Wind tunnel report

Overview

On November 14th, 2013 our team traveled to the Faster Aerodynamic Research Center in Scottsdale, AZ to validate the aerodynamic performance of our newly released Dimond superbike. Benchmark testing was performed comparing the 2014 Dimond against two current triathlon bicycle frames. We chose to test against the Cervelo P5 and Specialized Shiv Tri for their reputed aerodynamic effectiveness and popularity within the triathlon community. Our goals during these tests were to compare the aerodynamic performance of all three bicycles and obtain quality data that can be reproduced, verified, and used to make meaningful decisions for future frame and component development. A precise and repeatable testing protocol was carefully chosen to eliminate uncontrollable variables and increase the quality of the collected data. Test results indicate that the Dimond frame design is more effective at reducing aerodynamic forces in both the longitudinal and lateral axes when compared to either of the other tested bicycles.

Test Product

Dimond Superbike, size medium:

- SRAM Red drivetrain, 11-23 cassette, 53/39t SRAM TT chainrings
- Profile Design Pro Svet basebar 42cm, Cobra T2+ extensions
- TriRig Omega brakes, front and rear
- Zipp Super-9 CC rear wheel, 808 Firecrest CC front wheel
- Maxxis Xenith Equipe 20c front tire, inflated to 100psi
- Maxxis Xenith Equipe 23c rear tire, inflated to 100psi
- No pedals
- Chain set to largest gear ratio and crank fixed in a horizontal position
- Fit dimensions:

Fit stack	615mm
Fit reach	410mm
Saddle height	725mm
Saddle fore/aft	25mm
Saddle tilt	0°
BB drop	75mm
Aerobar pad width	70mm inside
Extension tip width	70mm inside
Forearm angle	+5°

Cervelo P5, size 56cm:

- Shimano Dura-Ace Di2 drivetrain, 11-23 cassette
- Rotor 3D TT Crank 170mm, 53/39t Rotor 3D TT chainrings (round)
- Profile Design Volna 42cm integrated aerobar
- Magura RT-8 hydraulic brakes, front and rear
- Zipp Super-9 CC rear wheel, 808 Firecrest CC front wheel
- Maxxis Xenith Equipe 20c front tire, inflated to 100psi
- Maxxis Xenith Equipe 23c rear tire, inflated to 100psi
- No pedals
- Chain set to largest gear ratio and crank fixed in a horizontal position
- Fit dimensions:

Fit stack	615mm
Fit reach	410mm
Saddle height	725mm
Saddle fore/aft	28mm
Saddle tilt	0°
BB drop	75mm
Aerobar pad width	70mm inside
Extension tip width	70mm inside
Forearm angle	+5°

Specialized Shiv Tri, size medium:

- SRAM Red drivetrain, 11-23 cassette, 53/39t SRAM TT chainrings
- Zipp Vuka Bull 42cm base bar, Zipp Race Vuka Shift carbon extensions
- Specialized Shiv Aero brakes
- Zipp Super-9 CC rear wheel, 808 Firecrest CC front wheel
- Maxxis Xenith Equipe 20c front tire, inflated to 100psi
- Maxxis Xenith Equipe 23c rear tire, inflated to 100psi
- No pedals
- Chain set to largest gear ratio and crank fixed in a horizontal position
- Fit dimensions:

Fit stack	620mm
Fit reach	405mm
Saddle height	725mm
Saddle fore/aft	25mm
Saddle tilt	0°
BB drop	72mm
Aerobar pad width	80mm
Extension tip width	70mm
Forearm angle	+4°

Testing Protocol

Wheel-only baseline

- *Product*: Zipp 808 Firecrest CC, Continental Grand Prix 4000S 23c tire, 100psi.
- *Speed:* 30±0.25mph wind speed, 30 ± 1mph wheel speed[1].
- *Yaw sweep:* 20° to 0°, then -20° to 0° in 2.5° step increments. Clockwise is positive.
- *Sampling interval:* 20-second average data collection interval, 20-second settling period before data collection[2]. Measure loads along longitudinal and lateral axes of the wheel (body axis).

Bike-only testing

- *Product*: Fit geometry must be matched between product samples. All components not being compared must be matched between product samples as closely as possible.
- *Speed*: 30 ± 0.25mph wind speed, 30 ± 1mph wheel rotation speed.
- *Yaw sweep:* 15° to 0°, then -15° to 0° in 2.5° step increments[3]. Clockwise is positive.
- *Sampling Interval:* 20-second average data collection interval, 20-second settling period before data collection. Minimum of 2 full sweeps per test sample to verify repeatability and take an average of the two runs. Measure loads along longitudinal and lateral axes of the bike (body axis).

Bike with rider testing

- *Rider:* Rider pedaling at endurance effort, 75rpm ±5rpm. Unless investigating effects of clothing, helmets, or personal accessories, rider should keep head engaged against a fixed reference (e.g. down on forearms) to reduce form-factor variation due to fatigue over the duration of the test day.
- *Product:* Fit geometry must be matched between product samples. All components not being compared must be matched between product samples as closely as possible.
- *Speed:* 30 ± 0.25mph wind speed, 30 ± 1mph wheel rotation speed.
- *Yaw Sweep:* -15° to 0° in 5° step increments[4]. Clockwise is positive.
- *Sampling interval:* 20-second average data collection interval, 30-second settling period before data collection. Minimum of 2 full sweeps per test sample to verify repeatability and take an average of the two runs. Measure loads along longitudinal and lateral axes of the bike and rider (body axis).

