MADONE SLR WHITE PAPER

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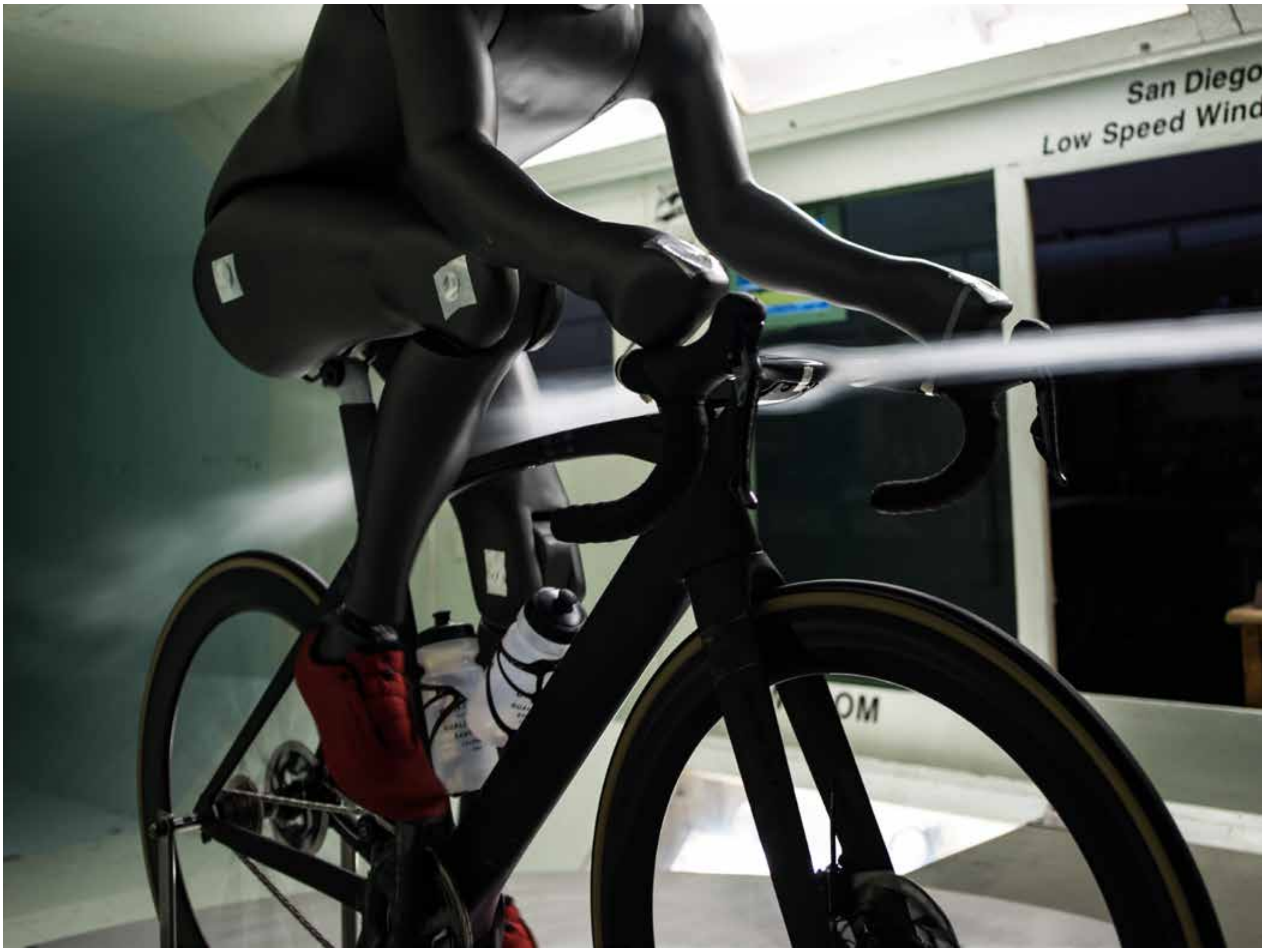


INTRODUCTION

Creating an aero racing bike requires a delicate balance of many variables. Sway in one variable direction, the result yields a compromise to another or several other variables. To create an exceptional all-around aero racing bike, important variables first and foremost include aerodynamics and weight. However, there are several others including, comfort, fit, ride handling, frame stiffness, aesthetics and integration. The new Madone aims to be the best all-around racing bike and a refinement of the current Madone.

The current Madone white paper went into detail describing Trek's Computational Fluid Dynamics (CFD) and design iteration processes, as well as focusing on the bike's ride-tuned performance. Once again, Trek employs those same methodologies and techniques on the new Madone. This new white paper will review aerodynamic performance and various bike build weights compared to the current Madone.

Also, detailed improvements in comfort, fit, integration and refinement over the current Madone that greatly enhance a rider's experience will all be discussed.

Trek's focus and attention to details on the completely new Madone bike package is unparalleled. The all-new Madone is engineered for all-around performance, for unmatched integrated design language/aesthetics and to inspire its riders to ride

AERODYNAMICS

Trek focuses on several measures in CFD analyses to identify drag reduction opportunities to improve or maintain aerodynamic performance. While the greatest attention is focused on obtaining a smaller drag force number, the following are also investigated to inform design engineers for areas of improvement. Surface flow separation tendency, low-energy eddies near the bike surface, amount of wake turbulence, local and accumulated force on the wheel, fork, frame and components (Figure 1). These are also ways that Trek uses CFD to understand and develop aerodynamic components. Accounting for all of these measures and rigorously calibrating CFD models to wind tunnel results puts Trek's CFD accuracy within 3% of experimental results.[1]

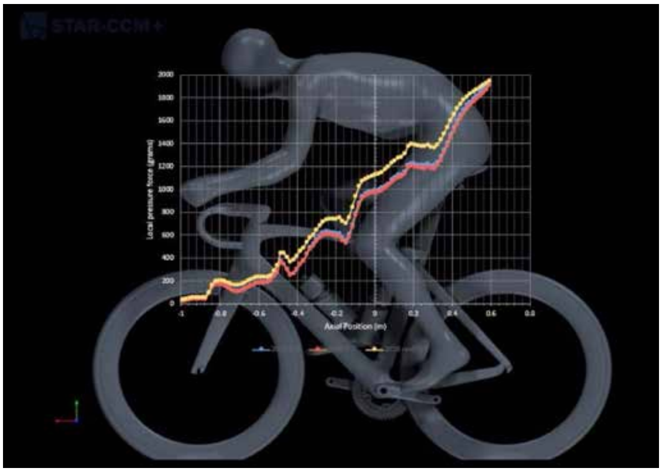


Figure 1. CFD Simulation (Local & Accumulated Force vs Axial Position), showing design iteration process from first revision to last revision (Yellow – new Madone first iteration, Blue – current Madone, Red – new Madone last iteration).

Trek's goal for the new Madone was to maintain aerodynamic drag performance of the current Madone (within 30 g) across an averaged -12.5° to 12.5° yaw sweep. Trek considers this range to be the most common yaw a rider experiences, based on real-world data collection studies.[2] With the addition of disc brakes to the model line, new fit requirements, new comfort technologies, updated component aesthetics and creating one of the lightest aero bikes in the market; Trek was still faced with a great challenge to maintain aerodynamic performance. Trek's iterative design improvement is summarised in Figure 1. The first designs were slower than the current Madone and by the time Trek reached production tooling, performance was predicted to be right on top of the current Madone.

Experimental results collected at the San Diego Low Speed Wind Tunnel are displayed in Figure 2. Final new Madone numbers show an average of 3,216 g across a -12.5° to 12.5° yaw sweep vs the current Madone at 3,202 g. A 14 g difference that is within Trek's project goal and within a wind tunnel's experimental error band.

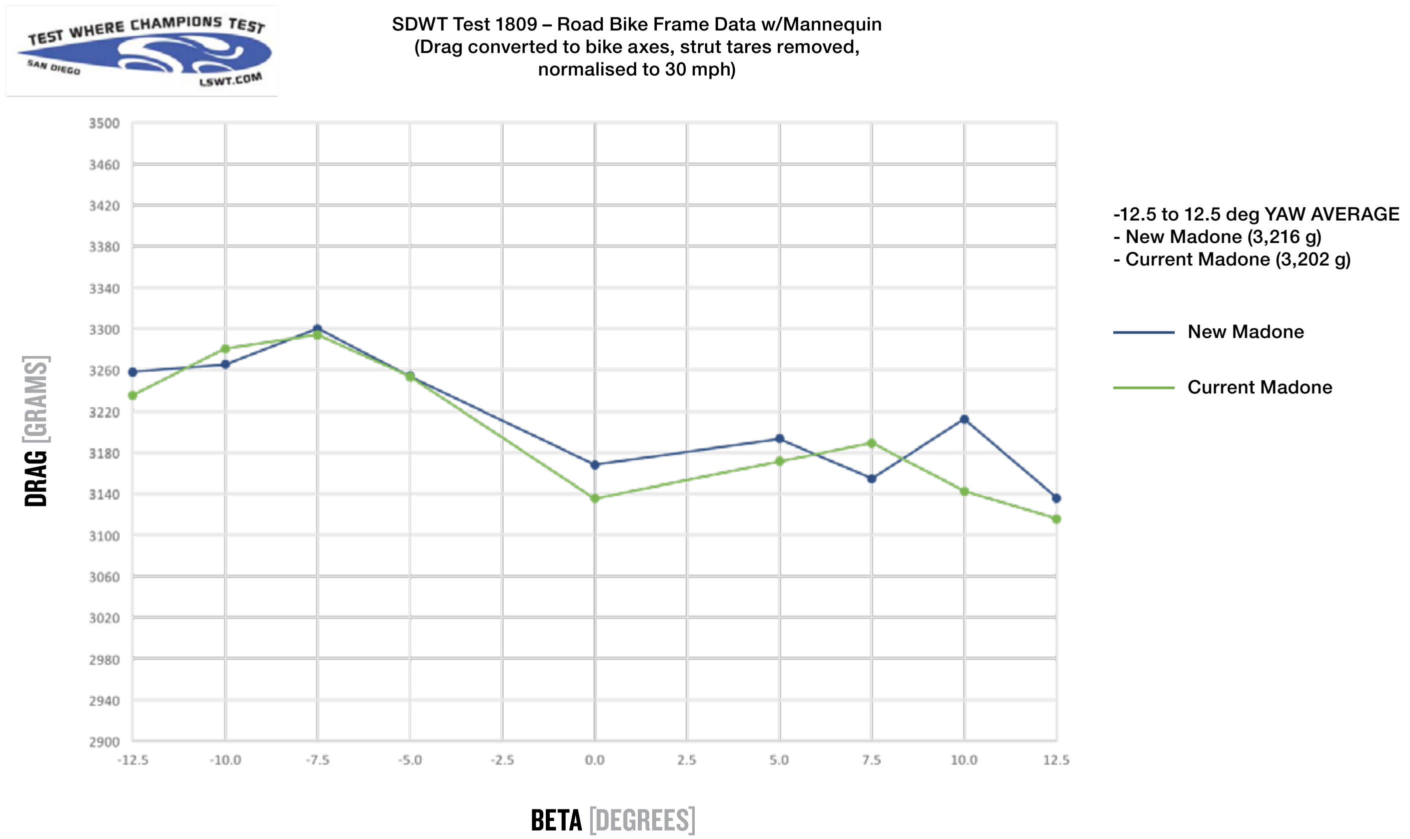


Figure 2. Wind Tunnel Results (SD LSWT, April 2018) Run 101 new Madone (Blue) vs Run 107 current Madone (Green), bikes with pedalling mannequin + 2 water bottles.

