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DESIGNING WITH TITANIUM

I wish to thank Dr. Marco Ginatta and Dr. Ugo Ginatta for the opportunity to be here with you today and to be part of this second Torino Symposium on Titanium. Being part of the first program last year, it is certainly an honor for me to participate again. Today my comments will be addressed to concepts utilized in aerospace designs with titanium. (Slide No.1) I will discuss current and future trends for titanium alloys primarily in aerospace applications.

There are several unique design properties of titanium (Slide No.2), and I have listed several here: First of all, corrosion resistance. As many of you know, titanium is excellent in most salt environments. The second unique characteristic is its specific strength, or the ultimate strength divided by density. This is a measure of efficiency.
The third characteristic that is unique is thermal expansion. The thermal expansion of titanium is relatively low for metals, which means it is very compatible with composite structures and with ceramics having nearly the same thermal expansion. The heat transfer of titanium is also excellent primarily because of its good corrosion resistance. And last the low elastic modulus. Because of this low modulus and high strength, it is able to absorb large amounts of elastic energy and makes it very useful in spring applications. But I am not going to

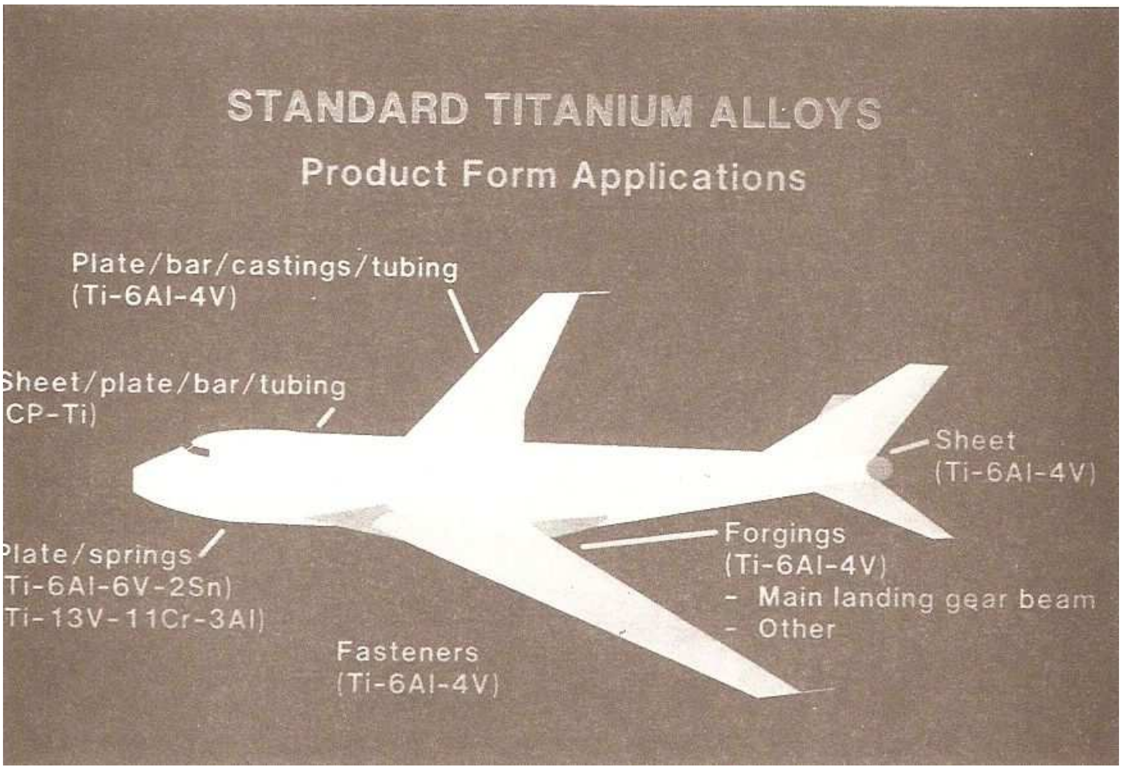
Slide No. 1

Slide No. 2

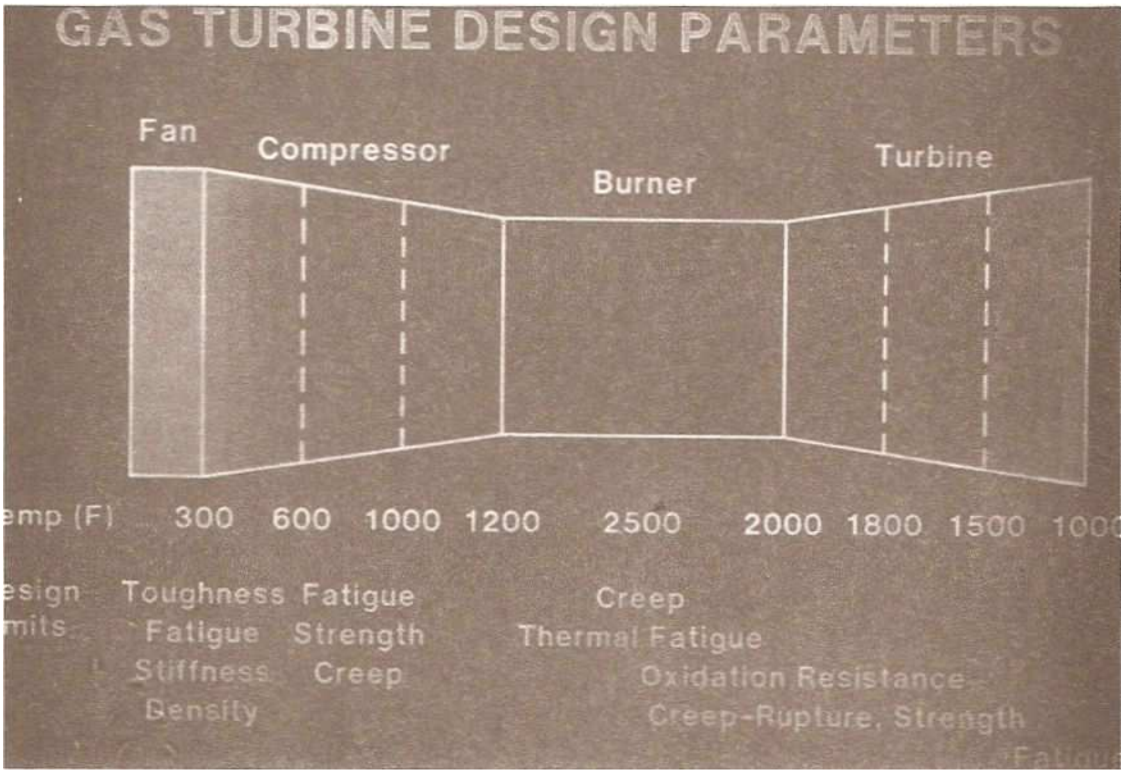
discuss all of these characteristics today. I am going to center on the specific strength of titanium. This is the key property that is necessary for aerospace applications. My talk will primarily center on specific strength as applied to airframes and as applied to jet engines.

The titanium industry grew out of post World War II development of jet-driven aircraft, and for the most part it is still heavily dependent on the aerospace industry. In airframe titanium alloys are used in numerous applications, as you can see in Slide No. 3. The important design features for airframe applications are the specific strength, as I said, the ultimate strength divided by density, the toughness of the material, and heat resistance.

The largest usage of titanium (Slide No.4) is in the gas turbine engine, where titanium alloys are approximately 30 percent of the total weight of the gas turbine engine. Titanium alloys are used in the compressor section up to temperatures as hot as 550° C. The design properties in the cooler portions are toughness, fatigue resistance, stiffness and, of course, low density is very important. As you move into the warmer sections of the engine, creep strength becomes a dominant design factor.



