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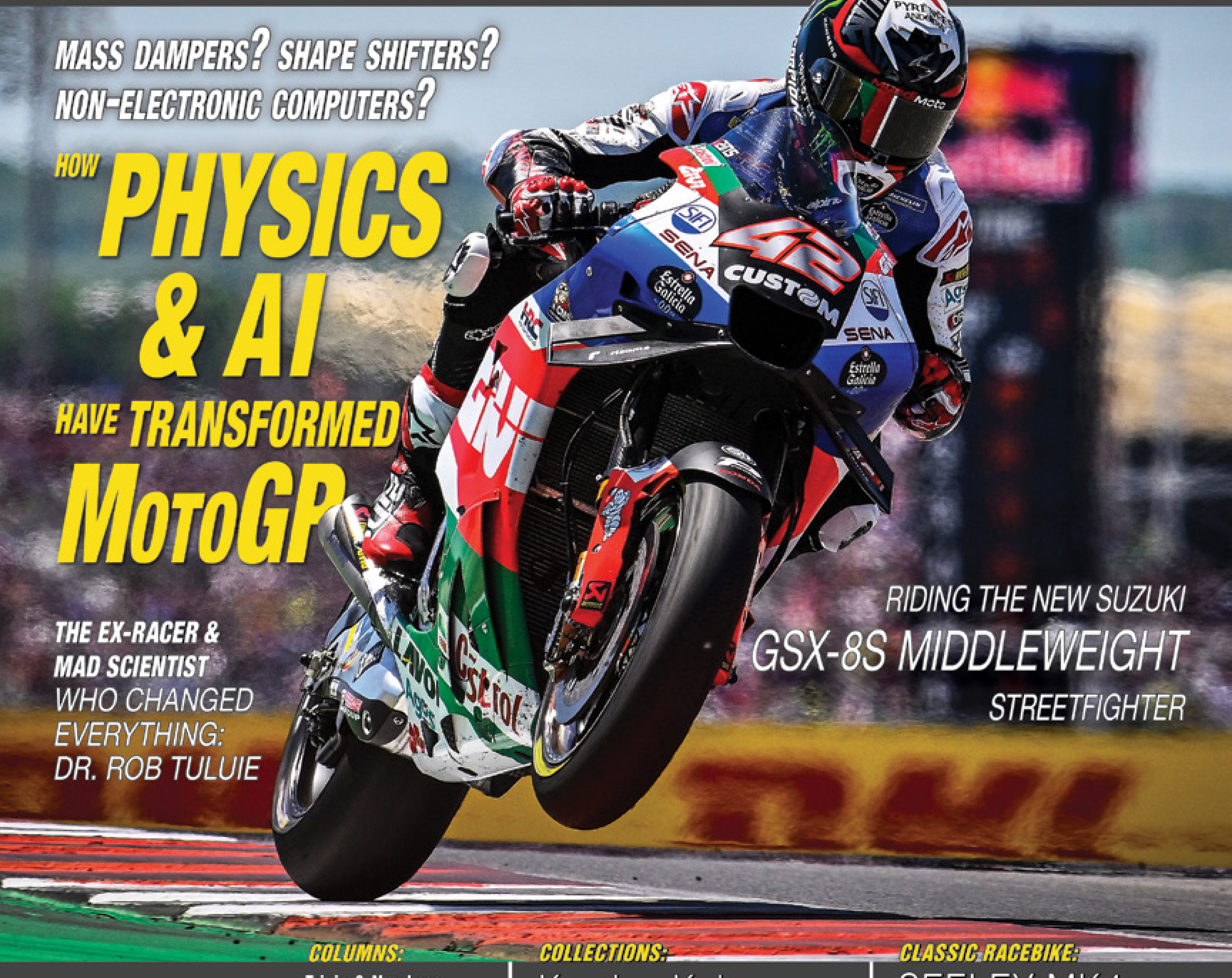

MASS DAMPERS? SHAPE SHIFTERS? NON-ELECTRONIC COMPUTERS?

HOW PHYSICS & AI HAVE TRANSFORMED MotoGP

THE EX-RACER & MAD SCIENTIST WHO CHANGED EVERYTHING: DR. ROB TULUIE

RIDING THE NEW SUZUKI GSX-8S MIDDLEWEIGHT STREETFIGHTER

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MotoGP ANALYSIS

HOW Physics + AI = MotoGP SPEED!