[2] Trek 2014 Speed Concept White Paper, Section 3.2 'Measuring aerodynamics in the real-world'

WEIGHT

Bike weight is a tangible feature that athletes and consumers greatly care about. Creating one of the best all-around aero racing bikes requires a delicate balance of aerodynamics, frame stiffness and by extension of those two, the bike's weight.

Aerodynamic air foils, in general, are a poor choice when considering frame stiffness and weight. When properly aligned to a bike frame to gain an aerodynamic advantage, their cross-sectional properties do not serve frame stiffness and weight very well due to the load requirements that a bike frame predominantly experiences. Pedalling loads are lateral in nature and the cross-sectional bending properties that an aero bike frame receives are in the weakest performing direction to counter those loads. Generally, a bike frame provides higher stiffness and lower weight with wider symmetrical tube shapes. On the flip side, a bike frame provides better aerodynamic properties with narrower tubes. An all-around aero racing bike requires a careful balance of these two competing characteristics. Skew towards aerodynamics and a faster bike, a heavier frame is generally the outcome to achieve the proper stiffness for a great riding bike. Skew towards a lighter bike, a slower frame is usually the result due to the wider tube shapes that increase the bike's aerodynamic drag and slow the bike down.

Trek's goals for the new Madone were to maintain the aerodynamic performance of the current Madone and reduce or maintain the bike weight of the rim brake version, all while adding several new features. Adjustable compliance technology, a rebound damper, split bar and stem, and a redesigned aesthetic are just some of the new features that make this the best all-around racing bike. The disc brake bike was assigned a target of 7.5 kg with the same features previously listed.

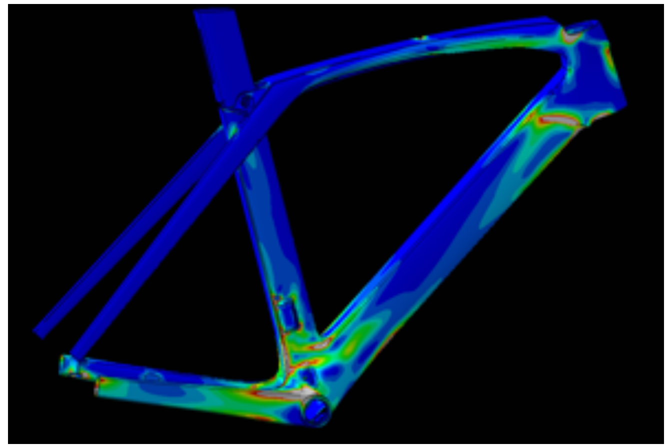
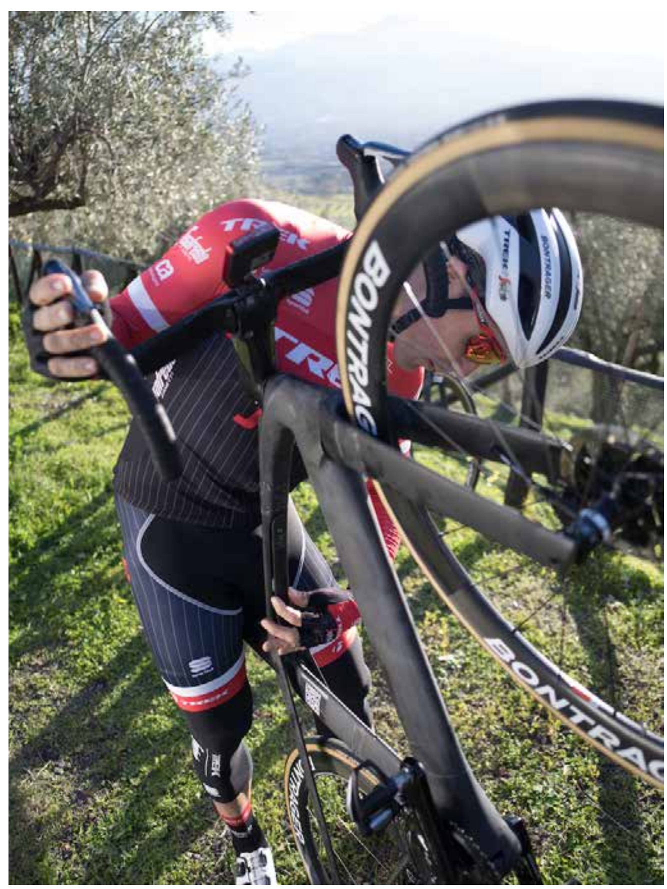


Figure 3. FEA Simulation (strain energy density), One of many iterations displaying areas of high strain to help design engineers improve structural efficiency.



To overcome this challenge, Trek went to great lengths to ensure that the new Madone frame could aid in reducing or maintaining bike weight from the current Madone. Numerous finite element models were analysed to fine-tune various areas of the frame and shave as much weight as possible, all while balancing aerodynamic requirements. Once Trek engineers felt comfortable with simulations and predictions, it was time to see what was possible on the manufacturing side for all the carbon components of the bike.

Trek worked closely with suppliers to ensure that every detail of the new Madone's carbon component laminates were scrutinised to help achieve bike weight targets. The effort resulted in a bike that has additional features that benefit the rider, and is as fast and light as the current Madone. The rim brake bike matches the current Madone (7.1 kg), and the all-new disc brake bike that weighs in at 7.5 kg, depending on paint scheme. The following three tables display a complete breakdown of bike weight for a variety of builds: Shimano Di2 Disc, Sram Red eTap HRD and Shimano Di2 Rim.

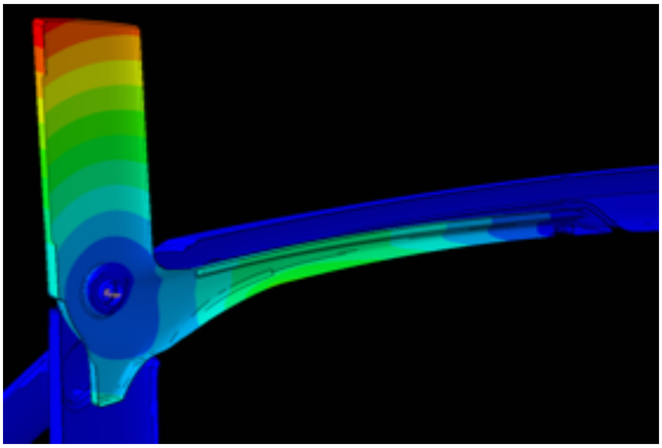


Figure 4. FEA Simulation (Vertical Compliance): One of many iterations displaying how the seatmast element behaves under vertical loading at the saddle.

Table 1. New Madone Bike Weight, Shimano Disc Brake Dura-Ace Di2 specification.
(Disclaimer: unpainted bike, slammed stem, headset spacers are not accounted for in the total)

	COMPONENT	**SPEC**	
Front Wheel	Wheel w/ rimstrip	Bontrager Aeolus 6 Disc Clincher	740.2
	Wheel QR	DT RWS [12 x 124]	51.0
	Rotor + lockring	SM-RT900-S [160 mm]	126.6
	Tyre	Bontrager R4 320 TPI 25C	230.0
	Tube	Bontrager Lightweight [80 mm valve]	65.0
Rear Wheel	Wheel w/ rimstrip	Bontrager Aeolus 6 Disc Clincher	858.6
	Wheel QR	DT RWS [12 x 124]	59.6
	Rotor + lockring	SM-RT900-S [160 mm]	126.6
	Tyre	Bontrager R4 320 TPI 25C	230.0
	Tube	Bontrager Lightweight [80 mm valve]	65.0
	Cassette w/ lockring	CS-R9100 [11-28T]	193.0
BB	Crank	FC-R9100 [170 mm 53-39T]	621.0
	Bottom Bracket	NSK w/seals and Axle Shield	52.7
Cockpit/Steering	Upper Headset Bearing	513538 [MR031S]	24.5
	Lower Headset Bearing	540243 [MR006]	22.5
	Headset Spacers [DS/NDS]	15 mm [561913/4]	11.7
	Headset Spacers [DS/NDS]	5 mm [561911/2]	4.4
	Top Cap/Bolt & Compression Plug	566031	39.8
	Compression ring	563834	7.6
	Bearing Top Cap	561910 [SRP]	23.8
	Stem	110 mm x -7deg – all hardware + faceplate	207.0
	Handlebar	42 cm VRCF	276.0
	Electrical tape	3M Super 33+ [200 mm]	1.3
	Bar Tape + plugs	Bontrager Gel Cork [534772 – Black]	62.0
	Steer Stop + Bolt	565905/318529	1.4
	Shifter (left)	ST-R9170	158.0
	Shifter (right)	ST-R9170	158.0
	Fork	(slammed = 196 mm)	421.0
Saddle/Post	Saddle	Bontrager Montrose Pro [138 mm]	169.0
	Seatpost + wedge hardware	Short x 25 [all hardware]	234.8
	Seatpost Rubber Tail	557630	8.0
Brake	Front Brake + resin pads + stock hose	BR-9170-F	162.1
	Rear Brake + resin pads + stock hose	BR-9170-R	165.5
	Rear Brake 160 mm Adapter		11.8
	Rear Brake Housing Grommet	330578	1.8
Drivetrain	Front Derailleur	FD – R9150	104.0
	Front Derailleur Bolt + Carbon Washer	531901 + 543903	5.8
	Rear Derailleur	RD – R9150	198.0
	Charge Port	Shimano Di2 EW-RS910	10.4
	Internal Battery	Shimano Di2	50.0
	Wire kit	JC130-MM [550/50/550], 350, JC200, 700, 550, 650, 150	50.0
	Chain	CN-HG901-11	247.0
	Chain Keeper w/ Washer and Bolt	566021 + 321693 & 521137	16.5
	DT Junction port	561882 + 510973 and 2 Zip-ties	44.1
	Front Derailleur Wire Exit Grommet	440697	0.5
	Rear Derailleur Wire Exit Grommet	317292	0.5
Frame	Frame	1478U0519 – SRP	870.0
	Seatmast	564480 – SRP	151.0
	Rear Derailleur Hanger w/ Bolts	524884 + 524188	11.7
	DuoTrap Cover	521455	3.0
	Damper	564027 – Carriage, housing, bumper, 2 mount bolts, pre-load bolt	17.4
	Pinch Bolt + Bumper	564444 + 568099	4.7
	Adjustment Slider	564294	3.9
	IsoSpeed Hardware	569265 -Bolt, nut, washer, wave washer, 2 bushings, inner bushing	26.0
	IsoSpeed cover [external]	565903 – SRP	7.6
	IsoSpeed cover [internal]	565904	8.0
Total		**Totals**	**7.405 kg**

Table 2. New Madone Bike Weight, SRAM Red eTap HRD specification.
(Disclaimer: unpainted bike, slammed stem, headset spacers are not accounted for in the total)