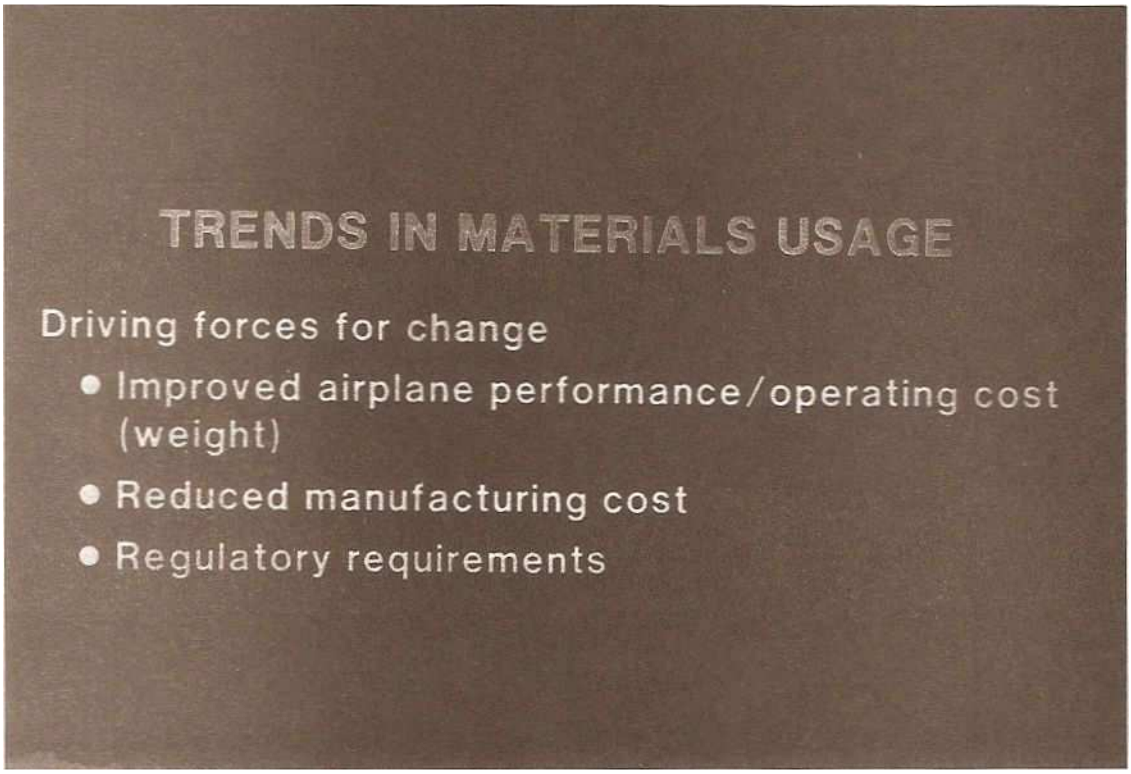
Slide No. 3



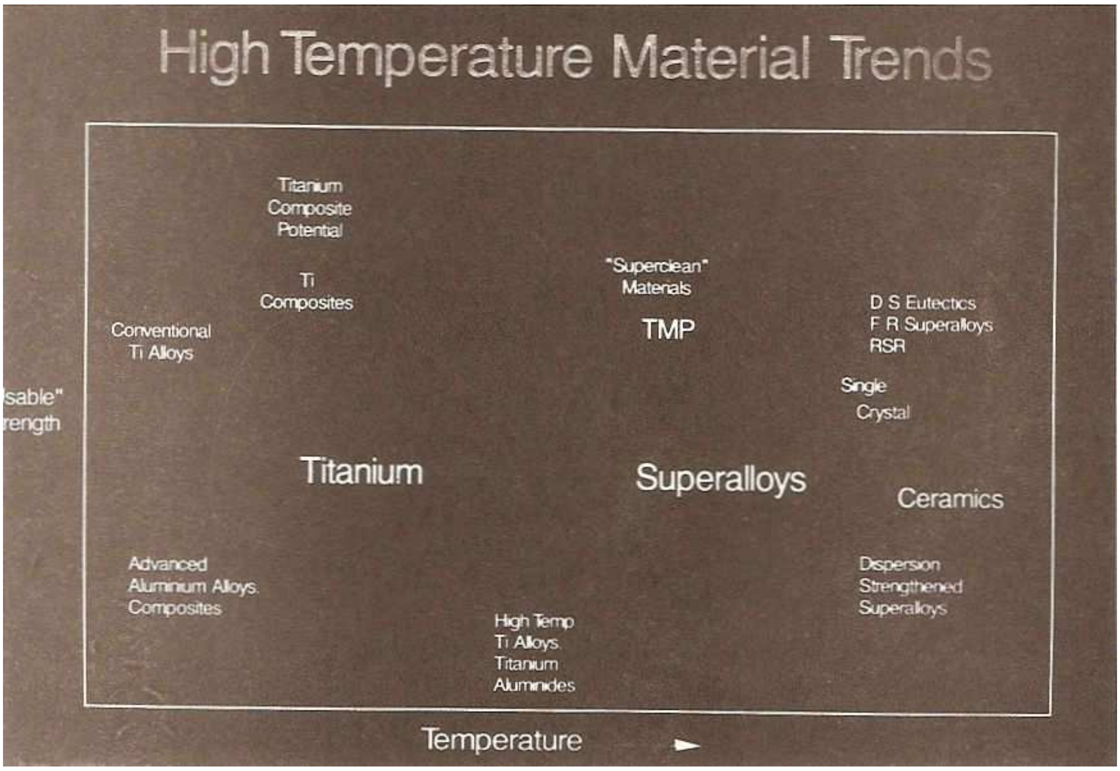
Slide No. 4

In the future (Slide No.5) the choice of materials of constructions of airframes and engines is expected to be influenced by continued efforts to, first of all, reduce operating costs, and this generally means reduced weight; second to reduce the manufacturing costs, and this can be done through new technologies, such as super plastic forming, isothermal forging, diffusion bonding, net-shape castings. And the third factor is to meet new regulatory requirements that we have such as noise reduction and pollution control. These needs are continually requiring a readjustment in material considerations for aircraft. Slide No.6: shows usable strength as a function of temperature. Titanium alloy's sphere of influence is in the low temperature area. At higher temperatures the superbase alloys are used, while at very low temperatures aluminum base alloys are used. At one time each metal had its own distinct area of influence, but with the development of new materials such as advanced aluminum alloys and also carbon composites, we find that we are receiving competition from these new materials.

