

Numerical CFD Investigation of Shortboard Surfing: Fin Design vs. Cutback Turn Performance [†]

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Abstract: The surfing performance of two shortboard fin types with surface features were compared to a standard (control) fin with a smooth surface using dynamic computational fluid dynamics (CFD) simulations. The fins with surface features included designs with a partially grooved and serrated surface (CR), and humpback whale-inspired fins with tubercles and other features (RW). Surfboard roll, pitch and yaw during cutback maneuvers were simulated based on field data from surfers of intermediate, expert and professional (WCT) skill level surfing on ocean waves. Sustained resultant forces relative to the rider direction were significantly different between fin types, and lowest for RW at WCT-level rotations. CFD results also revealed RW's ability to dampen effects of turbulent flow. RW fins were always the last to stall during a turn, and always exhibited the most gradual stall. CR fins had significantly lower pre-turn drag, and the highest mean resultant forces during the turn. Overall, CR fins appear best for forward acceleration and hold on the wave, while RW fins appear best for maneuverability and stability.

Keywords: shortboard fin performance; STAR-CCM+, CFD; tubercled leading edge; cutback maneuver; passive flow control; grooved surface; delayed stall; gradual stall; biomimetics

1. Introduction

Surfing is an aquatic sport where riders must maintain balance and control while standing on a fast-moving surfboard fitted with fins. In high performance shortboard surfing, between one and five fins are used. Three-fin “thruster” configurations are the most common, introduced by Australian shaper and (former) competitive surfer Simon Anderson in 1980 [1]. He developed the 3-fin system for improving control in larger waves, compared to the conventional twin-fin system used at the time by most competitive surfers.

Limited research exists on the hydrodynamic performance of surfboards and surfboard fins, with most studies focusing on the fins [2,3], the board [4,5], or board plus fin interactions [6–9].

Coupling hydrodynamics to actual surfing performance is even more limited [10,11]. However, one of those studies [11] revealed the importance of including dynamic roll/pitch/yaw interactions, as well as the air/water interface, in surfing simulations. To date, only limited, lateral board motions (yaw) have been considered in both experimental [8] and numerical [9] studies. While many studies

discuss the importance of fin selection for surfers, only one compares behavior of 3-fin configurations [11].

A recent study [12] described the introduction of fins with tubercles plus other passive flow control features found on humpback whale pectoral fins. Humpbacks are known for their maneuverability [13], and others have suggested control benefits of tubercled designs for surfing applications [14,15]. Tubercle applications are known for delayed and gradual stall behavior [16–18], which could benefit surfer control by minimizing abrupt changes in lift and increasing the range over which the flipper contributes to maneuverability [18].

Most standard fins available from commercial manufacturers have smooth surface features; although, there are a small number of companies offering non-standard fins. For example, an Australian company is offering fins with three narrow channels located on the tip of the fin [19]. According to the manufacturer's information, these fins would provide more hold and more speed on the wave. Wingtip additions like these are also well known for reducing induced drag. Lanchester patented the concept of a wing end plate in 1897 and suggested that it would reduce wing drag at low speeds [20].

In competitive surfing, surfers receive points for performing maneuvers such as barrel riding, aeriels, and cutbacks (also known as top-turns). A cutback involves transitioning from the bottom of the wave to the top of the wave (see Figure 1). During the bottom turn, speed is gained, enabling the surfer to “climb” to the top wave, where the energy is used to rotate the board and “smack the lip,” thereby generating large amounts of spray (which translates into points for the maneuver).

In this paper, we investigate the performance of three different fin designs during cutback maneuvers using dynamic computational fluid dynamics (CFD) simulations. The fin designs include fins with surface features such as grooves and tubercles which are compared to standard fins with a smooth surface used as a control.