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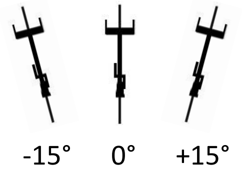
[1] 30mph wind speed is chosen instead of more commonly observed cycling speeds in order to amplify actual differences between test subjects while still operating the wind tunnel within its optimized control and sensor capabilities.

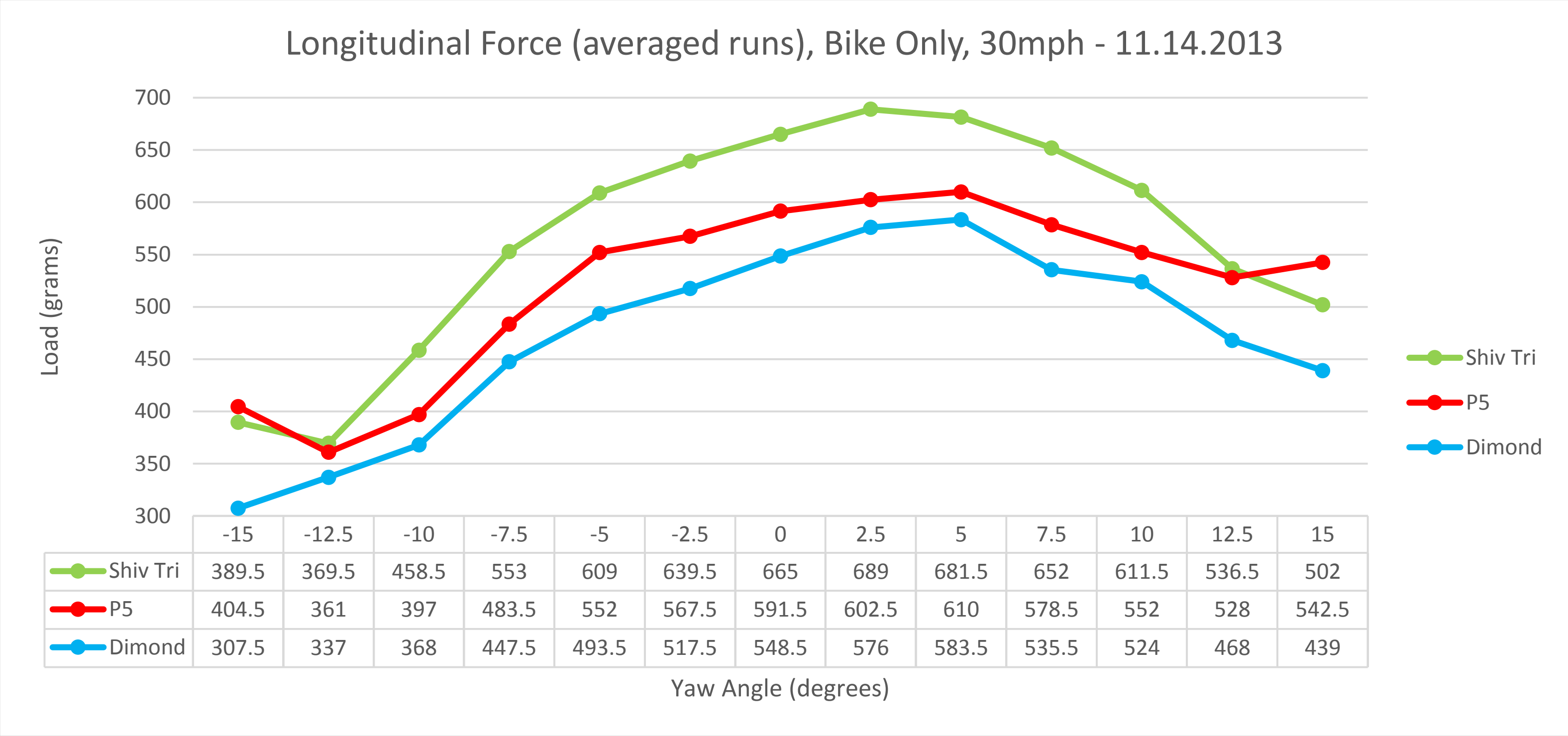
[2] Wheel-only baseline is conducted at the beginning of each test day to compare tunnel and environmental factors against a high-confidence baseline to verify tunnel accuracy.

[3] Forcing flow separation by starting the yaw sweep wide and ending at 0° increases repeatability of each test run and avoids artificially low data anomalies that can occur using the opposite sweep direction.

[4] One-sided sweep and lower resolution yaw increments are an attempt to reduce rider fatigue and preserve posture and repeatability.