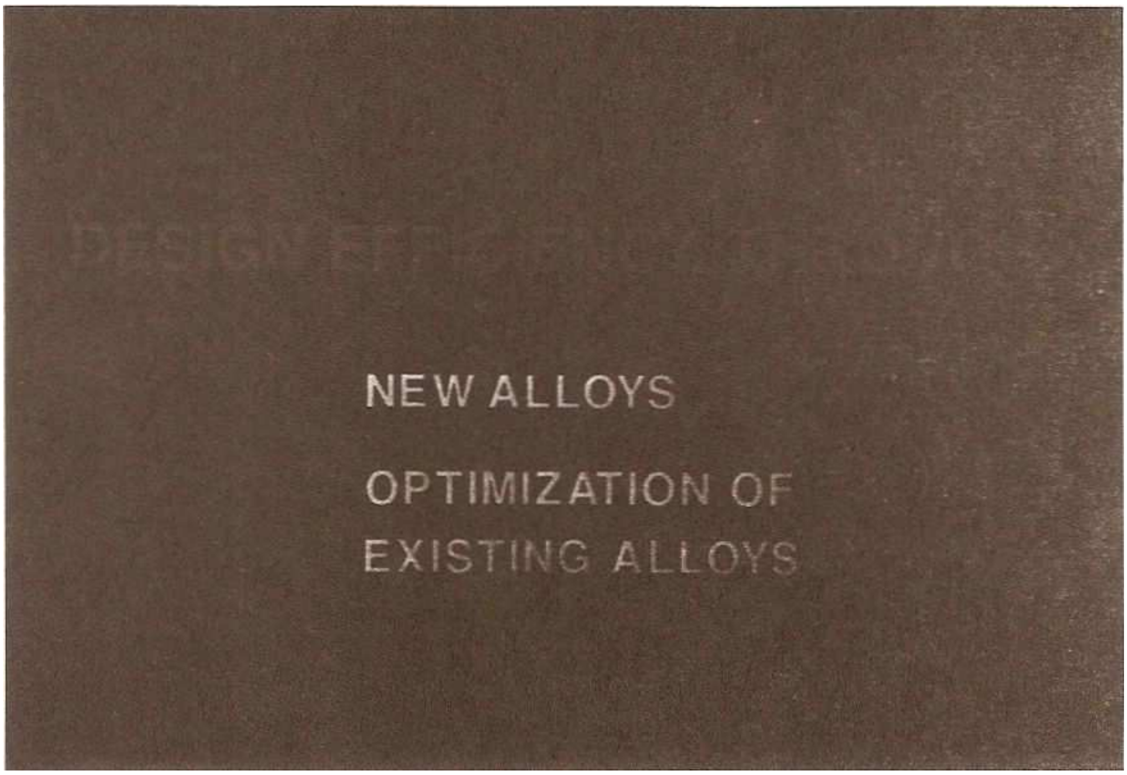
This material competition from advanced aluminum alloys and nickel-base alloys is healthy and will result in more efficient designs. But my message today is quite simple. Titanium will meet the challenge of new materials by offering new opportunities for design improvements, and I think this can be achieved two ways (Slide No. 7).
First, new alloys with improved properties, and second optimize existing titanium alloys.



Slide No. 5



Slide No. 6



Slide No. 7

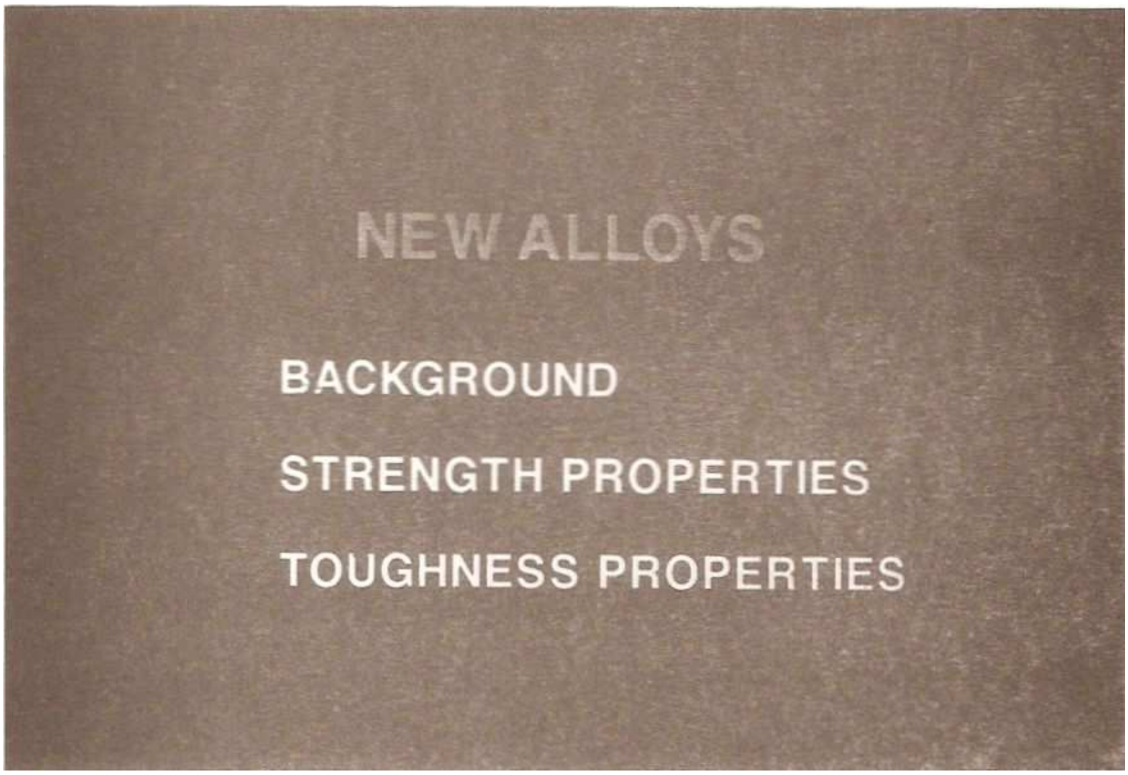
I will briefly discuss these two subjects in the remaining portion of my presentation.

In discussing new titanium alloys (Slide No.8), I will cover three areas. I will provide a brief background on titanium alloys; and then review strength and toughness properties.

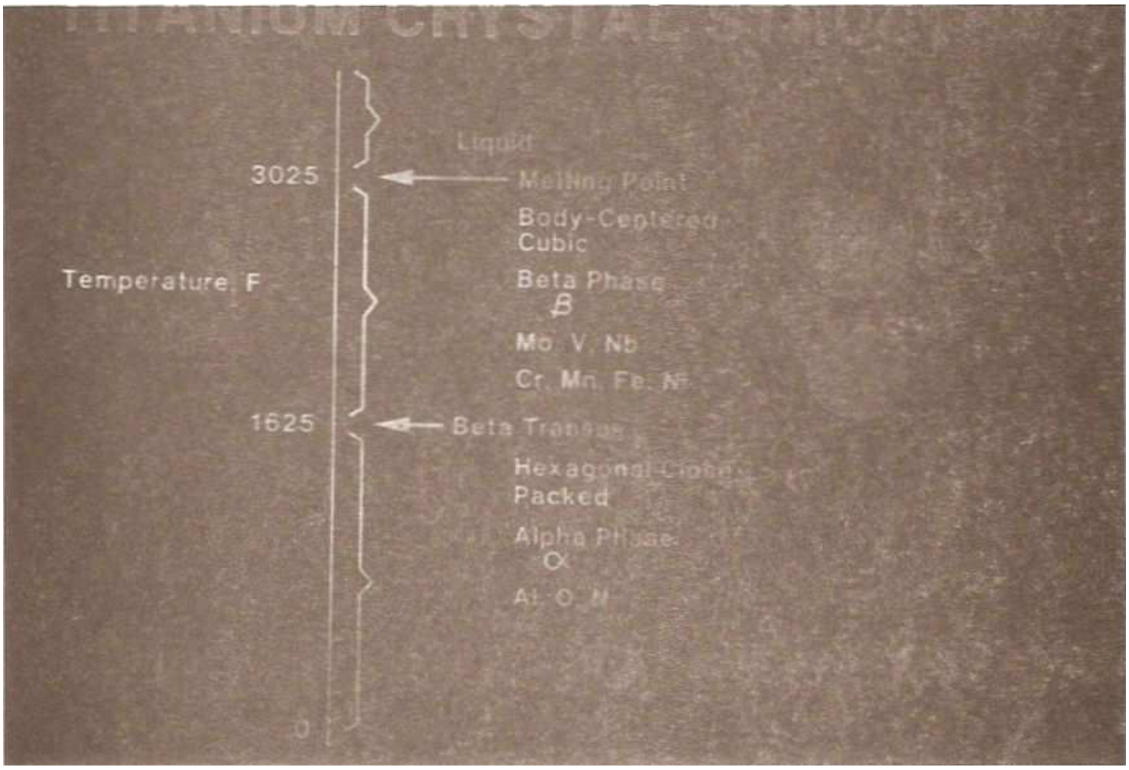
First, I would like to define very briefly the classification of titanium alloys.

