White Paper on Electric Standup Paddleboard Technology

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1. Introduction

The new sport of electric standup paddleboarding enables paddlers to go faster and travel further at sub-planing speeds. Speed from electric propulsion also adds stability to the board allowing paddlers to go out in a wider variety of conditions and perform a greater range of maneuvers. A well-designed electric standup paddleboard provides the paddler with an incredible amount of freedom and mobility on the water making the sport fun and engaging.

Electric standup paddleboarding products were first offered in 2014. Their introduction evolved out of a convergence between standup paddleboards and lithium-ion batteries. Over the past ten years companies have strived to offer electric standup paddleboards that are easy to transport, simple to operate and that handle well on the water. This paper describes electric standup paddleboard technology as it exists today with the intent of helping the industry improve their products.

2. Types of Drives for Electric Standup Paddleboards

Electric standup paddleboard (electric SUP) drive technology can be classified into three distinct types; 1. integrated jet drives, 2. fin-box mounted drives, and 3. forward mounted drives. Both fin-box and forward mounted drives can be added onto a regular standup paddleboard converting it into an electric SUP. In contrast, integrated jet drives are built into a dedicated electric SUP board.

a. Integrated Jet Drives

Boards with integrated jet drives have the motor and battery integrated into the body of the board. The drive utilizes an impeller located inside a channel in the board to generate propulsion. Integrated jet drives have the advantage of being located in the midsection of the board keeping the board balanced both on and off the water. In addition, they are equipped with a fin on the tail of the board to improve stability as the board moves through the water.

Boards with integrated jet drives are heavier and more expensive when compared to fin-box and forward mounted drives. This is because jet drives are less efficient at converting battery power into propulsion when compared to drives that use a propellor. Jet drives require about three times the onboard battery capacity of a fin-box or forward mounted drive having similar speed and range characteristics.

Because boards with integrated jet drives do not have an external rotating propeller, they provide an unmatched level of safety in the water. In addition, the lack of protruding or external moving parts protects the board from unintended mishaps, such as damage from running the board onto the beach.

b. Fin-Box Mounted Drives

Fin-box mounted drives are those with a motor/propeller assembly (motor) located on the tail of the board where the fin is normally positioned. Fin-box mounted drives have two advantages. First, they use an efficient propeller to convert battery power into propulsion. Second, they are easy to install on a regular standup paddleboard by removing the board's fin and replacing it with a motor. The battery is placed on the tail of the board and the power cable from the motor is run over the rail of the board and connected to battery.

Although fin-box mounted drives are a convenient way to convert a regular standup paddleboard into an electric SUP, they have numerous disadvantages. The main disadvantage is the board's poor maneuverability on the water. With the fin removed and a motor installed in its place, the board tends to turn by pivoting around the tail. Consequently, the rider must conduct a turn by applying drag with the paddle to force the nose of the board to port or starboard. And if they move their weight back in an effort to assist the turn, the weight of the drive gear tends to sink the tail. This weight imbalance at the tail also makes the board difficult to carry at the beach.

c. Forward Mounted Drives

Forward mounted drives use an efficient propeller for propulsion and are located in the midsection of the board. The term "forward mounted" is used to describe the drive's location relative to the paddler. However, the drive is located with the midsection of the board when dividing the board into three equal lengths. Locating the drive in the midsection ensures the board is balanced both on and off the water. It also serves to maintain a fin on the tail of the board for improved stability.

Forward mounted drives attach to a board with a fitting that is fabricated into the board. This fitting can be installed while the board is being manufactured. It can also be installed as an aftermarket modification to the board. For the do-it-yourself customer, a mounting plate can be adhered to the board to support the motor.

Forward mounted drives combine the main advantages of both integrated jet drives and fin-box mounted drives. Like fin-box mounted drives they use an efficient propeller for propulsion and can be used to convert a regular standup paddleboard into an electric SUP. And like integrated jet drives the motor and battery are centrally located leaving the fin in place on the tail of the board for added stability.