	COMPONENT	SPEC	
Front Wheel	Wheel w/ rimstrip	Bontrager Aeolus 6 Disc Clincher	740.2
	Wheel QR	DT RWS [12 x 124]	51.0
	Rotor + lockring	Centreline CenterLock [160 mm]	124.6
	Tyre	Bontrager R4 320 TPI 25C	230.0
	Tube	Bontrager Lightweight [80 mm valve]	65.0
Rear Wheel	Wheel w/ rimstrip	Bontrager Aeolus 6 Disc Clincher	858.6
	Wheel QR	DT RWS [12 x 124]	59.6
	Rotor + lockring	Centreline CenterLock [160 mm]	124.6
	Tyre	Bontrager R4 320 TPI 25C	230.0
	Tube	Bontrager Lightweight [80 mm valve]	65.0
	Cassette w/ lockring	XG-1190 [11-28T]	169.0
BB	Crank	Red [GXP 170 mm 53-39T]	609.0
	Bottom Bracket	NSK w/seals and Axle Shield	52.7
Cockpit/Steering	Upper Headset Bearing	513538 [MR031S]	24.5
	Lower Headset Bearing	540243 [MR006]	22.5
	Headset Spacers [DS/NDS]	15 mm [561913/4]	11.7
	Headset Spacers [DS/NDS]	5mm [561911/2]	4.4
	Top Cap/Bolt & Compression Plug	566031	39.8
	Compression ring	563834	7.6
	Bearing Top Cap	561910 [SRP]	23.8
	Stem	110 mm x -7deg – all hardware + faceplate	207.0
	Handlebar	42 cm VRCF	276.0
	Electrical tape	3M Super 33+ [200 mm]	1.3
	Bar Tape + plugs	Bontrager Gel Cork [534772 – Black]	62.0
	Steer Stop + Bolt	565905/318529	1.4
	Shifter (left)	See Brake	0.0
	Shifter (right)	See Brake	0.0
	Fork	Note steer tube length (slammed = 196 mm)	421.0
Saddle/Post	Saddle	Bontrager Montrose Pro [138 mm]	169.0
	Seatpost + wedge hardware	Short x 25 [all hardware]	234.8
	Seatpost Rubber Tail	557630	8.0
Brake	Front Shifter +Front Brake + resin pads + stock hose	Sram Red eTap HRD	390.2
	Front Shifter +Front Brake + resin pads + stock hose	Sram Red eTap HRD	380.1
	Rear Brake Housing Grommet	330578	1.8
Drivetrain	Front Derailleur	Front Derailleur + Battery	164.0
	Front Derailleur Bolt + Carbon Washer	531901 + 543903	5.8
	Rear Derailleur	Rear Derailleur + Battery	236.0
	Chain	Red 22 [114 links]	246.0
	Chain Keeper w/ Washer and Bolt	566021 + 321693 & 521137	16.5
	Front Derailleur Wire Exit Grommet	440697	0.5
	Rear Derailleur Wire Exit Grommet	317292	0.5
	Chain Keeper w/ Washer and Bolt	566021 + 321693 & 521137	16.5
	DT Junction port	561882 + 510973 and 2 Zip-ties	44.1
	Front Derailleur Wire Exit Grommet	440697	0.5
	Rear Derailleur Wire Exit Grommet	317292	0.5
Frame	Frame	1478U0519 – SRP	870.0
	Seatmast	564480 – SRP	151.0
	Rear Derailleur Hanger w/ Bolts	524884 + 524188	11.7
	DuoTrap Cover	521455	3.0
	Damper	564027 – Carriage, housing, bumper, 2 mount bolts, pre-load bolt	17.4
	Pinch Bolt + Bumper	564444 + 568099	4.7
	Adjustment Slider	564294	3.9
	IsoSpeed Hardware	569265 -Bolt, nut, washer, wave washer, 2 bushings, inner bushing	26.0
	IsoSpeed cover [external]	565903 – SRP	7.6
	IsoSpeed cover [internal]	565904	8.0
Totals			**7.423 kg**

Table 3. New Madone Bike Weight, Shimano Rim Brake Dura-Ace Di2 specification.
(Disclaimer: unpainted bike, slammed stem, headset spacers are not accounted for in the total)

	COMPONENT	SPEC	
Front Wheel	Wheel w/ rimstrip	Bontrager Aeolus 6 Clincher	712.1
	Wheel QR	Race Lite (Internal Cam 100mm)	55.0
	Tyre	Bontrager R4 320 TPI 25C	230.0
	Tube	Bontrager Lightweight [80 mm valve]	65.0
Rear Wheel	Wheel w/ rimstrip	Bontrager Aeolus 6 Clincher	861.7
	Wheel QR	Race Lite Road (Internal Cam 130 mm)	60.0
	Tyre	Bontrager R4 320 TPI 25C	230.0
	Tube	Bontrager Lightweight [80 mm valve]	65.0
	Cassette w/ lockring	CS-R9100 [11-28T]	193.0
BB	Crank	FC-R9100 [170 mm 53-39T]	621.0
	Bottom Bracket	NSK w/seals and Axle Shield	52.7
Cockpit/Steering	Upper Headset Bearing	513538 [MR031S]	24.5
	Lower Headset Bearing	540243 [MR006]	22.5
	Headset Spacers [DS/NDS]	15 mm [561913/4]	11.7
	Headset Spacers [DS/NDS]	5mm [561911/2]	4.4
	Top Cap/Bolt & Compression Plug	566031	39.8
	Compression ring	563834	7.6
	Bearing Top Cap	561910 [SRP]	23.8
	Stem	110 mm x -7deg – all hardware + faceplate	207.0
	Handlebar	42 cm VRCF	276.0
	Electrical tape	3M Super 33+ [200 mm]	1.3
	Bar Tape + plugs	Bontrager Gel Cork [534772 – Black]	62.0
	Steer Stop + Bolt	565905/318529	1.4
	Shifter (left)	ST-R9150	113.0
	Shifter (right)	ST-R9150	113.0
	Fork	Note steer tube length (slammed = 196 mm)	378.0
Saddle/Post	Saddle	Bontrager Montrose Pro [138 mm]	169.0
	Seatpost + wedge hardware	Short x 25 [all hardware]	234.8
	Seatpost Rubber Tail	557630	8.0
Brake	Front Brake w/ wedge	559499	119.8
	Front Brake Cover	562717 – SRP	27.6
	Front Brake Stop	562098	4.6
	Housing + cable	Shimano BC-9000	32.0
	Rear Brake w/ wedge and cover	559758	154.3
	Rear Brake Stop w/ ferrule	516820	4.5
	Housing + cable + Foam Tube [5.7]	Shimano BC-9000	72.0
Drivetrain	Front Derailleur	FD – R9150	104.0
	Front Derailleur Bolt + Carbon Washer	531901 + 543903	5.8
	Rear Derailleur	RD – R9150	198.0
	Charge Port	Shimano Di2 EW-RS910	10.4
	Internal Battery	Shimano Di2	50.0
	Wire kit	JC130-MM [550/50/550], 350, JC200, 700, 550, 650, 150	50.0
	Chain	CN-HG901-11	247.0
	Chain Keeper w/ Washer and Bolt	566021 + 321693 & 521137	16.5
	DT Junction port	561882 + 510973 and 2 Zip-ties	44.1
	Front Derailleur Wire Exit Grommet	440697	0.5
	Rear Derailleur Wire Exit Grommet	317292	0.5
Frame	Frame	1477U0519 – SRP	885.0
	Seatmast	564480 – SRP	151.0
	Rear Derailleur Hanger w/ Bolts	315464 + 318604	12.4
	DuoTrap Cover	521455	3.0
	Damper	564020 – Carriage, housing, bumper, 2 mount bolts, pre-load bolt	17.1
	Pinch Bolt + Bumper	564444 + 568099	4.7
	Adjustment Slider	564294	3.9
	IsoSpeed Hardware	569265 -Bolt, nut, washer, wave washer, 2 bushings, inner bushing	26.0
	IsoSpeed cover [external]	565903 – SRP	7.6
	IsoSpeed cover [internal]	565904	8.0
Totals			**7.087**

MADONE ADJUSTABLE COMPLIANCE TECHNOLOGY

ADJUSTABLE TOP TUBE ISOSPEED

The new Madone builds upon Trek's Adjustable Compliance Technology from the award-winning Trek Domane SLR. The Madone Adjustable Compliance technology is comprised of two frame elements integrated into each other just like the Domane SLR but that have been rotated into the top tube for aerodynamic advantage. This method also aids in more uniform compliance for all frame sizes. Lastly, Trek has implemented hardware on the back of the seat tube that offers rebound damping characteristics to the bike.

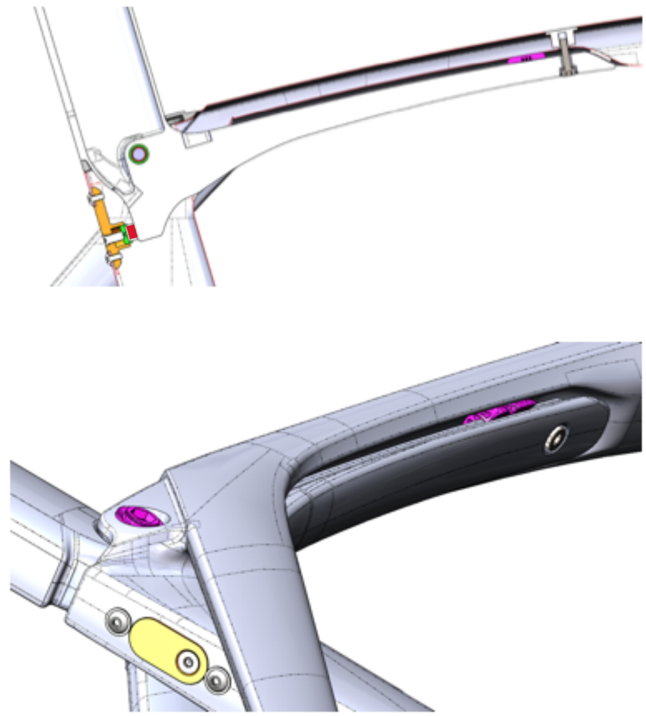


Figure 5. New Madone Adjustable Compliance Tech CAD Model (Top – Frame centre-plane cross-sectional view,

Bottom – Iso view of the bottom of the top tube and IsoSpeed area).

The two frame elements are connected by the IsoSpeed Decoupler (see Figure 5) and the bolted joint at the front. In between the two frame elements is a vacant space with an adjustment slider that can move along the entire path. The seatmast element utilises the IsoSpeed Decoupler to transfer the aft deflection of the upper aero section of the seatmast to an upward deflection of the lower seatmast element. The vacant space allows the lower seatmast to deflect in the upward direction while the main frame top tube element remains independent from the lower seatmast. The slider contacts both the lower seatmast element and main frame top tube element to limit the upward deflection of the lower seatmast per the rider's preference. If the slider is towards the front of the frame, a rider will experience more compliance because of the greater vacant space that allows the lower seatmast to deflect more. If the slider is near the back of the frame towards the IsoSpeed Decoupler, a rider will experience less compliance because the slider is inhibiting deflection in the vacant space in front of it.

Subjective test riding, instrumented test riding and lab testing were among the validation procedures to inform Trek that this new method of Adjustable Compliance Technology was performing as expected and allowing a rider to adjust the vertical compliance at the saddle.

In the test lab, vertical stiffness testing at the saddle shows that for a size 56 frame, the compliance ranges from approximately 119 N/mm to 175 N/mm throughout the slider's adjustment range as shown in Figure 6. The current Madone had a stiffness of approximately 144 N/mm. This means that the new Madone is capable of more compliance (+17%) and less compliance (-22%) than its predecessor.

Movements in the slider position from the foremost and middle positions have a greater effect on changes in compliance, and movements of the slider from the middle to aft-most positions have a lesser effect on compliance.

