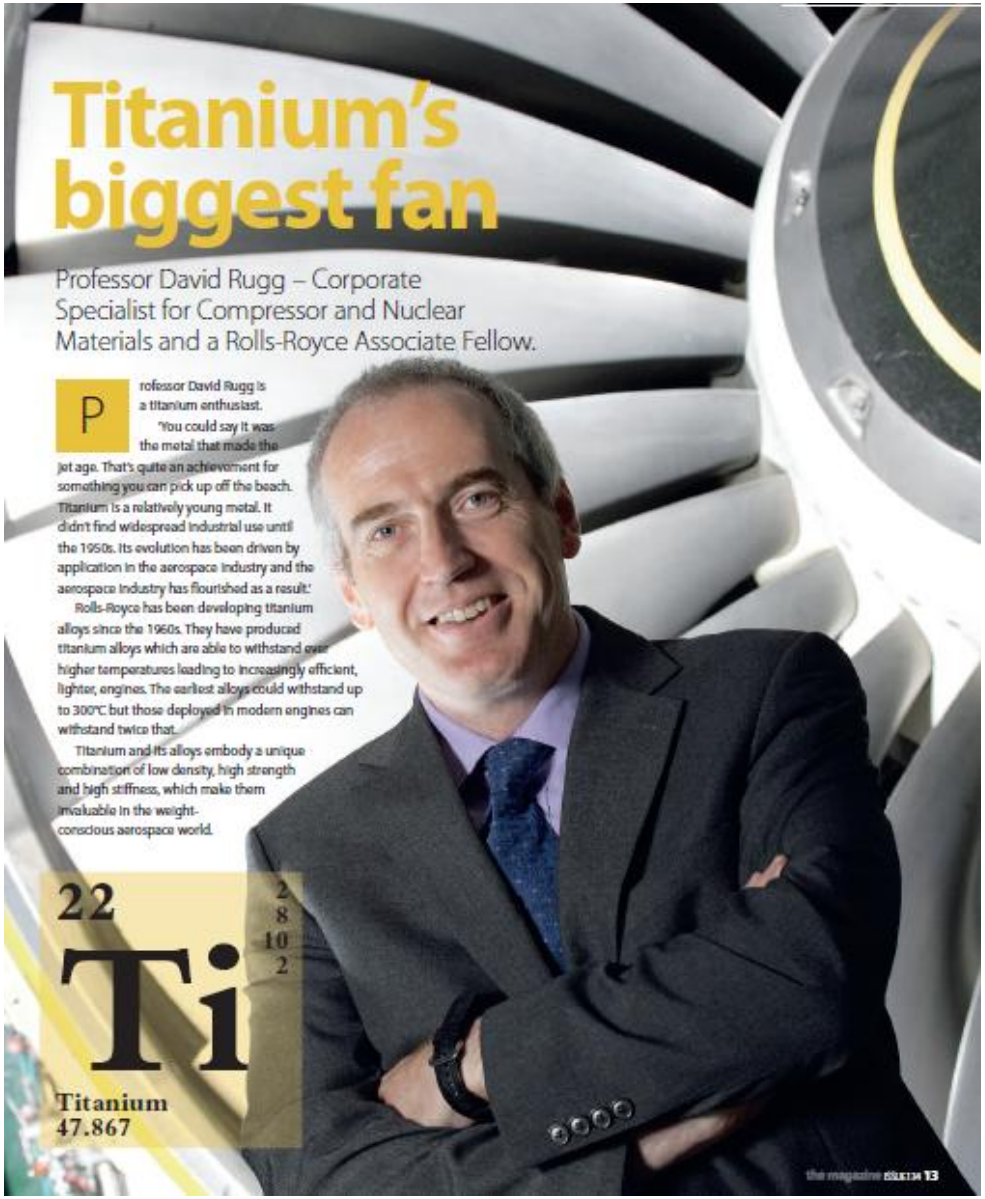


Titanium's biggest fan

Professor David Rugg – Corporate Specialist for Compressor and Nuclear Materials and a Rolls-Royce Associate Fellow.