3. Physical Design Elements

The following physical elements are important when designing an electric standup paddleboard. They effect how the board handles and ultimately determines the rider's experience on the water.

a. Speed

Speed makes an electric paddleboard more comfortable to paddle and exciting maneuver. Paddling is more comfortable because the paddler is delivered a smoother, faster glide through the water. And with speed the board becomes more stable. This dynamic stability is similar to the feeling you get when riding a bicycle. At slow speeds the bike is unstable. As you speed up the bike becomes stable and more controllable. This same dynamic stability is at play on an electric standup paddleboard. As speed increases, the board becomes more stable, and the rider feels more in control. With speed and control, a broader range of maneuvers becomes available to the paddler making the experience on the water engaging.

Non-motorized, recreational paddleboarders realize speeds of about 2 to 3 mph. Since each paddle stroke propels the board forward, the motion is not necessarily smooth. The addition of an electric motor smooths the board's forward motion and makes paddling less strenuous. Motorizing a paddleboard without substantially increasing the paddler's speed is called "Paddle Assist". At Paddle Assist speeds the shape of a board is not critical, and the electric drive components tend to be smaller and less expensive.

As speeds increase the board becomes more stable and maneuverable. At speeds of 4 to 5 mph the board is moving at an exciting pace. When an electric drive is designed to propeller the rider faster than they would normally paddle without a motor, it's called "Paddle Enhanced ".

Speed is nonlinear. That is, the faster the board moves through the water, the greater its resistance through the water. This hydrodynamic resistance is a function of many factors. One factor is the board's capacity to generate waves. At Paddle Assist speeds of 2 to 3 mph, a board generates small waves that propagate off the bow and sides of the board. As speeds increase, the waves get bigger and are spread further apart because larger waves have longer wavelengths. At Paddle Enhanced speeds of 4 to 5 mph, the length of the board and the wavelength of the wave it generates align, and the board starts surfing in the trough of its own wave. This is the sweet spot for an electric standup paddleboard. This is where the board feels stable, yet responsive on the water. It is also the most efficient speed for a board operating in the Paddle Enhanced mode. This optimal speed range begins where the speed to resistance curve flattens with a commensurate leveling of propulsion efficiency.

The upper limit of this range is just below the board's theoretical hull speed. Above its hull speed, propulsion efficiency drops precipitously as the board tries to ride up on the wave it generates.

Figure 1 illustrates the optimal speed range for a 11' 6" board operating in both Paddle Assist and Paddle Enhanced modes. With a theoretical hull speed of 5.2 mph, the optimum Paddle Assist speed is 2 to 3 mph and the optimum Paddle Enhanced speed is 4 to 5 mph.

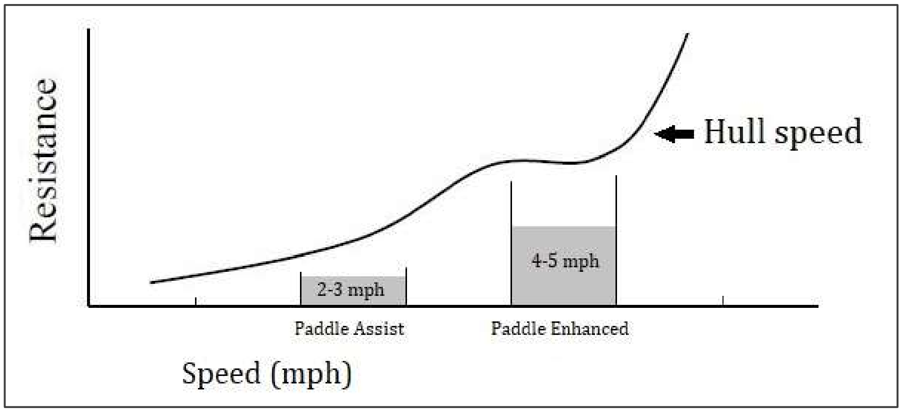

Figure 1 – Speed to resistance curve for a 11 6" electric standup paddleboard.

