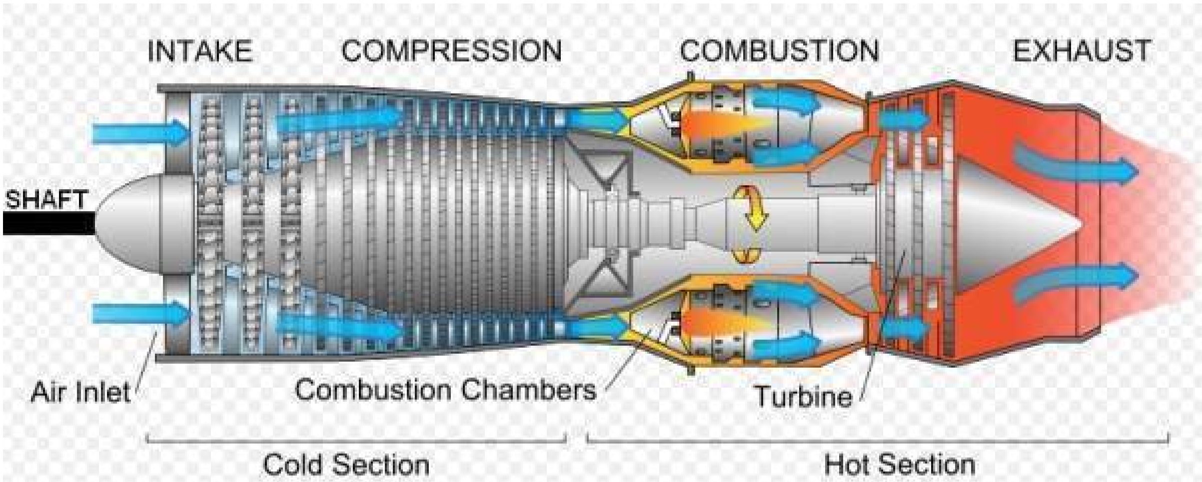
What do the multi-billion F-35 fighter, the A-320 NEO, A-220 & Embraer E2 have in common? They all source their engines from the same company, the Pratt & Whitney which has been facing teething problems with metallurgy.

For a layman, it is a technological challenge for all manufacturing industries. Size reduction yet maintain same efficiency. We have seen battery size reduced to produce slimmer and smaller gadgets, resulting in thermal runaway and battery fires.

Gas turbine thermal efficiency increases with greater temperatures of gas flow exiting the combustor and entering the turbine. In modern, high-performance jet engines, the temperature of this gas can exceed 1,650 degrees Celsius (non-aviation gas turbines operate at 1,500 degrees or lower, whereas military jet engines can reach 2,000 degrees, which exceeds the boiling point of molten silver).

PW promotional video

Good news, its just the heat



PW F135 Engine for the F35

Heat was the cause of a cracked blade in an engine on an F-35 fighter jet that prompted the entire fleet to be briefly grounded last month, manufacturer Pratt & Whitney said in 2013.

Bennett Croswell, president of the company's military engines division, said on a conference call that finding the cause was "very good news." Heat is preferable to the effects of fatigue on the engine part because fatigue spreads, making the problem worse, he said.

Croswell said an inspection found the 6/10-inch long crack in a turbine blade. The Pentagon grounded its F-35 fleet on Feb. 22 after discovering the crack on a jet at Edwards Air Force Base in California.

"It was prudent to suspend flight operations while we inspected the blade," he said.

https://www.manufacturing.net/operations/news/13090537/heat-caused-f35-engine-blade-crack

Superalloys

The material is called a "superalloy" because it retains strength and resists oxidation at extreme temperatures., when they are cast using conventional methods in a vacuum furnace to prevent oxidation, soften and melt at temperatures between 1,250 and 1,400 degrees. This temperature limit means blades and vanes closest to the engine combustor may be operating in gas path temperatures far exceeding their melting point, and thus must be cooled to typically eight- to nine-tenths of the melting temperature to maintain integrity.

To maintain these temperatures, turbine airfoils subjected to the hottest gas flows must be cast with intricate internal passages and surface hole patterns needed to channel and direct cooling air (bled from the compressor) within and over their exterior surfaces. After casting, the working surface can be sprayed with ceramic thermal barrier coatings to increase life and act as a thermal insulator (allowing inlet temperatures a few hundred degrees higher).

Why do problems happen?

Untoward events happen at grain boundaries, such as increased chemical activity, slippage under stress loading, and the formation of voids. Among other problems, these conditions can lead to *creep,* an insidious life limiter: the tendency of blade material to deform at a temperature-dependent rate under stresses well below the yield strength of the material. Corrosion and cracks also start at grain boundaries. Thus grain boundaries greatly shorten turbine vane and blade life, and require lowered turbine temperatures with a concurrent decrease in engine performance.