Astrophysicist and former motorcycle road racer Rob Tuluie is the visionary genius behind many of the go-faster technologies that have taken Ducati to MotoGP glory...

FIRST PERSON/OPINION:

By Mat Oxley

In physics, all things are connected, which is why technology pioneered in skyscrapers found its way into Formula 1 cars and MotoGP bikes, thanks to a petrol-head astrophysicist.

In the 1970s, as skyscrapers grew taller, architects ran into a problem: The tallest towers swayed in the wind, giving people motion sickness, at best, and scaring the living daylights out of them, at worst.

Engineers from the American testing and simulations company MTS Systems solved the problem by inventing the tuned mass damper. Their first, atop Boston's 60-story Hancock Tower, featured two 300-ton lead weights that moved this way and that to stabilize the building.

Some years later an astrophysicist and motorcycle nut who had worked at MTS became Head of Research & Development at the Renault Formula 1 team, which was struggling with chassis instability. His name was Robin Tuluie and his far-out ideas were about to have a huge impact in F1 car racing and later in MotoGP.

"Neil Petersen at MTS Systems invented the tuned mass damper for skyscrapers," says Tuluie. "That led to the idea of us using it at Renault F1 because that was the solution to the chassis instability we had. You think of tuned mass dampers in buildings, F1 and now in other race categories—that's a direct lineage from MTS, which is so great!"

Tuluie is that rare beast: A top scientist who can speak to the common man (me) without boggling your mind, while at the same time exciting you about things you'd otherwise not get excited about.

The Renault mass damper gave Fernando Alonso 0.3-second per lap—a huge advantage and the title! A few years later Tuluie became Chief Scientist at the Mercedes F1 team, where he created a hydraulic ride-height regulator that helped Lewis Hamilton win the 2014 F1 title.

Don't worry, motorcycle stuff is coming…

Next Tuluie moved to Bentley as Director of Vehicle Technology. Bentley is owned by Audi, which also owns Ducati. Audi's R&D chief suggested that his genius for innovation and his love of motorcycles might be useful at Ducati, which was trying to extricate itself from several grim seasons in MotoGP.

"The vehicle dynamics of a racing motorcycle are far more interesting and more complex than an F1 car," adds Tuluie. "You have a different tire stiffness at every lean angle, you have the chassis flexing, and you have the rider moving around and leaning off, which affects the aerodynamics…."

Tuluie's work at Ducati is top secret and he's not allowed to say a word about what he does there. However, although I'm no astrophysicist, I'm quite sure that two plus two makes four, so I think I

"MOTORCYCLE RACING IS A VEHICLE DYNAMICS LABORATORY…"

can guess who's responsible for two game-changing technologies that have contributed much to the success of Ducati's 225-mph Desmosedici MotoGP bike.

First, there was the tuned mass damper, which appeared on the Desmosedici in 2017, when Ducati challenged for the title for the first time in almost a decade. The mass damper sits in the seat hump to damp out vibration and chatter, which seriously limit the performance of a racebike.

Second came Ducati's hydraulic ride-height and holeshot devices. Both systems compress the rear shock to squat the motorcycle, thus lowering its center of mass, effectively turning it into a dragster, so it wheelies less, for much better acceleration.

Tuluie's F1 ride-height regulator was an immensely complicated piece of kit, which connected the car's front and rear to maximize grip and control. Both this and his MotoGP ride-height device were created to bypass bans on electronic suspension.

"Essentially we built a hydraulic, pneumatic, and mechanical computer," Tuluie explains. "The total parts count for the system, including options, was 2,000. An F1 car normally has (a total of) 5,000 or 6,000 parts."

And all this started with a 15-mph two-stroke Malaguti moped in the 1970s…

"When I was 16 I got a moped, which was so cool," recalls Tuluie, who was born in Germany, before moving to the USA to study and then to the UK to work in F1. "It had this ridiculous 6mm carburetor, so of course I fitted a 26mm Dell'Orto and learned a bit about porting and exhaust pipes. It used to redline at 4,000 rpm, which was 25 kph (about 15.5 mph), and after I'd done everything it redlined at 12,000 rpm, so 75 kph (about 46.6 mph). Nothing below 8,000 rpm!

"My friends were also tuning their mopeds. The police would pull us over frequently but there were only certain things registered in your moped's logbook and it didn't list the carburetor size. So they'd go all over the Malaguti, counting the sprocket teeth and this and that, saying, 'Hmm, why's it going so fast?'"