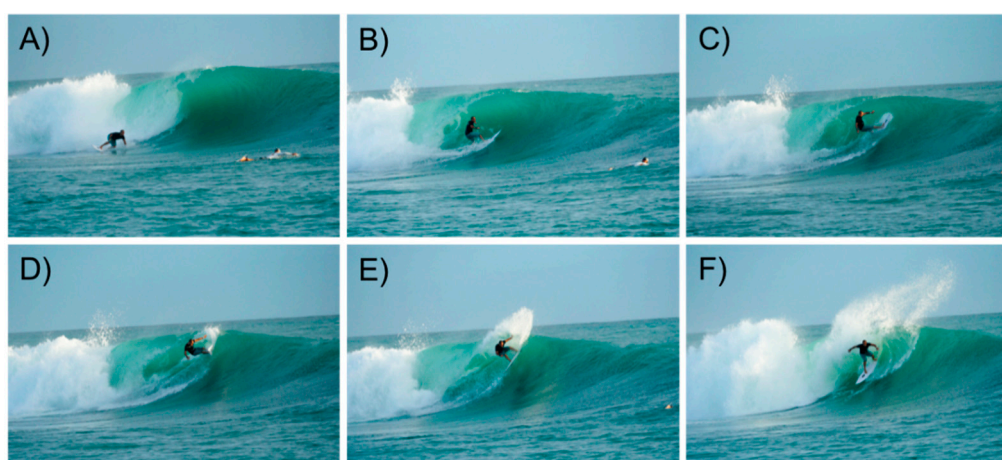


Figure 1. Image sequence showing a surfer (Dylan Perese) transitioning from a bottom turn to a cutback (also known as top turn). (A) bottom turn, (B) climbing the wave, (C) setting up the cutback, (D,E) performing the cutback, and (F) descending the wave. Photo credit: David “IndoEye” Biner.

2. Materials and Methods

2.1. CFD Research

Dynamic CFD methods using STAR-CCM+ are similar to those detailed in [4,5]. Details of the domain and grid used, along with confirmation of mesh independence, are found in [4]. An Unsteady Reynolds Navier Stokes (URANS) approach was used, applying the volume of fluid (VOF) method for free surface discretization. Simulations used a Detached Eddy Simulation (DES) approach, where the turbulence modeling part is solved using the $k-\omega$ turbulence model.

Mean results of data collected from almost 2000 surfed waves with GPS/motion sensors attached to the shortboards [11] were used in the CFD simulations (Table S1). The data is based on rotation

rates achieved during the cutback maneuver. Field results from [11] showed rotation rates increased with skill level, while the surfer’s speed during the cutback was more of a function of wave energy. Therefore, flow speed remained constant at 7 m/s for each skill level. The time step between simulations was 0.002 s, resulting in 400 simulations per treatment, run from 0.0 to 0.8 s. A total of 9 simulations were run (3 fin types × 3 treatments). Fin lift and drag forces were used to calculate a resultant magnitude and direction, relative to the rider, and per methods in [11].

2.2. Description of Fin Types

The three fin types used are shown in Figure 2. The control fins (C) are standard, “dolphin style” fins with a smooth leading edge and a smooth surface. The fin with tubercles (RW) includes other passive flow control features found on humpback whale pectoral fins [12]. The grooved fins (CR) have surface features in the form of a series of 6 grooves at the top half of the right and left fin, both with a serrated leading edge. The CR center fin has no surface features and is similar to the center fin of the control set. Dimensions and other details are found in Supplementary Information Table S1. Widths and heights are similar for all fins, and total wetted surface areas vary by less than 3%. RW’s volume is up to 16% less than the other 2 designs.