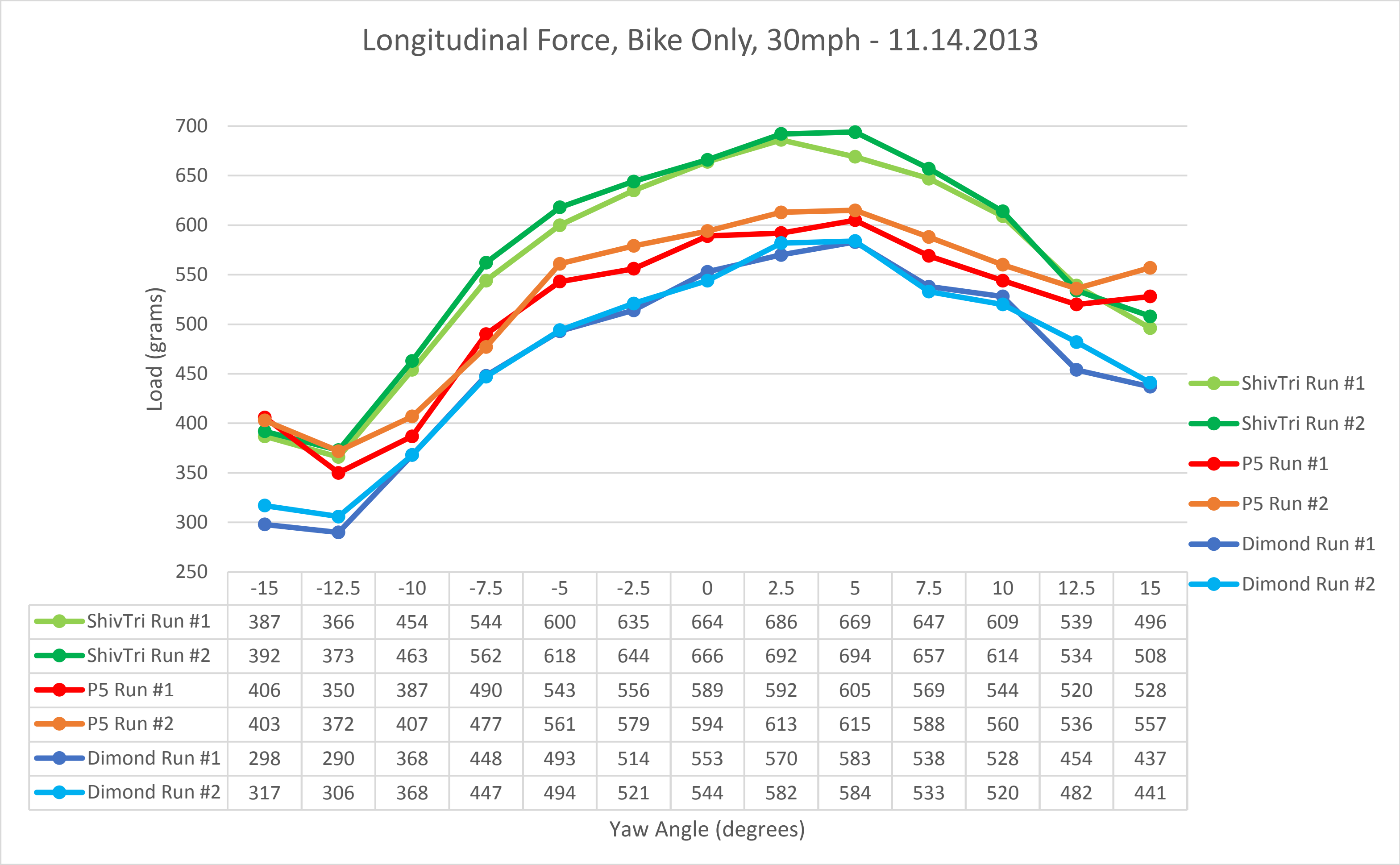


Data



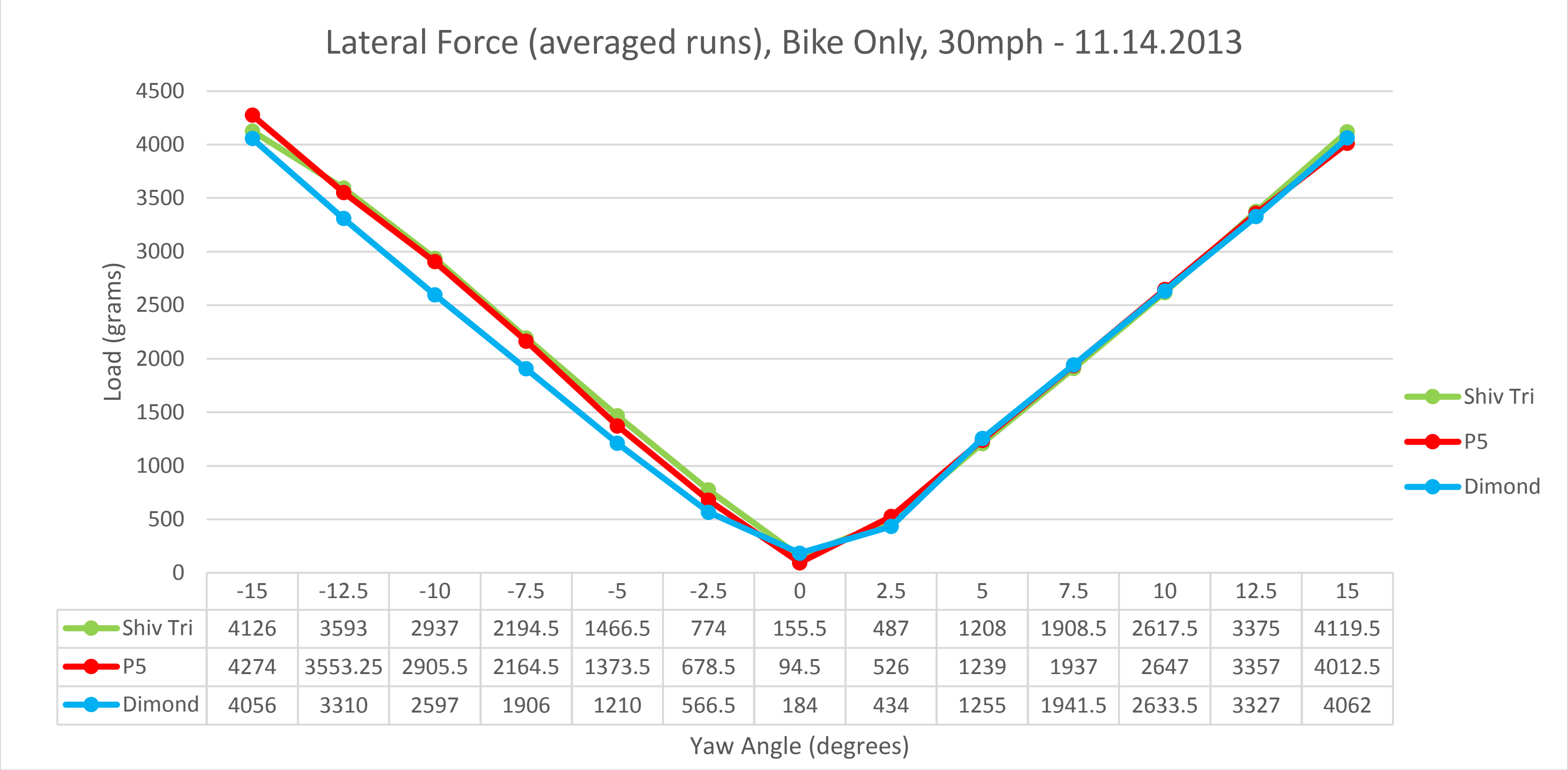
	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15
Shiv Tri	389.5	369.5	458.5	553	609	639.5	665	689	681.5	652	611.5	536.5	502
P5	404.5	361	397	483.5	552	567.5	591.5	602.5	610	578.5	552	528	542.5
Dimond	307.5	337	368	447.5	493.5	517.5	548.5	576	583.5	535.5	524	468	439