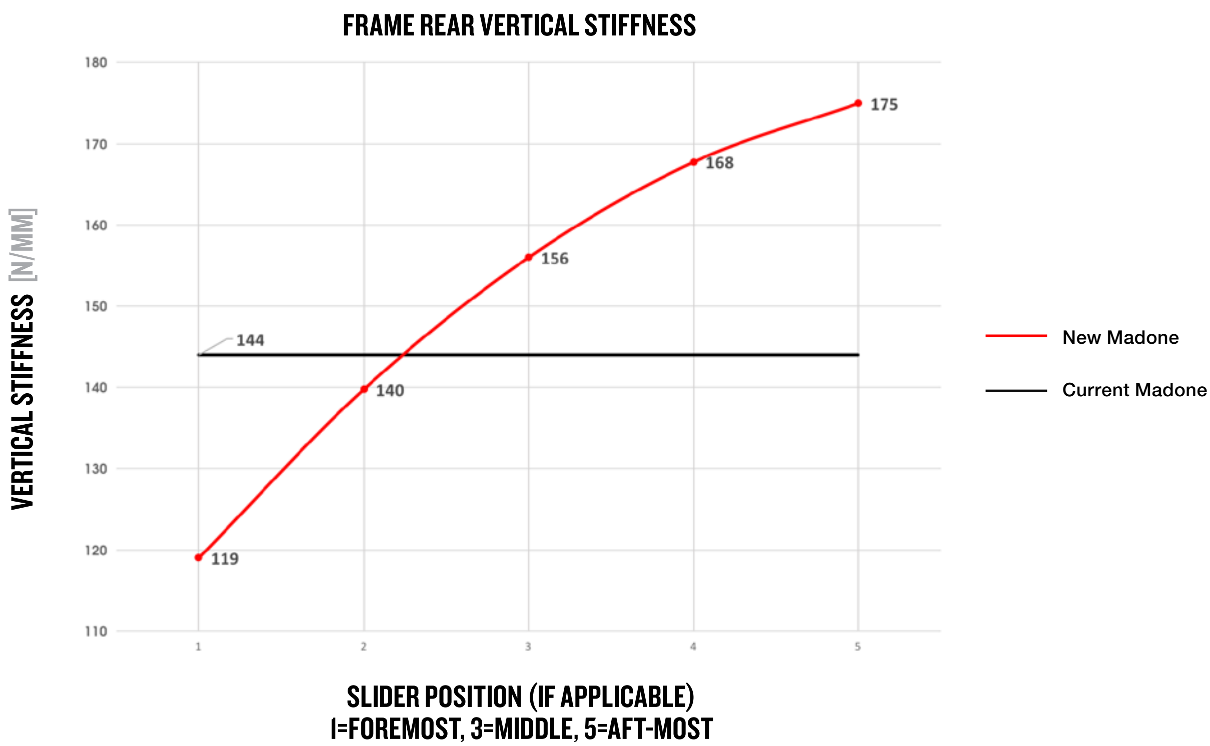


Figure 6. Frame Rear Vertical Stiffness.

Another benefit of this technology is the ability to closely match the vertical compliance values across all frame sizes. This is due to the removable seatmast element being nearly the same size for all frame sizes. On typical road bikes, vertical compliance values on smaller bike frames produce stiffer results and gradually decrease in stiffness with increasing frame size. This phenomenon is due to basic bending theory, where longer bike tube elements are generally more susceptible to greater deflections and vice versa for short tubes. Think of a thin, long metal tube that will fit in your hands. It is much easier to bend it in half versus a short tube because it is very difficult to induce any deflection. Since the seatmast elements are the same length on each size frame, there are more consistent vertical compliance values on all sizes with this new technology.

Figure 7 shows the MIN/MAX vertical compliance values of all sizes. There is a slight downward trend in vertical stiffness with increasing frame size. This is due to the frame top tube getting longer with increasing size. On a traditional bike, values of upwards to 30-40% different on book end sizes could be achieved. On the new Madone, there is about a 3-6% difference on the book end sizes. Comparing 50 cm frames alone (current vs new), the new Madone has the capability of up to 27% more compliance.

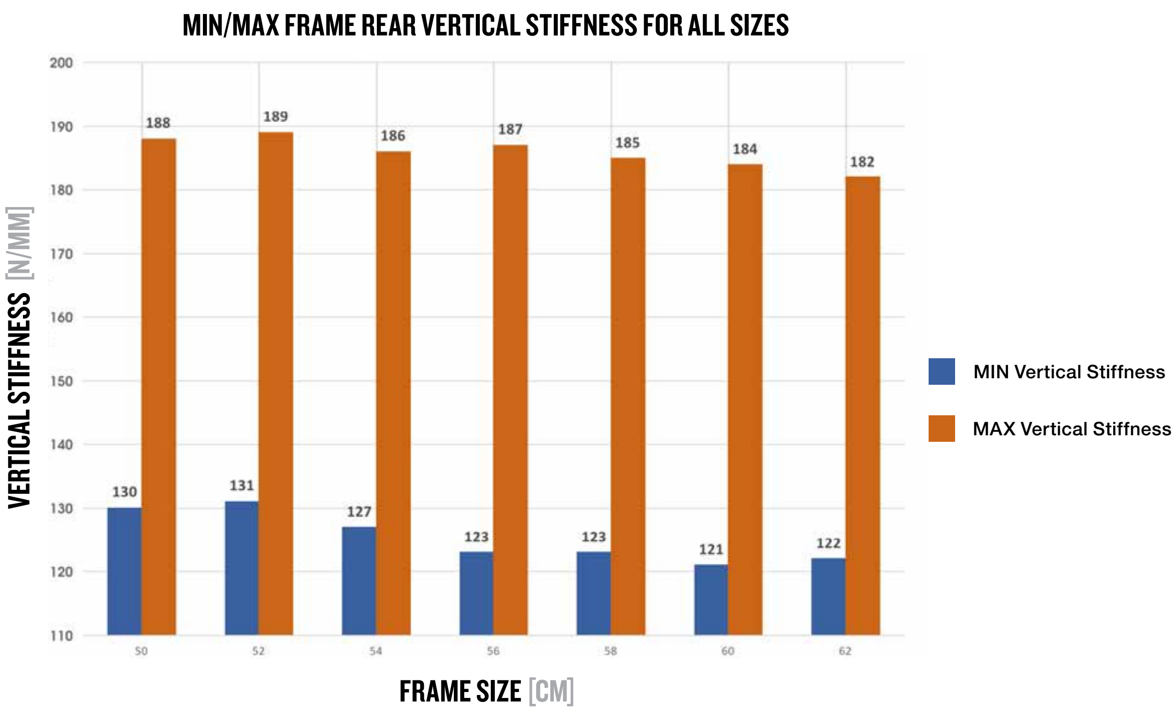


Figure 7. Frame Rear Vertical Stiffness (Maxima and Minima), all frame sizes.

DAMPER

For the first time in Trek's IsoSpeed history, Trek introduces a damper to the system to help control rebound of the seatmast. When a large excitation (impact event) was introduced on previous IsoSpeed frame designs, riders would experience the main benefit of the technology through a large deflection of the seatmast that promotes a comfort benefit. This motion was largely isolated from the main frame features that would normally limit or constrain a more traditional frame under the same excitation. However, on the rebound phase of this event (where the seatmast begins to return to it's nominal position), the imposed velocity limited control for the rider where the sensation of separation from the saddle could occur.

This sensation can both be uncomfortable and annoying due to the potential need to readjust your position on the saddle and can create long-term fatigue to the rider. How severe this rebound is, is dependent on the size of the excitation. By implementing a damper to the IsoSpeed system, Trek can control and reduce this rebound that riders may experience.

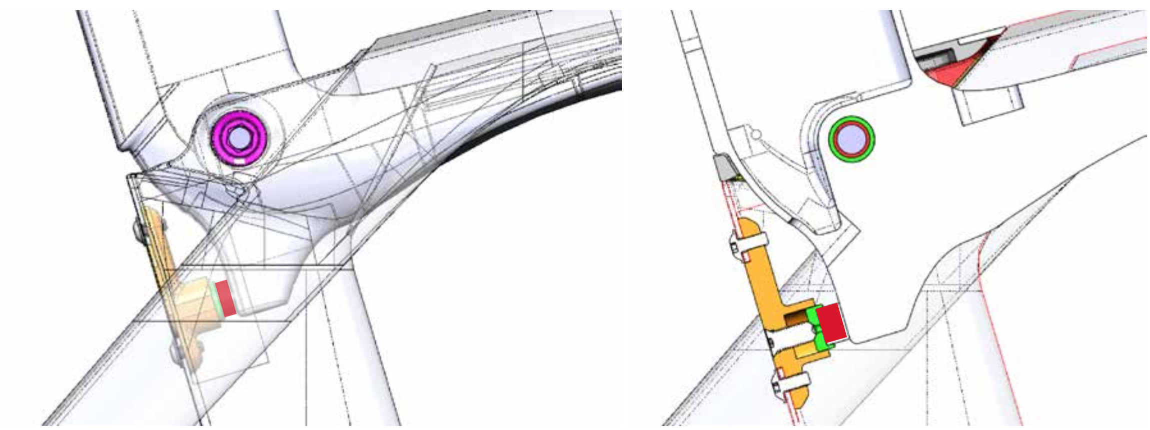


Figure 8. Madone Damper CAD Model (Left – Drive side view with main frame transparency, right – Frame centre-plane cross-sectional view).

The damper is comprised of three main parts; an elastomer damper (red), damper housing (green) and the frame carriage (orange). These parts are mounted to the carbon main frame on the back of the seat tube and interface with an embossed feature on the seatmast element as depicted in Figure 8 above. The main frame is transparent to aid for visualisation. In the referenced figure and in the frame's nominal state, the damper is pre-loaded in compression by a set screw against the seatmast. This set screw allows a rider to unload the damper so that they can reposition the adjustment slider, if desired. Once the desired position is selected, the last step will be to once again pre-load the damper by adjusting the set screw until it bottoms out on the damper carriage. This is an on/off set up with no intended micro adjustments.

When the seatmast element is loaded during an impact event at the saddle, it creates anti-clockwise rotation when viewed from the perspective of Figure 8 or the drive side of the bike. This motion unloads the damper slightly and prepares it for the rebound event. As the seatmast begins to rotate back to nominal, the damper is re-loaded, thus slowing the motion and absorbing the rebound energy

TREADMILL TESTING

Trek goes beyond static lab tests to understand bicycle behaviour in dynamic settings. What occurs in a static lab test does not always indicate or represent what a rider may experience in various road conditions. To aid in this process and to minimise as many environmental variables as possible, Trek performed instrumented testing on a newly developed treadmill to further validate the adjustable compliance and damper technology. This treadmill allows Trek to change the surfaces to replicate various road conditions. Hitting a large pothole or bump, chip seal, gravel and cobbles are some of the various conditions that Trek can reproduce in a controlled environment. See Figures A1 – A4 in the Appendix to see the test set-up. Triaxle accelerometers and linear displacement sensors were strategically placed to capture differences between the current Madone and new Madone. They measure the deflection between the rear axle and saddle, which is effectively a measure of the bike's rear suspension travel.

Trek set out to collect data to show the effect that the new adjustable compliance/damping technology has on the rider and what this means for them regarding comfort. A test plan was developed that involved three internal test riders and five road surface types on the treadmill that produced 37 individual test runs depending on run intent.

Variables such as treadmill speed and the IsoSpeed adjustment slider placement were a couple of the other variables that were contained within the test plan.

Figure 9 below details the average peak to peak deflections between the rear axle and saddle. Think of the saddle compressing towards the rear axle. We see that the single bump and kerb drop test runs agree best with the static test lab results as previously indicated in Figure 6. Figure 9 is showing that the dynamic compliance of the current Madone is within the new Madone dynamic compliance adjustment range. A slightly deeper look reveals a generally consistent change in compression as the adjustment slider is moved, where slider position 1 represents most-compliant and slider position 3, least-compliant. Lastly, the effectiveness of the slider becomes more apparent with increasing bump size. This is especially important because this gives the rider added dynamic compliance when needed most.

