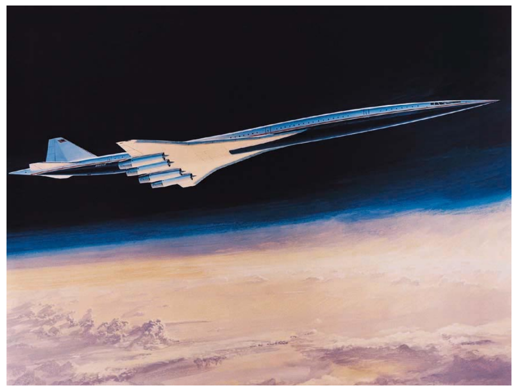
The materials used in the engine components depends on the temperature of the gas flowing over them. At the front of the engine, at temperatures up to about 700°C, the components can safely be made from titanium alloys. These are sufficient for the engine compressor. However, the gas temperature in the turbine region, towards the back of the engine, reaches a temperature in the region of 1600°C, so nickel based super alloys, or nimonics are used. These are complex alloys based on nickel with elements such as chromium, niobium and aluminium added to control the microstructure and properties. But it is not just the materials which are important in this area of the engine as even nimonics melt at approximately 1250°C. The design of the turbine blades is crucial as they contain a self cooling system. The blades are hollow and the outer surface has a fine pattern of tiny holes laser machined into it ,which reduces weight but also allows cooler air from the compressor (at about 600°C) to be forced through the hollow channels forming a protective blanket which prevents the extremely hot air from coming in to contact with the blade itself. The pictures to the left show a nickel based super alloy high pressure turbine blade from a Trent 800 engine and its cross section. The processing route is also vital as the blades are produced as single crystals, to eliminate grain boundaries and minimise the risk of creep. Creep occurs when a material under a constant stress at elevated temperature stretches. The turbine blades are typically rotating at 10,000rpm and under a load equivalent to hanging an articulated lorry of each one and these are very extreme conditions. The blades are produced by the lost wax process and investment casting. Jet engines are still assembled by hand and as such the process is very costly. To equip a Boeing 777 with the two engines necessary for it to fly would cost in the region of £32 million!

In order to push the performance of the engines to the next level the temperature must increase further. The efficiency of the combustion process increases with temperature but this leads to problems with the choice of materials. Nimonics are at the limit of alloy performance and the way forward is to use intermetallics or even ceramics. Both of these groups of materials have extremely high melting points owing to their structure and bonding. However at the moment they do not have the strength and particularly impact resistance needed to survive in an aircraft engine.

Ways forward…

This concept aircraft from Boeing is just one possible way that aircraft design could move forward. There has been a great deal of concern about the amount of air pollution caused by aircraft and the damage that this is doing to the atmosphere. One possible solution would be for the air craft to fly on the outer limits of the atmosphere. However, this would rely on a complete rethink in the design of the wings and engines as both of these rely on air to provide lift and thrust.



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Materials in Aerospace

Materials for air craft bodies

Materials jet engines

Ways forward…

Materials in Aerospace

The materials used in aerospace applications represent those at the peak in performance and the aerospace industry is very much materials led. It is only through the development and introduction of new materials that advances in technology can be made.

The industry only produces a small number of aircraft each year, but at very high cost. The Boeing 737 has been in production since the 1960's and is the only civil airliner to have made a profit for the manufacturers. About 2800 of these aircraft have been produced and they have a lifetime of 25-30 years in service.

Airliners are generally designed to do 50,000 to 100,000 flying hours. Long haul aircraft (for example trans-Atlantic flights) will typically do 700 journeys or cycles per year (one cycle represents a take-off, flight and landing), which translates to 2,500 to 3,000 flying hours. The characteristics for a short haul aircraft are somewhat different. These will typically undertake 1,000 to 1,500 cycles per year, but this is only equivalent to around 1,500 flying hours. As a consequence short haul aircraft need to be made more robust as the majority of stresses are experienced during the take-off and landing.

Safety is of paramount importance when designing and aircraft as there is little chance of survival if something goes wrong at 30,000 feet. The Comet was the first pressurised aeroplane, but the design of the windows had changed little from its predecessors. The stress cycle associated with the pressurisation ad depressurisation of the fuselage caused fatigue cracking around the corners of the windows (the sharp corners act to concentrate the stress), these cracks joined up leading to catastrophic failure. This overwhelming need for safety has meant that manufacturers are often reluctant to introduce new technology until it has been proven.

Materials for Aircraft Bodies

The first really successful aircraft was the biplane and it was very efficient. The components and structure were mainly made from wood (bamboo or spruce) surrounded by catgut or fabric. Piano wire was used to control the steering surfaces and support the wings. As the size of the aircraft increased these materials would no longer withstand the stresses associated with the higher levels of loading and new materials were introduced.

The most important parts of the aircraft are the wings, as these allow a large object, which is considerably heavier than air, to fly. The design of the wing is crucial for take-off and efficiency during flight. The wings must have excellent fatigue resistance as the loading conditions change during flight. On the ground the lower surface of the wing is in compression and the upper surface in tension, however this is reversed during flight. Often the materials used for the upper and lower surfaces have experienced different heat treatments, to give different properties as, in addition to good fatigue resistance, strength and stiffness, the lower surface must also be damage tolerant (from sand, gravel etc. flying up from the runway). The position of the wings on the fuselage also varies, for example short take-off and landing, military aircraft have their wings positioned high on the fuselage whereas most civil aircraft have their wings either centrally located, or low down on the fuselage (e.g. Concorde).