At Paddle Assist speeds there is minimal resistance moving the board through the water and the battery will last for extended periods. At Paddle Enhanced speeds the board uses more power but is noticeably more stable and maneuverable on the water.

Surf style boards with generous rocker are the most efficient type of board when operating at Paddle Enhanced speeds. This is because they are effectively surfing on their own wave and the rocker curve on the bottom of the board emulates the shape of that wave. This makes the board feel lively underfoot while still being stable and maneuverable.

Surf style boards with generous rocker are particularly sensitive to their hull speed limit. As the board tries to push past the speed of the wave it generates, the board hits a resistance wall at its hull speed. Boards with flat to gentle rocker are less sensitive to this hull speed limit. This is particularly true for boards with a narrow displacement hull and flat rock line. These attributes minimize hydrodynamic resistance when paddling faster than the board's hull speed. Boards with these attributes can be used as an electric SUP, but their responsiveness on the water in terms of liveliness and maneuverability will be compromised.

The following equation is used to calculate the theoretical hull speed for any given paddleboard.

$$V = 1.542\sqrt{L}$$

Where, V = Hull speed in mph, and L = Length of the board in feet

Using this equation on a 14’ board gives us a calculated hull speed of 5.8 mph. For a 12’ board the hull speed is 5.3 mph, and for an 11’ board, 5.1 mph. Based on these calculations, the maximum speed for designing an electric drive system for paddleboards is 5 to 6 mph. This will allow most boards to operate at speeds within their Paddle Enhanced range without exceeding their hull speed.

b. Rocker

As noted above, rocker is an important characteristic of an electric standup paddleboard. Rocker is defined as the amount of upward curve on the bottom of a board measured from nose to tail. A race or touring board with flat rocker may have only a few inches of curve upwards at the nose and tail. Whereas a surf style board may have a rocker line with the nose and tail up to 6 inches off the ground when the center of the board is sitting level to the ground. Boards designed to surf have generous rocker making them easier to take off on a wave as the curve on the bottom of the board emulates the curve of the wave. This bottom curve also helps an electric standup paddleboard slip into their sweet spot at Paddle Enhanced speeds.

Another benefit to having rocker on an electric paddleboard is the fact that the rider can reposition their weight fore and aft on the board without compromising the board’s performance on the water. As the rider’s weight shifts, the water/board interface remains relatively constant as the curve on the bottom of the board readjusts. This is in contrast to a board with a flat rocker line. As the rider shifts their weight back, the tail of the board digs into the water stalling the board and significantly increasing its resistance through the water. This does not happen on a board with generous rocker because the relatively continuous curve on the bottom of the board accommodates shifts in the rider’s position. Allowing weight shifts fore and aft provides the rider with the opportunity to perform a wider variety of maneuvers on the water.

Integrated jet drives and forward mounted drives take full advantage of the benefits of boards having generous rocker. However, fin-box mounted drives do not. On fin-box mounted drives, tail rocker raises the tail of the board potentially cavitating the fin-box mounted propeller. When the rider moves back on the board to mitigate cavitation, the nose raises making the board awkward to ride. It is therefore advised that fin-box mounted drives be used on boards with a flat to gentle rocker line.

c. Fin

Fins are a critical component of any performance oriented electric paddleboard due to their role in maintaining stability on the water. The faster the board is propelled, the more critical its role. This discussion applies to boards with integrated jet drives and forward mounted drives because they have a fin on the tail of the board that is separate from the centrally located electric drive. This discussion does not apply to fin-box mounted drives because they do not have a fin, or the fin is modified to the extent it is ineffective.