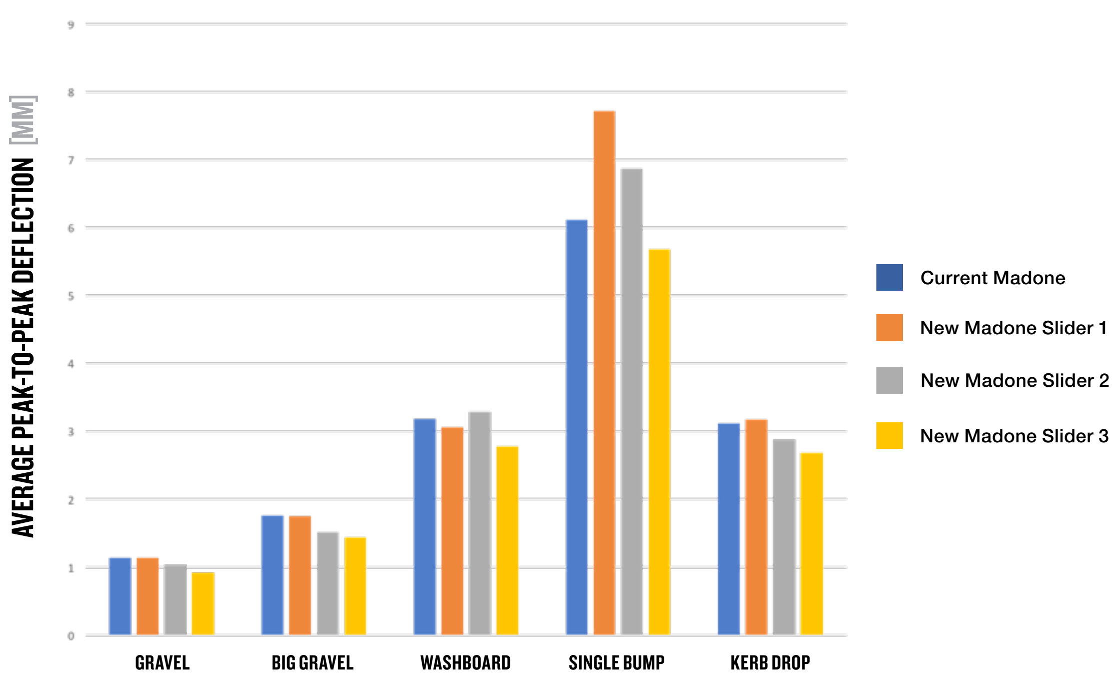


Figure 9. Peak to Peak deflections, New Madone vs the Current Madone (Slider 1 = most-compliant setting, Slider 2 = mid-range, Slider 3 = least-compliant setting).

Figure 10 below shows the pulse curves of the new Madone at the various adjustment slider settings on the single bump runs. The curves are generated by averaging many single bump impacts during a test run and overlaying them by normalising the sag just before impact. Once again, we see the trend shown in Figure 9 in a different way that can offer a better visual effect of the slider positions on the new Madone. The main interest of Figure 10 is to show what the damper component is offering to the rider. Recall that the intent of this component is to reduce what a rider is experiencing after an impact event, and to integrate controlled compliance to the system. If we zoom into the region immediately after impact (Figure 11), we see separation between slider runs and when comparing damper on vs damper off. This shows that the damper is reducing the amount rebound magnitude after impact by as much as 13%.

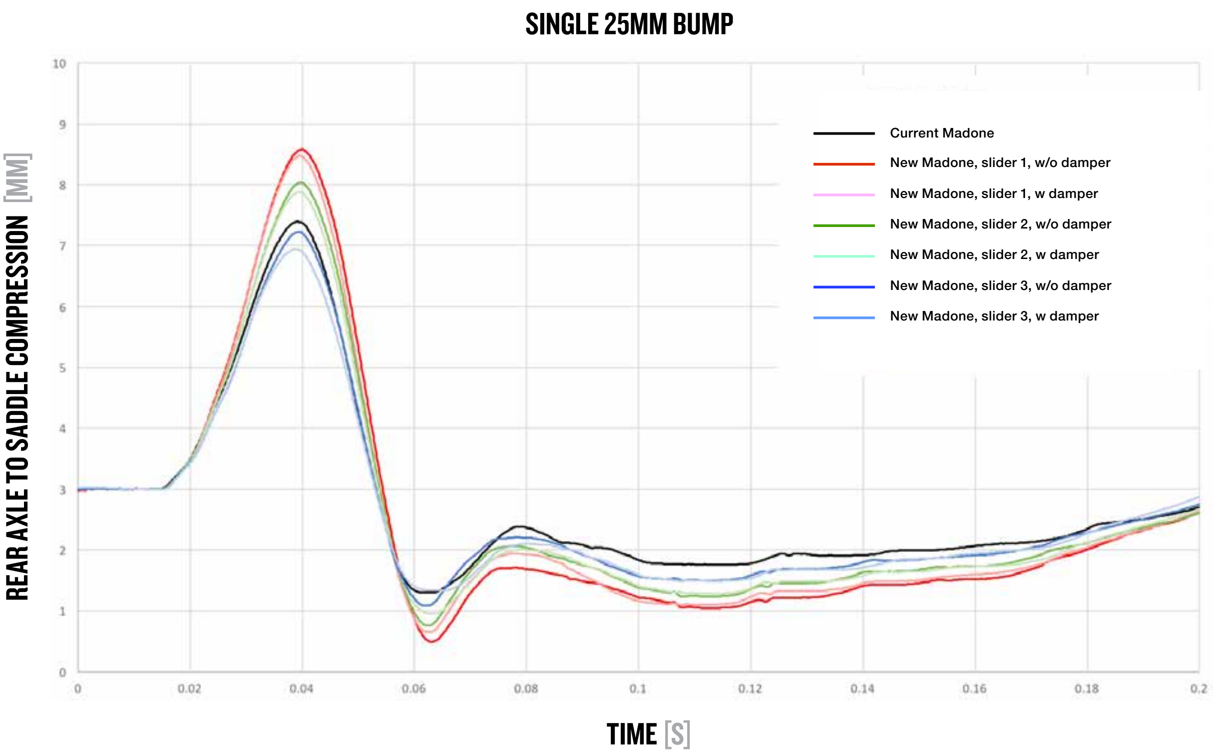
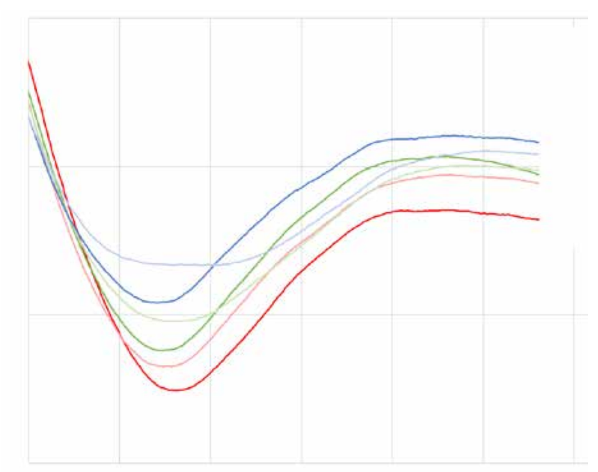


Figure 10. Single 25 mm bump Pulse Curves, New Madone (Slider positions 1 – 3, Damper on/off) (Slider 1 = most-compliant setting, Slider 2 = mid-range, Slider 3 = least-compliant setting).

Figure 11. Zoomed in depiction of Figure 10 at point of rebound after impact (Slider 1 = most-compliant setting, Slider 2 = mid-range, Slider 3 = least-compliant setting).



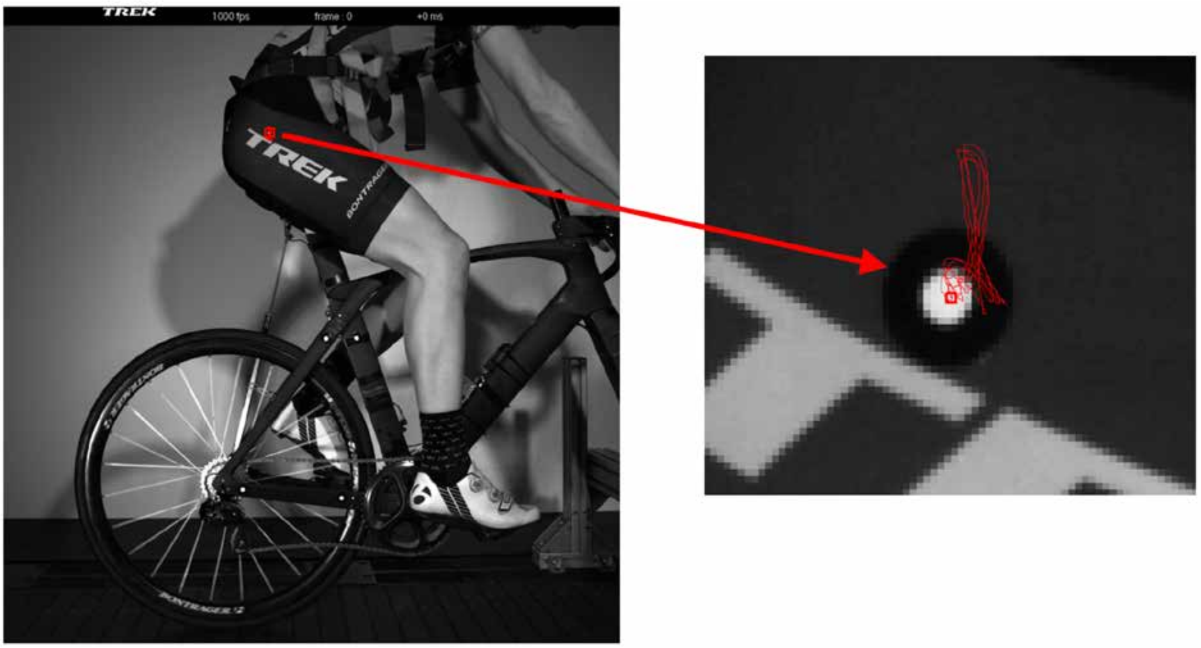


Figure 12. Hip Motion tracking using a High-Speed Camera.

This reduction can also be quantified by tracking a rider's hip motion as was conducted in Trek's lab using a high- speed camera (Figure 12). Analysing the vertical motion (Figure 13) between the new Madone (slider setting 1, damper on) and current Madone reveals that these effects add up to a significant reduction in the vibration of the cyclist's body: the end goal of any suspension technology.