After leaving school in Germany, Tuluie moved to California, ostensibly to study physics at University of California at Berkeley.

"My motivation for moving to America was that you can do anything to your motorcycle. Berkeley was secondary!

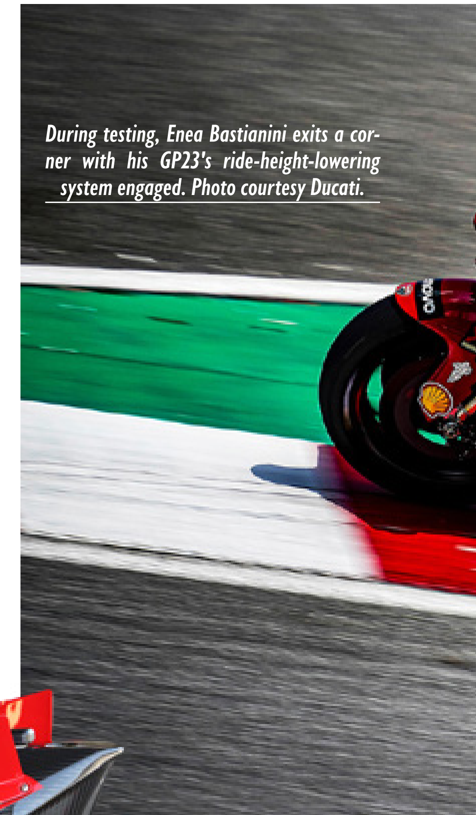
"The first time I went to the States, before Berkeley, I went into a motorcycle shop and looked at this hot-rodded bike. I was like, 'You can ride this on the street? Oh wow!' I didn't fully appreciate physics at the time, but when I started at Berkeley it was different.

"There were 11 Nobel prize winners in the physics and chemistry departments alone and my first quantum mechanics teacher was Owen Chamberlain, who won a Nobel prize winner for discovering anti-matter. I remember the first time I spoke one-on-one with him I was standing there feeling my hair standing on end. I still get moments like that!"

So, physics, equations, motor-

(Opposite Page, Top) MotoGP World Champion Francesco Bagnaia during pre-season testing in Portugal. Photo courtesy Ducati. (This Page, Top) Rob Tuluie, 59, is a motorcycle racer, engineer, physicist and AI (Artificial Intelligence) master. (Above) The Tul-Aris on display at PhysicsX headquarters in London. (Right) Tuluie and PhysicsX colleagues working on an artificial heart simulation. Photos by Chippy Wood.

Tuluie in the foyer of the PhysicsX office in London, with his ex-Mike Baldwin Yamaha TZ750 racebike. Photo by Chippy Wood. ➤



During testing, Enea Bastianini exits a corner with his GP23's ride-height-lowering system engaged. Photo courtesy Ducati.

(Above) The Ducati GP23 holeshot system is controlled by silver lever on the left bar. (Above, Right) The GP23 mass damper is built into the tailsection. (Right) Accumulators seen at lower right are hydraulic pressure storage reservoirs. When the rider turns on the holeshot/ride-height system, pistons drop to displace damper fluid in the shock and lower the bike. Photos by Mat Oxley.

cycles and going as fast as possible became Tuluie's life, sometimes but not always intertwined. "I bought a Honda CB400F (four-cylinder), then I got a Norton Twin and hot-rodded it. A friend took me to the races at Sears Point in 1984 and I thought, 'This is so cool!' People were still racing TZ750s and big over-bored superbikes on methanol —crazy s--t, fun stuff! Fast people, too; we saw Mike Baldwin, Randy Mamola, Freddie Spencer, Kenny Roberts, and Eddie Lawson at Laguna Seca. The year after I started racing the Norton and my first time at Laguna I ended up on the podium. That was great fun and we celebrated like mad.

"I was OK, a fast Amateur. At Laguna Seca I was doing the (AMA) Battle of the Twins race when Marco Lucchinelli [1981 500cc World Champion] lapped me on the factory Ducati. I knew he would lap me, so I thought I'll follow him for a few corners, maybe learn something. I hear this 'Boom!' behind me, he comes around the outside, then all I see is this huge fat rear tire with a helmet bobbing on top and 'Voooom!' he's gone! That made me realize I didn't have the talent. I better do some engineering…"

Tuluie followed his degree in physics at Berkeley with a PhD in theoretical physics and two years as a postdoctoral fellow at the Center for Gravitational Physics and Geometry. Serious stuff.

