MARINE JET DRIVES
Operation and Maintenance

Abstract
This document is an overview of the operation, maintenance, and repair of a marine jet drive. A brief history of the origin of the jet boat is provided. The characteristics of operating a craft with a jet drive are discussed, along with the advantages and disadvantages of using this type of design. The principles of the pump's operation are explained as well as considerations for improving its performance. The document concludes with a review of common maintenance and repair procedures.

Keywords
Water Jet Propulsion, Marine Jet Propulsion, Jet Drive, Jet Boat, Personal Watercraft

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OBJECTIVES

- Describe the operating characteristics of marine jet propulsion systems.
- Explain the advantages and disadvantages of jet propulsion systems.
- Discuss considerations for optimum pump performance.
- Explain the maintenance procedures involved in keeping the pump in proper condition.

HISTORY OF WATER JET PROPULSION

Keenan Hanley introduced his Hanley Hydrojet at boat shows in 1953 after partnering with Kermath Manufacturing to produce an application for recreational boating (FiberGlassics, n.d.). Sir William Hamilton, an engineer from New Zealand who created his own version of the jet boat in 1954 after being inspired by the Hanley Hydrojet (Hamilton Jet, 2019). The shallow waters in the rivers of New Zealand made it necessary to design a watercraft that could operate without its propulsion system getting damaged on the riverbed. By moving the jet outlet above the waterline and eliminating parts from protruding from the bottom of the hull, Hamilton was able to improve on the performance from earlier designs. Pleasurecraft of today have evolved even further by replacing centrifugal jet pumps with more efficient axial flow designs. (Figure 1)

![Figure 1 - Axial flow pump](image-url)
SHALLOW WATER

Since a jet boat’s drive components do not protrude below the bottom of the hull, the boat can travel in very shallow waters compared to other drive systems. The depth of water the craft can travel through would be very close to its draught. While the drive can clear objects in shallow waters, other considerations must be made during this type of operation. Shallow waters make it easier for the pump to suck up foreign objects from the bottom that could damage or adversely affect the operation of the drive. Objects like rocks, shells, and even ropes can get caught in the drive and result in damage that affects drive performance and can require costly repairs. It is not uncommon for weeds to get sucked into the drive and affect its performance as well. This is normally an annoyance and requires the operator to reach under the hull and clear the obstruction. Another common problem is when the drive is operated in shallow water where there is a sandy bottom. Sand pulled through the drive can quickly wear the impeller and housing, increasing the pump clearances and dramatically affecting the performance of the drive. The manufacturer should have a recommendation for water depth requirements below the bottom of the craft. For example, Seadoo recommends 3 feet of water under the bottom of the hull to run the engine on a 1996 Seadoo Sportster (Bombardier Inc., 1995). (Figure 2 and Figure 3)

Figure 2- Jet boat intake grate
STEERING CONSIDERATIONS

Steering must be done under power with a jet-driven craft because there is no rudder and the force for turning comes from the thrust created by the drive. This thrust is directed by the nozzle as it is aimed using the handlebars or steering wheel. (Figure 4) Faster engine speeds will result in more thrust and faster steering. This can be an issue when the operator’s instincts are to back out of the throttle in an emergency and then steer out of the situation. Doing this in a jet drive system will result in little or no steering ability. Some manufacturers have developed ways to retain a certain amount of steering at low engine speeds (Becker, 2018).
REVERSE GATE DESIGNS

To reverse the direction of a jet driven craft, the impeller cannot be reversed as is done with the propeller in a traditional stern drive design. The pump works by controlling the flow of water through it in one direction. There is no gearbox in a jet drive system to change the impeller’s direction of rotation. Instead, the jet pump is connected directly to the engine and its impeller turns in the same direction whenever the engine is running. When operating in reverse on a jet drive, a reverse gate is positioned behind the pump nozzle to redirect the thrust toward the bow of the craft. (Figure 5) There are typically two options for reverse gate design.

Figure 5- Reverse gate operation and positions
The simplest design directs the reverse thrust 180 degrees from the direction of the forward thrust. (Figure 6) The gate moves with the steering nozzle to change the direction of thrust when steering. This gate design is very small and simple, the operation causes the craft to maneuver similar to a sterndrive in reverse, this is very intuitive for most operators. The downfall to this design is that, when the thrust is straight forward, turbulent water is passed across the inlet of the pump and can adversely affect its performance. To correct this problem some designs will use a reverse gate that splits the thrust into two paths that pass on either side of the pump inlet. (Figure 7) The gate does not move with the steering nozzle. Instead, the nozzle moves independently, directing more thrust toward one side of the gate or the other as it moves. With this design, the thrust is sent toward the opposite side of the craft compared to the previous design. Some operators may not find this design to be intuitive as it does not respond in the same manner as a sterndrive boat. It seems the best method for operating a craft with this design is to picture the reverse gate design and understand that the thrust will move toward the same side of the boat that the handlebars or steering wheel are turned.