As many of you know, titanium has two crystalline structures. At room temperature, there is the alpha structure (Slide No.9), which is hexagonal, and then at higher temperature in pure titanium it transforms to a body-centered cubic structure which is called the beta phase. By alloying, we can develop the beta phase at room temperature; we can also have the alpha phase at room temperature so we can have a third classification, where we have both the beta and alpha phase at room temperature. This is all done by alloying. So we now have three classifications of alloys: alpha alloy, beta alloy, and the mixture, alpha plus beta.

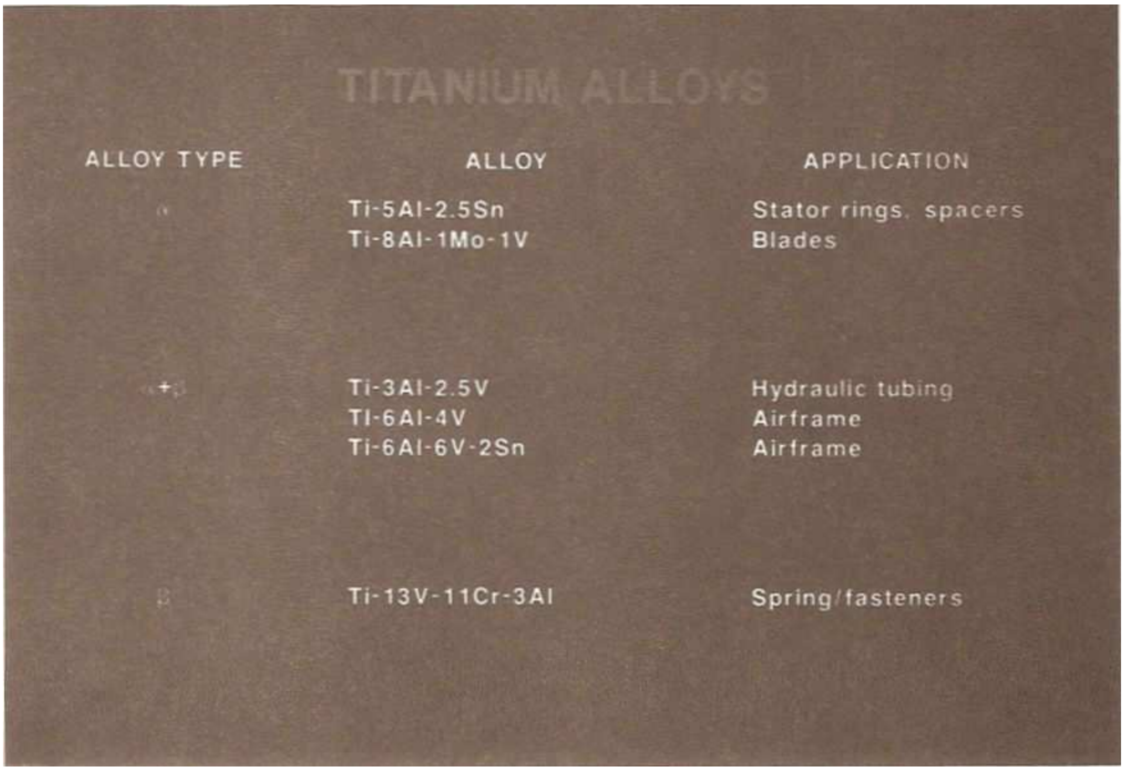
These are the original titanium alloys (Slide No. 10), and they date back about 20 years. The applications are in both airframes and engines. The alpha alloys are used primarily in engines, staters, spacers, and blades. The alpha-beta alloys are used in airframes; hydraulic tubing, and a beta alloy is used in springs and fasteners.



Slide No. 8



Slide No. 9

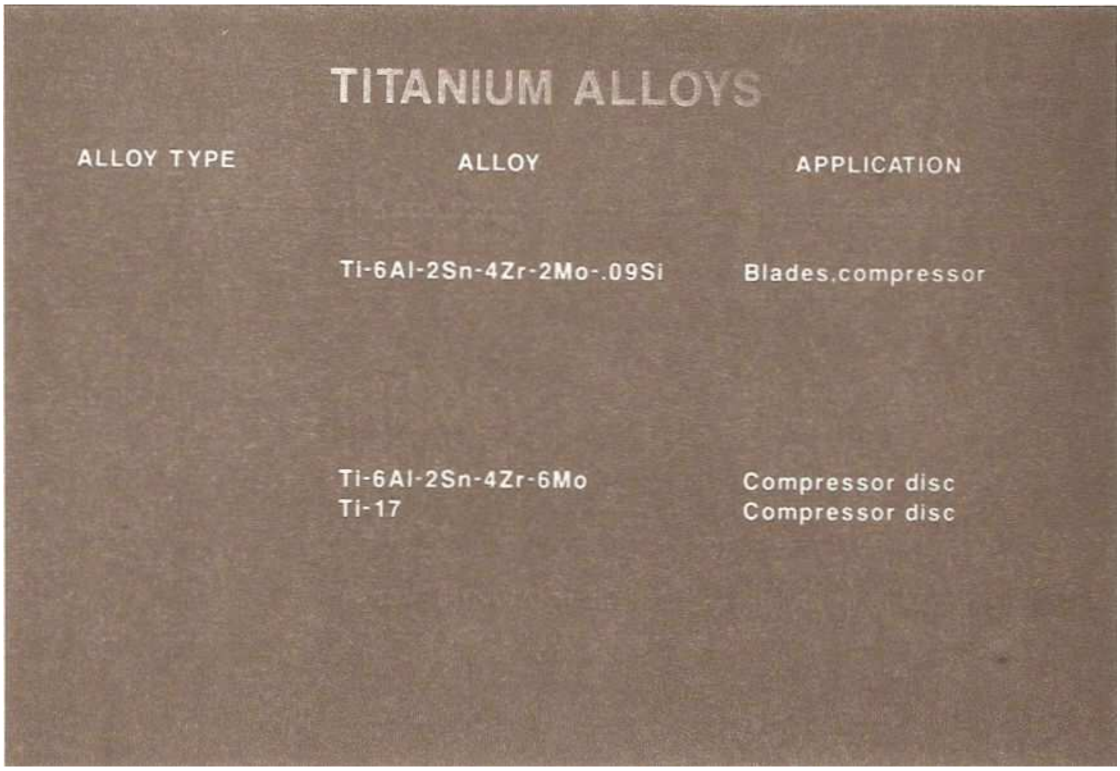

TITANIUM ALLOYS
ALLOY TYPE
ALLOY
APPLICATION
α
Ti-5Al-2.5Sn
Stator rings, spacers
Ti-8Al-1Mo-1V
Blades
α+β
Ti-3Al-2.5V
Hydraulic tubing
Ti-6Al-4V
Airframe
Ti-6Al-6V-2Sn
Airframe
β
Ti-13V-11Cr-3Al
Spring/fasteners