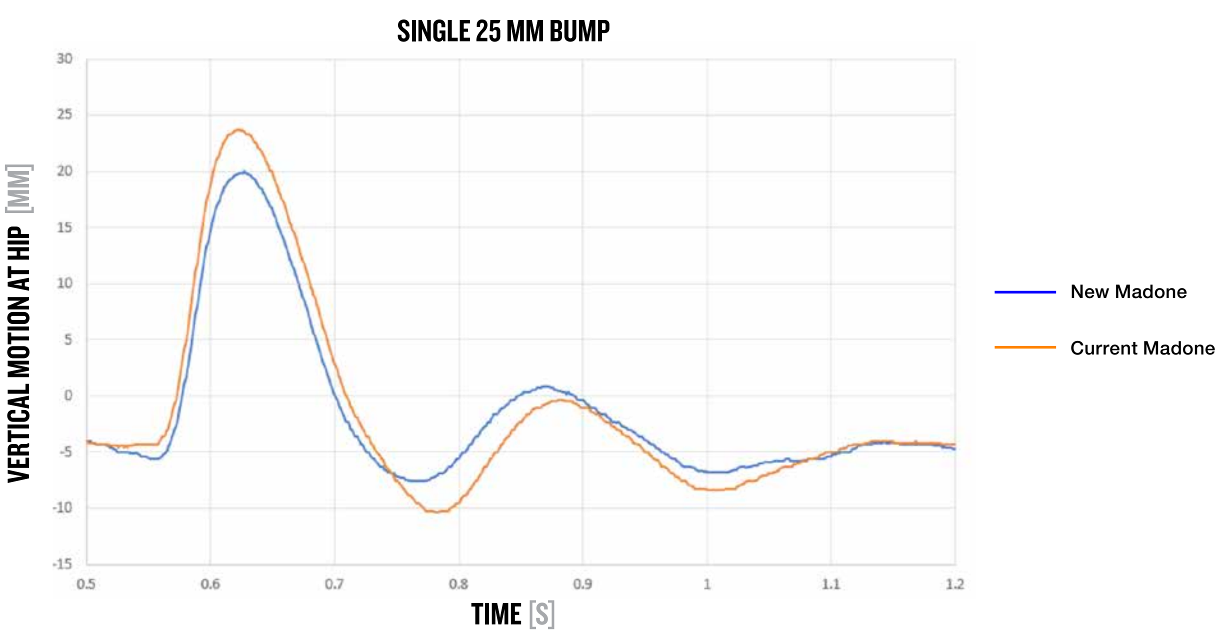


Figure 13. New Madone vs the Current Madone hip-motion tracking during Single 25 mm bump.

Lastly, Trek set out to define how the new Madone behaves compared to the current Madone with a damping ratio. A damping ratio is a common dimensionless measure to describe how oscillatory systems decay after an excitation. Put another way, how rapidly an oscillation decays from one peak to the next. Think of holding a basketball and dropping it from a given height and letting it bounce until it no longer does. Each successive bounce is less than the previous. An example of this type of oscillation can be seen in Figure 13 where each successive peak is less than the previous. Put in the context of a bicycle when travelling over a large bump, we want the successive motion of the saddle and the rider to return to a steady state as soon as possible after that bump. This effect provides more controlled comfort and limits long-term riding fatigue. Smaller damping ratios imply longer decay rates and on the flip side, a larger ratio implies a faster decay rate.

Figure 14 below shows the damping ratios of the new Madone in various slider positions versus the current Madone. These ratios were calculated by means of the logarithmic decrement method and are briefly outlined in the Appendix. Figure 14 shows that the new Madone offers anywhere from a 44–61% increase in the damping ratio.

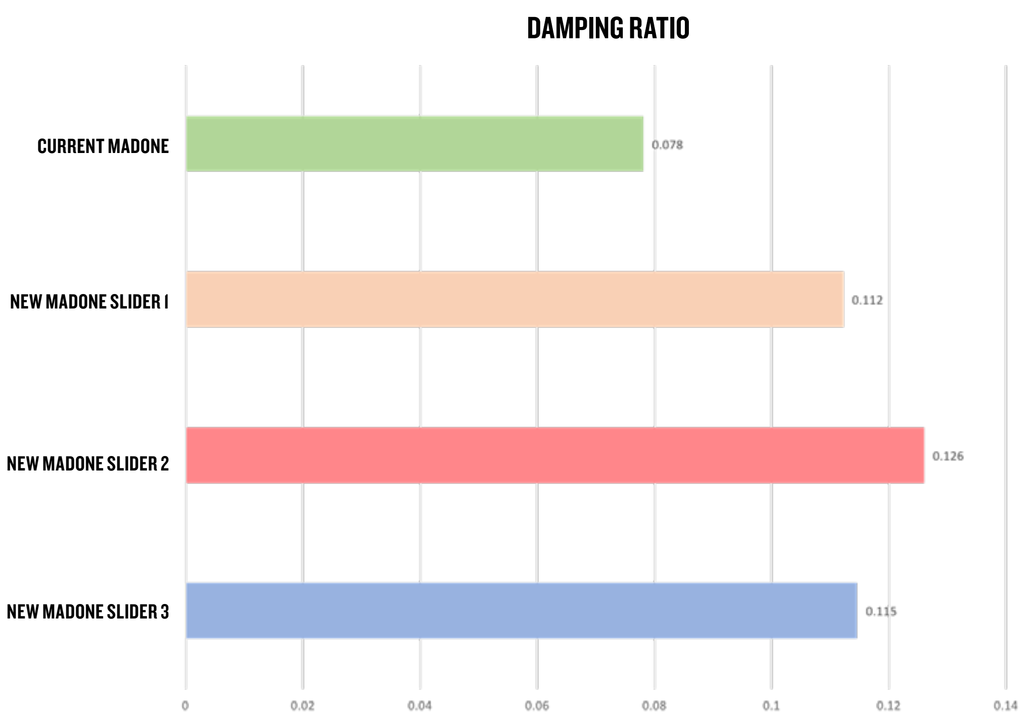


Figure 14. Damping ratios of the new Madone at various slider positions vs the current Madone (Slider 1 = most-compliant setting, Slider 2 = mid-range, Slider 3 = least-compliant setting).

– The Appendix also illustrates the positive effects of the new Madone vs the current Madone on washboard-type surfaces. –

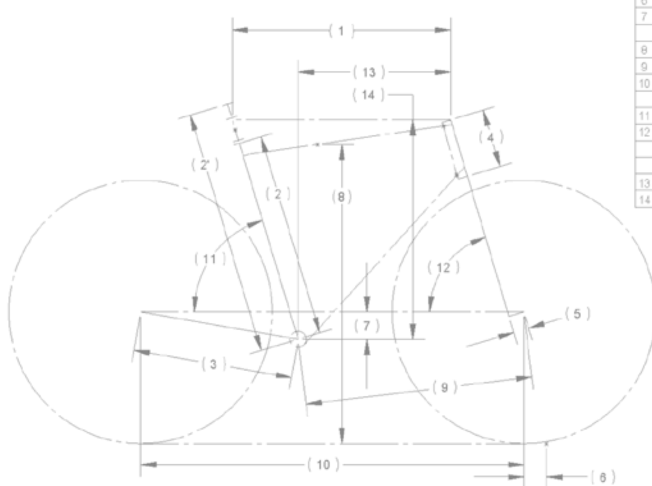
FIT

Trek previously offered Madone bikes through the H1 and H2 fit on frames, selecting an appropriate integrated bar/stem combination option and adding applicable headset spacers to complete a rider's bike cockpit. Due to the integrated nature of the previous generation Madone bar/stem combination, sizing options were somewhat limited and expensive investment to make a change to a new bar/stem combo compared to what customers can choose on other Trek road models like Emonda and Domane. Trek saw this as an opportunity to improve and expand its fit range and still maintain the same and – now expected – integrated nature of the Madone cockpit.
`

Trek introduces the H1.5 Fit on frames, more stem options, an additional bar size and +/-5degrees of bar roll for the new Madone. With this new fit update, Trek offers one of the broadest spectrums of possible fits for men and women with an integrated cockpit.

Rather than producing Madones in the H1 and H2 fit in both disc and rim type braking (28 unique frames), Trek focused on what would be appropriate for its consumers and cut that number in half by implementing one fit (H1.5) for each brake type. Frame stack, reach and head tube length are the three important features that changed. The new fit did not change any other frame geometry attributes from the previous generation Madone which produced the exceptional ride quality that the Madone name is known for. With the addition of disc brakes to the arsenal and while still producing the rim brake bike, Trek engineers were able to focus greater analytical efforts on aerodynamic drag and weight on fewer frames. Frame sizes still range from 50 cm to 62 cm for each braking type. The centreline chart for the new Madone can be seen in Figure 15 below. The best attribute this fit offers is greater flexibility for a fit change with the new stem, bar and bar roll options.

H1.5 Madone Frame Geometry



#	Frame Size	50 CM	52 CM	54 CM	56 CM	58 CM	60 CM	62 CM
1	EFFECTIVE TT	521.4	534.2	543.6	559.9	573.2	586.1	598.0
2	SEAT TUBE (c-t)	453	483	496	525	553	573	593
2'	SEAT MAST (c-t)	545	575	600	630	650	670	690
3	CHAIN STAYS (c-c)	410	410	410	410	411	411	412
4	HEAD TUBE	111	121	131	151	171	191	211
	HEADSET LSH	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	TIRE DIAMETER	676	676	676	676	676	676	676
	FORK, AXLE-RACE	374	374	374	374	374	374	374
5	FORK OFFSET	45	45	45	40	40	40	40
6	TRAIL	61.9	57.5	56.3	58.4	56.5	56.1	55.7
7	BB DROP	72	72	70	70	68	68	68
	BB Height	266	266	268	268	270	270	270
8	STAND OVER, MAX	711.3	732.1	743.6	768.1	792.9	811.1	829.4
9	FRONT-CENTER	575	577.4	581	583	590	599	607
10	WHEELBASE	974	977	981	983	992	1001	1010
11	ST-GROUND Angle	74.6°	74.2°	73.7°	73.3°	73.0°	72.8°	72.5°
12	HT-GROUND Angle	72.1°	72.8°	73.0°	73.5°	73.8°	73.9°	73.9°
	ST-CS Angle	64.5°	64.1°	63.9°	63.5°	63.5°	63.2°	63.0°
13	Frame REACH	378.1	383.2	385.8	391.0	395.5	399.6	402.5
14	Frame STACK	520.6	532.5	540.7	563.0	581.2	600.6	620.0

Figure 15. New Madone H1.5 Frame Centreline.

Trek's bar and stem for the new Madone has been separated into a more traditional, yet still proprietary system. Figure 16 shows the break-down of how the parts have been split. This new set up offers 40 possible configurations versus the 26 possible configurations when considering the H1/H2 frames. Riders also get the added benefit of the +/-five degrees of bar roll to allow deeper fit refinement.

Table 4 shows the bar and stem options that were offered with the current Madone and what is being offered with the new Madone. The -7 deg stems offer the industry standard set-up and the -14 deg stems are intended to allow current Madone H1 riders to match their usual fit as well as offer more flexibility to new consumers. Stems are offered in 90 mm to 130 mm lengths in both -7° and -14° angles. The bar receives one additional width size and is offered in Variable Radius Compact Flare (VRCF) fit in widths from 38 cm to 44 cm. With these expanded options, changing fit is now easier and more affordable.

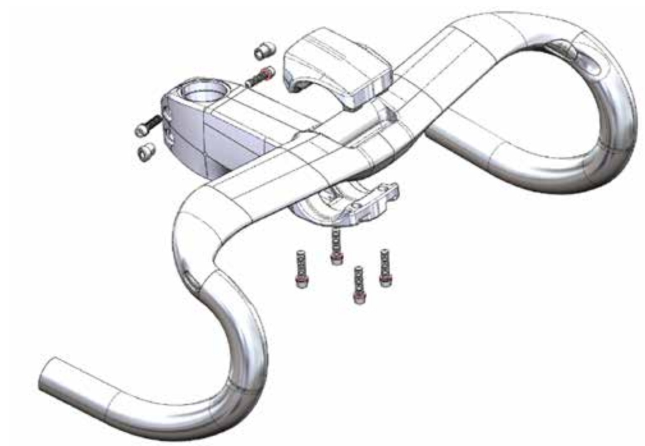


Figure 16. New Madone Bar & Stem CAD Model.