Figure 6- Reverse gate movement with nozzle

Figure 7- Reverse gate in fixed position
ADVANTAGES

Marine jet drive systems have several advantages over other marine drive systems. A couple of these advantages have been discussed already. Below are the advantages usually associated with this type of marine drive system.

**Good for shallow water operation:** The shallow operation of this drive system was discussed extensively at the beginning of the characteristics section.

**No exposed propellers:** Another benefit is that the impeller is contained inside a pump housing so there are no spinning propellers at the rear of the craft. This is important when considering the safety of individuals exiting and entering the craft from the stern. However, one should also consider the forces of the water leaving the nozzle of the jet drive and caution should be used when operating while individuals are in the water near the stern of the craft. The engine should be turned off when passengers are entering or exiting the craft at the stern.

**Responsive steering under power:** Operation of the steering system was briefly discussed earlier, explaining how the machine must be steered under power to work effectively. The craft responds with greater steering force as engine speed increases. Some operators may enjoy this characteristic of the jet drive.

**Less weight and overall size compared to a sterndrive:** The entire jet drive unit is very compact compared to that of a sterndrive or outboard motor of equal power. The engine is normally positioned lower in the hull and slightly forward of the transom.

DISADVANTAGES

Marine jet drive systems also have several disadvantages over other marine drive systems. Some of the drawbacks of using a jet drive have already been discussed as well. As with most things in life, there is a give and take. Here are some of the disadvantages of the marine jet drive.

**Little to no off-throttle steering:** While the jet drives steering system is very responsive under power, as discussed earlier, it does not work well, if at all, when the operator lets off the throttle. Besides the implications of this characteristic in an emergency situation it also causes the second disadvantage listed.

**Don’t perform well in low-speed environments:** A craft with this drive does not handle very well in low-speed operations and can be slow to react. This is due to the lack of a rudder protruding below the hull.

**Towing performance:** The towing performance of the jet drive is normally considered less desirable than that of a propeller-driven system that contains a rudder (Hemmel, 2017). The absence of the rudder tends to make the jet-driven craft more susceptible to side forces applied by the object in tow.
Lower efficiency: Jet drives are also less efficient than prop drive systems. A higher horsepower engine is required to achieve a similar level of performance in comparison to the propeller drive.

**PRINCIPLES OF OPERATION**

**THRUST**

While a propeller drive system works by traveling through the water as it rotates, the jet drive impeller is used to move the water through the pump housing and force it out the back of the pump at a high velocity. (Figure 8) The thrust created by the water being forced out of the pump propels the craft in the opposite direction. This is the same action experienced when operating a pressure washer and feeling the wand of the washer push back as the high-pressure water leaves the small nozzle.

**STATOR**

After water passes through the impeller it is then sent through the stator. The stator converts the rotational forces of the water leaving the impeller into linear force before it moves toward the venturi. Figure 9 shows a breakdown of the pump housing, showing the orientation of the impeller and stator. For reference, the stator housing would be found in the grey area to the right of the impeller in the pump identified in Figure 1.
VENTURI

The high velocity of the water leaving the pump is created by sending the water through a venturi. (Figure 10) The venturi is smaller than the housing’s internal diameter. Forcing the water through the smaller diameter area requires the water to speed up. To understand this, consider sending a defined volume of water through a four-inch diameter pipe within a specific time period. If the same volume of water were to be pushed through a pipe with a two-inch diameter, the water would need to travel faster if the operation were to be completed in the same time period as the larger pipe. Changing the size of the venturi has an effect on the amount of thrust created and how the pump performs at high and low speeds. Increasing the diameter of a venturi would improve low-speed acceleration but reduce the craft’s top speed. Reducing the diameter would improve top speed but reduce acceleration (Bombardier Recreational Products Inc., 2003).