Slide No. 10

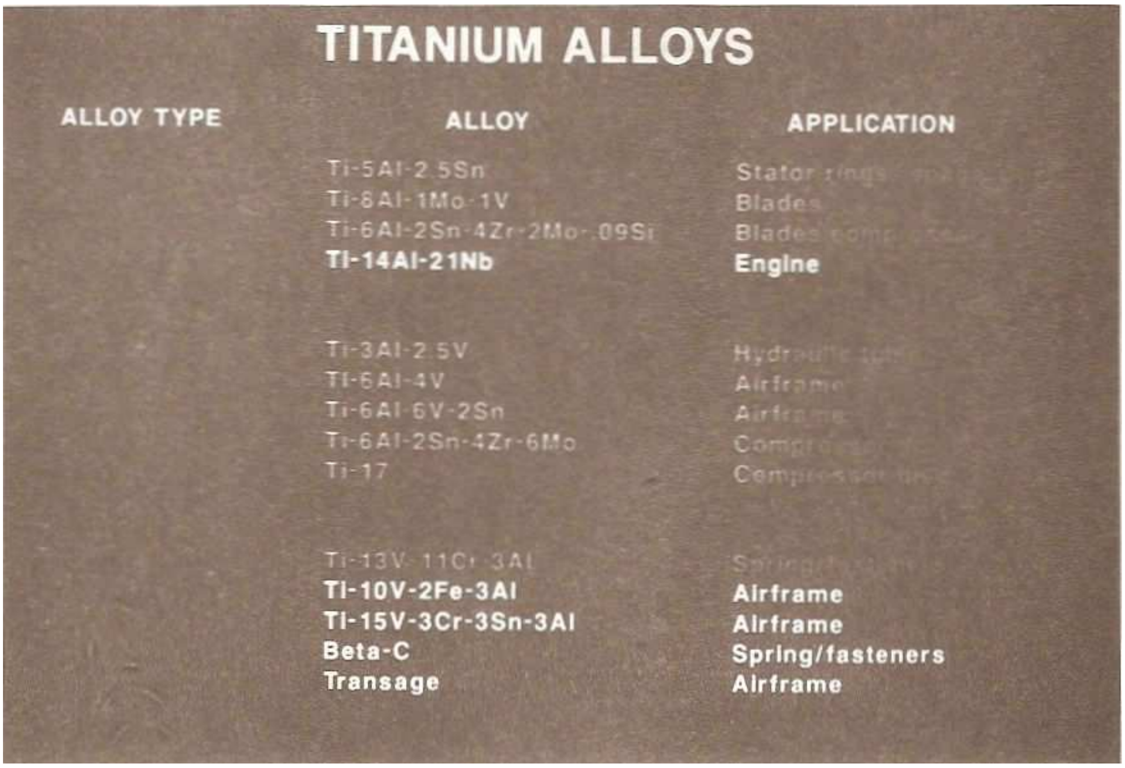
More recently new alloys have been added to the current alloys (Slide No. Il). For the Alpha Alloys, a six-two-four-two alloy is used at higher temperatures in blades and compressors. For the Alpha-Beta, two alloys have been added, a six-two-four-six, which is primarily used in Pratt-Whitney engines; and a Ti-17 which is used in General Electric Engines for very critical parts such as compressor discs.

The next slide (Slide No.12) will show the newest generation of developmental alloys. We have, as you can see in the Alpha Alloys, a very unique alloy, which is known as a Titanium Aluminide. No new Alpha Beta alloys, but there is a host of new Beta alloys; there is a 10 Vanadium, 2 Iron, 3 Aluminum for airframes used primarily as forgings. Another alloy, 15 Vanadium, 3 Chromium, 3 Tin, 3 Aluminum, again in airframe applications. It' s a sheet alloy, highly formable. Beta-C alloy, being used now in spring and fastener applications, is a high strength alloy, a developmental alloy. Transage developed by Lockheed Corporation, is aimed at airframe, but has very limited use thus far.

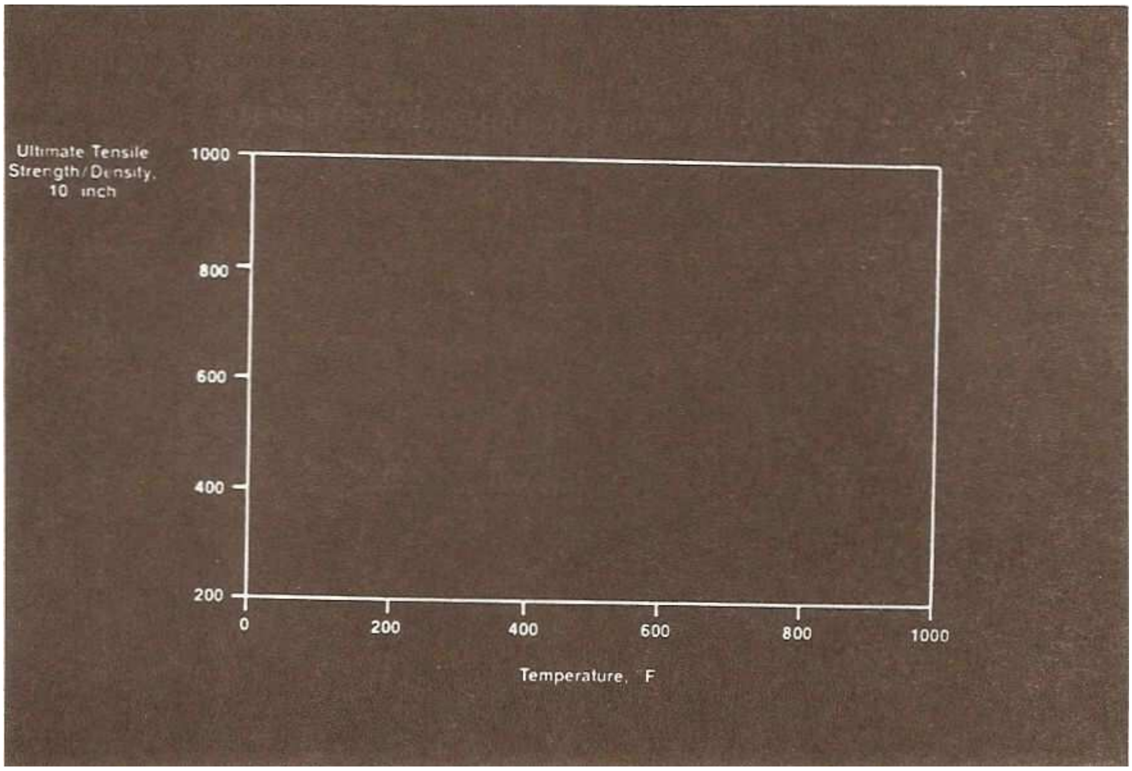
Now let's actually compare the properties of these alloys (Slide No. 13) with other metals utilizing specific strenght as a function of temperature. kg/dm^3, some steels, and two of the earlier Titanium alloys 8-1-1 and 6-4.



