Bloodhound SSC: On Track to Break the World Land Speed Record

Designers of an **innovative supersonic car** draw on technology to address **engineering challenges** – and to **inspire the next generation** of engineers and scientists. *By* **Beverly A. Beckert**

The year was 1997, and the place was Nevada's Black Rock Desert. The United Kingdom's Richard Noble and Andy Green were on a single mission: to break the world land speed record. Royal Air Force pilot Andy Green did just that, driving the jet-propelled Thrust Super Sonic Car (SSC) that Noble helped to develop at 763 mph.

Fast forward to 2010, and you'll find the two knee-deep in a dual mission: to design a supersonic car that travels at Mach 1.4 (approximately 1,065 mph) and to leverage the technology and experience gained from this iconic engineering adventure to inspire students to pursue careers in science, technology, engineering and mathematics.

The new mission is riding on the success of the Bloodhound SSC, a car that will be powered by a EuroJet EJ-200 engine and hybrid rocket motor. The vehicle will measure more than 42-ft long and weigh approximately 6.5 tons. Except for the EJ-200 engine, each component of the car will be custom-designed.

To adhere to the land speed record rules established by the F1A, the car must have at least four wheels and steer with at least two of them. Beyond that, designers are free to be as innovative as they choose, which makes designing the Bloodhound SSC equally exciting and challenging.

The lean Bloodhound team, based in Bristol, England, relies on a range of technology to spark their innovation, including computational fluid dynamics (CFD) and optimization programs. According to Noble, "The key to success with this project is to undertake extensive computer modeling in order to increase understanding and reduce risk. We need to prove our concepts by analysis and simulation before we take the car out for real high-speed runs."

Amazing Challenges

Noble, Bloodhound SSC project manager, remarks that the design challenges are intimidating. He explains that in order for the project to inspire a new generation of engineers, it had to be iconic – something that the public would find "amazing." That's one of the reasons why the team selected 1.4 times the speed of sound as its target.

Once committed to the goal, the team soon realized they were on their own in terms of design. The vehicle is a mix between an aircraft and a race car. While its chassis resembles an aircraft, the vehicle has wheels, suspension, steering and brakes, like a race car. According to Noble, the team has had to pioneer its own solutions in nailing down major design elements such as the aerodynamic package, the wheels and the powerplant – each of which has presented its own "engineering opportunities."

For example, Ron Ayers, chief of aerodynamics, explains the structure of the car must be incredibly strong and rigid. He estimates the dynamic air pressure at maximum speed is in the order of 12 tons per square meter. Aerodynamic forces could easily lift the car off the ground or crush the suspension, so precise control of vertical forces is essential.

Since the static and dynamic stability of the car will enter unchartered regions, the team is drawing on skills from automobile and aircraft engineers to address stability issues. At low speeds, gravity will be the dominant force; by 1,000 mph, aerodynamic forces will dominate.

The wheels will support up to 6.5 tons of the car's weight and rotate at over 10,000 rpm, which will induce forces of 50,000 g at the wheel rims. It will be important to keep the same loads on all four wheels for the duration of the run. Little winglets placed above the wheels are fully dynamic trimmers, making small adjustments in microseconds; they will help to maintain constant wheel load up to Mach 1.4.

In addition, how the tires and wheels interact with the ground's surface will be an important consideration. The team selected a site with a salt surface (a deformable medium). The force generation mechanism will be controlled by the wheel/soil friction as well as the internal soil friction when it deforms. Predicting the behavior of the car will be tricky since there is a lack of data on this wheel/soil interaction.

An EJ-200 jet engine and a hybrid rocket motor containing a solid propellant and liquid oxidant will power the vehicle. The rocket will deliver raw power while the jet engine will provide power controllability. The rocket, designed to produce 27,000 lbs of thrust, is 14 ft long and 18 in. in diameter, about the same length as a Formula One car. The jet engine will produce 20,000 lbs of thrust, giving the car a total of 47,000 lbs of thrust – the equivalent of 135,000 hp or the power of 180 Formula One cars.

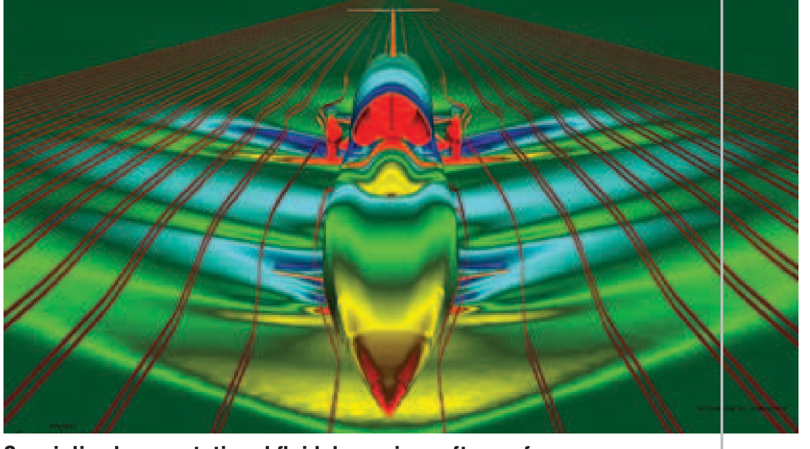
In addition, an 800 bhp race engine will pump high test peroxide (HTP), the liquid oxidant, to the rocket's solid fuel to ignite it. The hybrid rocket only burns its solid fuel as long as the HTP is flowing. When the HTP flow stops, the rocket safely shuts down.

