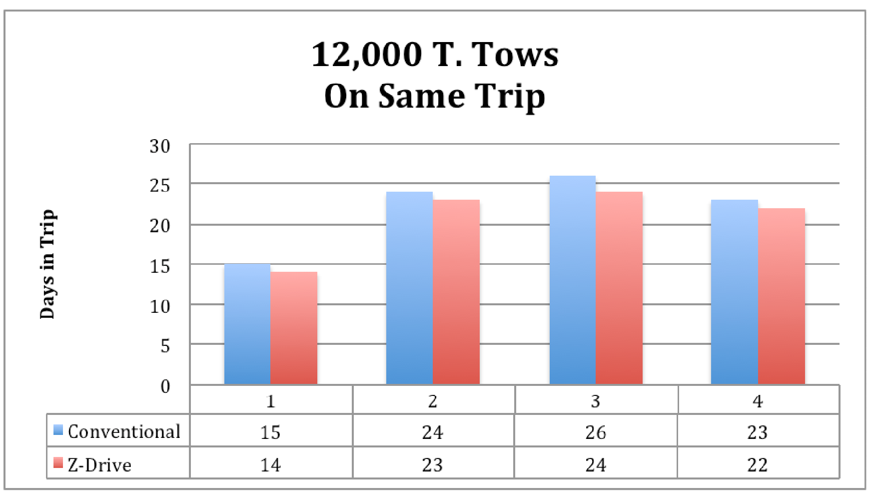
The above assumptions predicted a possible ten percent fuel savings using a z-drive towboat versus a conventional towboat. Z-Drive towboats have now operated long enough to gather comparative data for trip times and fuel used on the same trips with the same tows as conventional towboats. The charts below show 5,000 ton two barge tows and 12,000 ton four barge tows. It appears the z-drive towboats do make quicker trip times by one to two days per trip and the fuel consumed per trip is typically reduced in excess of twenty percent. In fact, the average fuel savings for a z-drive towboat versus a convential towboat is 28% for the data shown here:





Trip time is another metric worth noting. By increasing the amount of thrust for any given tow size, total trip times are reduced. This means that a towboat, which normally makes one or two trips per month, can now make one or more extra trips per year for the same yearly cost (depending on the length of the trip, i.e., the shorter the trip time the more extra trips can be made). While fuel cost reduction will be significant with a z-drive towboat and help control operating expenses, extra trips included in the same yearly cost will have a more significant effect on the operator's operating profit. The operator or charterer with the z-drive inland towboat will have the opportunity to increase revenues and reduce operating costs versus the operator/charterer with the standard inland towboat. The average trip time for a z-drive towboat is 11% less than that for a conventional towboat, based on the data shown below:





CONCLUSION

If a towboat is put on charter by the operator/owner, the charterer will accrue the advantages of the additional revenue opportunities and reduce fuel-operating cost. What advantages would then accrue to the operator/owner who paid for the construction cost?

By using the z-drives, many mechanical components are eliminated which compose most of the major operating costs of a towboat. The steering system for the main rudders and flanking rudders is composed of hydraulic oil tanks, pumps, pump motors, directional valves, hoses, rams, jockey bars, tiller arms, bushings, and pins. This would be eliminated. The main engine reduction gearboxes with engine couplings, air or hydraulic clutches, drive shaft couplings, oil coolers, and oil hoses would also be eliminated. The drive shaft with couplings, support bearings, through hull seals and support bearings, outside support struts, and strut bearings would be eliminated. The steering rudders and flanking rudders with rudder stock bearings and seals would be eliminated. The problem of continually lubricating the steering system and rudders would be eliminated. There is the opportunity to eliminate the use of air compressors, air tanks, and airlines running throughout the towboat (which was accomplished on the STC z-drive towboats). If electric starters are used for the main engines and generator engines, then there is no need for engine air starters (z-drive units incorporate electric throttle controls for the main engines).

With the elimination of nearly all of the mechanical components using grease, lubricating oil, and hydraulic oil, grease and oil leaks would be almost eliminated and damage to equipment caused by the lack of proper lubrication can be eliminated Further, by putting the main engines and generator sets on the main deck with the z-drive units control platform, oil and fuel in the bilges would be eliminated.

All of the small horsepower towboats working in the Gulf Intracoastal Waterway operate without a full time engineer. They use a crew position called a Deckineer who works as a fulltime deckhand or tankerman and who periodically checks the fluid levels in different mechanical components and changes filters. If any other maintenance needs to be done, shore side personnel perform the maintenance. River towboats have always used full time engineers as part of the crew. With the elimination of most of the operating machinery by using z-drives, the full time engineer position could also be eliminated. Checking to see that the z-drives, main engines, and generator units are operating properly could be done in the pilothouse using off the shelf monitoring technology.

All inland towboats will be United States Coast Guard inspected vessels in the near future. Most inland towboat operators have similar operation, maintenance, and safety programs due to being members of the American Waterways Operators and complying with the AWO Responsible Carrier Program. The marketing of the services of an inland towing company will become more difficult and more competitive in the future because it will become more difficult to distinguish between companies as all towing companies comply with the new regulations. When the next downturn comes, there will be no reason to retain or pay premium rates for the same type of towboat offered by ten companies. The company with the z-drive towboat will have a competitive advantage in up cycles or down cycles for years to come.

So a good question to ask is if a z-drive towboat can provide all of the advantages listed above, why aren't more companies building z-drive towboats? The answer is simple: the inland towing industry is very reluctant to change anything on its towboats involving large costs. If it ain't broke, don't fix it. In the first paragraph, three generations of towboat design over a 150-year period are mentioned with the last major change having been made over 50 years ago. The change from steam engines to diesel engines increased efficiency in boat handling and thrust, reduced fuel costs, and made the towboat safer to work on. The next generation will do the same.

ACKNOWLEDGEMENTS

Mr. William Stegbauer, a consultant to The Shearer Group, Inc.

Mr. Eddie Conrad of RiverBarge Excursion Lines, Inc. for his foresight in using and proving the z-drive concept in the M/V *MISS NARI*. Also thanks for his personal insights and information about the operation, maintenance, and performance of the *MISS NARI* and z-drive units.

Ed Shearer of Shearer & Associates and The Shearer Group, Inc. for advice and his willingness to have many discussions on the concept of a z-drive inland towboat and his involvement in the design of the original four z-drive towboats for Southern Towing Company; and The Shearer Group, Inc. for the design of the four follow on z-drive towboats.

Southern Towing Company for providing information on the construction and subsequent operation of their first four z-drive inland towboats.

Information was gathered from different manufacturers of z-drive units including Steerprop, Thrustmaster of Texas Inc., Rolls Royce/Ulstein Aquamaster, and Niigata. Pictures on pages 3, 5, and 7 are of Thrustmaster units.

Information was used from the test study done by Jeffboat Shipyard and Aquamaster on using z-drive units on inland towboats.

Barry Griffith for his 2009 picture of the *M/V David Stegbauer* with two tank barges at Newburgh Lock and Dam on the Ohio River.