SECTION 9
Brian W. King
Propulsion Systems

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THE THRUST END

Disregarding the possibility of paddlewheels or sail, the only practical alternatives for putting thrust to the water are propellers and waterjets. Each have their inherent strengths and weaknesses. The best choice for the small research vessel depends largely on the intended mission profile. Generally, waterjet drives have found the most applications on semi planing or planing boats intended to go over 25 knots. Propellers are more often applied to slower speed vessels with displacement or semi planing hulls.

To understand when each is used, one must understand a little about their principles of operation. The propeller screws its way through the water. As propeller RPM varies, so does propeller thrust and vessel speed. The jet drive is an axial flow or mixed flow pump. The amount of thrust it develops is independent of the waterjet drive RPM. The distinguishing characteristics of a propeller-driven vessel at the propeller are large diameter, large propulsion system momentum, large water flow, low flow velocity, and low propeller RPM. Propellers are very good at maintaining a relatively constant vessel speed when the vessel is being slammed by waves and gusting winds. As hull speeds increase, the shaft support and rudder appendages cause increasing drag and the propulsive efficiency goes down. The distinguishing characteristics of a waterjet-driven vessel at the waterjet are small diameter, small propulsion system momentum, low water flow, high flow velocity, and high waterjet RPM. Waterjet drives are much more sensitive to varying wave and wind forces. As hull load varies due to wind and wave forces, waterjet thrust varies and a constant vessel speed is harder to maintain. Waterjet drives have little or no appendages, so as vessel speed increases, there is no increasing appendage drag affecting propulsive efficiency.

Conventional Shaft and Propeller

A conventional, fixed-pitch propeller, when driven by a high speed diesel engine with reversing reduction gear and shaft, is perhaps the most economical and mechanically least complex of the small research vessel's propulsion system options. (Illustration 1). The conventional system is well proven and reliable. Most shipyards have experience installing a conventional propulsion system and can do it without a high degree of technical sophistication, not necessarily true of the other propulsion system options. Repair parts and technical support for the major equipment are, for the most part, readily available throughout the world. Over a fairly narrow designed speed range, the conventional propulsion system provides the highest overall propulsive efficiency of all propulsion systems available to the small vessel operator. The hull form for a conventional propeller with rudder may be configured so that the vessel is suitable for shallow draft operation or at least presents no delicate appendages below the bottom of the vessel.

When a propeller has been selected to provide the best cruising characteristics, it will not allow the vessel to go slow without constant attention from the operator. An 1800 RPM rated engine may have an idle RPM of 650. This corresponds proportionally to thrust at the propeller. This lack of ability to go slow may present a significant problem for some research vessel operational requirements. Another significant disadvantage is the propellers and the requisite rudder's ability, even talent, at fouling any lines or umbilicals that may be hanging over the side. The conventional propulsion system does not lend itself readily to dynamic positioning.

There are variations of the conventional propulsion system that make it more suited to the small research vessel operational needs. First to consider is use of a controllable pitch propeller system. It adds complexity and a higher initial cost, but it does provide the operator almost infinite speed variation from nearly zero thrust right up to the vessel's rated speed. The reduction gear is simpler because no reversing gear and clutch is required. A controllable pitch propeller system lends itself more readily to dynamic positioning, provided there is also a thruster and, it too, is part of the dynamic positioning system. Many small vessel controllable pitch propeller systems are well-proven, very reliable, and do not significantly increase operational costs or maintenance requirements. Other options to overcome the fixed pitch propellers lacking low speed control are slipping clutch systems or two-speed reduction gears.

Placing a propeller in a nozzle will generally increase low speed thrust. This may be important if the vessel operational requirements include towing. Over 10 to 12 knots, nozzles increase drag and will likely decrease the cruising performance. Nozzles have the added advantage of protecting the propeller and rudder from impacts and may reduce the probability of a propeller fouling with lines.

Waterjet Propulsion

Once waterjets were used exclusively for small, high-speed boats. They, in fact, are more efficient than conventional propellers when speeds are over 25 knots. (Illustration 2). Waterjets now are being built for work boats that need to go slow. Like the conventional fixed-pitch propeller, they lack very-low-speed thrust modulation. Unlike the propeller though, they can moderate their thrust by partially engaging reversing buckets so that they do have the ability to go very slow. Depending upon the configuration, the waterjet drive usually includes a clutch but often does not require a reduction gear. Occasionally a reversing reduction gear is installed to allow back flushing of the waterjet.