"But it took too long for physics to yield answers, so I got a job at Victory Motorcycles, with a small engineering team designing and developing their first bike [the V92C cruiser]. I was the chassis development engineer."

Victory was owned by Polaris, which also made snowmobiles. One day at work Tuluie spotted a twin-cylinder 700cc two-stroke used in snowmobiles.

"It made 120 horsepower, which was a lot back then, so I was going to build my own streetbike. I laid the thing out in CAD [computer-aided design], did all the calculations and my friend Greg Ericksen and I ended up building a vehicle dynamics simulation model. We did proper simulations – fatigue analysis, finite element analysis and so on, because lots of it was new, like the shock linkage, which we patented. Then I quickly realized that the bike had to be a racebike."

Tuluie's creation—the Tularis—was probably the first motorcycle design determined by simulations. His gang of "Rocket Scientists" raced the bike with some success, setting two outright lap records and winning races, and he adored its wild two-stroke character.

"It wheelied everywhere—it gained 50 horsepower in 500 rpm! It was terrifying," Tuluie said, "but I just love things that are terrifying!"

In 1999 Tuluie moved to MTS, working on vehicle dynamics simulations. This is his biggest area of work, which means building computer models of a motorcycle, a car, or pretty much anything to simulate what it will do, before it's even been built. This fast-accelerating technology now affects the design of just about everything—in racing and in everyday life—and it's mind-blowing.

So I ask Tuluie if racing is the entertainment branch of physics.

"Motorcycle racing is a vehicle dynamics laboratory," he replies. "Lots of multi-physics simulations—we're talking about structural modeling, aerodynamic modeling, hydraulic modeling, tire models. And the interaction of all those things together is important. A successful race team must be able to handle all those disciplines in physics in a numerical way and a simulation way."

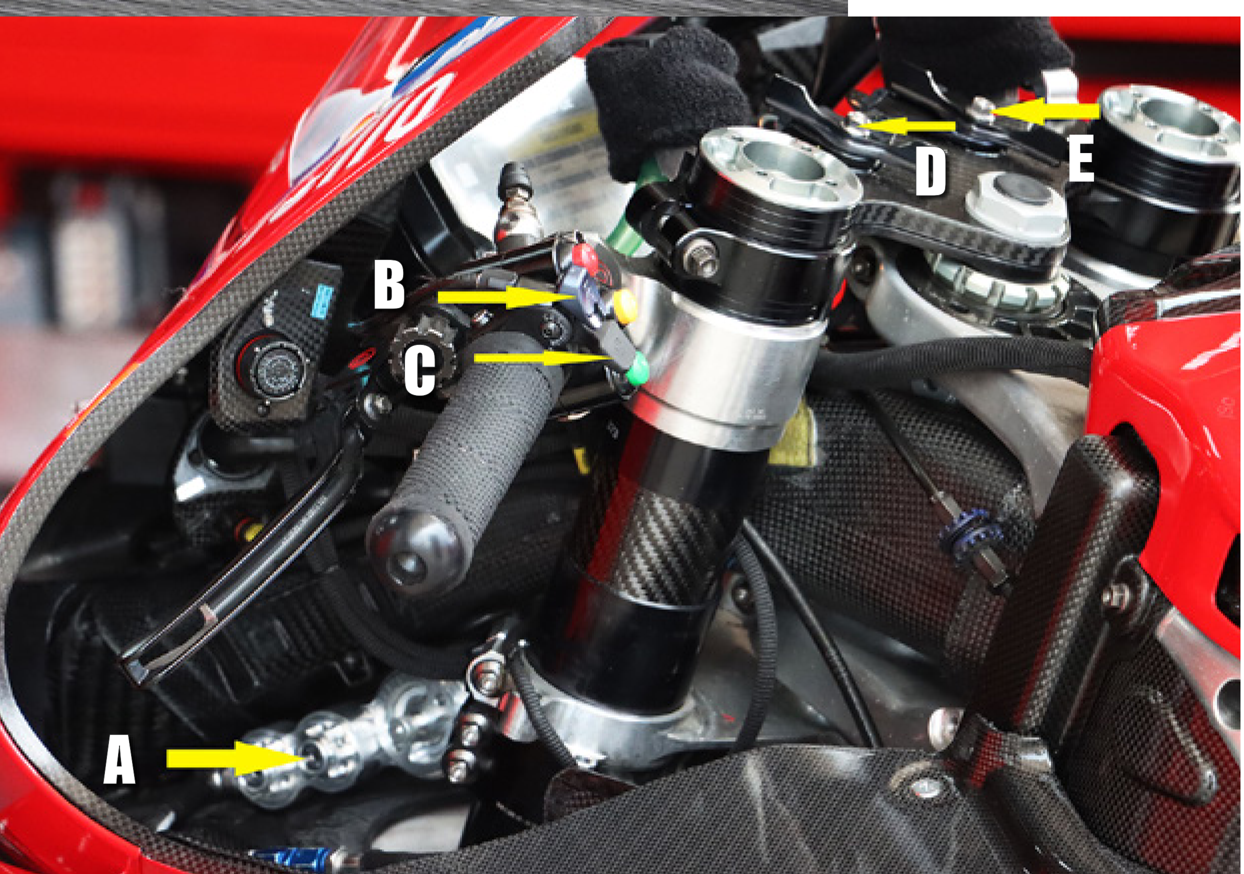
Ducati, possibly due to Tuluie's input, currently leads the way in computer modeling and simulation in MotoGP. "A.I. [artificial intelligence] is really important for