Current Madone	
Stem Length (mm) [all -7 deg]	Bar Width (cm) [VRCF]
90	40
	42
	44
100	40
	42
	44
110	40
	42
	44
120	40
	42
	44
130	42

New Madone			
Stem Length (mm) [-7 deg]	Stem Length (mm) [-14 deg]	Bar Width (cm) [VRCF]	Bar Roll (deg)
90	90	38	+/- 5
		40	
		42	
		44	
100	100	38	
		40	
		42	
		44	
110	110	38	
		40	
		42	
		44	
120	120	38	
		40	
		42	
		44	
130	130	38	
		40	
		42	
		44	

Table 4. New Madone Bar & Stem options vs the Current Madone Bar/Stem Combination.

REFINEMENT & INTEGRATION

RIM BRAKES

The all-new rim brakes have been redesigned with improved functionality and ease of set up in mind. The brake arms use independent spring tension adjustment screws to centre the brake pads, allow for precise pad adjustments as brake pads wear and adjust lever pull force to the desired feel. The spacing screws range allows swapping between rim widths ranging from 23–28.5 mm without adjusting the centre wedge.

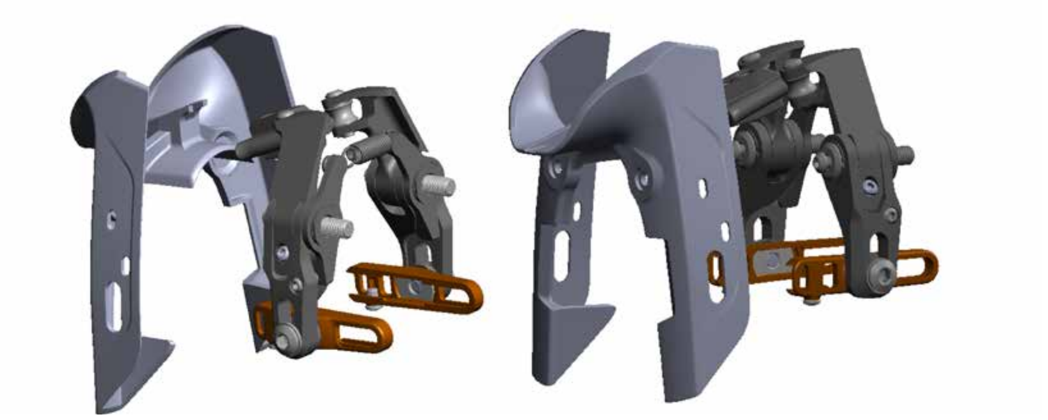


Figure 17. New Madone Front Rim Brake CAD Models

The biggest change on the rim brake bike from the current Madone is the front brake position. Trek saw an opportunity to further enhance the Madone's aero benefits by placing the front brake on the back of the fork so that it seamlessly integrates with the fork and downtube form. The front brake cover has now been designed to allow for colour matching with the frame and fork. Utilising a similar centre-pull design from the current Madone, the front brake housing is routed down the front of the steer tube, through the base of the steer tube and lower head tube bearing, and out the back of the fork. With the same centre-pull design and form design, the rear brake housing again passes through the top tube with a stop at the damper carriage on the back of the seat tube, allowing a small length of brake cable to be exposed to the wind.

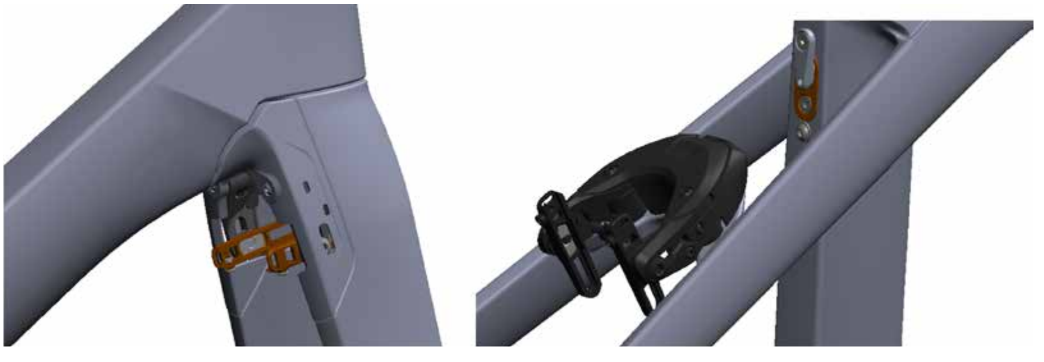


Figure 18. New Madone Front Rim Brake & Rear Rim Brake CAD Models, assembled to frame to show form factor

The front brake (brake, unpainted cover and stop) comes in at 152 g, saving about 5 g from the current Madone. The rear brake (brake and stop) comes in at 152 g to match the current Madone. Tyre clearance is designed for 25 C tyres in saleable form to comply with ISO tyre-clearance regulations.

DISC BRAKES

Disc brake adoption was a critical pillar during the research and development phase of the new Madone. Aerodynamics and brake hose routing were two areas that needed to be addressed and carefully considered. On the aerodynamic side, disc brakes become a concern when considering wind at yaw on the non-drive side of the bike. Trek built detailed CFD models of disc brake callipers and rotors by utilising in-house 3D scanning software. Maintaining fully internal hose routing required Trek to explore unique ways to route both the rim and disc brakes through the lower head tube bearing. One solution that Trek came up with, and that accommodated both braking types, was routing in the fork steer tube above the lower head tube bearing and from there routing their separate paths. However, on the disc brake side, it was more difficult to pass brake hose from the steer tube to the non-drive side fork leg.

To overcome this obstacle, Trek bonded in a routing tube to easily push the brake hose from the fork leg up to the steer tube for a trouble- and tool-free experience.

Disc brakes also offer larger tyre specification. The new disc brake Madone frame and fork tyre clearance is designed for 28 C tyres in saleable form to comply with ISO tyre-clearance regulations.

SEATPOST/LIGHT MOUNT

As on the current Madone and now again on the new Madone with more aero refinement, the IsoSpeed system once again frees up the seatpost to use the proven KVF technology, matching the wind cheating seat tube profile and offering unrivalled vertical compliance. The seatpost head continues to use an independent pinch bolt and rail clamp system to allow for infinite tilt and setback adjustment.

Also, new for the seatpost is an integrated internal wedge design (Figure 20) to provide a cleaner look to the back of the seatmast. No more external wedge clamp design and now the back of the seatmast will be fully painted. The post now comes with four colour options as well as full customisation through Trek's P1 programme. Lastly, to integrate safety into the design, a Flare R light mount has been designed to clip onto the back of the seatpost head and offers a clean and integrated look (Figure 19). The reflector bracket mount fits seamlessly into the back of the seatpost slot for a clean, integrated look as well.

Figure 19. New Madone Seatpost with Integrated Light Mount

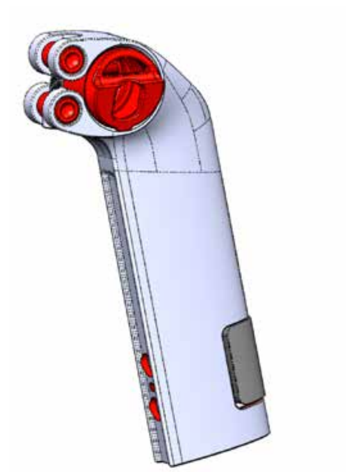


Figure 20. New Madone Seatpost showing internal wedge

BAR/STEM

As discussed previously, expanding the Madone fit range was one of the top priorities for Trek engineers. Splitting the bar and stem into two pieces was the best and most obvious solution but Trek also needed to maintain aero requirements. The result is a faceplate design that provides an aerodynamic, clean, integrated look. Also, the bar now features swept-back tops for better ergonomic hand placement when riding in this position. A side-by-side comparison of the current Madone and new Madone can be seen in Figure 21 below.

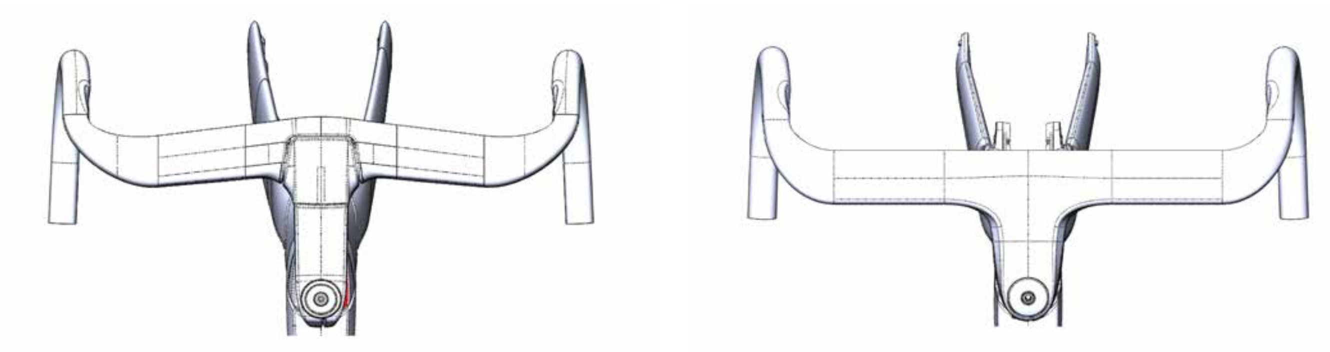


Figure 21. New Madone Bar (left) showing swept-back design for ergonomics vs the current Madone (right)

Headset spacers continue to use a two-piece clam shell design to allow for easy addition or removal without rerouting any housing or cables after bike build. Updates to the spacers include a reduction in visible parting lines, an all-new interlocking design that improves bike build ease, and two stack size options of 5 mm and 15 mm. Lastly, the bearing top cap features an update to a one-piece design and another update that removes the NDS cutout that was for the rear rim brake routing on the current Madone. See Figure 22 for comparisons

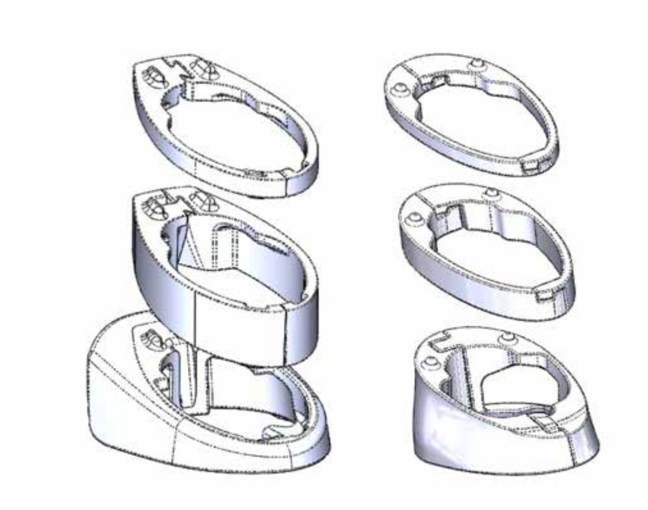


Figure 22. New Madone headset spacers (left) vs the current Madone (right)

CONTROL CENTRE

The control centre has been updated to accommodate all build specifications with one single part (Figure 23) and has been relocated to the aero-optimised downtube water bottle position. The water bottle cage itself is mounted to the control centre as well. On mechanical set-ups, the control centre houses both the front and rear derailleur. There is no longer a dial for front derailleur adjustment due to OEM advancements. For electronic set-ups, the control centre locates the Di2 battery and junction B box in one location, and no longer houses the charge port, which has been relocated to the handlebar end. The control centre also accommodates the rear disc brake hose to prevent rattling in the downtube.