Virtual Understanding

Noble reports that the team has spent the last 33 months focused on the aerodynamic aspects of the car and developing a viable rocket booster. In fact, the vehicle has undergone 10 design iterations. "We had to make sure that the center of gravity and center of pressure were in the right places," he says. "During one stage of conceptual design, we had 12 tons of lift at Mach 1.3. We have finally ended up with a design that's safe – one that does not produce lift under the car. We're grateful to our partner Intel, which has provided access to three of the largest computer clusters in Europe [to perform the simulations]."

The team devoted 18 months to a concept that positioned a 441-lb rocket above the heavier EJ-200 jet engine. However, as conceptual design progressed, the team discovered that more thrust was required to overcome aerodynamic drag. After careful evaluation, they decided to use a hybrid rocket weighing 882 lbs. Unfortunately, the extra thrust from the heavier rocket destabilized the vehicle. The team went back to the drawing board and developed concepts that repositioned the jet engine over the rocket.

CFD software has been a crucial tool in that and other aspects of the car's development. The team has utilized unique CFD software developed at Swansea University in



Specialized computational fluid dynamics software from Swansea University enables designers of the Bloodhound SSC to understand the car's aerodynamic behavior.

Wales. According to Ben Evans, CFD engineer, the visualizations from the simulations help the design team understand the behavior of the car's aerodynamics in terms of flow phenomena such as shock waves, boundary layers and pressure distributions.

Mark Chapman, chief engineer, says the team relies mostly on CFD to validate the car's design: "The flow dynamics drive the shape of the car and the space inside. There is no wind tunnel testing."

At this stage in development, the car's exterior design is essentially locked down. Development now shifts to internal design and then the build phase.

Out-of-the-Box Thinking

According to Chapman, optimization software also has played a key role in Bloodhound SSC's proof of concept. For example, it was used to validate the rear chassis structure and to analyze components on the front and rear wheels.

When the team redesigned the car, placing the jet engine over the rocket, the rear chassis had to be reconfigured. The team used Altair OptiStruct, structural optimization technology in the HyperWorks CAE software suite, to determine the most efficient use of material. The software includes capabilities for topology, shape and size optimization, enabling engineers to quickly determine the main load paths in multiple design envelopes early in the conceptual design phase.

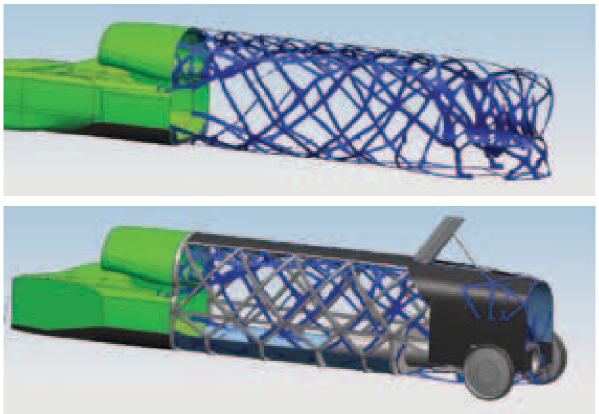
Chapman says the team's first choice in material was a carbon composite. However, testing determined it was not stiff enough to meet their needs. Noble adds that the composite structure would not be able to contain a fire if one broke out at the rear of the vehicle, where the jet engine and hybrid rocket were repositioned in the updated design.

The best solution was to develop a steel structure. Because the team wanted to get the best strength-to-weight ratio, they turned to Altair OptiStruct.

Bloodhound engineers built various models, putting in stringers and trusses. "OptiStruct," says Chapman, "showed us where we needed to put the material. We ended up with an organic, geodesic shape – and it was not a shape that we would have thought of."

The team had a similar experience with the uprights on the wheels. Due to the tremendous loads on the wheels, the team had originally designed them out of titanium, a strong but lightweight material, albeit expensive. Their goal was to optimize wheel design – to use the least amount of material without compromising functionality. By using a Design of Experiments methodology, the design was optimised to reduce the loads sufficiently to allow the wheels to be made of aluminum.

"OptiStruct," says Chapman, "showed us where to add and remove material from the parts. For us, it was invaluable in turning around designs. We saw the effects of our changes, and the software guided us in terms of adding or subtracting more material. Without OptiStruct, we would not have had a clue to the shape we were looking for."



The Bloodhound SSC team optimized the chassis of the vehicle with Altair OptiStruct. The top image represents the optimized output from OptiStruct while the bottom image overlays how the team will produce it.