us to achieve our results." confirms Ducati race boss Gigi Dall'Igna, with whom Tuluie works on his regular visits to Bologna.

Ducati's electronic engineers use vast amounts of data to build computer models of their bikes—consisting of individual computer models of the engine, chassis, tires, aero and so on—which they run on computer models of racetracks.

They do many thousands of virtual laps before each race weekend, using virtual reality, artificial intelligence and what's called machine learning to improve the motorcycle before they've even loaded it into the truck. The software makes the bike better, all on its own.

"Once you have validated the accuracy of your simulation model you can make changes to the bike—set-up changes and also trying new concepts and new ideas. How much lap time do I get if I do X, Y, or Z? You can imagine that some of the innovations in MotoGP [another two-plus-two-equals-four moment] were evaluated like this, prior to being implemented and prior to being designed even, because you don't need a CAD design to ask those questions in a simulation model.



A close-up of a Ducati GP22 Desmosedici MotoGP Racebike's ride height and holeshot device controls, taken just before a crew member intervened. (A) is the hydraulic unit. (B & C) are on/off ride height selector switches. (D & E) are holeshot device selector levers for the front and rear suspension. Mat Oxley photo.

"Then you say, 'OK, I can predict what that's going to do, so now rather than just predicting something, why not make a set-up change or a design change to the model?' Then let me run the whole model automatically and let me tell it 'Lower lap times are good.' Then I can tell the simulation model to automatically change its parameters to drive towards the lowest lap time. This is machine learning automation."

Therefore the computer works out what changes need to be made to make the bike faster, suggesting tweaks that many engineers would never have considered.

Even better, Tuluie's company, PhysicsX, has developed software that makes CFD (computational fluid dynamics] look positively Victorian. CFD has been used for many years in racing, to solve airflow and other issues. Usually it takes hours to run one CFD loop on a vehicle, to gauge aerodynamic efficiency and other performance factors.

"You get the CFD to self-optimize itself to the best outcome, whether that's the level of drag, downforce, heat exchange, or whatever. Normally it takes half-a-day to run that loop, but we can run that same loop in a fraction of a second, with 99% accuracy. Our record is 400,000 optimizations in a day."

This is a staggering development, because Tuluie can accomplish in one day what normal CFD would take several years to achieve. This is important in any high-tech industry, but in motorcycle racing it gives any team that uses this know-how a huge advantage.

