Steam sensation

The technology behind last year's record-breaking steam car has been shrouded in mystery. Brian Tinham gets project manager Matt Candy to reveal all

> **Pointers**
> - Steam technology has developed faster over the last decade than during any other
> - Miniaturisation, automatic controls and generation rates are the key improvements
> - The British steam car used 12 mini-boilers and one steam turbine to develop 360hp at its wheels
> - It burnt 14.4 kilos of liquid propane per minute to develop 3MW of power
> - Among the challenges was running sensitive electronics and electrical systems just inches from 3MW of heat

It is six months (25 August 2009) since the British steam car team broke the 103-year-old land speed record for a steam-powered vehicle by just 12mph – or 24mph, if you're feeling generous. The car, nicknamed the 'fastest kettle in the world', notched up an average speed of 139.843mph on two runs over the measured mile at the Edward's Air Force Base in California, but then scored another record (for the measured kilometre) at an average of 148.308mph, although the project team claimed a top speed of 159.6mph.

Whichever you prefer, those relatively modest numbers mask an exceptional, nine-year-long engineering achievement, the tale of which has, until now, been kept under wraps. That is a shame, not only because it's quite a story, but also because it proves the error of those doubters who stated that steam technology was at or near the top of its game a century ago.

As Murdo MacDonald, major projects manager at Spirax Sarco, stated at the time: "Steam technology has developed faster over the last 10 years than in any other decade." That's quite a claim and probably not strictly justified – although in terms of miniaturisation, control and sheer rate of steam generation, you'll find he has a point. And with a project team comprising graduates from Southampton University in disciplines as diverse as aerodynamics, thermodynamics, electronics and mechanical engineering – as well as some of the talent from the Thrust SSC supersonic jet car, which finished in 1997 – you shouldn't be surprised.

Massive steam

Let's start with the boilers – yes that's boilers plural. There were 12, arranged circumferentially around the car body internals and feeding into the single steam turbine. Why? Project manager Matt Candy takes up the story: "The decision was taken at the start of the project to go with a turbine, because it's simple to manufacture, known technology and was the easiest way to get 360hp to the wheels. But the consequence was that we needed to generate a lot of steam."

And he means a lot: this had to be a non-condensing, total loss system, so the boilers

needed to deliver 40 litres of superheated steam per minute at 40bar and 400ºC. That sheer rate of steam meant some serious challenges around the boiler design, not least because the plant adopted also had to be as lightweight and small as possible – capable of fitting into the envelope of a streamlined jet car. Candy's team turned to steam boiler development work carried out in the 1970s, '80s and '90s in the automotive industry, by the likes of VW, Saab, BMW and Mazda.

"Saab's project in the '70s, for example, was about generating steam for motive force and it boasted mega torque from a nine-cylinder axial engine with very few parts," says Candy – adding that similar single-tube boiler designs quickly led to a derivative for the project, capable of generating 3.3 litres per minute of steam at the required pressure and temperature.

"It wasn't the 40 litres we needed, but design iterations were taking three or four months each. So, allowing three cycles to get a scaled-up version would have meant kissing goodbye to another year and a lot of money. It was much quicker and safer to stick with the design and build 12 to get the car ready in time for the new record attempt."

Fine, but that presented its own challenges – in particular, a nightmarish failure mode analysis, driven by the requirement to keep all 12 boilers running at peak output, in sync. Any problem with any one of them would shut them all down. And there was plenty of scope for that, as Candy explains: "The car needed 200 amps at 24V and, because there was so much in the way of electronics and sensing systems, we were also inverting 6kW at 240V ac, as well as running 24V, 12V, 5V and -10V rails. Getting all that around a car 25ft long in a horrible, hot environment had never been done before. And there were potential hazards from our 300bar on-board air system and the burners, which were consuming 14.4kilos of liquid propane per minute."

Why that much propane, you may ask? "The

Commercial applications

What about technology transfer? Matt Candy makes the point that these small, portable boilers can produce vast amounts of steam.

"The most elegant commercial application we've found is in fire pumps. Steam from our ejector can drive bulk water to produce a huge lukewarm stream that not only fires a long way, but, because the exit steam is travelling at supersonic speeds, also produces a deluge mist over a very wide surface area. That's much better than a conventional hose.

