**Steam Turbines** Over 30% of the downtime of powerplants is caused by failures of steam turbine components. The use of Ti-6Al-4V turbine blades in the Wilson Line region increased the efficiency and life of the low pressure steam turbine while decreasing downtime and maintenance.

**Automotive** Titanium is already extensively utilized in high performance vehicle components such as valves, valve springs, rocker arms, connecting rods and frames due to its high strength and low weight. Evaluations have demonstrated that use of a titanium valve train improves fuel efficiency by 4% in commercial engines. Because of this factor, titanium valve train components are being evaluated in several commercial engines.

**Castings** Commercial casting production started in the late 1960s and today the technology has matured to the point where critical gas turbine engine, air frame, chemical process and marine products are routinely supplied. Castings are the most commercially advanced and diversified of the net shape technologies available to the user. They offer greater design freedom and greatly reduce the need for expensive metal removal or fabrication to attain the desired shape.

Both precision lost wax as well as rammed graphite (sand) molding systems are employed. The same pattern equipment normally used to produce steel parts is often used to produce titanium chemical pump and valve components while aerospace parts normally require their own tooling.

Mechanical properties of titanium castings are generally comparable to their wrought counterparts. Toughness and crack growth resistance are generally superior and strength is almost the same while high cycle fatigue is normally a little lower.

The introduction of hot isostatic pressing (HIP) in the late 1970s tumbled the barriers associated with X-ray interpretation of normal internal casting shrinkage cavities since such indications were closed and diffusion bonded by the process. By the elimination of typical internal microshrink, mechanical property scatter was reduced and average property levels improved. As designers began to have greater confidence, applications increased dramatically.

**Sports Equipment** Titanium golf shafts, tennis racquet frames, pool cue shafts, ball bats and bicycle frames are currently being fabricated using the Ti-3Al-2.5V alloy. Ti-3Al-2.5V has demonstrated the properties needed for sports applications: good strength-to-weight ratio, good corrosion resistance, low modulus of elasticity, and dampening characteristics.

**In the aerospace industry, titanium is currently being utilized in:**

**Engines** The largest single use of titanium is in the aircraft gas turbine engine. In most modern jet engines, titanium-based alloy parts make up 20% to 30% of the dry weight, primarily in the compressor. Applications include blades, discs or hubs, inlet guide vanes and cases. Titanium is most commonly the material of choice for engine parts that operate up to 1100°F. (593°C.).

**Airframes** Titanium alloys effectively compete with aluminum, nickel and ferrous alloys in both commercial and military airframes. For example, the all-titanium SR 71 still holds all speed and altitude records. Applications run the gamut of airframe structural members; from massive, highly stressed, forged wing structures, and landing gear components, to small critical fasteners, springs, and hydraulic tubing.

Selection of titanium in both airframes and engines is based upon titanium's basic attributes; weight reduction due to high strength to weight ratios coupled with exemplary reliability in service, attributable to outstanding corrosion resistance compared to alternate structural metals.

**Space Structures** Starting with the extensive use of titanium in the early Mercury and Apollo space craft, titanium alloys continue to be widely used in military and NASA space applications. In addition to manned space craft, titanium alloys are extensively employed in solid rocket booster cases, guidance control pressure vessels and a wide variety of applications demanding light weight and reliability.

**Thick Section Titanium** Heavy section size is generally defined as forged or rolled thickness that exceeds four inches. Titanium alloys have been successfully used for heavy sections thickness, in both airframe parts, and in rotating components such as heavy section fan disks for PWA and G.E. high bypass jet engines, and Sikorsky helicopter rotor forgings.

The primary alloys that have been involved are Ti-6Al-4V, in the annealed or STOA (Solution Treated and Overaged) condition; the near-beta Ti-17 (Ti-5Al-2Sn-2Zr-4Mo-4Cr), Ti-10V-2Fe-3Al and the Ti-6Al-2Sn-4Zr-6Mo compositions in the STA (Solution Treated Aged) condition; and the beta alloys Ti-13V-11Cr-3Al and Ti-3Al-8V-6Cr-4Mo-4Zr, also in the STA condition. Certainly the most extensive heavy section applications in one project to date featured the Ti-13V-11Cr-3Al alloy in the SR-71 Blackbird (fuselage frames, wing beams and landing gears). In this program, Lockheed engineers stated that while only titanium and steel had the ability to withstand the operating temperatures encountered, aged Ti-13V-11Cr-3Al titanium weighed one-half as much as stainless steel per cubic inch and it's ultimate strength was about equal to stainless. Using "conventional" fabrication techniques, fewer parts were needed with Ti-13V-11Cr-3Al than with steel.

For a given process and heat treatment condition, titanium alloys such as these demonstrate superior fatigue and fracture toughness properties, not only in the absolute sense, but also from the standpoint of uniformity throughout the heavy section thickness, and as the section thickness increases from 4" to 6", or even to 8". Titanium alloys offer a useful and in many cases, a superior alternative to steel alloys for heavy section application.

# Emerging Applications

Besides existing applications, there is tremendous potential for titanium usage which include the following:

**Aerospace** As new titanium products, alloys and manufacturing methods are employed by the aerospace industry, the use of titanium will expand. Today the use of precision castings and new alloys such as Ti-15V-3Cr-3Al-3Sn and Ti-3Al-8V-6Cr-4Zr-4Mo are making it possible for titanium to displace alternate, less efficient structural materials in a wide spectrum of aerospace applications.

**Downhole** The exceptional resistance to attack from $H_2S$ and other aggressive compounds combined with high strength and low density make titanium especially attractive for downhole applications such