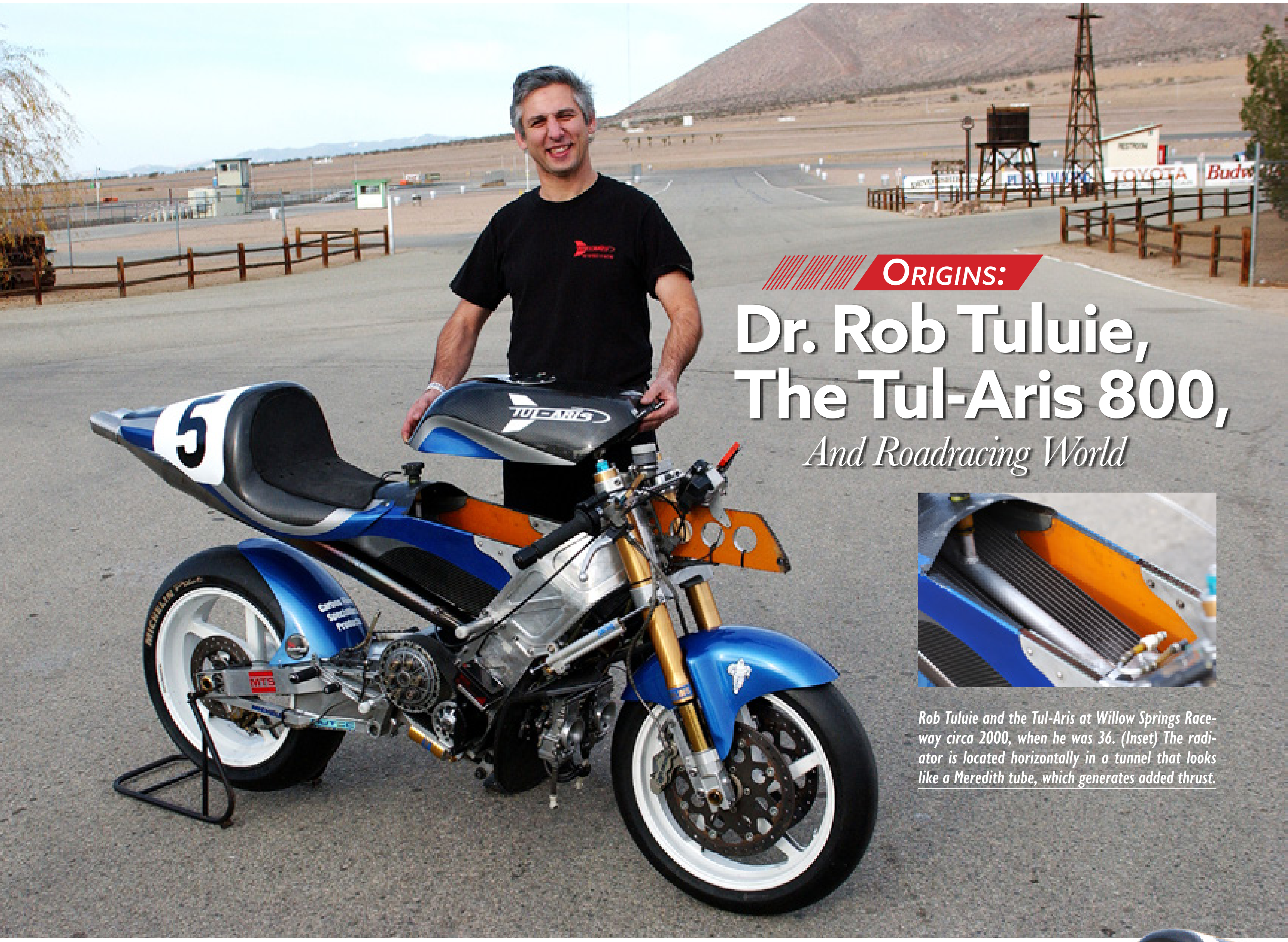
PhysicsX (its slogan is "Equations For A Better World") builds A.I. and simulation engineering technologies for clients in advanced industries and racing. Current projects include an artificial heart, hydro-electric and wind turbines, aerospace, and working with Velo 3D, a 3D metal printing company that makes parts for SpaceX, the American spacecraft manufacturer.

My mind is boggled by the thought of making a computer model of a racebike, but a computer model of blood? Despite its association with gas-guzzling, bone-breaking MotoGP bikes, PhysicsX specializes in medical and renewables work [it won't touch military and polluting industries], so I can't finish the interview without asking Tuluie a couple of deep and meaningful questions. Because it's not often I get to talk to an astrophysicist.

"Are we all doomed or do physicists have all the answers?" I ask him.

"No and no," Tuluie laughs. "I'm an optimist, so climate change can be solved, no doubt about it, absolutely. But will it be solved quickly enough to mitigate the worst-case scenarios? I don't know."

To which there's only one answer: Get out and ride your motorcycle, before it's too late... **RW**



ORIGINS:

Dr. Rob Tuluie, The Tul-Aris 800,

And Roadracing World

Rob Tuluie and the Tul-Aris at Willow Springs Raceway circa 2000, when he was 36. (Inset) The radiator is located horizontally in a tunnel that looks like a Meredith tube, which generates added thrust.