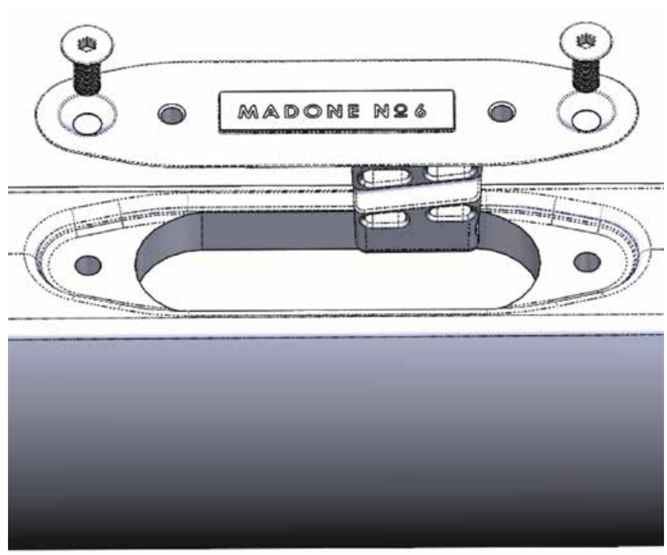


Figure 23. New Madone Control Centre

TREK SEGAFREDO VALIDATION

The Trek Segafredo team was used several times throughout the development process of the new Madone to ensure that the bike offered athletes and consumers an advantage over its competitors, as well as against the current Madone. In December of 2017, the team rode the first Madone prototypes in Sicily. This first major test offered the team two unique laminates of the new Madone and tested all aspects of the bike's performance in climbing, cornering, sprinting and comfort against the current Madone. The feedback provided led to a more polished laminate that was a combination of the two previously tested laminates, further scrutiny of the adjustable compliance technology and an improved bar/stem interface.

A second major test ride was held in Mallorca in January 2018. The team feedback on the follow up Madone prototypes confirmed that updated laminates provided best-in-class ride handling and the new H1.5 geometry/fit was optimal. It also showed Trek that the technological and feature updates created a bike that was above and beyond the current Madone. This is a true testament to Trek Engineering's ability to create and improve existing products that are already best-in-class and the irrefutable value of what owning a pro cycling team offers to a bike manufacturer.

APPENDIX

SUPPLEMENTAL TREADMILL TESTING FIGURES & INFORMATION

Figure A1. Treadmill Test Lab

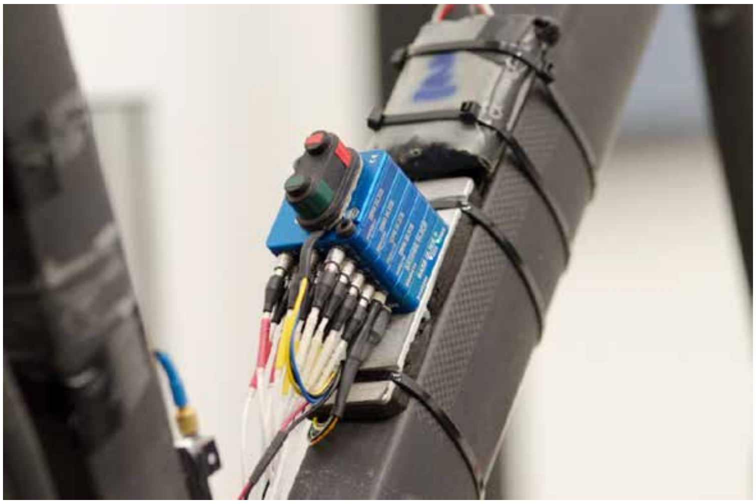


Figure A2. Data Acquisition System on Downtube.

APPENDIX

SUPPLEMENTAL TREADMILL TESTING FIGURES & INFORMATION

Figure A3. Linear Displacement Sensor.

Figure A4. Triaxle accelerometer distribution.

APPENDIX

SUPPLEMENTAL TREADMILL TESTING FIGURES & INFORMATION

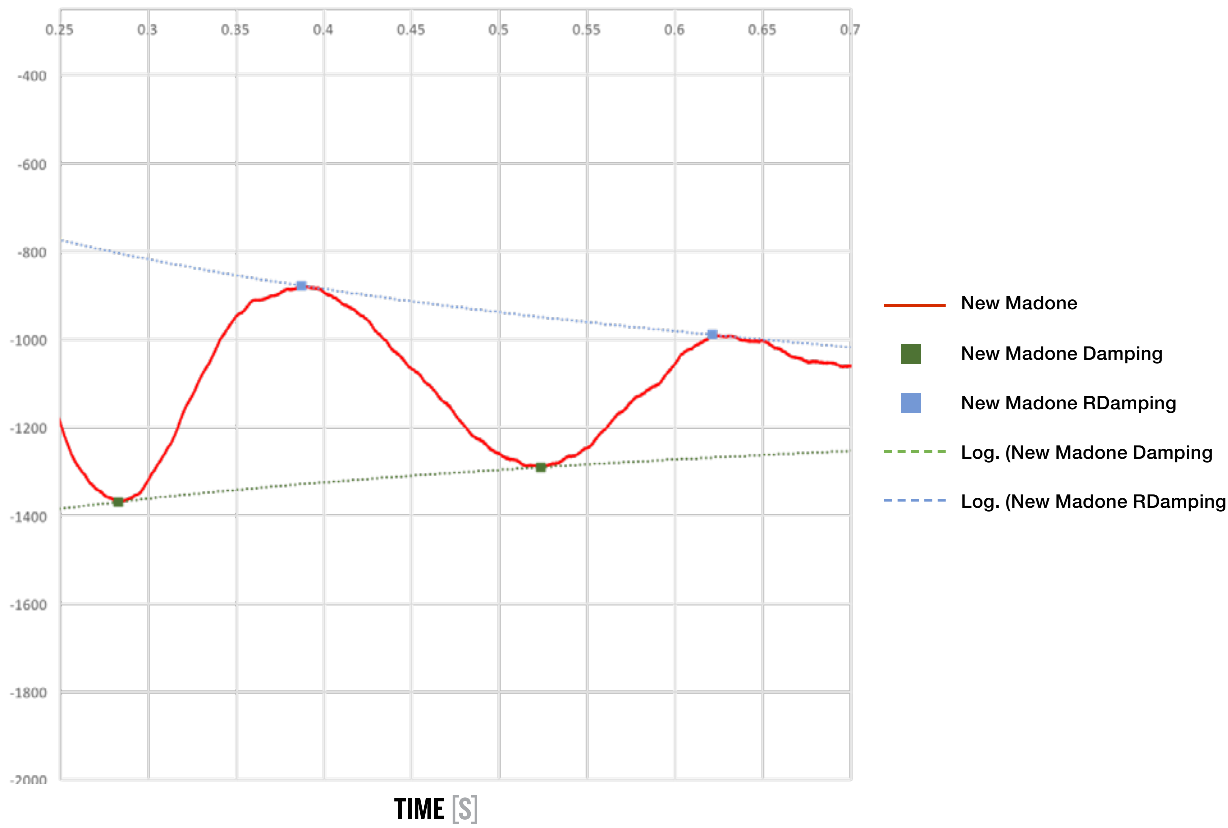


Figure A5. Example of an oscillatory curve used to calculate the damping ratio via the logarithmic decrement.

For under-damped systems that exhibit oscillatory motion, the damping ratio can be calculated by means of the logarithmic decrement method. It is defined as the natural log of the ratio of any two successive amplitudes as shown in Figure A5. The damping ratio is then calculated by the following, where zeta (ζ) is the damping ratio and delta (ζ) represents the logarithmic decrement.

$$\zeta = \frac{\delta}{2\pi} \quad \text{where} \quad \delta \triangleq \ln \frac{x_1}{x_2}$$

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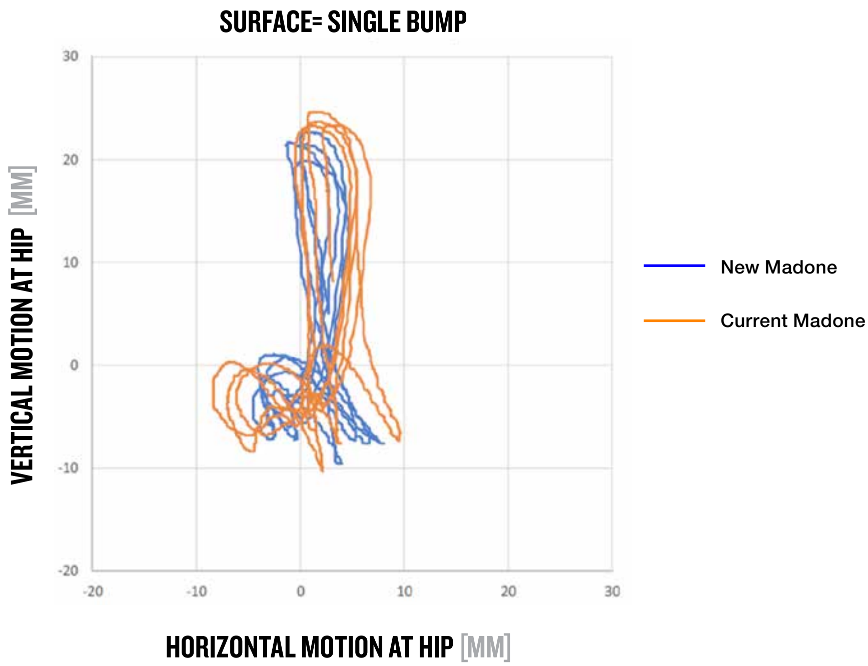

Figure A6. Graph of hip motion tracking per Figure 12 for several repeated bumps.

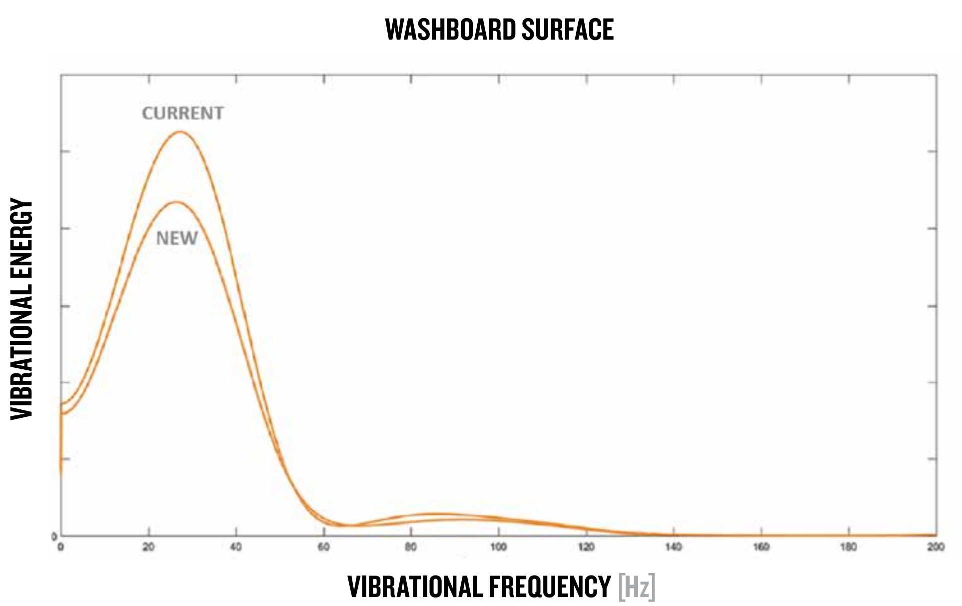

Figure A7. Power spectral density analysis showing the reduction in acceleration magnitude for the washboard surface tests.