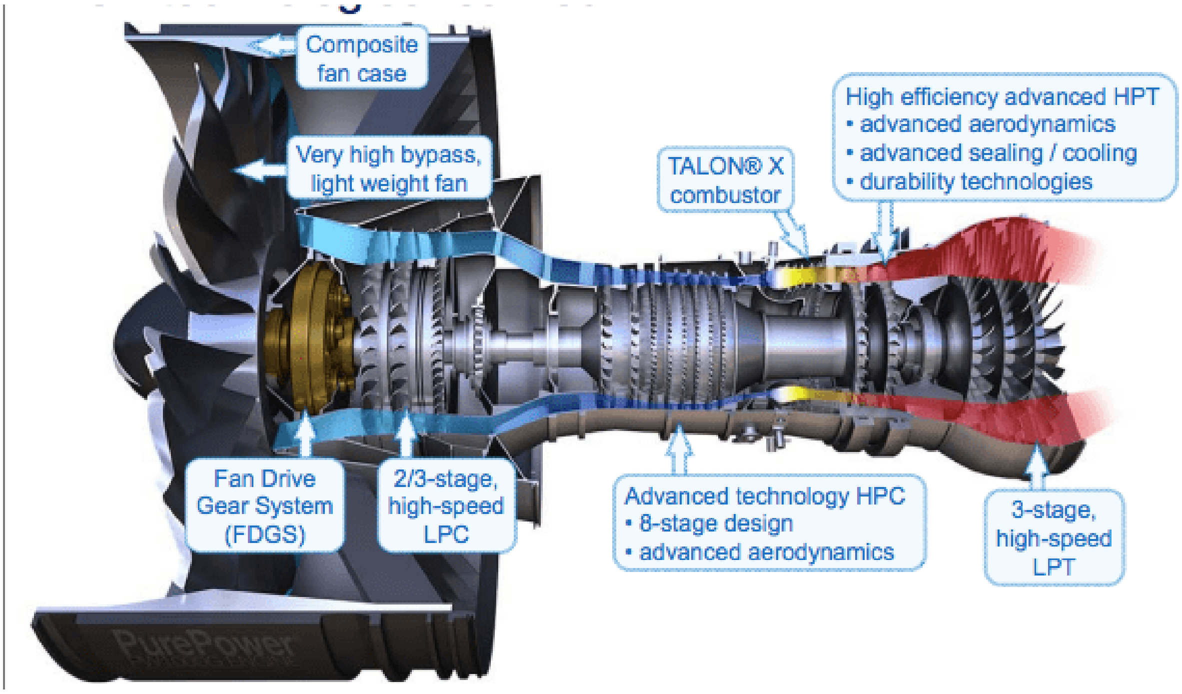
PW solution

Researchers invented techniques to cast single-crystal turbine blades and vanes, and designed alloys to be used exclusively in single-crystal form.
Because single-crystal properties such as elastic modulus (the tendency of the material to deform along a specific axis) vary with lattice angular orientation, the optimization of this property can improve specific problem areas of blade design, such as creep life or critical vibration modes.
An alloy dubbed PWA 1484, which Pratt & Whitney developed in the early 1980s, consists (by weight) of nickel (59 percent), cobalt (10 percent), tantalum (9 percent), aluminum (6

percent), tungsten (6 percent), and a few other elements (10 percent). One of the others is rhenium (3 percent), which provides a significantly higher metal temperature capability.

https://www.americanscientist.org/article/each-blade-a-single-crystal

A320/220 & E2 PW Engines



Low Pressure Turbine

The PW GTF engines have been having teething issues since 2016. Starting with after in-flight failures of PW1100G with its high pressure compressor aft hub modified – apparently problems of its knife edge, followed by increasing engine vibrations, sometimes before 1,000 flight hours and mostly at high power settings in the climb phase, requiring an early engine change.The latest being the Low Pressure Turbine (LPT).

The A-220 users have been issued emergency directive to reduce climb thrust to introduce a buffer between the maximum climb thrust.

A220 Emergency Airworthiness Directive

Leistritz, the company has claimed to have developed an isothermal forging process for blades made of TiAl alloys during the past 18 years. The optimal process window was determined as 1100 °C to 1250 °C with extremely low strain rates. The high process temperature requires die material such as Molybdenum alloys under protective atmosphere. Leistritz have established the isothermal forging process on a special hydraulic press.

All machining of these blades was done in the Leistritz Nürnberg works. More than 10.000 LPT stage 3 blades for the PW 1100G for MTU have been forged of cast TNM. Currently Leistritz are the only approved supplier for these parts.