By David Swarts

I had just started working at *Roadracing World* when I went out to Willow Springs International Raceway to meet a guy who had built his own racebike. But this wasn't just some guy and this was no ordinary home-built motorcycle.

The guy was Dr. Robin "Rob" Tuluie, a German immigrant who has more degrees than a thermometer. He had a Bachelor's degree in Physics from the University of California Berkeley; a Ph.D. in Theoretical Physics from the University of Texas in Austin; and for good measure he had done a two-year post-doctoral fellowship in Astrophysics at Penn State University. In other words, he was literally a rocket scientist.

He was also a motorcycle racer. He had won two WERA National Championships on his home-engineered Tulda Eccentric 500—a 197-pound, 75-horsepower road racer he built around a Honda CR500 two-stroke engine.

He went to work for Polaris as a Chassis Developmental Engineer and later served as Senior Test Engineer on Victory motorcycle projects. Then he was hired away by MTS Systems Corporation, a Minnesota firm that did all sorts of top-secret testing for Formula One and NASCAR race teams as well as automobile and motorcycle manufacturers.

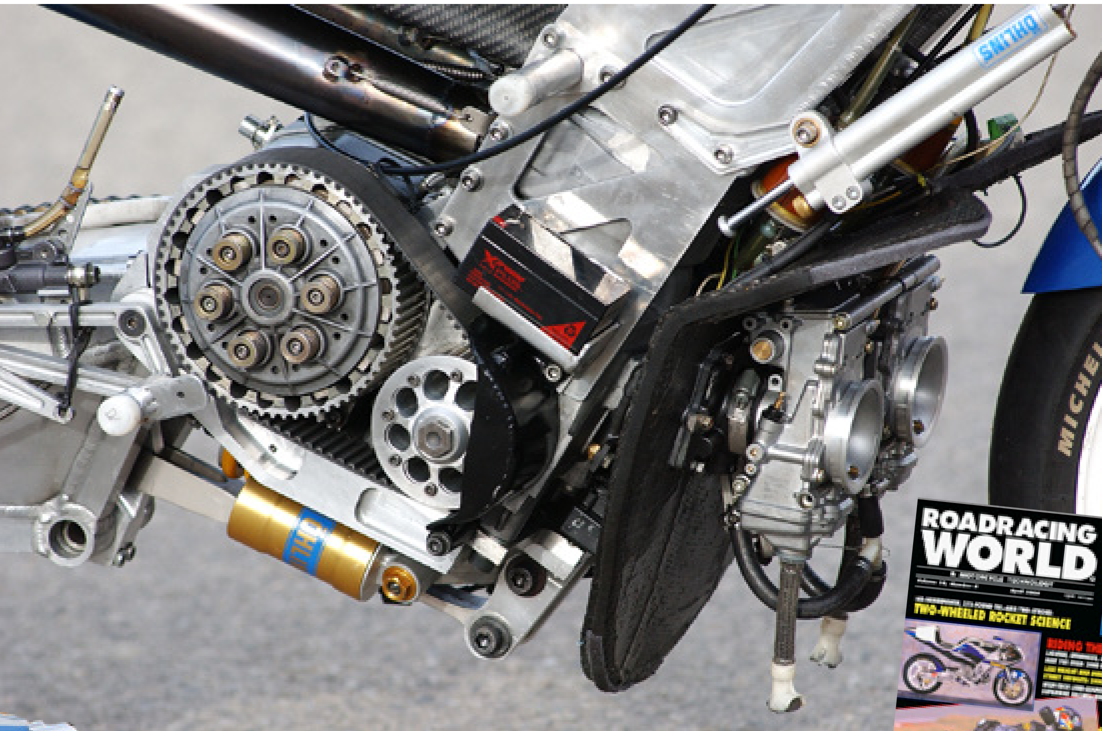
While at Polaris, Tuluie saw the company's liquid-cooled 700cc Parallel Twin two-stroke snowmobile engine and spent over a year drawing the successor to the Tulda. Then, with some help from his new friends at MTS, Tuluie started turning his wireframe computer model into a solid CAD model, and in 1998 started cutting metal on the 1950s-era mill in his garage.

About two years later, the first version of the Tul-Aris (*Tul*uie-Pol*Aris*) was born, but this creation was light-years ahead of Tuluie's steel-tube-framed Tulda (*Tul*uie-Hon*da*). For starters, Tuluie rotated the engine 180 degrees so the carburetors were facing forward and the expansion chambers shot straight out the tailsection.