Waterjet propulsion lends itself to shallow water operation. Boats can generally be beached or sit on the bottom without damage to the propulsion system. Waterjet propulsion is safer to divers than any of the other propulsion options and is least likely to foul lines and umbilicals.

Z-Drives
Z-drives are so named because of their drive shaft configuration, horizontal off the engine, vertical through the hull, and horizontal again at the propeller hub. (Illustration 3). Modern Z-drives are proving themselves robust and reliable and are now the preferred propulsion system for most ship-assist and line-haul tugs. Initial cost and operational maintenance costs are higher than either the conventional propeller or the waterjet propulsion systems. Z-drives are available in fixed-pitch or controllable-pitch propeller versions and with open propellers or in nozzles. Z-drives may vector their thrust in any direction, making the vessels in which they are installed extremely maneuverable. Rudders are not used with Z-drive installations. Of all propulsion systems available, they are the system most suited for dynamic positioning.

For Z-drives to work effectively, they need to extend below the hull on a small vessel so their thrust is not blocked. This gives the vessel a comparatively deep draft and vulnerable appendages making the Z-drives unsuited to shallow draft work. As with a tug, Z-drives may be tucked under the stern, giving them some protection against bottom impacts, but this does reduce their all-around thrust vectoring capability.

Cycloidal Drives
Cycloidal drives orient their propeller blades vertically and generate lift over them much as an airplane wing does. (Illustration 4). Like Z-drive propulsion installations, cycloidal drives may vector their thrust in any direction and do not use rudders. Cycloidal drives are installed with a docking platform built under them and a skeg around which the vessel pivots, this allows some protection from bottom impacts. Cycloidal-drive vessels have comparatively deep drafts; they are less suitable for shallow water than some other forms of propulsion. Only recently, proportional electro-mechanical control systems have been developed for cycloidal drives making them suitable for interfacing with dynamic positioning systems and autopilots. Cycloidal drives have a higher initial cost and higher operating maintenance costs than the other propulsion system options described here. Cycloidal drive systems have generally proven themselves to be extremely robust and reliable.

Steerable Thrusters
Steerable thruster systems are available and are entirely flush with the hull. They work by ducting in water, either through ports in the bottom or in the side of the hull, increasing its velocity pressure through an impeller and then discharging it out through the bottom through a directable nozzle or steering vane assembly. (Illustration 5). They are well-suited to shallow water work and work where divers, lines and umbilicals may be in near proximity to the vessel. They are well-suited for dynamic positioning systems.

Steerable thrusters should be considered as auxiliary propulsion and take-home propulsion as they are too slow and inefficient to be effective main propulsion. By themselves, steerable thrusters may be suitable for propelling the vessel up to about 6 knots cruising speed.

THE PRIME MOVER END

At the end opposite the thrust end in the propulsion system, is a diesel engine, gas turbine, or electric motor. Due to its very good power-to-weight ratio, the gas turbine has found application on high-speed vessels particularly in combination with a waterjet. The gas turbine has found little application on vessel projects wherein high power-to-weight ratio is not a driving criteria and low cost is a driving criteria. Thus, they are not typically found on the small research vessel. More typical for the small research vessel, and discussed here, are diesel- and diesel-electric drive installations.

Diesel Drive

The most common propulsion installation is the direct diesel drive. (Illustration 1). As used herein, this is a diesel engine coupled to a reversing reduction gear, coupled to a shaft that drives a fixed-pitch propeller. Ahead or astern thrust is determined by the propeller rotation which is changed by which clutch and portion of the gears are engaged in the reduction gear. Changing the speed signal to the diesel engine governor controls propeller thrust and vessel speed. The diesel engine, the reduction gear, and the shaft supports are all typically bolted to the vessel's primary structure (the engine girder).