Figure 1



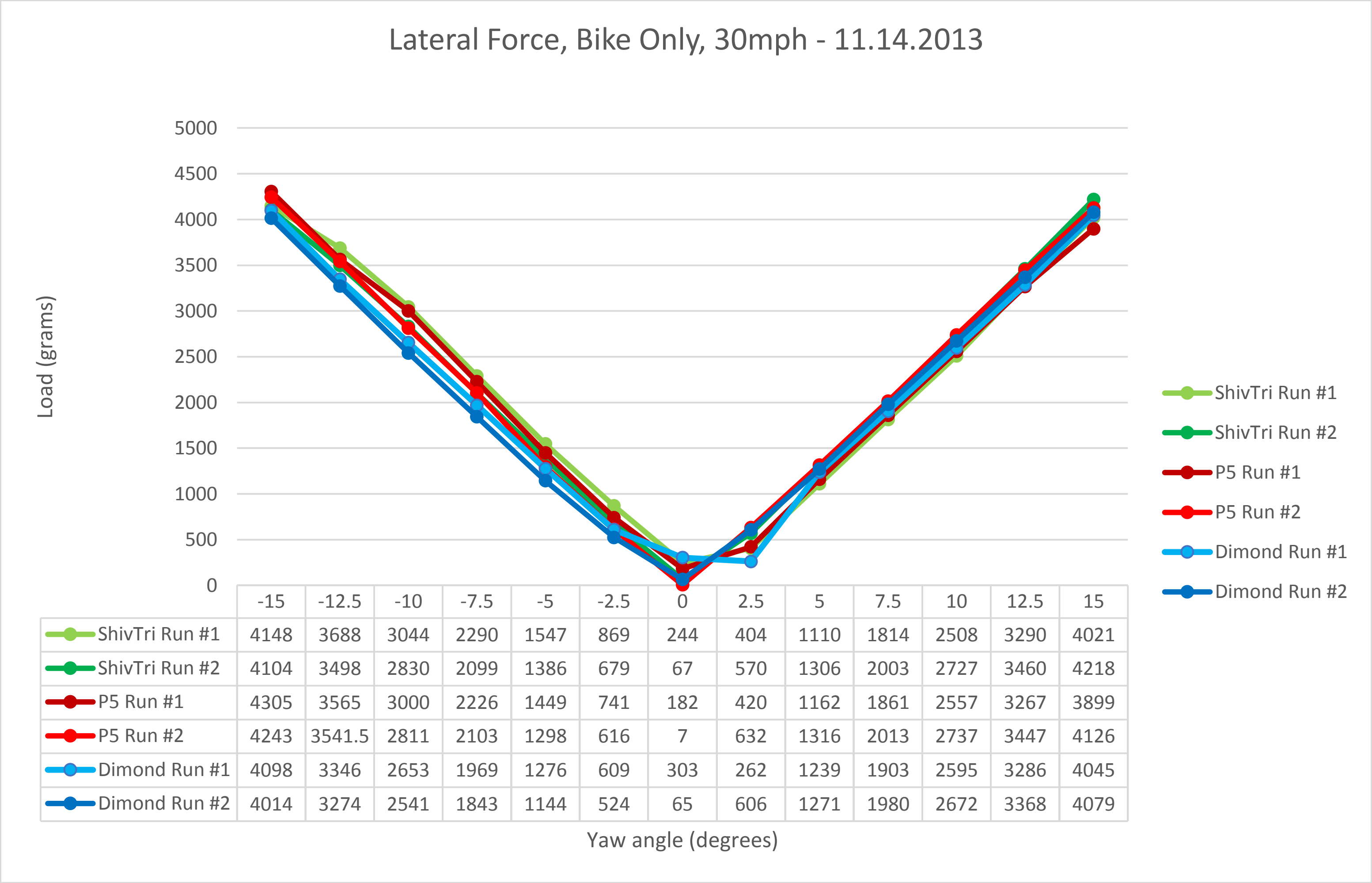
	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15
ShivTri Run #1	387	366	454	544	600	635	664	686	669	647	609	539	496
ShivTri Run #2	392	373	463	562	618	644	666	692	694	657	614	534	508
P5 Run #1	406	350	387	490	543	556	589	592	605	569	544	520	528
P5 Run #2	403	372	407	477	561	579	594	613	615	588	560	536	557
Dimond Run #1	298	290	368	448	493	514	553	570	583	538	528	454	437
Dimond Run #2	317	306	368	447	494	521	544	582	584	533	520	482	441