The engine didn't have a gearbox, so Tuluie made one with his own belt primary drive; billet aluminum side plates extending back from the engine; a carbon-fiber shell (the first ever used on a motorcycle); gears from a Ducati 916; and stacked input and output shafts—a very new concept at the time. Tuluie also located the swingarm pivot inside his custom gearbox, incorporating eccentrics so the pivot position could be changed in relation to the output shaft.

Tuluie's home-made aluminum swingarm

Test rider Michael Hannas on the Tul-Aris at WIllow Springs in 2000. "Insane!" he said. "Fast but violently explosive engine! Vibration made my hands go numb after a few laps!"



(Above) Close-up of the Tul-Aris engine and clutch, linked by a belt primary drive. Forward-facing carbs run in a carbon-fiber airbox, and titanium exhaust expansion chambers have a straight shot back to the tailsection. (Right) Cover of the April 2000 issue featuring the Tul-Aris. Photos by Bret Karakey.

was very long and braced underneath, where it connected to a shock and linkage that laid horizontally under the engine. An entire article could be written about Tuluie's compact, Formula One-inspired, adjustable titanium linkage, which he later patented.

There was no traditional frame on the Tul-Aris. Instead, it used the engine as a fully stressed member. A Kevlar-reinforced honeycomb structure attached to the back of the engine and formed a self-supporting subframe/seat. And metal plates attached to the sides of the engine and extended upward to a front frame that did double duty locating the steering head and containing some of the fuel.

The original front end consisted of stock parts off a Suzuki GSX-R750, but the cooling system was anything but ordinary. Instead of a large radiator mounted in the customary vertical orientation in front of the engine, Tuluie had a Formula One supplier make him a radiator that laid nearly horizontally behind the engine and underneath the seat. Not only did this arrangement improve aerodynamic drag, it also increased the efficiency of the radiator, allowing a smaller and lighter unit to be used. And the original Tul-Aris was very light at 273 pounds dry with 136 horsepower at the crankshaft.

Tuluie brought the Tul-aris back to Willow Springs during three consecutive winters, and each time it had been improved. The final version had a 794cc big-bore kit; 43mm Mikuni carburetors in a pressurized carbon-fiber airbox; titanium expansion chambers; a new custom exhaust power valve with a custom controller; Öhlins forks and an Öhlins shock tuned by Grand Prix veteran Mike Watt; AP Racing front brakes; forged magnesium Marchesini wheels; a CNC clutch basket; and a slippery carbon-fiber fairing designed and tested in a wind tunnel at the University of West Virginia.

The bike weighed 278 pounds dry with a lead-acid battery and data acquisition system installed and made 155 horsepower and 104 lbs.-ft. of torque at the rear wheel.

During our testing, the machine handled extremely well. exhibited agility and stability, and its long MotoGP-like swingarm had some anti-wheelie characteristics. The home-made gearbox that borrowed Ducati parts shifted better than any Ducati of the time, and the whole thing looked really good.

But the engine had no counter-balancer and in spite of Tuluie bringing all of his brainpower to bear and designing custom handlebars and special bar-end weights, our test riders still had problems with their hands going completely numb after just a few laps.

That exaggerated the Tul-Aris engine's aggressive powerband. During our final test, Tuluie shared a dyno graph that showed the Tul-Aris going from 120 horsepower and 90 lbs.-ft. of torque at 7,000 rpm to 155 horsepower and 104 lbs.-ft. of torque at 7,800 rpm!

Unhappy with the results of our final test together, Tuluie turned down an offer to go work with Ducati on the development of the Ducati Desmosedici MotoGP bike, to continue his work on the Tul-Aris. That resulted in more horsepower—160.7 at 8,200 rpm—and an improved power curve thanks in part to a new adjustable ignition system from Polaris. But even with some race wins and a track record while being raced by Robert Jensen and Steve Johnson from 2001-2003, the Tul-Aris was parked in 2004 when Tuluie accepted the position of Head of Research and Development for the Renault Formula One team in England.

During my interview with Tuluie in the winter of 2000-2001, he said something that explained why he was drawn to racing more than testing in a lab, and his words will probably resonate with many reading this.

"On Sunday evening, you know if you did good or not," said Tuluie. "When I was a theoretical astrophysicist, you make theories about the universe and you have to wait 20 years, or sometimes much, much longer, to see if those theories were right or not. With racing it's different. You have a theory about how to improve the bike. You can try that through the weekend, and if you are right, you find out on Sunday." **RW**