The direct drive diesel engine/reduction gear installation is comparatively low-cost, simple to install, and is reliable and simple to operate. As discussed previously, it has some disadvantages for low-speed operation. Most often the speed control of the direct diesel drive is enhanced by the use of a controllable-pitch propeller. With a controllable- pitch propeller, direction of thrust is controlled by reversing the propeller blade pitch, not by reversing the direction of rotation of the propeller; thus the reversing clutch and gear portion of the reduction gear may be eliminated. Instead, a hydraulic and mechanical means of propeller pitch control is added to the installation. With a controllable-pitch propeller system, the propeller thrust and vessel speed are controlled by combination of changing the speed signal to the engine governor and by varying the propeller blade pitch.

The direct-drive diesel engine, when rigidly coupled to the reduction gear and shaft, must maintain near-perfect alignment between each of the main components, or premature failure of the equipment will occur. Alignment is maintained by bolting the equipment to the engine girder. The engine girder extends under the engine and reduction gear and often is integral with structure supporting the shaft bearings, stern tube, propeller strut bearing and the rudder. It is massive and rigid, and part of the vessel's primary structure. The engine girder, in part, is designed to maintain alignment between the propulsion system equipment even with the hull flexing in a seaway and, in part, it supports and spreads the propulsion system static and dynamic loads to the vessel's other structure. This direct attachment of the equipment to each other and to the vessel structure also means though that the equipment vibrations, torsional and otherwise, have a method of transmission to each other and throughout the vessel's structure. If not carefully considered in the design and selection of equipment, these vibrations may have a detrimental (sometimes dramatic and catastrophic) effect to the well-being of the other equipment.

Additionally, the vibrations will be felt and heard as structural-borne noise, both within the ship and in the surrounding sea. A research vessel which must keep habitable working and living conditions for its crew and scientists, and a minimally intrusive profile in the marine environment, must have designed-in measures to reduce the propulsion system's noise. An effective way to dramatically reduce structural-borne noise is by resiliently mounting the engine and reduction gear to the engine girder and by putting a coupling able to take a certain amount of motion between the reduction gear and shaft. Other methods of reducing noise include sound insulation, and proper design and selection of equipment for the vessel's systems. Resiliently-mounted engines add considerable cost and complexity to the direct-drive diesel installation.

Diesel-Electric Drive

The diesel-electric drive propulsion system is a favored approach for larger research vessels with shaft horsepower of 1000 and more. (Illustration 6). In the past, the diesel-electric drive system complexity and cost has generally precluded their application for smaller vessels. Recent technological advances, however, have lowered the size of vessel for which it is a practical alternative. The electrical connection between the diesel generator and the propulsion motor offers design flexibility not possible with the direct-diesel drive. The typical installation is to have several diesel-driven generators providing power to an electrical bus which provides both ship's service power and propulsion electrical power. The propulsion prime mover in such an installation is then an electric motor. Propulsion motors may either be alternating current or direct-current, with direct-current motors being much more common on smaller installations. With either motor, propeller thrust is controlled by varying the motor RPM. Thrust direction is controlled by reversing motor direction. In the direct-current motor installation, speed is controlled by altering the motor voltage. In an alternating-current motor installation, speed is controlled by altering the frequency to the motor. With either motor type, speed is continuously variable from zero RPM to the rated RPM of the motor. More than any other attribute, it is the fine speed control of the diesel-electric system that makes it popular for research vessels. Unlike the direct-drive diesel system, there is little need for controllable-pitch propellers or reversing reduction gears with a diesel-electric drive system, although reduction gears with no reversing function are often installed between the motor and shaft to allow use of a smaller, high-speed motor.

In a modern installation, power converters are used to change the constant frequency output of the diesel generator to the direct current used by the direct-current motor or the changeable frequency for the alternating-current motor. The power converters introduce harmonic currents to the otherwise clean sine wave of alternating current on the electrical bus. These harmonic currents are notoriously damaging to the sensitive electronic equipment found in the laboratory or in the wheelhouse.

A diesel-electric vessel must either split the propulsion electrical bus from the ship’s service power electrical bus, or it must include equipment that isolates and filters the harmonic currents from the clean power sine wave. In a split bus configuration, separate diesel generators are connected to the propulsion bus and to the ship’s service power bus with no electrical connection between the two busses.