Figure 2



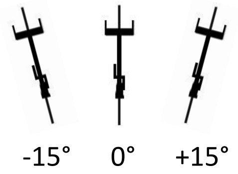
	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15
Shiv Tri	4126	3593	2937	2194.5	1466.5	774	155.5	487	1208	1908.5	2617.5	3375	4119.5
P5	4274	3553.25	2905.5	2164.5	1373.5	678.5	94.5	526	1239	1937	2647	3357	4012.5
Dimond	4056	3310	2597	1906	1210	566.5	184	434	1255	1941.5	2633.5	3327	4062

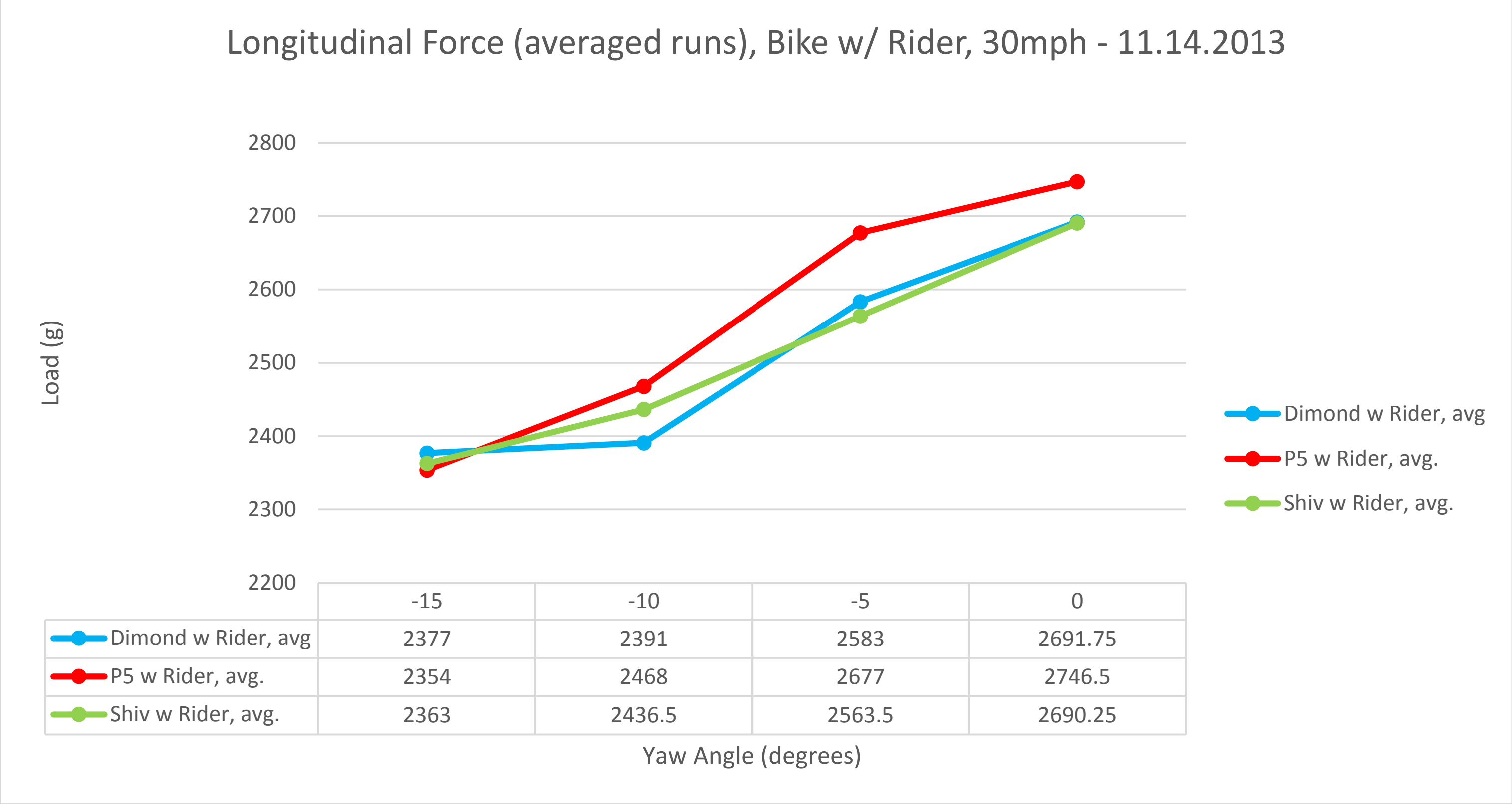
Figure 3



	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15
ShivTri Run #1	4148	3688	3044	2290	1547	869	244	404	1110	1814	2508	3290	4021
ShivTri Run #2	4104	3498	2830	2099	1386	679	67	570	1306	2003	2727	3460	4218
P5 Run #1	4305	3565	3000	2226	1449	741	182	420	1162	1861	2557	3267	3899
P5 Run #2	4243	3541.5	2811	2103	1298	616	7	632	1316	2013	2737	3447	4126
Dimond Run #1	4098	3346	2653	1969	1276	609	303	262	1239	1903	2595	3286	4045
Dimond Run #2	4014	3274	2541	1843	1144	524	65	606	1271	1980	2672	3368	4079