Slide No. 11



Slide No. 12


Ultimate Tensile
Strength/Density,
10 inch
1000
800
600
400
200
0
200
400
600
800
1000
Temperature, F

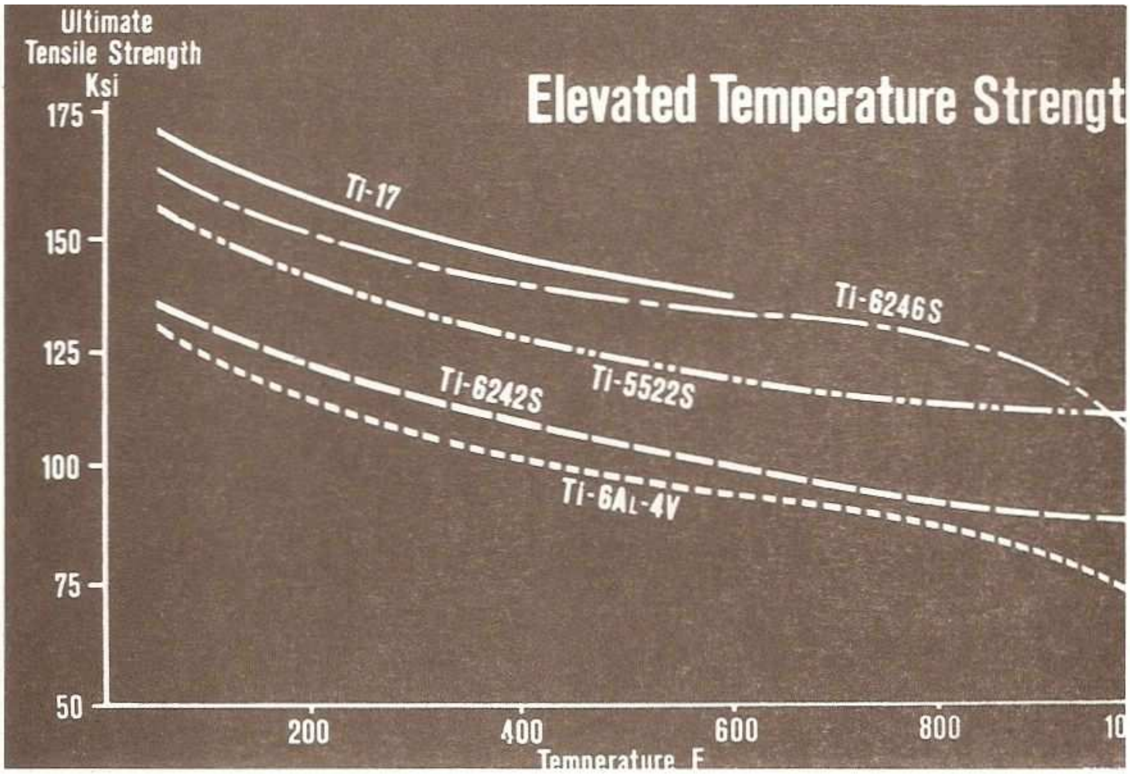
Slide No. 13

The titanium alloy, Ti-6Al-4V, has significantly better efficiency than the steels. The interesting aspect is that this alloy is often used as comparison for new materials including new aluminum alloys. However, Ti-6Al-4V is a moderately low-strength titanium alloy, Slide No. 14, is a similar plot. There are several new alloys such as Ti-17, Ti-6-2-4-6 that have appreciatively higher strength. These alloys are now being used in airframe and engine applications.

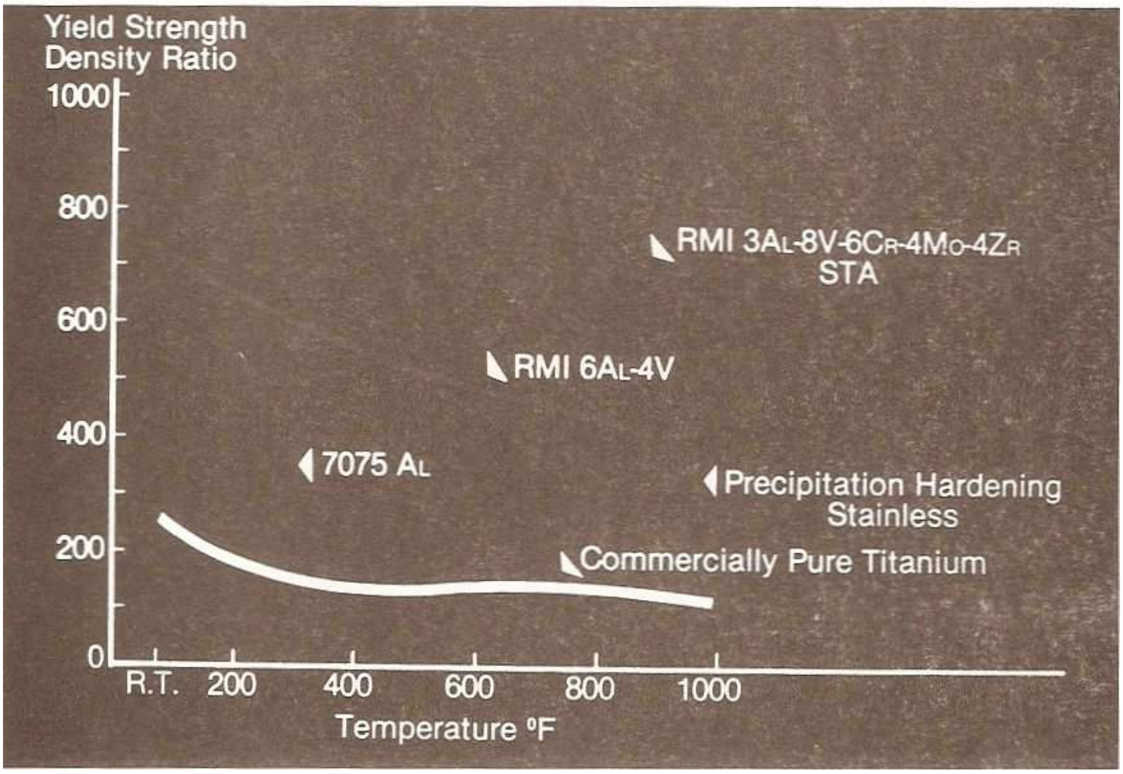
Now let's see how these high strength alloys compare (No. 15) with other materials base on density adjustment. Pure Titanium, is very low strength. Again, Ti-6Al-4V is similar to the precipitation hardening stainless steels, and the aluminum alloys drop off in strength very rapidly at moderately high temperatures. The new generation of Titanium alloys are approximately 20 to 30 percent higher strength.

As temperature is increased, creep strength becomes an important design criteria, as we see in the next slide. (Slide No. 16).