Figure 10- Venturi

NOZZLE

After the water leaves the venturi it passes through a nozzle that controls the direction of the water as it leaves the pump. Aiming the nozzle to one side of the craft or the other steers it in the desired direction. Some systems also allow for the nozzle to be pointed up or down to change the trim adjustment. (Figure 11) Changing the trim affects the attitude of the bow. Trimming down forces the bow into the water and makes the hull cut through the water making it more effective in turns. Trimming up causes the bow to rise, reducing the area of the hull in contact with the water when on plane, lowering its drag and improving high speed efficiency. Trim adjustment is more common as a feature in outboard and inboard-outboard systems.
NEUTRAL OPERATION

Jet drives do not have a true neutral because the impeller is always spinning with the engine and water is moving through the pump. In order to obtain what could be called neutral, the reverse gate is dropped into a position where an equal amount of thrust is directed towards the front and rear of the craft. (Figure 12) The position of the reverse gate when in neutral is key to proper operation. Manufacturers normally provide specific instructions for adjusting the reverse gate when in the neutral position. These instructions should be followed carefully. Water is still moving through the nozzle and partially against the reverse gate in the neutral position. As a result, the craft may still move around slightly and turning the wheel will still change the direction of thrust and cause movement of the craft.

Figure 11- Nozzle Trim Adjustment
PERFORMANCE CONSIDERATIONS

IMPELLERS

Impellers are a very important component of the marine jet drive and they come in many designs and sizes. The pitch of an impeller is identified differently than the pitch of a propeller. Where the propeller's pitch is the distance it moves through a solid medium in one rotation, the pitch of an impeller is a measurement of the blade angle. (Figure 13) The impeller pitch is selected to match the operating rpm of the engine. The desired pitch can vary depending on the manufacturer and impeller design. Comparing pitches between different impeller designs alone may not provide a direct correlation to actual performance (Impros, 2019). In general, when dealing with the same impeller design, decreasing the pitch of the impeller will increase the wide-open throttle operating rpm, improve low-speed acceleration, and reduce top speed. Increasing the pitch of the impeller will lower wide open throttle rpm, increase top speed, and reduce low-speed acceleration (Impellers.com, 2019) (Impros, 2019).

In order to reduce the sacrifice that must be made in low and high-speed operation when selecting impeller pitch, progressive pitch impellers have been developed. With a progressive pitch impeller, the leading and trailing edges of the blades have a different pitch. (Figure 14 and Figure 15) The angle at the leading edge of the blade has the most effect at low rpm and the angle of the trailing
edge has the most effect at high rpm (Bombardier Recreational Products Inc., 2003). Some impeller designs that can affect performance are blade overlap, sweeps or a swirl design on the leading edge, and using different materials. Building impellers with stainless steel provides strength for improvements such as using smaller hubs to allow more area for water to move through the pump (Impros, 2019).

Figure 14- Straight Pitch

![Straight Pitch Impeller](image1)

Figure 15- Progressive Pitch

![Progressive Pitch Impeller](image2)
The edges of the impeller are made to fit very closely to the pump housing's inner diameter. The clearance between the impeller and housing is critical to pump performance. Excessive clearance can cause cavitation, poor acceleration, and reduced top speed. Changes in clearance could be due to wear of the impeller or the housing. SeaDoo uses a liner in their pump housing called a wear ring that is purposely made of a polymer material that is softer than the impeller. If wear occurs only to the wear ring, and it is caught in time, the cost to replace the ring is much less than the impeller. Other manufacturers use a solid metal pump housing that may wear at a similar rate as the impeller. Replacing the entire pump housing is much more expensive than polymer liners and because they wear at a similar rate as the impeller, replacement of both the impeller and housing may be needed to correct excessive clearance.

**CAVITATION**

Cavitation happens when low-pressure areas in the pump cause water to boil near room temperature, creating gaseous bubbles which then collapse violently back to a liquid state as they enter a high-pressure area. This phenomenon is not desirable and can be caused by many factors. Under heavy acceleration, pressures low enough to cause cavitation may be developed before the impeller. This can be improved or exacerbated by impeller selection. Imperfections in the inlet grate, pump housing, or the impeller blades are some of the other causes of cavitation. The results of cavitation can be seen in the form of burn marks and pitting on the impeller, stator, and possibly other areas of the pump housing or intake.

**BLUEPRINTING**

Blueprinting can be done to the intake and pump housing to improve the performance of the pump. (Figure 16) Extreme and minor changes can be made to pump components to improve and fine-tune the flow of water through the pump, eliminating disturbances that reduce performance. For this reading, we will discuss the minor improvements that can be made to correct variations from the manufacturing process. The water enters the drive through the intake grate and the profile of the grate can have an effect on how the water flows through the drive. Different grates can be purchased to improve flow but cleaning up imperfections such as casting marks and slag leftover from manufacturing can reduce disturbances as water passes through the grate. The intake track and pump housing should also be inspected for imperfections and casting marks or slag buildup on areas like stator vanes should be smoothed. It is also important to inspect where the intake scoop and ride plate, or ride shoe, are mounted to the hull. If these are not sealed correctly it will affect pump performance. If leaks are suspected in this area they should be corrected by removing the components and reinstalling them correctly.
OTHER CONSIDERATIONS

Slight damage to the impeller can be cleaned up but care should be taken not to remove too much material. Impeller blades can also be re-pitched using an appropriate gauge and carefully bending each blade equally to the desired angle.