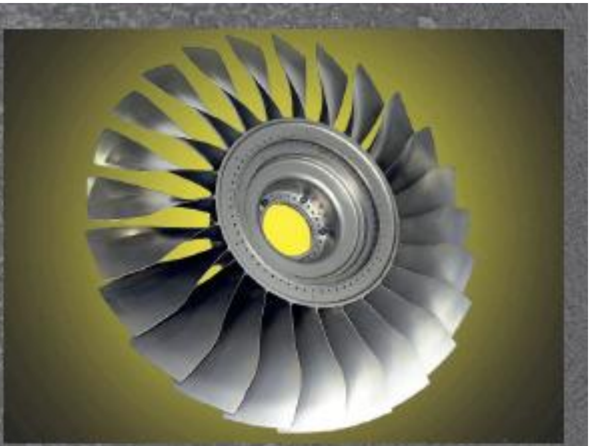
Professor David Rugg is a titanium enthusiast.

'You could say it was the metal that made the jet age. That's quite an achievement for something you can pick up off the beach. Titanium is a relatively young metal. It didn't find widespread industrial use until the 1950s. Its evolution has been driven by application in the aerospace industry and the aerospace industry has flourished as a result.'

Rolls-Royce has been developing titanium alloys since the 1960s. They have produced titanium alloys which are able to withstand ever higher temperatures leading to increasingly efficient, lighter, engines. The earliest alloys could withstand up to 300°C but those deployed in modern engines can withstand twice that.

Titanium and its alloys embody a unique combination of low density, high strength and high stiffness, which make them invaluable in the weight-conscious aerospace world.

22
2
8
10
2
Ti
Titanium
47.867



As a consequence, titanium has worked its way back through the engine, gradually replacing heavier steel and nickel. 'By the entry into service of the Trent 700 (in 1995) titanium had made it all the way back to the end of the High Pressure (HP) compressor on the very edge of the combustion chamber.' In later generations of engines, the Trent 900 onwards, increased cycle demand has raised the exit temperature at the rear of the compressor. This has seen a resurgence of nickel alloys which are able to withstand these higher temperatures.

According to Rugg: 'Over ten different titanium alloys can be found in thousands of parts within a Rolls-Royce engine.'

In modern aerospace engines titanium has two main functions; the manufacture of compressor aerofoils and discs and in components of the fan system; fan blades, discs and in some circumstances fan cases.

Titanium is widely abundant in nature. As a metal it's highly reactive combining with nearly every element in the periodic table. It is particularly fond of oxygen and is always found in nature as an oxide rather than a metal.

PURITY

Less than two per cent of the titanium oxide processed is used for the manufacture of titanium metal, the rest is used for things like white paint and toothpaste. To get the level of metal purity needed you go through a time consuming, energy intensive and consequently expensive process, the Kroll Process, to isolate the metal from the oxygen.

Worldwide production of titanium is 70,000 tonnes per year, of which three quarters is consumed by the aerospace industry. This, says Rugg, 'equates to about one hour of global steel production.'

Pure titanium is very ductile, meaning it's not brittle and can be bent without snapping. It is also quite soft and weak so you put other things in to strengthen it. That's where the whole alloy development programme begins. Alloy development involves looking for the optimum combinations of weight, the lighter the better in the case of aerospace components, strength and resistance to both creep and fatigue.

'A metallurgist's role in life is to look at the raw metals and search for ways you can combine them together to give you the most attractive property balance. Back in the 50s that was bucket chemistry, you mixed all kinds of things together to see what you got. Nowadays, we control the chemistry and microstructure correctly.

HOW TO MAKE AN ALLOY?

First take all the raw ingredients, mostly metals, but also small quantities of oxygen and sometimes silicon which you believe will give you the properties required in your new alloy. Squeeze them together into an electrode: that's a cylinder several metres high with a diameter of around 400mm and weighing about three tonnes. Then strike an arc to form a circuit between the electrode and a cooled copper crucible. This will need electric power of well over 10,000 amps and 20 volts and will cause the electrode to melt and the constituent parts to blend. Repeat three times to ensure the ingredients are well mixed.

