

# The Design of The Rolls Royce Trent 500 Aero Engine

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My talk is about design and the way that we in engineering perceive it. I hope you will recognise similarities in the fundamental design process. I hope to show you the contribution that design makes to business strategy and the interaction with customers. I would also like to stress the importance of creativity

I believe there is a view that engineering design is simply about selecting the appropriate formula, inputting numbers and the answer emerges and the advent of computers has simply helped us to do it faster. I hope to show you that the creativity necessary of individuals and teams and a rigorous approach to evaluation of concepts.

Finally I hope you will leave feeling that when you next fly on a Rolls-Royce powered aircraft the engine has been well designed.

I have chosen as a vehicle for the talk our latest engine the Trent 500 as that has completed the total cycle from concept design to entry into service

My role on the Trent 500 was Assistant Chief Design Engineer, since then I have been Chief Design Engineer V2500 and recently 7E7.

The business is

- Global
- Competitive
- Safety conscious
- Capital intensive
- High value

We power 8 out of worlds top 10 airlines.

Rolls-Royce is more than this, we have Defence, Energy, and Marine products, core is gas turbine technology.

Rolls-Royce Heritage, started 100 years ago not many miles from this site remains in the company with our aims of Innovation, Integrity and Reliability.

Turning now to the specific engine project. In the mid-90's Airbus decided that they were going to improve their existing successful A340-200 aeroplane by increasing the size and increasing the range and in order to do this they needed to increase the wingspan and the weight of the aeroplane necessitating new engines, which leads me on to the major project the Trent 500.

Lets look at the design challenge

- 60 000hp at Take-off - equivalent to:
- 800 family cars
- 160 000 people jogging at the same time
- Fuel efficiency per passenger equivalent to full family car... but 10 times faster!
- Sucking in 1 ton of air per second  
would empty a squash court in less than 1 second
- Distance covered between overhauls ~7m miles  
(250 times round world)700 000 passengers

carried every day by RR-powered aircraft

- On take-off generates enough power to heat and light a small town

All these customers affect the design.

Many influences are conflicting and require the designer to balance and trade attributes.

Before we start designing we need to capture and integrate all the requirements. Many of these requirements set the style of the design, but as you'll see later, the designer still has creativity and choice and a phrase I use is "things are never black and white". Engineering is in the "gray" - dealing with ambiguity.

The timescale for this was that Airbus had been working during the early-90's and issued their engine requirements at the beginning of 1997. So that was the formal start of our concept definition. In anticipation I had started looking at what Airbus may need towards the end of 1996 and trying to anticipate the customers needs. In June of 1997 Airbus selected the Trent 500 as the sole engine and the concept definition was complete towards September 1997.

The first airline order was taken at about the same time and this was for delivery of aircraft in 2002 so a great deal of confidence had to be placed in both the engine and the aircraft delivering. In 1999 the first development engine went to test and completed certification in the end of 2000 with a total of 8 development engines. Enabling the first flight to start in May 2001 and the aircraft certification to be achieved in May 2002 and entry into service in August 2002 with Virgin Atlantic.

## **Back to first principles**

Jet propulsion has been known for a long time, it was demonstrated in the 1st century AD and later explained by Newton. Today the principle is used in many .

Its easy to teach, many students claim thermodynamics is difficult, too many equations. Show them a practical demonstration then by releasing an inflated balloon!

Now a little more seriously.

A large turbo fan

Basically it's suck squeeze bang blow - continuously.

Design of an engine cycle is predominantly about efficiency both thermal and propulsive.

As illustrated in the previous slide the thrust of an engine is simply the product of the airflow and the exit jet velocity so a given thrust can be achieved by having a high flow, low velocity or low flow, high velocity.

The choice of engine size is most crucial because this will define for the rest of its life its noise, its fuel consumption and have a great impact on its weight and unit cost and so we can see that the large high flow, low velocity engine offers lower noise, lower fuel consumption but the penalty of higher aerodynamic drag, higher weight and higher unit cost.