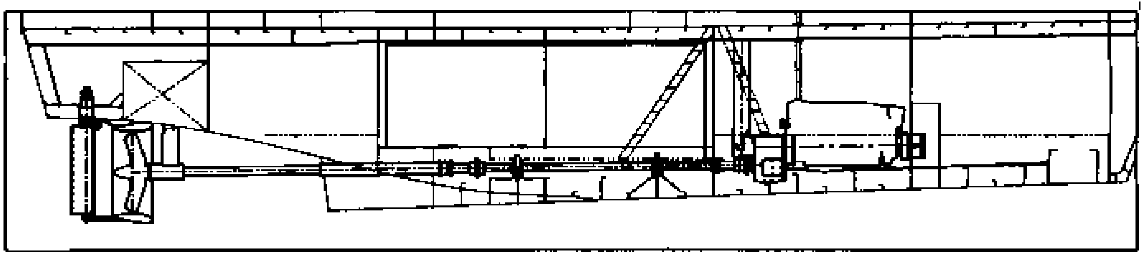

Illustration 1
Conventional Shaft & Propeller

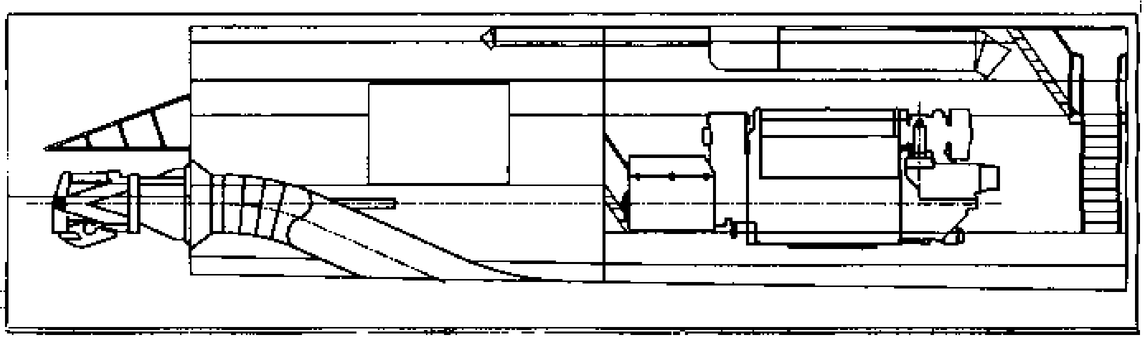

Illustration 2
Waterjet Propulsion

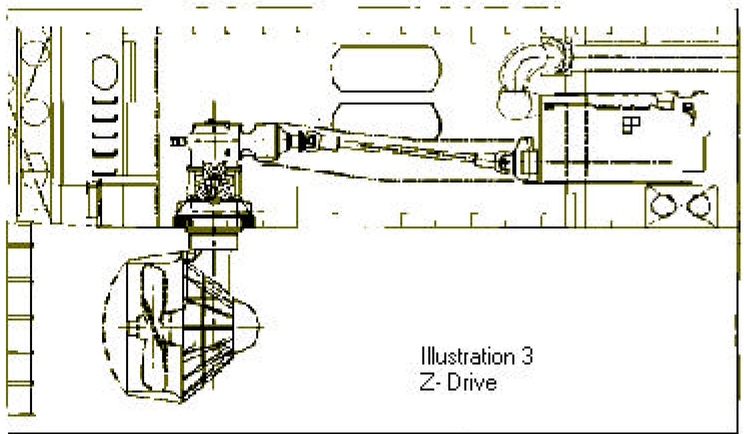

Illustration 3
Z- Drive

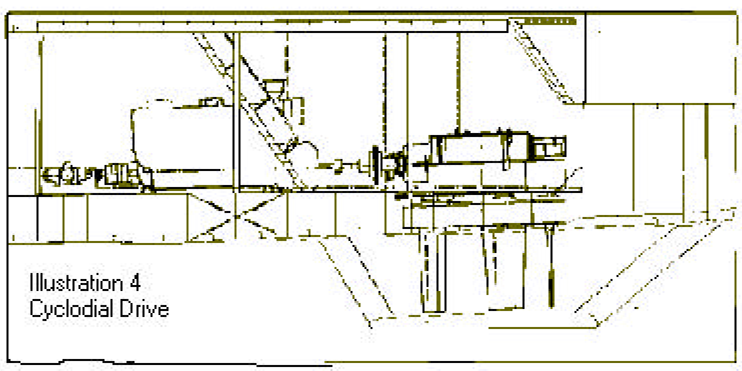