The main function of the fin is to provide stability as the board moves through the water. This occurs while the board is being propelled in a straight-forward direction. It also occurs when the board is being propelled through a turning maneuver. During turns, water has a lateral force on the fin creating hydrodynamic lift. This lift is generated because the fin has a cross-sectional foil shape. The lift is observed as a force with a vector forward and to the inside of the turn. The thrust from the drive located in the midsection of the board, plus lift from the fin results in a balanced turn with these two synergistic forces working together. As a result, the rider feels stable and in control while carving smooth, powerful turns. Similarly, the board will feel stable and in control when the rider performs other maneuvers that induce a lateral force on the fin. This is because thrust from the drive and lift from the fin are counterbalancing as the rider performs these maneuvers.

d. Directional Tuning

Directional tuning is a feature of forward mounted drives. To date, integrated jet drives and fin-box mounted drives are not equipped with this feature. However, with some design alterations this could be added to either type of drive.

Forward mounted drives are equipped with directional tuning because the direction of propulsion is affected by the fin. As the board is “pulled” through the water, down wash from the propeller contacts the fin. This causes the board to travel slightly to port or starboard depending on whether the propeller spins in a clockwise or counterclockwise direction, respectively. This travel deviation is corrected by adjusting the motor/propeller assembly in a commensurate direction to port or starboard. If the fin is replaced with a different size fin, directional retuning may be required to ensure that the board is propelled in the proper direction.

Directional tuning has two noteworthy advantages. First, the rider has the opportunity to change out the fin. Installing a smaller fin loosens up the tail allowing the rider to conduct quicker turns and maneuvers. Installing a larger fin adds stability which is better for paddling in rough conditions. Second, the rider has the opportunity to tune the direction of travel so that the board veers slightly to one side. In board sports (skate, snow, surf), riders have a personal stance preference. They are either “regular-foot” with their left foot forward, or they are “goofy-foot” with their right foot forward. Regular-foot riders often prefer a direction of travel slightly to starboard so that they paddle primarily on the starboard side. Conversely, goofy-foot riders will prefer a bias to port. This directional bias allows riders to stand in their preferred stance reducing the number of times the paddle must be switched from one side to the other. With directional tuning the rider can customize their paddling style to be more ergonomic and efficient.

4. Maneuverability

A maneuver called the “rail brace turn” is the primary method for turning an electric standup paddleboard. To conduct a rail brace turn, the rider places their paddle against the aft rail of the board. Initially the paddle is aligned parallel with the rail and there is little resistance from the water. The rider initiates the turn by twisting the paddle, forcing one edge of the paddle blade way from the rail while the other edge of the blade is forced against the board. At the same time, the rider repositions their weight slightly aft and into the turn. Done properly, the board carves a smooth arcing turn. Rail brace turns are easy to learn allowing beginners to comfortably control an electric SUP. Once the rail brace turn is mastered, paddlers can advance their skills by modifying this maneuver.

Boards with integrated jet drives and forward mounted drives are well suited for rail brace turns. This is because they have a fin that generates hydrodynamic lift paired with a centrally located propulsion system. During turns, these two points of thrust work together stabilizing the board while it transitions through the turn. Boards equipped with fin-box mounted drives are not well suited for rail brace turns because the fin has been replace with a propulsion unit requiring turns to pivot around the tail instead of the center of the board.

Rail brace turns serve as the main method for controlling the direction of an electric standup paddleboard. However, the concept of maneuvering encompasses a much broader range of techniques used to control a board as it moves through the water. Some examples include spinning tight turns in a small waterway, initiating turns using the paddle placed in a forward position (forward brace turn), or running downwind and using quick paddle strokes to maintain directional stability. There are a wide variety of maneuvers that can be done by a skilled paddler on well-designed electric SUP. Many that are only possible with the advantage of electric propulsion.

5. Electronics

All electric SUP drives include a manual on/off switch, speed controller, and auto-shutoff system for safety. They also include a way to monitor battery charge levels so that the rider can manage their time on the water wisely. The on/off switch and charge level readouts are located on or close to the battery. On integrated jet drives and forward mounted drives, the on/off switch and charge level readouts are conveniently located in front of the rider. However, fin-box mounted drives have the battery located behind the rider, requiring the rider to turn around to switch the system on and off, and to observe battery charge levels.