'We are able to deform the metal at high temperatures, allowing us to make low density high strength fan blades.' Three sheets of titanium are fused at an atomic level through the process of diffusion bonding. The process of super plastic forming is used to create a hollow within the blade, when the blade is placed in a furnace, operating at almost 1,000°C and inflated with Argon gas. This causes the two outer titanium panels to expand whilst the middle sheet is stretched into a zig-zag shape creating the final hollow 3-D aerodynamic shape of the blade and giving the structure rigidity.

POWDER

Knowledge of the microstructure has also allowed us to develop completely new manufacturing and repair processes.

Rolls-Royce has developed a world-leading technology for the repair of bladed discs (blisks). Blisks are a very high-value fan or compressor components, and we are looking for ways to repair minor damage to them rather than having to replace the whole part. Over the last ten years Rolls-Royce has developed a way of depositing metallic powder with lasers to repair damaged metal. The powder is melted into the existing metal to produce a microstructure that returns the part to a level of strength and durability consistent with its original manufactured state.

'Understanding how titanium works when it's loaded at high rates is very important to us, both in terms of understanding the implications of impact, such as when a bird strikes a fan blade, and containment, such as in the very rare occasions when a fan blade breaks.'

In the latter case the energy density and the total kinetic energy involved are huge, similar to that generated by military armour-piercing ordinance.

'For these very fast events the material properties are quite strange and they're not intuitive. Up to a certain point, if you deform titanium alloy at a faster rate it gets stronger. However, if it is deformed too fast it effectively falls apart – becoming molten in very thin microscopic layers. The challenge is to design new, more tolerant alloys which give us the lightest strongest case we can with the maximum amount of catching capability.'

The demand for Rugg's expertise is not limited to aero engines. He is active in the company's civil nuclear business as well.

> OVER TEN DIFFERENT TITANIUM ALLOYS CAN BE FOUND IN THOUSANDS OF ROLLS-ROYCE ENGINE PARTS.

Zirconium has the same crystal structure as titanium, a very similar metallurgy and is manufactured in a similar way. Zirconium is used in components in nuclear reactor cores.

Zirconium tubes are used to keep nuclear fuel away from the coolant water that surrounds it. Its main task is to stay metallic and resist oxidation when it comes into contact with hot water. Zirconium is perfect for the task because it is very corrosion resistant and is almost transparent to neutrons, it is having enough neutrons around that make the reactor work. 'You might think of water as fairly benign,' says Rugg, but as part of a primary circuit at the heart of a nuclear reactor it could dissolve a milk bottle in a few minutes.

'Lots of really interesting things happen to zirconium in reactor cores. It grows and changes shape. So in some types, the 4m long zirconium tubes can grow by up to two inches during their operational life and emerge twice as strong as when they were deployed.'

Despite the metallurgical parallels between titanium and zirconium there has been little cross fertilisation between the nuclear and aerospace industries. But this is beginning to change and Rugg says he is seeing research knowledge from one sphere beginning to inform the other.' Rugg works with three Rolls-Royce University Technology Centres (Manchester, Oxford, and Imperial) and sees 'a massive overlap between the work they are doing on reactor core technology and developments in titanium metallurgy.'

The highpoint for the volume of titanium use per engine might have been the Trent 700, but Rugg does not see the retirement of titanium anytime soon.

'It will be king in the compressor for years to come, nothing can compete with it there given its strength-to-weight ratio. And, if you look at the next generation of fan blades – which are expected to be made from polymer matrix composites, – there is titanium all round the edge which provides the blade with a balanced combination for impact damage, erosion protection, overall blade performance and durability. Titanium works well with carbon fibre composites; as the elastic properties of both are reasonably similar and electrochemical potentials are close, meaning they can be used in intimate contact with few issues. You can also see this in the latest generation of civil and defence aerospace airframes where carbon fibre composites and titanium have now largely displaced the use of aluminium and steel.'

Author: Simon Kirby is part of the Rolls-Royce communications team in Derby. He has previously worked in communications roles across the public sector.

Top left and here Titanium is used in high-value blisks (bladed discs).

Background The microstructure of a high strength alpha beta titanium alloy.