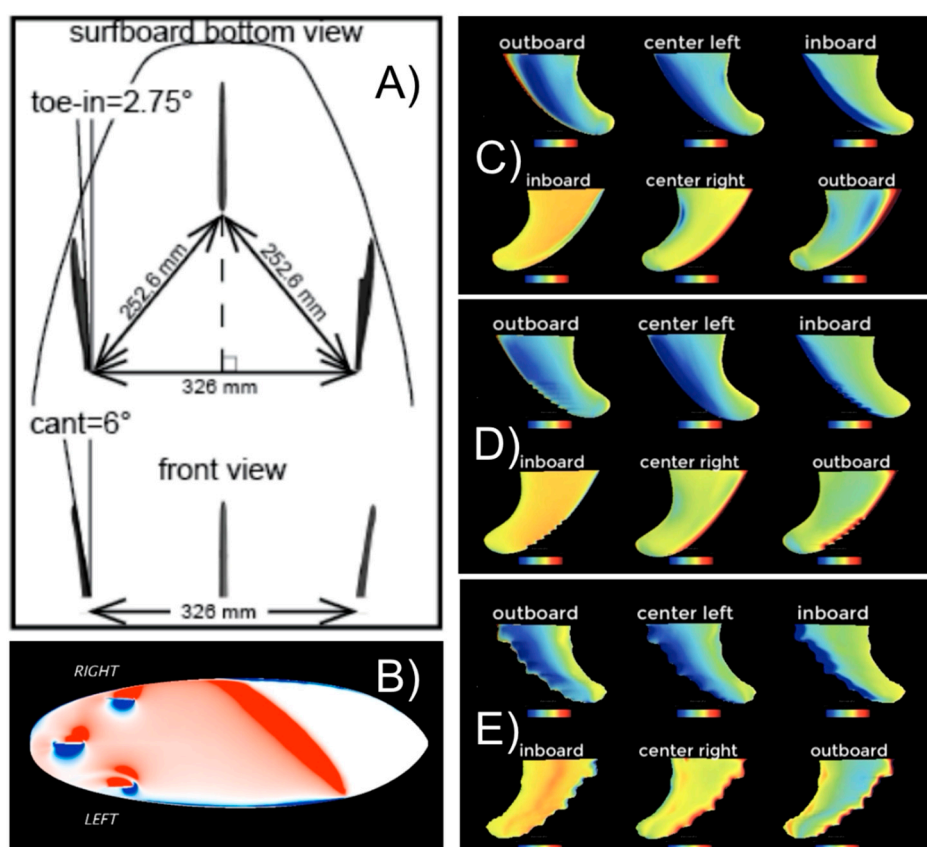


Figure 2. (A) Thruster fin positioning used in simulations. Toe-in refers to the angle the thruster fins are turned towards the nose. (B) Bottom of the board with thruster set of fins. Profiles of the fins with surface features: (C) control fins, (D) CR fins with grooves and (E) RW fins with tubercles. Dimensions of fins are detailed in Table S2. Images shown in (B–E) are snapshots from dynamic simulations of cutbacks, with colors referring to pressure values (see Supplementary Information Videos S1–S9).

3. Results and Discussion

Figure 3 shows the resultant forces versus time for all three fin types during cutback maneuvers performed at intermediate, expert and WCT level. The values displayed are the resultant forces in the rider direction, and represent the amount of sustained force a surfer must impart to perform the maneuver. The negative angles for all fins means they are resisting the turn and acting more as pivot

points, especially the left fin (see Supplementary Information Table S3). Resultant means were calculated for the duration of the cutback only, starting at 0.25 s into a simulation, and ending at 0.8 s for Intermediate, 0.7 s for Expert, and 0.6 s for WCT. Higher skill levels took less time to complete the turn because the rotation rates were faster (Supplementary Information Table S1). Simulation Videos S1 to S9 (in the Supplementary Information) show color-mapped pressures on each fin during the cutback simulation, and air/water interactions beneath the surfboard, including vortex formation.

CR always had the highest mean resultant force, and always had the most negative angle. In other words, CR generated the greatest overall force in opposition to the rider compared to C and RW fin designs. The feeling of force in opposition to the rider can be thought of as the binding with the waves, which is also described in surfing parlance as “hold” on the wave, or release from the wave. For Table S3 results, the closer the direction is to -90° , the better the hold.

RW generated the smallest left fin force, significantly different (or nearly so) for all skill levels. The left fin also had the most negative mean direction, suggesting it is the most important fin for pivoting the board during a cutback. RW’s consistently lower left fin resultant suggests it is the most maneuverable of the three designs. This is being described in surfing parlance as “pivot.” Passive flow control features of humpback whale pectoral fins are believed to be the key to explaining their extremely good maneuverability in spite of their large size [12,13]. In a summary of tubercled research, Aftab et al. [21] mentioned the typical low lift of tubercled designs was a problem to resolve. However, lower lift may actually benefit both whale and surfer, because it reduces the amount of power required to complete the same maneuver.

