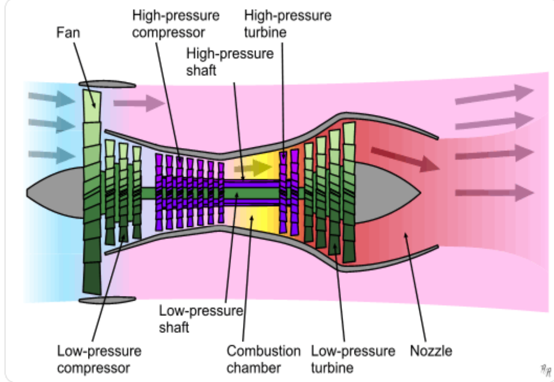
JET ENGINE MATERIALS

A quick overview of the materials requirements, the materials being used, and the materials being developed

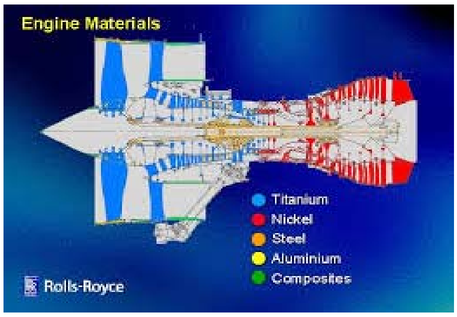


JET ENGINE

MOTIVATION FOR MATERIALS DEVELOPMENT

- Higher Operating Temperatures
- Higher Rotational Speeds
- Lower Weight Engine components
- Longer Operating Lifetime
- Decreased Failure Occurrence
- Oxidation and corrosion resistant
- low- and high-frequency vibrational loading
- High Thermal and mechanical stresses

- This all adds up to:
  - Better Performance
  - Lower Life Cycle Costs



COLD SECTION MATERIALS REQUIREMENTS

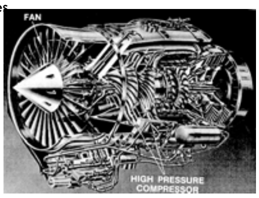
- Cold Sections
  - Inlet/Fan
  - Compressor
  - Casing
- High Strength (static, fatigue)
- High Stiffness
- Low Weight
- Materials:
  - Titanium Alloys
  - Aluminum Alloys
  - Polymer Composites
  - Titanium intermetallics and composites

FIBER REINFORCED POLYMER COMPOSITE PROPERTIES - GRAPHITE/KEVLAR

- Very high strength-weight ratios
- Fan cases can be Graphite Epoxy.
- On the exterior you have a kevlar wrap which has two purposes, Mechanical protection for the case and blade containment in the event of a radial failure.

TITANIUM ALLOYS USED FOR CRITICAL COLD SECTION COMPONENTS

- Titanium alloys can be used up to temperatures of ~ 590 °C
- Good oxidation/corrosion resistance
- Fan disks/blade Compressor disks/blades
- Typical Alloy: Ti-6Al-4V



TITANIUM ALLOYS AND COMPOSITES

- Ti_3Al Extends the temperature range of Ti from 590 °C to 650-700 °C
- Suffers from embrittlement due to exposure to air at high temperature - needs to be coated.
- Titanium forms a metal matrix composite with SiC fibers as it's matrix.
- This MMC decreases weight while increases strength and creep strength.

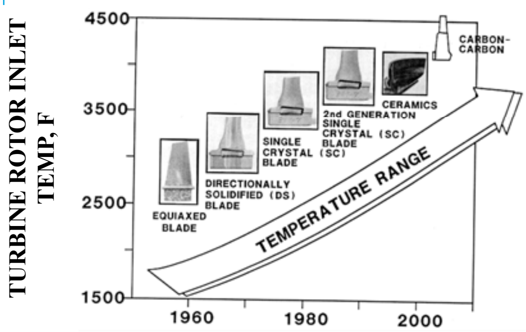
ALUMINUM ALLOYS CAN REDUCE WEIGHT OVER TITANIUM

- Conventional alloys have lower strength/weight ratios than Ti but more advanced alloys approach that of Ti.
- Specific gravity: 2.8 (62 % that of Ti)
- Lower cost than Ti
- Lower weight & rotating part inertia
- It is used to made the casing for the engine

HOT SECTION MATERIALS REQUIREMENTS

- Hot Sections :
  - Combustor
  - Turbine
  - Outlet
- High Strength against fatigue & creep-rupture.
- High temperature resistance 850 °C - 1100°C
- Corrosion/oxidation resistance

TRENDS IN TURBINE MATERIALS



HIGH TEMPERATURES - 1100 °C
WHAT MATERIALS CAN BE USED?