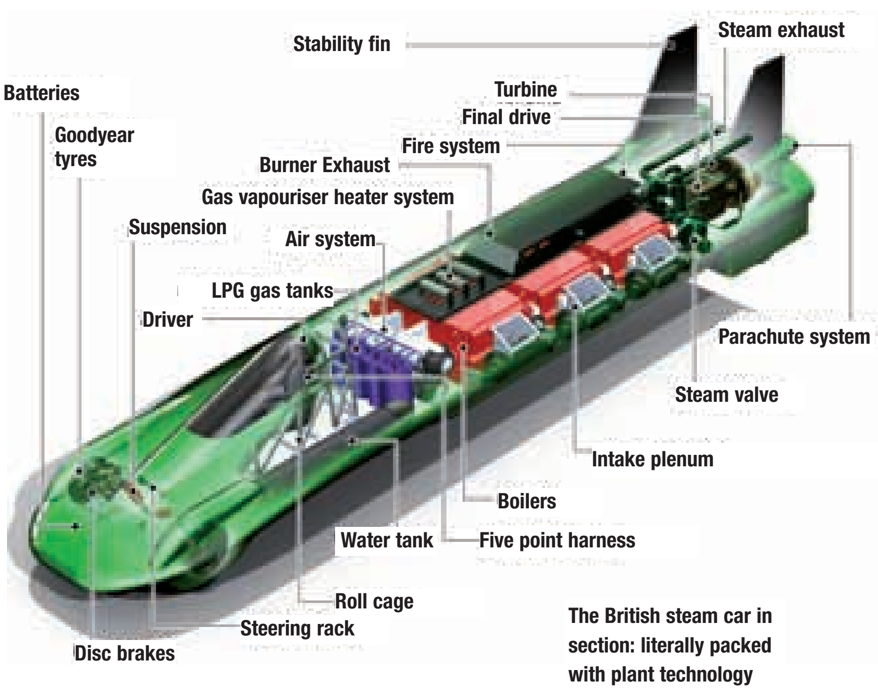
"We're talking to some people about how to progress that. There's also a possibility of the system being used to clean the enormous tanks on petrochemical farms – although there's still some work to do there."

Micro boilers

The boilers used on the UK steam car are essentially suitcase-sized mono-tube units, with the central tube split into 40 vacuum brazed pipes to produce a fine, high heat transfer core, before being brought together again.

"Nobody had done anything like this before – so compact and producing so much steam with that amount of energy," says Matt Candy. "Nobody had done it, because nobody needs it. But there were a couple of interesting developments, such as the techniques we developed for bringing together the multiple tubes in each boiler and our use of Beakert burner mats. Each of those mats handles 250kW and, even with the large amount of gas and air we were blowing though, the flame length was tiny, which meant we could transfer all that energy in the small space available."

And he adds: "We also used micro porous ceramic insulation – in some cases, 100% silica cloth just 15mm thick. You could put your hand on one side, while on the other side, well, we don't know how hot it was, because the thermocouples were topping out at 1,200ºC!"



The British steam car in section: literally packed with plant technology

Electronic sensing jigsaw

The British steam car sported some 170 sensors, monitoring temperatures (mostly of the feed water and steam out of the boilers, but also of the valves and the burner flames), as well as pressures (boiler steam, gas and tyres), flows (water and gas) and level (for tank monitoring). And there were lambda exhaust gas sensors and movement sensors (for example, for steering, throttle and brakes).

Electronics technician Nick Bass says there were problems with the thermocouples, only because they were being used at, or beyond, the top end of their capability – for example, in the flame plasma in the 1,200—1,500ºC range.

All sensors were off-the-shelf items – for example, Labfacility thermocouples, Litre Meter flowmeters and Bosch lambda sensors – with all monitoring and control provided by two on-board ruggedised PCs, with Blue Chip Technologies' PCI cards for the I/O. Those also controlled the on-board video cameras and GPS system.

The British steam car, which broke the 103-year-old land speed record for a steam-powered vehicle by just 12mph

whole thermodynamic system was only 9% efficient, so we had to generate 3MW to get our 360hp – and manage the 91% waste heat. So, with sensitive electronic and electrical systems sitting within inches of 3MW of heat, we had more than our fair share of infrastructure challenges, too," explains Candy.

He also cites problems such as air freezing, due to the rate of expansion demanded by the on-board water pump, and propane getting very cold, because of the burner feed rates. "Since all steam energy had to go to the turbine, we couldn't divert any for auxiliary components. So, for the two or three minutes the car was running, we used air to pump water to the boilers. But we're also driving 12 fans, blowing air and gaseous propane through the burner mats, and there wasn't a lot of space for storage. We already had four 90Ah batteries at front, to sustain the high power drain, and big torpedo-like hydraulic accumulators either side of the driver. That's why we compressed air to 300bar and went for rapid expansion through two control valves on the bladder – and hence the freezing."

Why no air scoop? "Once we got up to speed, a scoop would have blown the flames out, so the fans had to cope with the whole dynamic range from 0 to 156mph, while presenting a consistent gas-air mix at a consistent pressure into the boilers, to keep their performance as stable as possible."

And just to make that challenge even more interesting: "We had to do all our testing in the UK at low temperatures and, more or less, sea level. But the record attempt was at high altitude and high temperature – and with different propane!" PE