The low flow, high velocity engine gives low aerodynamic drag, low weight and low unit cost, but would give higher noise and higher fuel consumption. So in all things there is a compromise to be achieved. The Trent 500 tended towards the higher flow, low velocity style to ensure low noise and low fuel consumption the higher weight and higher unit cost were off set by the judicious use of high strength materials and a large interaction with manufacturing to reduce the unit cost.

To illustrate some of the interesting choices a designer has I'm going to focus on a particular component, the fan blade.

The fan system produces the lions share of the thrust, the core of an engine generates gas to drive the LP turbine and hence the fan.

Key facts speak for themselves. The designers job is to take all the interactive requirements e.g the blade weight affects the disc loading, the aero requirements for untwist affect the blade stiffness which affects weight, Leading edge aero shape affects bird strike capability which also affects stiffness, it's a circle of requirements which the designer has has to square to complete his task.

Clearly computers are a necessity to process the calculations, but the engineers skill is to use the tools to optimise the design, understand the component and ensure that the numeric results make sense. Garbage in means garbage out, irrespective on how big the computer is. Making sense of the answer is all about validation.

After many iterations, including those to ensure the blade can be manufactured, the design can be released to the maker.

Rolls-Royce fan blades lead the world in their technology, they are the lightest and strongest. They are made by a process of diffusion bonding and super plastic forming.

The manufacturing process technology is closely guarded in our competitive world.

The fan blade has some unique requirements placed on it in the form of the capability to withstand bird strikes.

Bird requirements are laid down by the Airworthiness Authorities.

Requirements vary - small 2.5lb up to large 8lb birds.

Again the design circle appears - bird worthiness affects panel thickness, panel thickness affects blade stiffness, blade stiffness affects untwist under centrifugal loading, which affects blade aerodynamic performance . Again validation of predictions and proof is required. Rig tests and engine tests are done to prove the engine.

The Engine demonstration is next. Observed by the Airworthiness Authorities. This is very expensive testing therefore before it takes place a high degree of confidence is gained in the outcome such that this is no longer an experiment - it is a demonstration.

Regulations also demand that in the unlikely event of a fan blade release, the blade needs to be fully contained and results in nothing more than an in flight shut down. Interactions with the trailing blade are important to understand. Interaction with the casing and resulting out of balance of the fan rotor need to be modelled including predictions of how the blade will break into fragments.

Then the big day .

In true stuntman style, one fan blade is partially cut through and loaded with a small explosive charge.

Important part of the test is to film and record the event.

An additional requirement is to avoid fluid leaks to minimise the chance of fire. Another key test is water ingestion. Does the combustion flame go out ? Does the engine start when it been soaked to -40 deg C ? A key requirement for some operators.

Finally, after all the design and testing has occurred, in this case the Civil Aviation Authority award the engine type certificate.

The first flight of a new aeroplane is a very important milestone for both the engine and the airframe it is a high visibility event. A successful first landing is equally if not more important!

Engines still go through more testing as the aircraft goes through its own certification process. At this stage the airframer simply wants engines that perform.

Hot and high performance is crucial to some airlines. In rarified atmospheres, engine capability can make the difference between profit and loss for the flight.

To the other extreme of temperature, testing of the aircraft to ensure that all the functions operate correctly in extreme cold and snow is vital.

The product that results is:-

Designed to cope with extremes.

Operating @ 35,000 ft -50degC external temperature to turbine temperatures at take off of 1500 degC +

Control systems with multiple levels of redundancy

Each component thoroughly designed and tested to ensure reliability.

In January 1997 Airbus Industrie wanted the most competitive engine for its new A340-500/600

The Rolls-Royce product strategy enabled an engine to be offered that offered:

best fuel burn

lowest noise

30% less NOx than regulations

‘We have selected the Trent 500 because with its low noise, excellent fuel efficiency and low operating costs, it offers the market the best technical and commercial combination.’

Jean Pierson

Airbus Industrie Managing Director

June 1997

Our order book is 80 firm plus 36 option a/c (including latest Thai order)

The next development is the A380 the largest civil aircraft yet produced.

Airport infrastructure will require modification to cope with loading and unloading all the passengers. Again engineers will be involved in wealth creation

The first Trent 900 engines are on test  
Technically the engine is meeting all its targets.

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