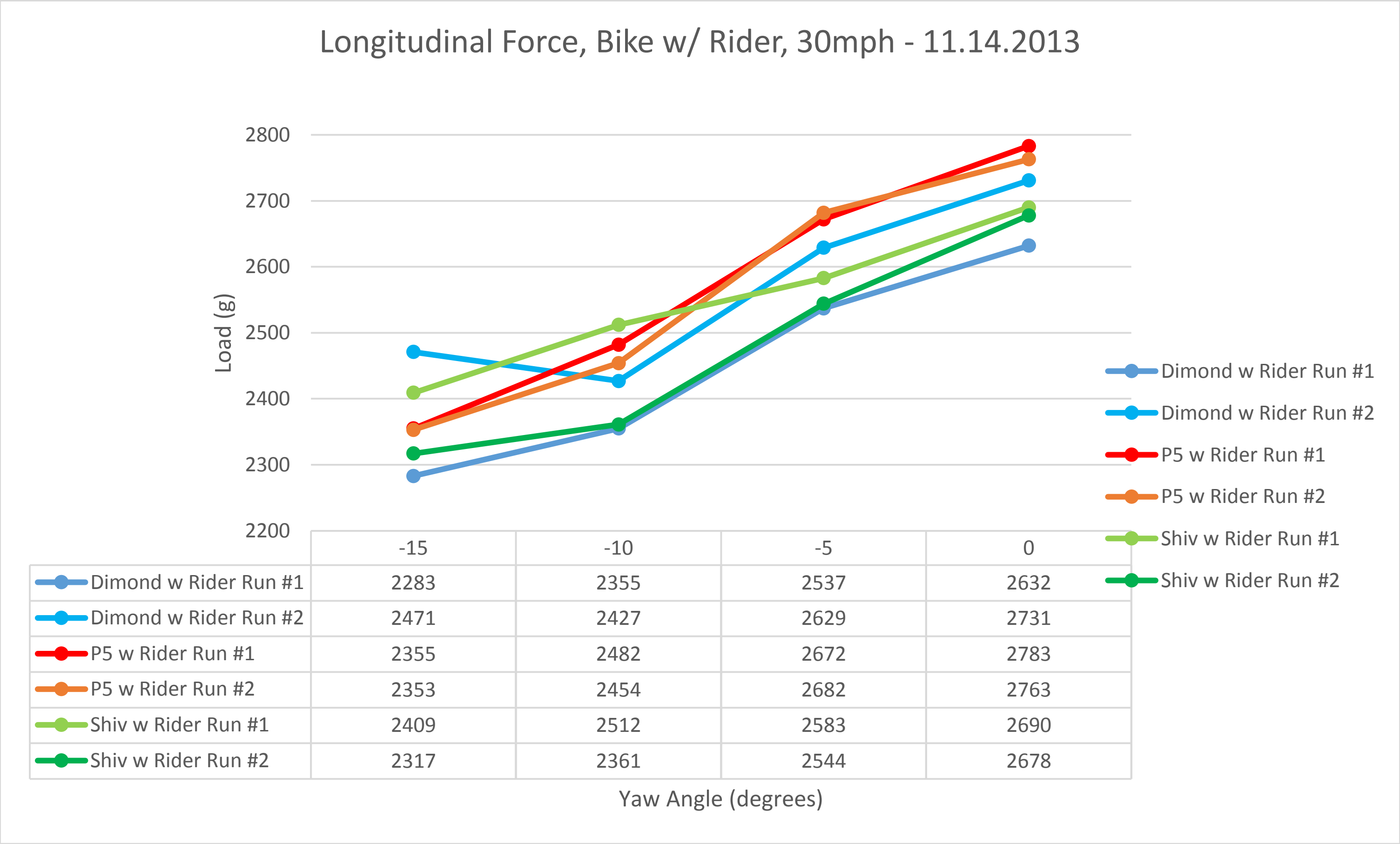
Figure 4





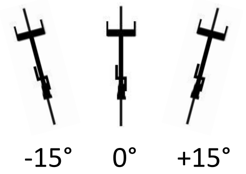
	-15	-10	-5	0
Dimond w Rider, avg	2377	2391	2583	2691.75
P5 w Rider, avg.	2354	2468	2677	2746.5
Shiv w Rider, avg.	2363	2436.5	2563.5	2690.25