"Using Altair OptiStruct," says Noble, "we are going to get a strong, light car. We could not have done it any other way."

Chapman explains that the team is not functioning in a traditional manufacturing setting. "We are not asking traditional [engineering] questions," he says. "We are very unique in what we are asking. OptiStruct made us think about our problems differently."

The Education Connection

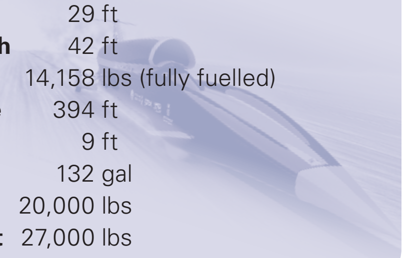
While the Bloodhound SSC team is immersed in design efforts, it is simultaneously collaborating with UK schools to make the project a national learning experience. The equally important mission is to promote careers in science, technology, engineering and mathematics.

As such, UK students across the educational spectrum – from primary to post-graduate classrooms – are following the progress of the team. Information about the research, design, building and testing of the car is available to teachers and students. Educational institutions also have access to grade-appropriate curriculum resource materials; they can also arrange visits to Bristol to see the car's development. In addition, students are encouraged to join Bloodhound youth clubs as well as to participate in scientific and engineering competitions.

"We have an educational foothold in the UK market with 11% of the schools taking part," says Noble. "The key feature of the program is to bring all those following Bloodhound up to speed so that they can understand and interpret the data being extracted when we start running. It's a tall order to achieve this in just over a year, but we are well on our way."

Making Its Mark

The Bloodhound SSC is named after the Bristol Bloodhound 2, a surface-to-air missile that would accelerate from standstill to Mach 1 in 2.5 sec. Bloodhound was used as a working title for the project – and the name stuck. Below is a snapshot of the vehicle's approximate specs to date.



Wheelbase	29 ft
Overall Length	42 ft
Car Mass	14,158 lbs (fully fuelled)
Turning Circle	394 ft
Max. Height	9 ft
Fuel Capacity	132 gal
Thrust EJ-200	20,000 lbs
Thrust Rocket	27,000 lbs

Down the Road

Much work still lies ahead for the Bloodhound SSC team. According to Noble, they plan to finalize detail design by the end of this summer and then turn to manufacturing the parts and assembling the vehicle. Rollout of the car is slated for late summer 2011, and it should be in action by 2012.

The team will conduct static tests first, for example, checking to ensure the engines run properly. Next, the team will test the car on UK runways at speeds up to 200 mph to train the operating team and debug the vehicle. The final phase of testing will take place on the playa-surface Hakskeen Pan, Northern Cape Province, South Africa, where the run for the land speed record will occur.

In the final phase of testing, the team will ramp the car up to 650 mph. In this transonic range, Chapman says things will get very interesting. It will be difficult to computationally predict the car's interaction with the ground as well as the airflow around the car and the effect of the shock waves on the car and ground. That's why the physical tests will be very measured – in 50 mph increments – and closely correlated with computer modeling.

"We'll gather the data," says Chapman, "measure the physical performance and then compare it to our predictive data. If we can't predict what's happening with the car, we'll decrease the speed increments and go back to our computer models. We want to ensure safety."

Why select the Hakskeen Pan as the site of the run? According to Noble, it fulfills some very specific criteria: The site is 10 miles long, has one mile of clear run-off at each end, is dead flat and is firm enough to support a 6.5-ton car moving at supersonic speed.

Noble explains that the land speed record is calculated from the average speed of the car over two runs, completed within 60 minutes. The team needs enough space to turn the 6.5-ton car around and accomplish other tasks – such as refueling the jet engine, reloading the solid fuel for the rocket motor and reloading the parachutes used to slow down the car.

An Iconic Engineering Adventure

The Bloodhound SSC team is up for the challenge – and the iconic engineering adventure. According to Chapman, "There are no right answers, and no ideas are wrong. It's very exciting."

Noble says, "We are outside any aircraft/car racing experience. Everything about the project is new, innovative and creative."

Chapman adds that simulation technologies, such as CFD and Altair OptiStruct, have been invaluable in sparking innovation. "The tools," he says, "are powerful in that they make you think of things you would not have thought of before. Using them lets us think out of the box. "

The team's reliance on technology is enabling them to push the limit on several fronts. Advances in metallurgy, low-level aerodynamics, high-vibration telemetry and low-level jet and rocket operation are expected to result from their efforts.

"There is no precedent for this project," says Noble. "Everything we do is innovative, and all is made available on the Web. Over the world, people will follow what we are doing, and it will stimulate engineering study. There is a duty upon us to push the technology frontiers as far as we can possibly go, and there are very real discoveries to be made."

Beverly A. Beckert is editorial director.

For more information about Bloodhound SSC and OptiStruct, visit *www.altair.com/c2r* or check 02 or 03 on the reply card.