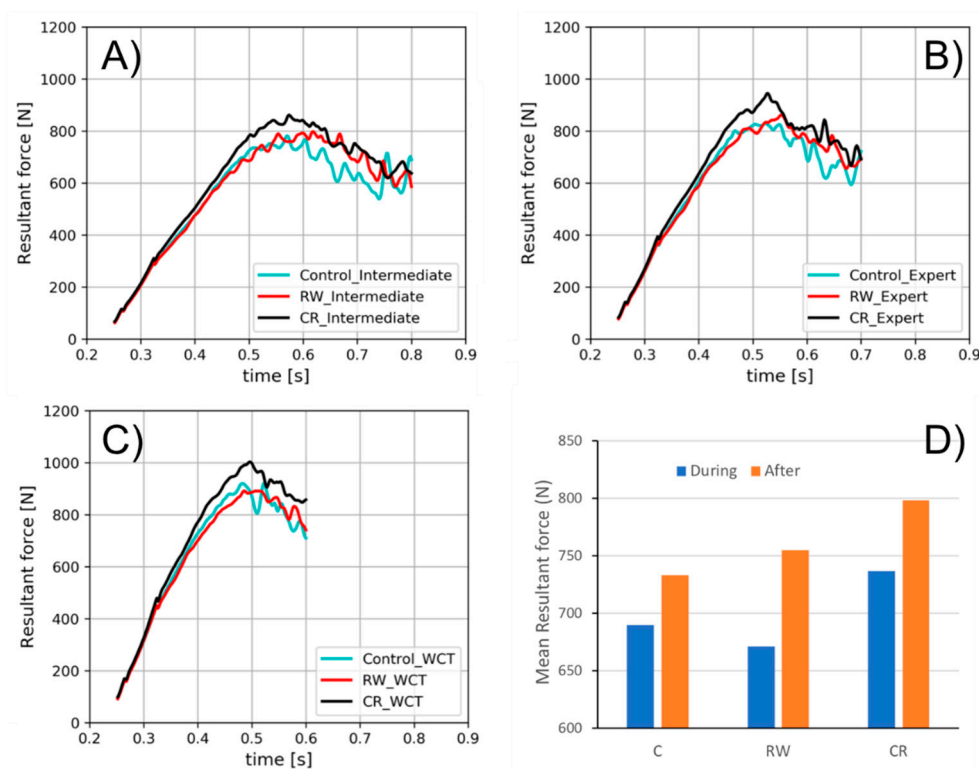


Figure 3. Time series of rider direction resultant forces for all fins during cutback maneuvers at intermediate, expert and professional (WCT) level. All turns start at 0.25 s, with (A) intermediate ending at 0.8 s, (B) expert ending at 0.7 s, and (C) WCT ending at 0.6 s. See Table S3 for detailed resultant forces and direction means. (D) Mean resultant force during (0.3 to 0.5 s) and after a WCT level cutback maneuver. C, RW and CR indicate control fins, fins with tubercles, and grooved fins, respectively.

The right fin in the control set always had a significantly lower mean resultant and least negative direction, suggesting degraded performance, possibly due to interactions with turbulence from the surfboard’s side, or rail, as evidenced in Videos S1 to S9. Figure 3 also shows increasing variability in

all designs towards the end of each turn, resulting from turbulence from both the board and fins. Towards the end of a turn, the center fin in particular receives heavy turbulence coming off the right fin and right rail. In field experiments surfing on ocean waves, Beggs [7] also found that surfing fins undergo large and rapid fluctuations in flow direction relative to a fin.

Ventilation (air mixing with water) also appears to occur along the right rail, impacting the fins towards the end of each turn (see Videos S1 to S9). Ventilated flow is turbulent, but its density is also highly variable, which can significantly impact a fin’s lift characteristics.

Table 1 provides further detail of the entire WCT level turn, revealing significant differences between fin designs before, during and after the turn. Before the turn, when board and rider are traveling in the same direction, the resultant force is mostly due to drag, and the CR fin set has up to 23% less drag. This could benefit surfers needing to generate forward acceleration, which is described in surfing parlance as “drive.” When just center fins are compared, RW has up to 12% lower drag compared to the C and CR center fins (which are identical).

Table 1 results for the WCT level turn show RW has the lowest resultant force, again suggesting it is the most maneuverable design. Note also the time interval is from 0.3 to 0.5 s, to focus more on pre-stall fin behavior and before turbulence increases. Regarding stall, Supplementary Information Table S4 lists stall times for each fin set, and shows RW is always the last to stall, a conclusion many others have reached for tubercled designs, including [16–18].