Speed controllers are wireless and typically worn on the wrist. Wireless connectivity between the controller and drive functions best with a clear line-of-sight between the controller and the drive. With integrated jet drives and forward mounted drives this line-of-sight is unobstructed. However, fin-box mounted drives tend to position the rider’s body between the controller and the drive when the rider is paddling. To address this, fin-box mounted drives have a strong wireless signal to overcome potential connectivity interruptions.

All electric SUP drives include an auto-shutoff safety system to prevent the board from running away in the event the rider falls off the board. Most auto-shutoff systems use a leash that connects from the rider to the drive. When the rider falls off the board, the leash disconnects from the drive and the motor shuts down. This auto-shutoff leash is often worn in addition to a standard SUP leash used by paddlers to ensure they don't get separated from the board. On a fin-box mounted drive, the rider is required to connect the auto-shutoff leash to the battery located on the tail of the board. This is not an easy task because the battery is located behind the rider and moving back on the board can sink the tail. Making the leash connection on an integrated jet drive or forward mounted drive is easier because it is conveniently located in front of the rider.

Some companies offer a fully wireless auto-shutoff system that does not require a leash, i. e. ePropulsion Vaquita and Firefly SUP Drives. When the rider falls and the wireless controller is separated from the drive by a distance of about 20 feet, connectivity is lost between the controller and drive, and the motor shuts down. As a secondary safety mechanism, the wireless controller is equipped with a sensor that will shut down the motor if the controller is submerged in water.

The auto-shutoff system is an important safety feature of all electric SUP drives. Whether you use an auto-shutoff leash, or a fully wireless device is a personal choice. That said, managing a single leash to ensure that the rider and board do not get separated, is simpler than having two leashes, one for the board and another for the drive.

6. Noise and Vibration

A well-designed electric SUP will have almost no discernible noise or vibration from the drive at Paddle Assist speeds. And at Paddle Enhanced speeds, the noise and vibration will be negligible compared to the noise and vibration generated from water impacting the board as it moves through the water.

Rigid paddleboards are comprised of a hard shell wrapped around a foam core. The foam core does little to dampen noise and vibration that can easily promulgate into the epoxy-fiberglass shell. Like a bell, the board can increase noise and vibration due to the resonance characteristics of a board. Inflatable boards don't have the potential to amplify noise and vibration compared to rigid boards. Using an inflatable board can be an effective way to reduce noise and vibration on an electric SUP.

All motors used on electric standup paddleboards generate some level of noise and vibration. However, some brands are quieter than others. Many of the fin-box mounted drives are also tailored for use on kayaks. Because kayaks are often larger, heavier and have fewer hollow spaces in their hulls, noise and vibration is less of a concern, and these motors may be louder. Some motors use higher rotational speeds (rpm) than others. Consequently, these motors have the potential to be louder and vibrate more than motors with lower rotational speeds.

Regardless of the motor chosen, some type of mechanical dampening is recommended on all drives to reduce the amount of noise and vibration that propagates into the board. Mechanical dampening can be used where the drive secures to the board or around the motor itself. Forward mounted drives that use a pin to secure the motor shaft to the board is an effective single point of contact dampening system. Fin-box mounted drives where the motor is attached to the board using the fin-box does not include mechanical dampening.

7. Portability

Portability refers to the ease with which an electric SUP can be transported and carried at the beach. Assuming a 30-pound board, 2-pound paddle and 10-pound drive, the total weight of a typical electric SUP is 42 pounds. This is a reasonable weight for most people to carry and load onto their vehicle if it were a suitcase or similar sized item. However, a paddleboard is elongated with a hand hold in the center. It can be nudged by a small breeze, or the person holding it can get off balance carrying it over rough terrain. Therefore, portability of an electric SUP is often based on the ability to quickly assemble and disassemble the drive gear from the board. This allows a person to carry the board with one hand, and the paddle and drive gear in the other.