The fuselage must also have good fatigue properties to cope with the pressure cycle associated with take-off, cruising at high altitude and landing. Aircraft are pressurised so that they can fly at high altitude whilst maintaining a comfortable atmosphere within the passenger compartment (the luggage area is not usually pressurised, this is why you shouldn't pack aerosols in your luggage). However there is a trade off between altitude and efficiency as at high altitude the air is thinner and it is more difficult to maintain lift.

The choice of materials for the aircraft skin also depends on the speed that the aircraft will cruise at. Although the air temperature at the cruising altitude is very low frictional heating between the air and the skin can lead to certain areas experiencing high temperatures. For example, Concorde cruises at a speed of Mach 2.2 and at this speed the nose cone can experience temperatures of up to 128°C, the tail 105°C and the wings 91-97°C. At these temperatures light weight materials such as aluminium alloys, polymers and composites can suffer a loss in their properties and have to be substituted with titanium alloys.

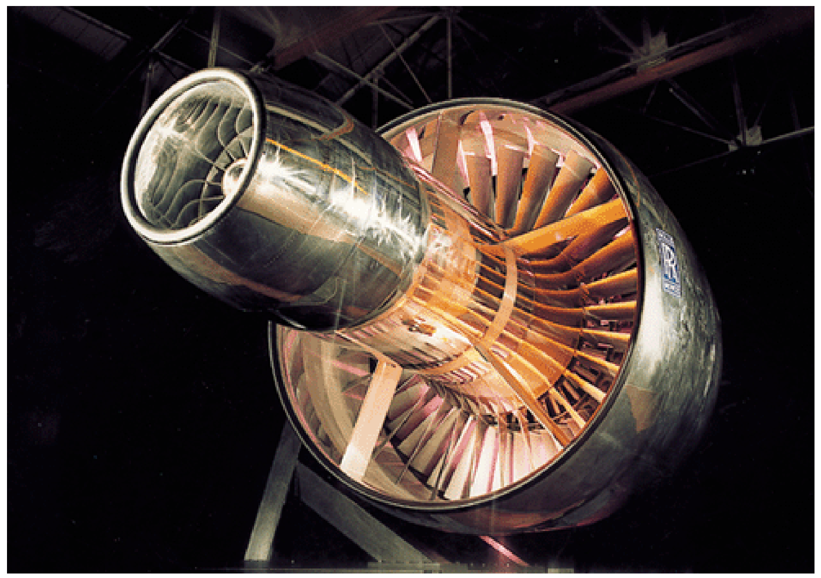
Typical materials used for the fuselage and wings of civil aircraft are:

- 2000 series aluminium alloys based on the aluminium – copper system
- 7000 series aluminium alloys based on the aluminium – zinc – copper – magnesium system
- Aluminium – lithium alloys
- Titanium alloys (used for airframes)
- Glass or carbon reinforced polymer composites (used for control surfaces for steering)
- Stainless steel (used for the skin, it has been largely replaced by titanium which is lighter)

The undercarriage or landing gear of the aircraft occupies about 5% of the total weight, which equates to approximately 3.5 tonnes for a typical 150 seat airliner. This essential component must be retracted during flight to reduce drag and it is constructed such that the legs retract in to the wings and the wheels in to the fuselage. The undercarriage must support the entire aircraft, at landing speeds of 120 to 150 mph, and this is essentially done on two struts. As a consequence of the enormous loading conditions the legs must have a yield strength in the region of 1.6 $GNmm^{-2}$, and special alloy steels are still used despite their weight. The aircraft's brakes are made from carbon and must be able to withstand temperatures in excess of 1000°C. Although the undercarriage is not used for the majority of the time over a 30 year life span the aircraft will taxi on runways a distance of 100,000 miles!

Materials for Aircraft Engines

The engines are the power houses of the aircraft, converting chemical energy from the fuel in to mechanical energy and providing the thrust needed to fly. As with the aircraft body, the push for the development of the materials used in the engines has been the desire to increase the size of the aircraft and fly larger distances. Engines have evolved from the simple piston engines supporting propellers, to modern gas turbine and after burner jets. The latest innovation in engine design is the SCRAM jet which is capable of flying at extremely fast speeds at very high altitude.



Gas turbine engines are found on the majority of civil aircraft and work on the very simple principle of SUCK, SQUEEZE, BANG, BLOW. A large volume of air is sucked in through the fan on the front of the engine, about 80% of this by-passes the engine core and passes straight through, generating most of the thrust. Over the past 30 years advances in engine technology have allowed the thrust per engine to increase from 42,000lbs for the RB211 – 22B (found on Tristar aircraft) to 90,000lbs for the Rolls-Royce Trent 800 engine (found on the Boeing 777). The remaining 20% of the air passes through the engine core where it is squeezed through a series of compressors, mixed with fuel and ignited (the bang stage), and the hot exhaust gas blown out of the back of the engine via a multi-stage turbine. It is the turbine which drive the fan which sucks air in etc. and so the cycle repeats.