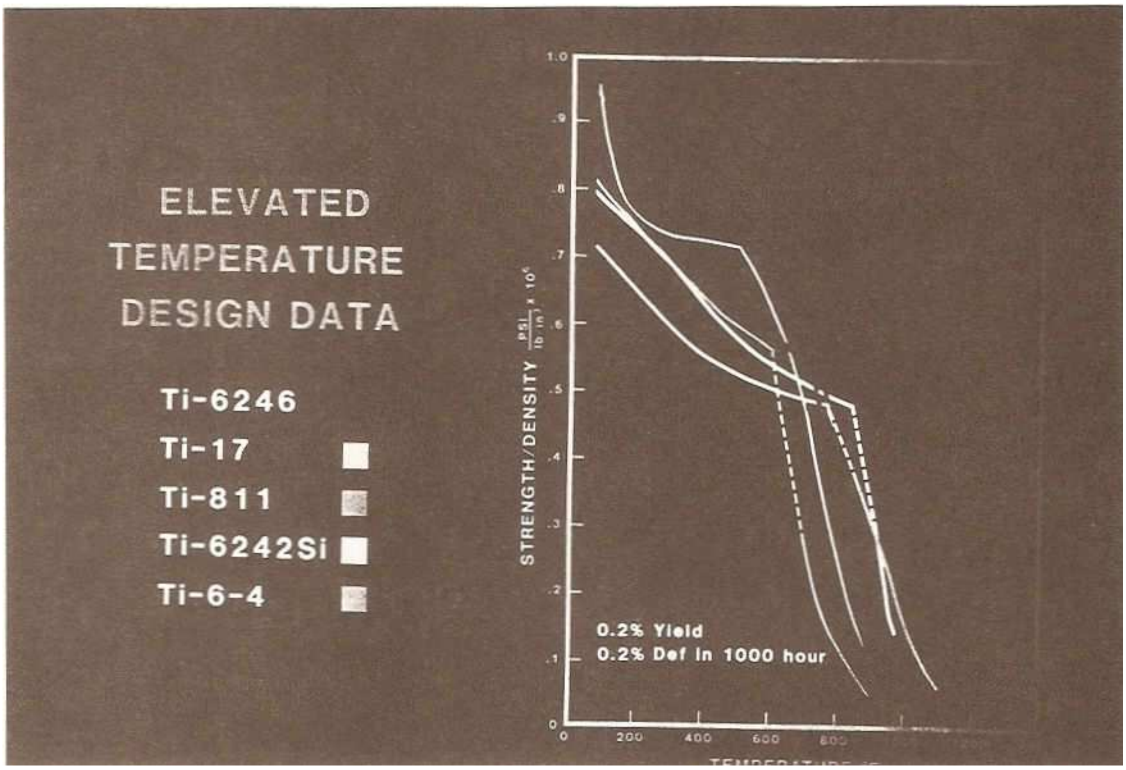
Shown on this graph is the short-term ultimate strength and the long-time creep strength.



Slide No. 14



Slide No. 15

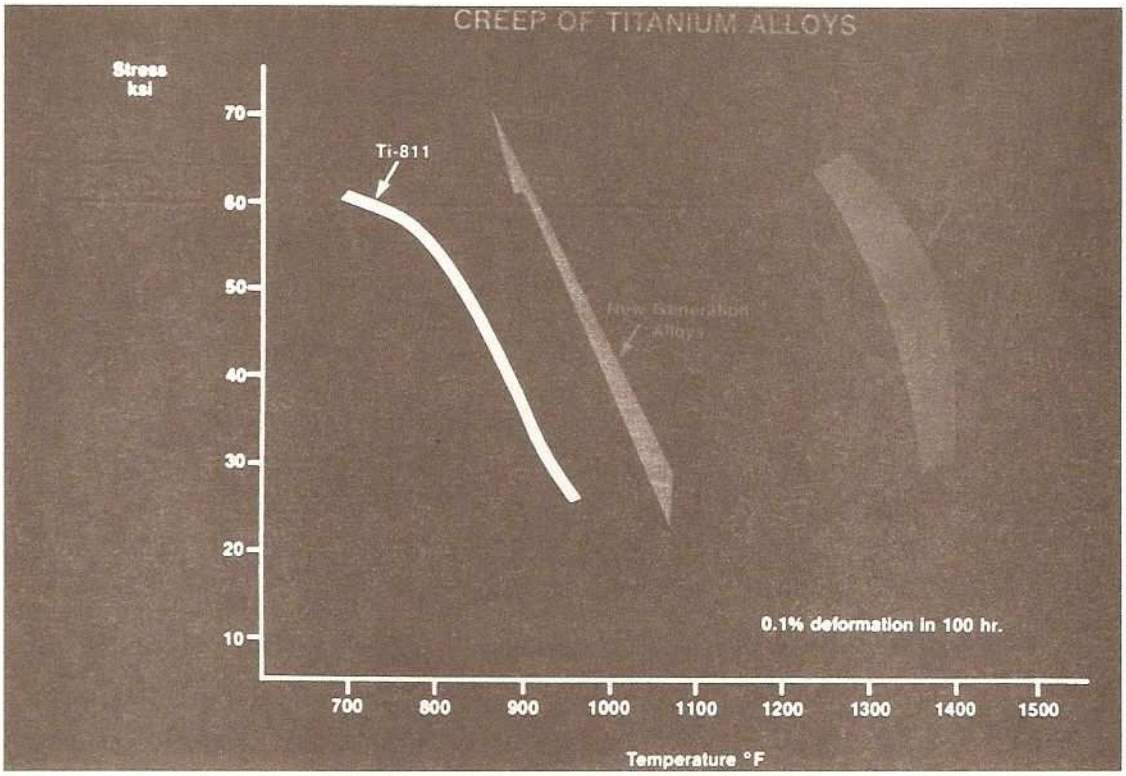

ELEVATED
TEMPERATURE
DESIGN DATA
Ti-6246
Ti-17
Ti-811
Ti-6242Si
Ti-6-4
STRENGTH/DENSITY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
200
400
600
800
0.2% Yield
0.2% Def in 1000 hour

Slide No. 16

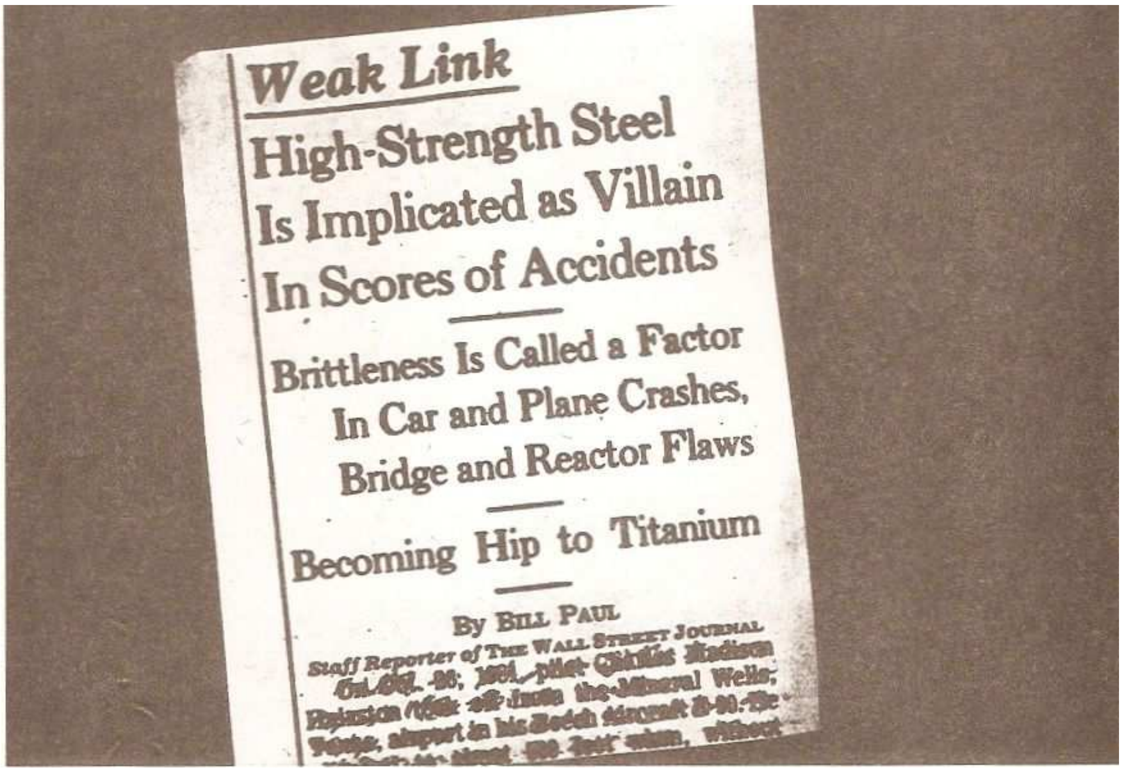
Where these two curves intersect is the point where creep must be considered in design. Below this intersect tensile strength is dominant; above this area, creep strength becomes the dominant design feature. This is in the area of approximately 600 Fahrenheit where this change occurs. Ideally we would like both high tensile and high creep strength materials.