The motor and battery on most drives are designed to be attached/detached from the board in some manner. The battery represents the heaviest component of the drive and is often designed with a quick release mechanism to improve portability. The motor may or may not be as easy to attach/detach depending on the drive.

A fully rigged electric SUP with an integrated jet drive or forward mounted drive is balanced when carrying using the board’s centrally located lift handle. Whereas a board with a fin-box mounted drive may be difficult to carry due to the extra weight of the drive gear being on the tail of the board.

8. Rigid v. Inflatable Boards

When designing an electric SUP, selection of a board’s construction material is a consideration. Inflatable boards are light, and easy to transport and store. Whereas rigid boards have the advantage of being more refined in their handling characteristics on the water. The board material is really a matter of preference as both rigid and inflatable boards can be outfitted with any of the three drive types. Electric standup paddleboards with integrated jet drives can be purchased as rigid or inflatable boards. While fin-box mounted drives can be installed on both rigid and inflatable boards with the appropriate fin box adapter. To date, forward mounted drives have only been installed on rigid boards.

9. Conclusion

It is recommended that electric standup paddleboards be designed to target the "Paddle Assist" experience with speeds of 2 to 3 mph or to target the "Paddle Enhanced" experience with speeds of 4 to 5 mph. Designing a board to go faster than 6 mph is not advised due to substantial hydrodynamic resistance when operating faster a paddleboard's maximum theoretical hull speed.

Important design criteria for Paddle Assist targeted drives include keeping the system lightweight and simple to operate. The shape of the board and the location of the drive are not critical. For portability, attention should be given to overall weight and how easy it is to take apart for transport.

Important design criteria for Paddle Enhanced targeted drives include ease of operation, and that an appropriate board is chosen that takes advantage of performance characteristics available at higher speeds. If maneuverability is important, select a board with generous rocker and a good quality fin. If touring is the goal, a board with more volume and a gentle rocker line is more suitable. For boards operating at Paddle Enhanced speeds an integrated jet drive or forward mounted drive is recommended. Both ensure good balance and control on the water, and both are easy to rig/derig for transport. Boards with forward mounted drives tend to be lighter for their given speed and range when compared to integrated jet drives. Forward mounted drives are also considered more customizable because they can be installed on a wide range of boards and feature directional tuning.

Regardless of which speed range you target, it essential that the electric drive be quiet and not induce vibration into the board. Where possible, mechanical dampening should be used to mitigate noise and vibration. It is also important to select a motor that operates with minimal noise and vibration.

Like the recent success of electric bicycles, the sport of electric standup paddleboarding is poised for growth. Applying good design practices will result in electric standup paddleboarding products that are easy to use and exciting to paddle.

About the Author

Daniel Mahar is owner of Firefly SUP Drives, located in Anacortes, Washington USA. The company has been in business building and selling electric standup paddleboards using their proprietary, forward mounted drive technology since 2014. Daniel is a professional engineering and holds U.S. Patent 11167831B2 "System and Method for a Motorized Standup Paddle Board" granted November 9, 2021.

List of Electric SUP Drives Currently Available

Integrated Jet Drives

SIPA Boards, Slovenia

Jobe Water Sports - E Duna, Netherlands

Torque - ISUP Electric, Australia

WaveJet, South Africa

Onean – Manta, Spain

Fin-Box Mounted Drives

ePropulsion – Vaquita, China

Bixpy – J-2, San Diego CA USA

Connelly Water Sports - Power Fin, Lynwood WA USA

Michael Dolsey - E-Fin, Norfolk, VA USA

ScubaJet - SJ Pro400, Austria (jet, not propellor)

Forward Mounted Drives

Firefly SUP Drives, Anacortes WA USA

* This list does not include products sold exclusively on Amazon because these products have been determined to be substandard or inconsistent in availability.