Isothermal forging of turbine blades

After having successfully produced compressor blades with relatively small blade length of about 30 mm the next challenge was forging of turbine blades with 200 mm length. Input material are cast billets of the TiAl alloy TNM . In this alloy the dominant phase in the as-cast condition at forging temperature is the forging friendly beta-phase, so no grain refinement by extrusion is needed prior to forging.

To meet the required properties the content of beta-phase is adjusted by a specific heat treatment after forging. Machining and grinding gives the blade he final shape.

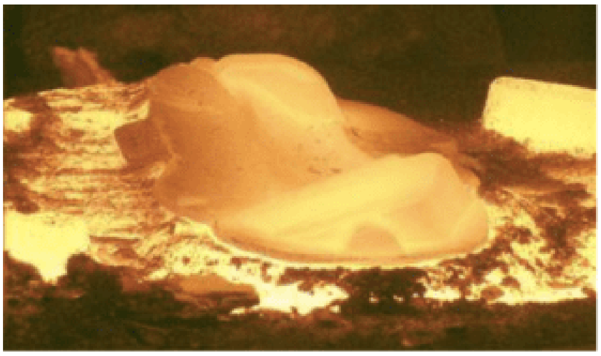


Fig. 8 Blade in isothermal die

Fig. 9 Forged LPT blade stage 3 for PW1134G

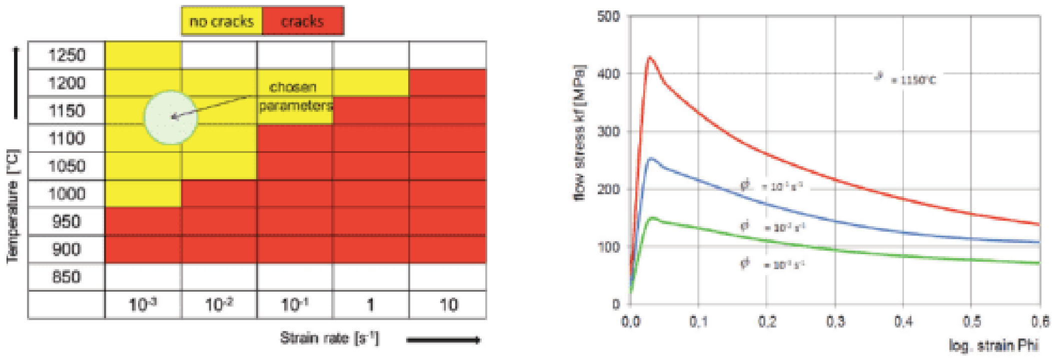


Fig. 2. (a) forging parameters and (b) flow stress

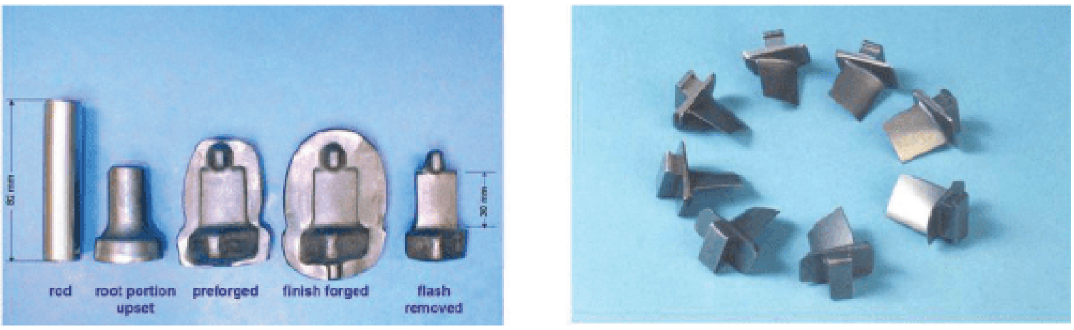


Fig. 3. (a) forging steps and (b) machined compressor blades

Wrought TiAl blades

P. Janschek

mindFly analysis

The need for a lighter and a more fuel efficient engine yet a powerful one has made the

OEM’s to use their innovation & research to the maximum. This combination is achievable by reducing the number of moving parts thereby reducing the weight and the size of the engine. High power means high heat and PW has intelligently combined the gear system to reduce the fan stage speed.

Small engine + high heat means that the fewer parts as compared to the conventional engine have to bear and dissipate the enormous amount of heat. This requires a great deal of research in metallurgy. PW is able to control the strength of the blades by varying the mixture of metals.

The failure of the low pressure compressor and the high pressure turbine in the recent past have again highlighted the need to improve the metallurgy to bear the heat, corrosion and a combination of other factors. While PW was relieved when the F35 engines were affected and the cause was just heat and not fatigue, the GTF engines are still struggling with the supposedly heat issue and its getting hotter as the number of failures increase by the day.

Iron pillar in Delhi resisting corrosion for centuries but pollution being blamed for engine troubles