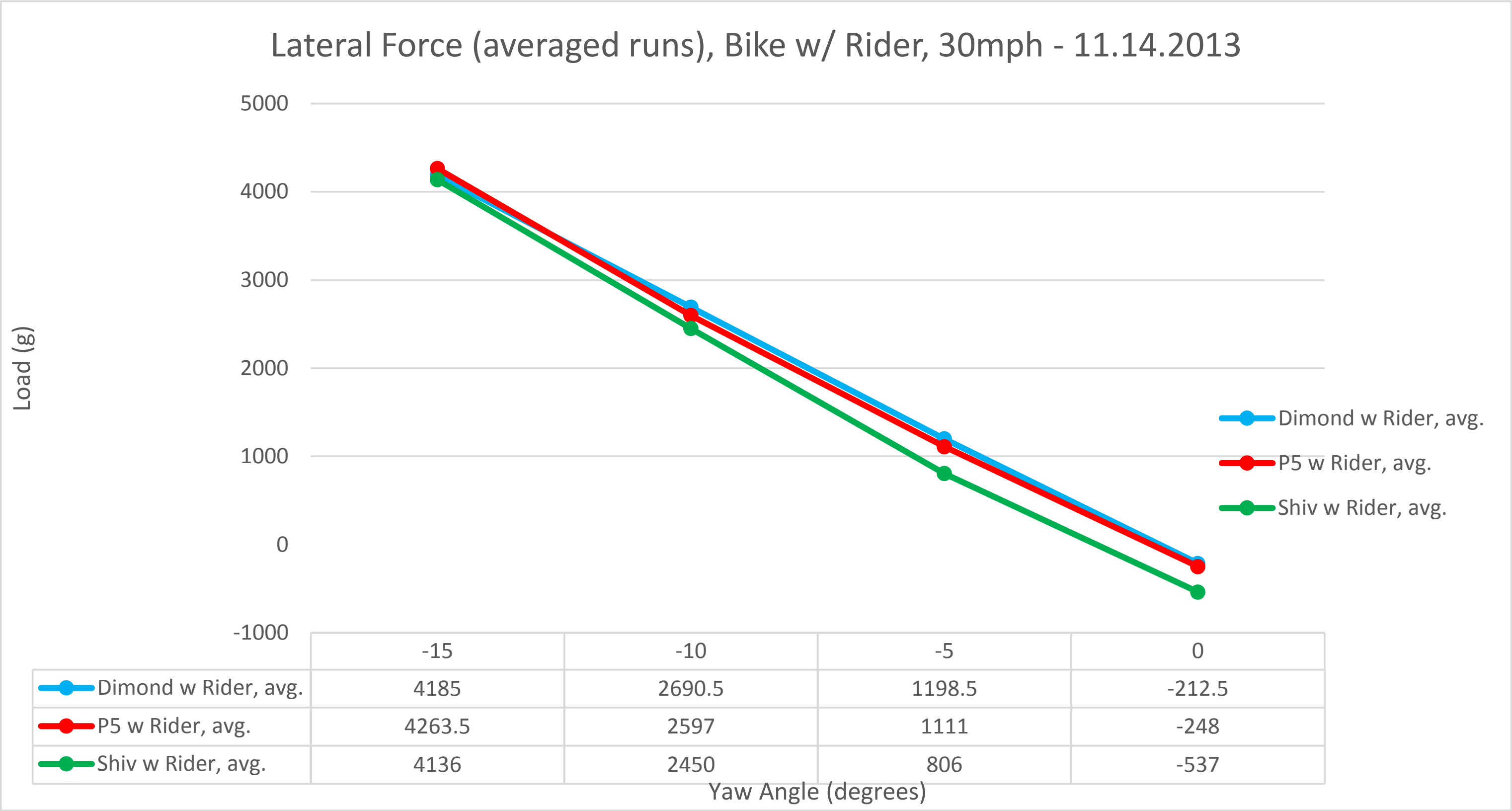
Figure 5



	-15	-10	-5	0
Dimond w Rider Run #1	2283	2355	2537	2632
Dimond w Rider Run #2	2471	2427	2629	2731
P5 w Rider Run #1	2355	2482	2672	2783
P5 w Rider Run #2	2353	2454	2682	2763
Shiv w Rider Run #1	2409	2512	2583	2690
Shiv w Rider Run #2	2317	2361	2544	2678