Illustration 4
Cyclodial Drive

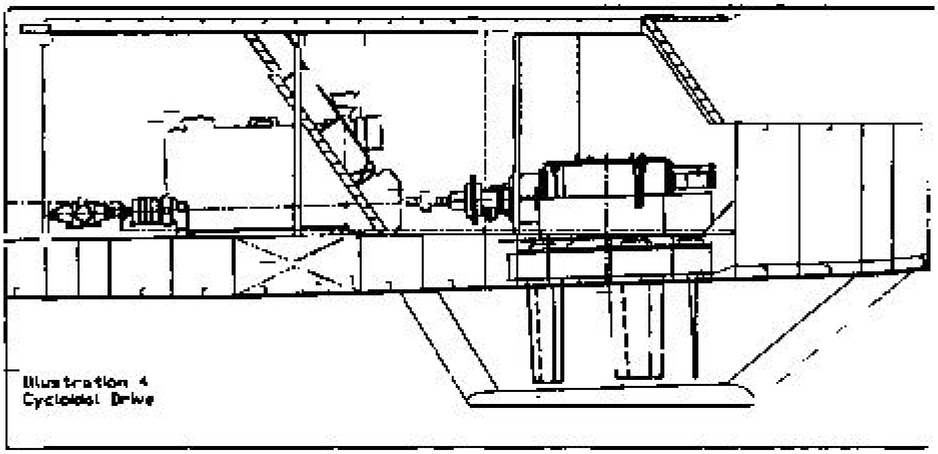

Illustration 4
Cycloidal Drive

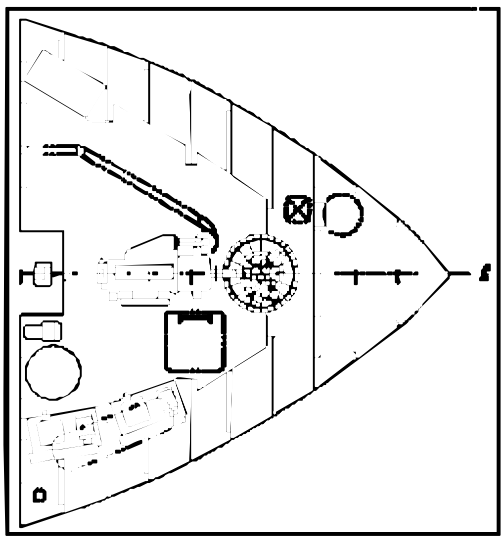

Illustration 5
Steerable Thruster

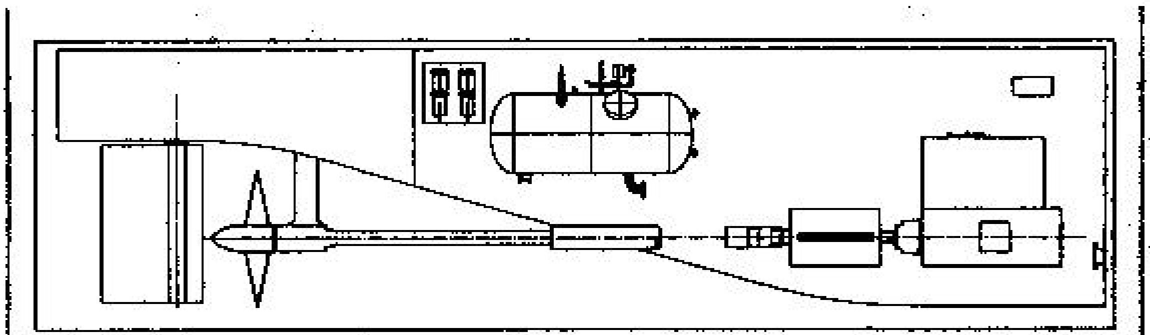

Illustration 6
Diesel-Electric Drive