Most impellers should have a right-hand rotation when viewed from the front of the craft. If this is the case, the pump load increases in left-hand turns reducing engine rpm and decreases in right-hand turns increasing engine rpm (Bombardier Recreational Products Inc., 2003).

MAINTENANCE

PUMP INSPECTION

The jet drive pump is a fairly simple assembly but the condition of its components is crucial to proper operation. The importance of maintaining proper impeller to housing clearance has been discussed earlier in this chapter. This measurement is taken with a set of feeler gauges. (Figure 17) If the pump is still mounted to the hull, a long set of feeler gauges will make the inspection process easier. (Figure 18) The clearance measurement can be taken from the inlet side of the pump housing through the inlet grate or the outlet side of the housing if the nozzle and venturi are removed (Bombardier Recreational Products Inc., 2003). If the pump is being removed anyway, this makes it...
easier to measure the clearance with a standard length set of feeler gauges. Compare the measurement to the specification found in the machine's service information. If the clearance is out of specification, further measurements of the impeller and pump housing diameter need to be performed to determine if one or both of them need to be replaced.

WEAR RING REPLACEMENT

If the pump housing shows signs of wear and contains a wear ring, the ring can be replaced without having to replace the entire housing. Wear ring replacement requires the removal of the pump housing from the hull and removal of the impeller from the housing. The ring can be carefully cut, to release the pressure holding it in place, and then removed from the housing. Care must be taken to cut only the ring material and not the pump housing. Installation involves simply pressing the new wear ring into the housing. The impeller and pump are then reinstalled.

IMPELLER REPAIR AND REPLACEMENT

Minor damage to the impeller such as nicks and burs can be filed to repair the impeller for continued use. As little material should be removed as possible. Some damage is not repairable and the impeller must be replaced if this is the case. The removal of the impeller normally involves the removal of the pump housing from the hull, a vise, and a few special tools. The impeller shaft in the stator is sometimes held by a special tool in a vise and another tool with a hex-shaped head and splines that match the impeller driveshaft splines is used to unthread the impeller from the impeller shaft. (Figure 19)
ENGINE ALIGNMENT

Proper engine alignment reduces driveline vibrations for smooth operation and a more enjoyable experience for the passengers. The alignment procedure should be done when the engine or its mounts are replaced. Manufacturer-specific tools and procedures will be needed to achieve proper alignment.

HUB SERVICE

The hub of the jet pump is housed in the stator assembly and contains the impeller shaft. The impeller threads onto the impeller shaft where it sticks out from the front of the hub. A cone is attached to the rear of the hub assembly. This hub seals the rear of the hub and provides a smooth transition for the water as it leaves the back of the stator and hub housing. (Figure 20) The hub cone should be removed at least once a year, normally when the craft is winterized, to inspect for water intrusion into the hub and replace the hub lubricant if necessary.
CONCLUSION

The marine jet drive has become a popular marine propulsion system, not only for personal watercraft but also for small boats. Its unique design and characteristics set it apart from propeller drive systems. A component of safety comes as a result of the impeller being positioned inside the pump housing when compared to the open propeller of a sterndrive or outboard. However, the force of water exiting the drive and the pinch points created by the steering mechanism should not be overlooked and the engine should still be shut down when people are at the stern of the craft. Decreased draught compared to other systems allows more freedom and less worry when navigating shallow waters and around underwater obstacles. Handling has an aggressive feel and steering is very responsive under power, creating a fun factor for the operator. However, the opposite is true when not under power. At low engine speeds it can be difficult to control the vessel. This drive system is fairly low maintenance and the need for repairs should be kept to a minimum as long as the operator understands the limitations of the system and keeps it maintained properly. While shallow water operation is considered an advantage of this system over others, pump speeds should be kept to a minimum in these situations to prevent sucking foreign objects or excessive amounts of sand into the drive that could cause damage. Regular visual inspections should be performed on the basic drive components and at least once a year a thorough inspection should be performed to ensure the drive is operating at peak performance.
REFERENCES