- Creep: Failure due to increase in strain over time under a static load when the operating temperature reaches approximately 0.4 T_m (absolute melting temp.)
- Unconventional metal alloys - or *superalloy*

Ceramics

- Turbine & high temperature sections Titanium alloy.

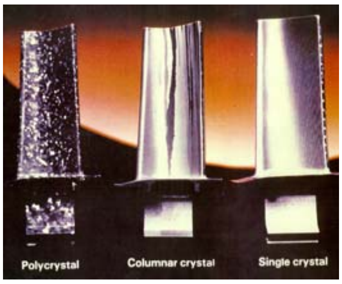
SUPERALLOYS

- Nickel (or Cobalt) based materials
- Can be used in load bearing applications up to $0.8T_m$ - this fraction is higher than for any other class of engineering alloys!
- Specific gravity ~8.8 (relatively heavy)
- Over 50% weight of current engines
- MCrALY is plasma-sprayed on the superalloys which increases resistance to corrosion and can reduce superalloy surface temperature by up to 40 °C.

MICROSTRUCTURE OF A SUPERALLOY

- Superalloys are *dispersion* hardened
- Ni_3Al and Ni_3Ti in a Ni matrix
- Particles resist dislocation motion and resist growth at high temperatures

CONTROLLED GRAIN STRUCTURE OF TITANIUM IN TURBINE BLADES:



Equi-axed | Directionally solidified (DS) | Single Crystal (SX)

Material for Aircraft Structural Applications

Group 16

WAR MACHINES

Features Vital to War Machines:

- Light & Strong
- Temperature Resistant
- Radiation Absorbing/Dispersing
- Heat Absorbing

Features Elaborated

- Light & Strong :

Material used should be light as it would provide more acceleration to the aircraft with same engine power. I.e. F=m*a. It must be strong so that minor damages do not affect its operational capabilities.

- Temperature Resistant :

As the war planes travel at over the speed of sound, the drag due to air is significantly high, causing wear and high temperatures. The material used must reduce wear and withstand high temperatures.

Features Elaborated

- Heat Absorbing :

In case of war planes,as the speeds that are dealt with are high and also the engine being extremely powerful, causes high temperatures inside the plane, which is undesirable, so we use heat-absorbing materials used which do not conduct the heat as the heat may damage the payload it carries.

Features Elaborated

- Radiation Absorbing/Dispersing:

One of the greatest threats to a war plane is RADAR guided missile.
In order to escape RADAR, the aircraft MUST MINIMISE reflection, in other words, must either absorb or disperse the radiation.
Chaffs : Metallic strips on the aircraft, which reflect different frequencies and thereby confuse enemy radar. They are made of aluminium coated glass fibres. They are light and create a large cloud of interference.

Stealth Technology : Escaping Heat Seekers

- Heat Seeking missiles are directed at the hottest part of the aircraft
  i.e. the engine of the aircraft
- To avoid these heat-seekers, decoys/flares are mounted on wings and tail of the war craft.
- These flares generate higher heat signature than the engine and thus confuse the incoming heat seeking missile

Escaping Heat-Seekers : Flares

- Flares are composed of pyrotechnic composition based on Magnesium or another hot burning metal
- Pyrotechnic Composition : designed to produce an effect (heat, light sound or their combinations) by non-detonating self sustained exothermic reaction

Flares

Stealth Technology : Escaping RADAR

Widely used in Fifth Generation Fighter Aircraft.
RCS -->Radio cross section.