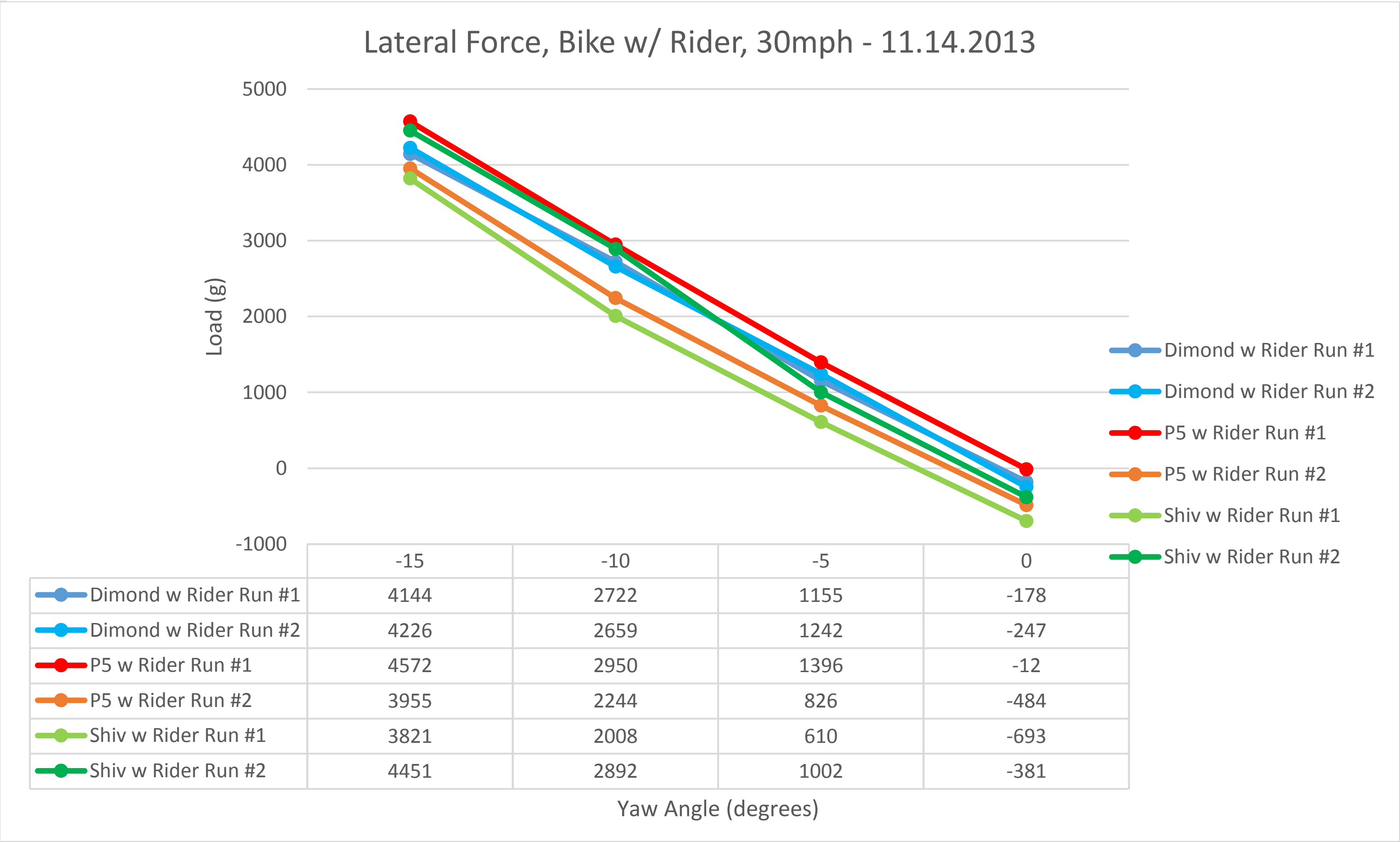
Figure 6





	-15	-10	-5	0
Dimond w Rider, avg.	4185	2690.5	1198.5	-212.5
P5 w Rider, avg.	4263.5	2597	1111	-248
Shiv w Rider, avg.	4136	2450	806	-537

Figure 7



	-15	-10	-5	0
Dimond w Rider Run #1	4144	2722	1155	-178
Dimond w Rider Run #2	4226	2659	1242	-247
P5 w Rider Run #1	4572	2950	1396	-12
P5 w Rider Run #2	3955	2244	826	-484
Shiv w Rider Run #1	3821	2008	610	-693
Shiv w Rider Run #2	4451	2892	1002	-381

Figure 8

Figure 9 - Rider position on Dimond

Figure 10 - Rider position on P5

Figure 11 - Rider position on Shiv Tri

Analysis

Within repeated tests, the data collected from bicycle-only tests showed significantly less variation than rider-with-bike tests. This is likely due to the fact that the rider on the bike introduces form-factor variations that are difficult to control between test runs and are highly impactful on the total aerodynamic drag of rider plus bike. On the other hand, bike-only tests showed an encouraging level of repeatability. We chose to rely more heavily on bike-only data to qualify our results, largely due to the lowered input variables and increased repeatability.

The longitudinal load on the Dimond superbike is shown to be less than that of either the P5 or Shiv Tri at all yaw angles tested (figure 1). From the averaged data over two test runs, the smallest difference between the Dimond and either of the other bikes was 24g occurring at -12.5° yaw relative to the P5, which is outside the margin of error for the Faster AZ wind tunnel sensitivity. The largest difference was 122g occurring at -2.5° yaw relative to the Shiv Tri.

The lateral load on the Dimond superbike is very comparable to either P5 or Shiv Tri (figure 3) when the drivetrain is leeward (2.5° to 15°). At 2.5°, the Dimond shows the lowest lateral load. Beyond 2.5° the three bicycles remain within 3% of each other. This could be explained by the drivetrain located downwind of the frame members disrupting flow attachment on the leeward surface of the frames. With the drivetrain windward (-2.5° to -15°), the Dimond shows considerably lower lateral force, with a peak difference of 340g (13.1%) occurring at -10° yaw relative to the Shiv Tri.

In rider-with-bike testing, loose trends may be extracted from the data. The variability in the data is evident, and further testing is required to generate statistical relevance for each test setup at each sampling yaw angle. The Dimond and Shiv Tri exchange places across the yaw sweep for the lowest longitudinal force, while the Shiv Tri shows lowest lateral forces for -15°, -10° and -5° of yaw.

Conclusions

The data collected during this wind tunnel session shows the Dimond superbike offers a meaningful reduction in aerodynamic drag compared to either the Cervelo P5 or Specialized Shiv Tri. Power output savings between yaw angles of -15° to +15° at 30mph fall between 3-14W relative to the P5 and 4-16W relative to the Shiv Tri. These power numbers are derived starting from a force-balance equation;

$$F_T = F_A + F_G + F_{RR}$$

where F_T is the force (Newtons) of the rear tire propelling a cyclist forward, F_A is the aerodynamic force slowing a cyclist, F_G is the gravitational force acting on a cyclist up or down an incline, and F_{RR} is the force of tire rolling resistance and drivetrain losses slowing a cyclist. This force-balance equation represents Newton's Third Law of Motion; that all forces propelling a cyclist (only F_T for a flat or uphill road) must equal the forces impeding the cyclist. All else unchanged (speed, incline, rolling resistance and efficiency losses), the difference in longitudinal aerodynamic force (F_A) between two cyclists can be accounted for by a change in the force of the rear tire on the ground (F_T). F_T is directly related to the power output at the rear wheel, P_T, by the equation;

$$P_T = F_T \cdot r \cdot 2\pi \cdot \frac{m/s}{m/rev}$$

where ($F_T \cdot r$) is the torque applied at the rear wheel and ($2\pi \cdot \frac{m/s}{m/rev}$) is the angular velocity of the rear wheel. By equating F_A (measured in the wind tunnel) to the change in force at the rear tire required to maintain a constant speed of 30mph, it is possible to calculate the change in power requirements between the bicycles. For a road bicycle traveling at 30mph (13.4112m/s), the equation finally becomes;

$$\Delta P_T = \Delta F_A \cdot 0.3375\text{m} \cdot 2\pi \cdot \frac{13.4112 m/s}{2.098 m/rev}$$

where ΔP_T is the change in power for a given ΔF_A between two bicycles.