Gradual stall behavior for RW is evidenced in Figure 3 for all skill levels, but also in the mean resultants and directions after the WCT turn (Table 1). For example, during the turn, RW’s mean resultant is 2.8% less than C and 8.9% less than CR. After the turn, RW’s mean resultant is 2.9% more than C, and only 5.4% less than CR.

Mean resultant direction in Table 1 also shows RW is maintaining the best after-turn hold. This could help the surfer regain control in preparation for the next maneuver. Perhaps more important, though, are the large differences in after-turn resultant variability, evidenced in Figure 3, but also in the after-turn confidence intervals in Table 1. For both center and all fin results, RW always has the lowest variability, up to 27% less. The RW fins appear to provide a damping effect to turbulent flow, a conclusion others have reached as well for tubercled designs [21,22].

Table 1. Mean resultants, 101 data points each, for before (0.022 to 0.222 s), during (0.3 to 0.5 s) and after (0.6 to 0.8 s) a WCT-level cutback. Center fin results on the left, all fins on the right. Confidence levels for after resultant means rounded to 1 decimal place to show detail. Note: Directions are in degrees. Center fin data included for reasons described above.

WCT Cutback	Center Fin Resultant (N)				All Fins Resultant (N)			
	Control	RW	CR	p-Value	Control	RW	CR	p-Value
Before	3.36 ± 0.01	2.95 ± 0.01	3.34 ± 0.02	<0.001	12.3 ± 0.09	12.5 ± 0.05	9.6 ± 0.05	<0.001
During	258 ± 13	251 ± 12	278 ± 14	0.013	690 ± 36	671 ± 34	737 ± 39	0.033
After (resultant, N)	303 ± 7.0	320 ± 6.0	335 ± 9.3	<0.001	733 ± 7.6	755 ± 6.8	798 ± 9.3	<0.001
After (direction, °)	-23 ± 2	-24 ± 2	-23 ± 2	0.825	-22 ± 2	-24 ± 2	-23 ± 2	0.623

4. Conclusions

Whether it is humpback whales grouped in close formation while feeding, or a surfer performing a powerful cutback maneuver, maintaining control in turbulent conditions is key to a successful maneuver in the ocean. Our simulation results demonstrated that fins with surface features can offer significant benefits over fins with smooth surfaces. In particular, we believe that the lower resultant forces acting on RW fin designs during cutbacks suggests that fins with tubercles are more maneuverable compared to the fin designs with grooves and smooth surfaces. In surfing parlance, this would translate to improved ability to “pivot.” In addition, the RW’s delayed stall, more gradual stall, and improved turbulence damping provides a more steady force for the surfer to respond to during the cutback and recovery, thereby improving control. In contrast, we found that CR fins (with a grooved surface) always exhibited the highest mean resultant forces at the most negative angle, the

greatest overall force in opposition to the rider, usually described by surfers as “hold.” Other results for the CR fins revealed that they could be more suitable for speed generation or “drive” in surfing parlance. This could suggest that they perform best in wave conditions where speed generation and increased hold on the wave are required. Surfers could therefore enhance their surfing experience depending on the type of surfing they want to achieve, i.e., fins with tubercles would lead to more maneuverability, whereas fins with grooves would result in increased ability to generate speed (and hold) compared to fin designs with smooth surfaces.

Supplementary Materials: The following are available online at <https://surfengineers.com/isea2020b>, Figure S1: Bottom turn and cutback maneuvers, Table S1: Matrix of speeds and rotation rates used in CFD simulations, Table S2: Surfboard fin specifications, Table S3: Mean resultants, forces and directions for all fins, Table S4: Times for onset of stall in 3-fin sets, Video S1: Intermediate C.mp4, Video S2: Intermediate RW.mp4, Video S3: Intermediate CR.mp4, Video S4: Expert C.mp4, Video S5: Expert RW.mp4, Video S6: Expert CR.mp4, Video S7: WCT C.mp4, Video S8: WCT RW.mp4, Video S9: WCT CR.mp4.

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Conflicts of Interest: The authors declare no conflict of interest.

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