- Measure of detectability from a RADAR.
- Passenger planes -high RCS
- Fighter planes -low RCS
- Metals -->Highly reflective of RADIO frequency.
- RAM (Radiation absorbing materials)- Absorb radiation and converts to heat

Radiation Absorbing Materials

1. Iron Ball Paint

Contains tiny spheres coated with carbonyl iron.
Radar waves induce molecular oscillations from the alternating magnetic field in this paint.
The heat is then transferred to the aircraft and dissipated.

2. Carbon Nanotubes Coating

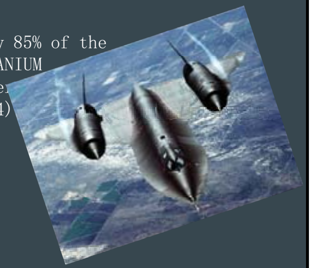
Doesn't reflect RADIO and Visible light frequency
Not visible in Dark.

Radiation Absorbing Materials

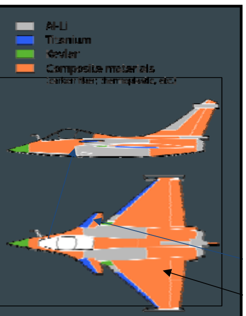
3. Neoprene Polymer sheets--->Developed by Taiwan's Defence
4. Nano particle Paint--->Developed by Israel's Defence

SR71 (Black Bird)

SR71 uses Titanium, literally 85% of the Weight of the airframe is TITANIUM
It is the fastest known fighter
Today!!! (first built in 1964)



F22 (US Air Force)



Material Used:

1. Titanium Alloy
2. Composite materials
3. High Frequency RAM Paint

The most advanced Aircraft till date.

Advantages

Titanium Alloys (Ti +Al +V) :
High tensile strength and toughness (even at extreme temperatures)
Light, have extraordinary corrosion resistance
Undergo precipitation strengthening.

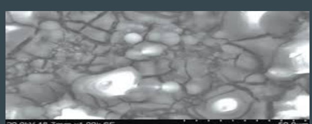
LCA Tejas (Indian Air Force)

- Materials used :
- Aluminium-lithium alloys.
- Carbon-fibre composites(45% of its airframe by weight including fuselage, wings)

Aluminium -Lithium alloys:

Lithium-Aluminium Alloys:

Light :
Lighter Lithium atom displaces Aluminium atom in crystal lattice. 1% Lithium(by weight) reduces density of alloy by 3% and increases stiffness by 5%.



Strong due to strain hardening :
Introducing Lithium strains lattice,which helps block dislocations. The resulting material is thus stronger.

Precipitation hardening:
When properly aged, Lithium forms a metastable Al_3Li phase (δ') with a coherent crystal structure. These precipitates strengthen the material by impeding dislocation motion during deformation.

Carbon fiber reinforced polymer:

- Biggest advantage is that they exhibit directional strength exceeding traditional metals used.
- Aluminium alloy Carbon reinforced polymer density - 2.8 g/cc 1.52 g/cc (For same Ultimate tensile strength of 572 Mpa)
- a component built with composite material would weigh only half [~54%] as much as metallic part yet be as strong.

Takeaways:

Titanium : One Stop Solution

Titanium is a light metal able to withstand virtually any external damage caused by heat, chemicals , environmental effects or corrosive contaminants.However, Titanium has a drawback, it is very expensive.So, Aluminium (light metal) and carbon composite polymers are also used in airframes.Some amount of steel also goes into the structure (to reduce costs).

Takeaways:

- To dodge RADAR guided missiles, we use chaffs (strips of Aluminium) mounted on the wings.
- Along with these we use special paints, which absorb the radiation, convert it into heat (by vibration) , and thereby deny the enemy radar of a strong signal
- To escape heat-seekers, we saw how thermit mixtures or pyrotechnic combinations allow us to deceive the incoming heat-seeker

Takeaways:

- Most of the aircrafts have different parts made of different materials like Composites,Ti alloy, Al alloys or steel.
- Al-Li Alloy: Al-Li alloy is lighter and stronger when compared to only Al.
- Composites presently are the most ideal materials for building aircrafts due to their exceptionally low density and are very strong and are resistant to high temperatures.

The Boeing Dreamliner 787