The next slide (Slide No. 17) shows improved creep resistant alloys. Ti-6Al-4V, has moderate strength while Ti 6-2-4-2, is the best of the current commercial alloys. There is a new generation of Titanium alloys, IMI alloys, that offer a slight improvement in creep strength and are being utilized by Rolls Royce, there is some interest in these alloys in U.S.A. But the new Titanium Aluminides offer a very dramatic improvement in high-temperature characteristics. These alloys, we expect to see in jet engines of the nineties.

We have talked about the high specific strength of Titanium alloys. I would like to move to the next slide (Slide No. 18) and relate strength to toughness. This was a headline article in one of our financial papers, The Wall Street Journal. It discusses all the high-strength failures that are occurring in steel, and they were suggesting in this article that designers ought to look to Titanium for improved toughness.



Slide No. 17

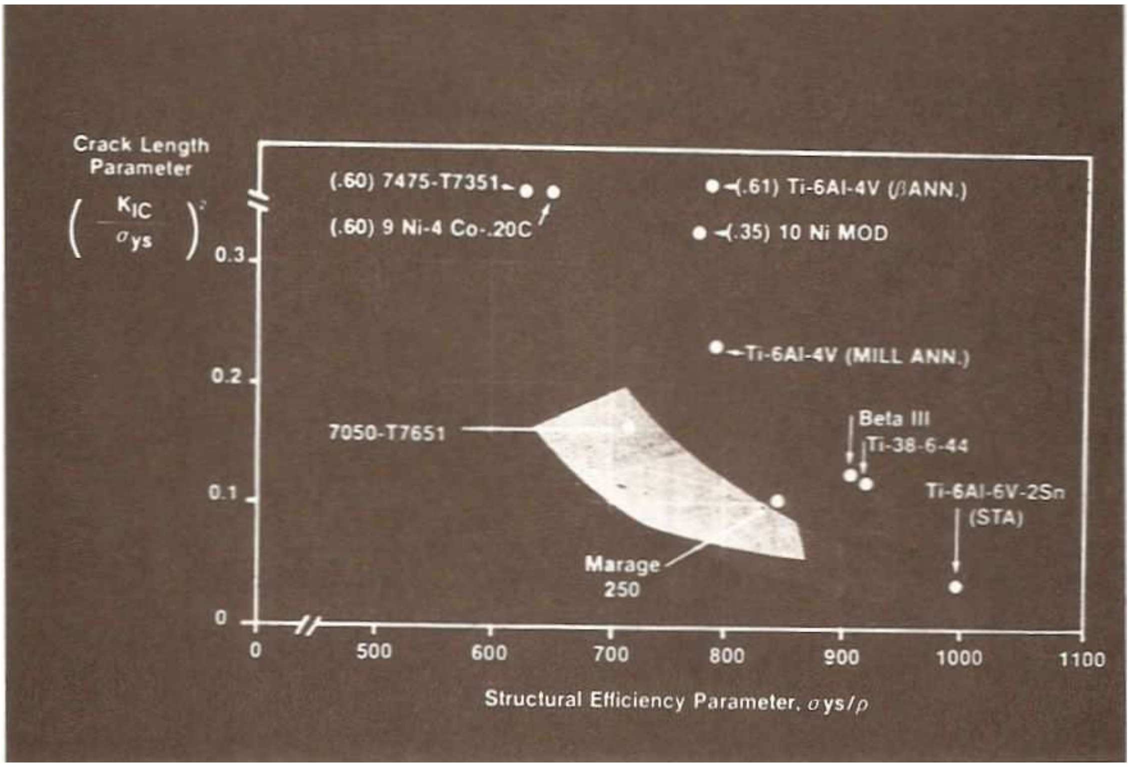


Slide No. 18

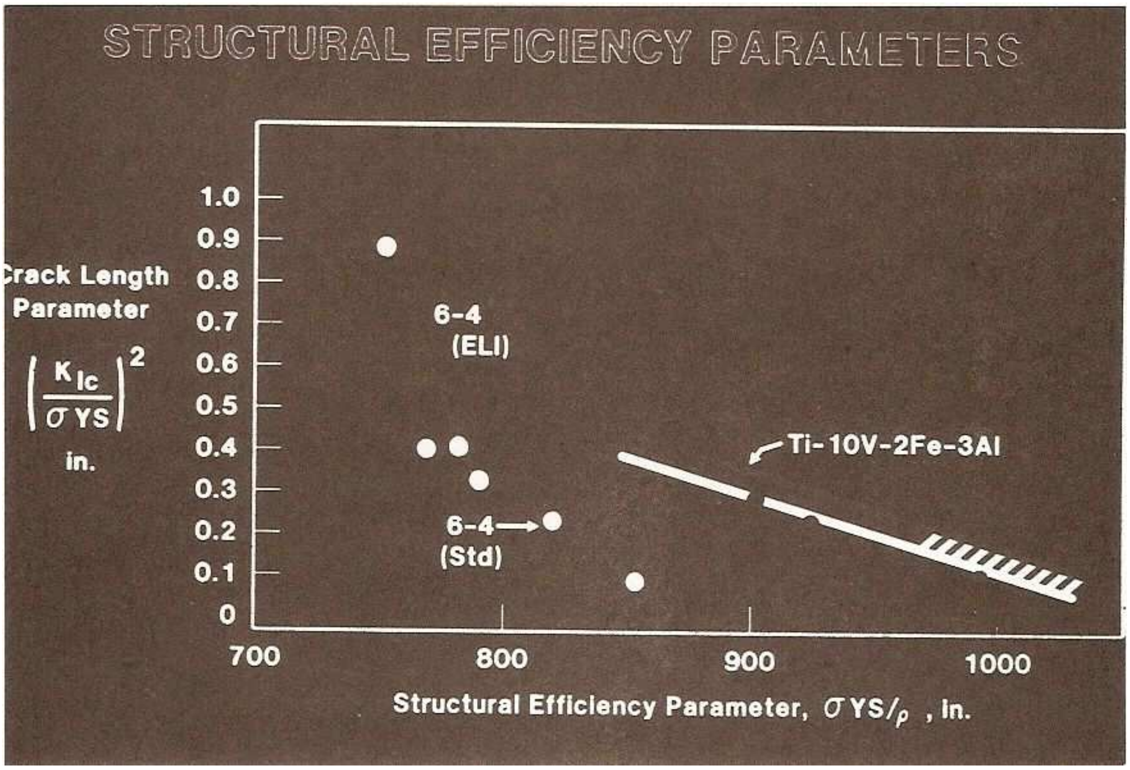
Titanium does have very good toughness. In slide 19 the tolerable crack length is shown as a function of specific strength. For a given strength you can see that the tolerable crack size is much larger for Titanium base alloys indicating very good toughness compared to steels and aluminum.

The next slide (Slide No. 20) shows more detailed data for specific Titanium alloys in a similar manner. Included in this is the standard material that has been used in airframe and in engines, Ti-6Al-4V alloy in a variety of different conditions. Also included is some of the newer alloys: 6-2-4-6, TI-17, Beta-C and 10-2-3. These alloys have improved toughness compared to Ti-6Al-4V.

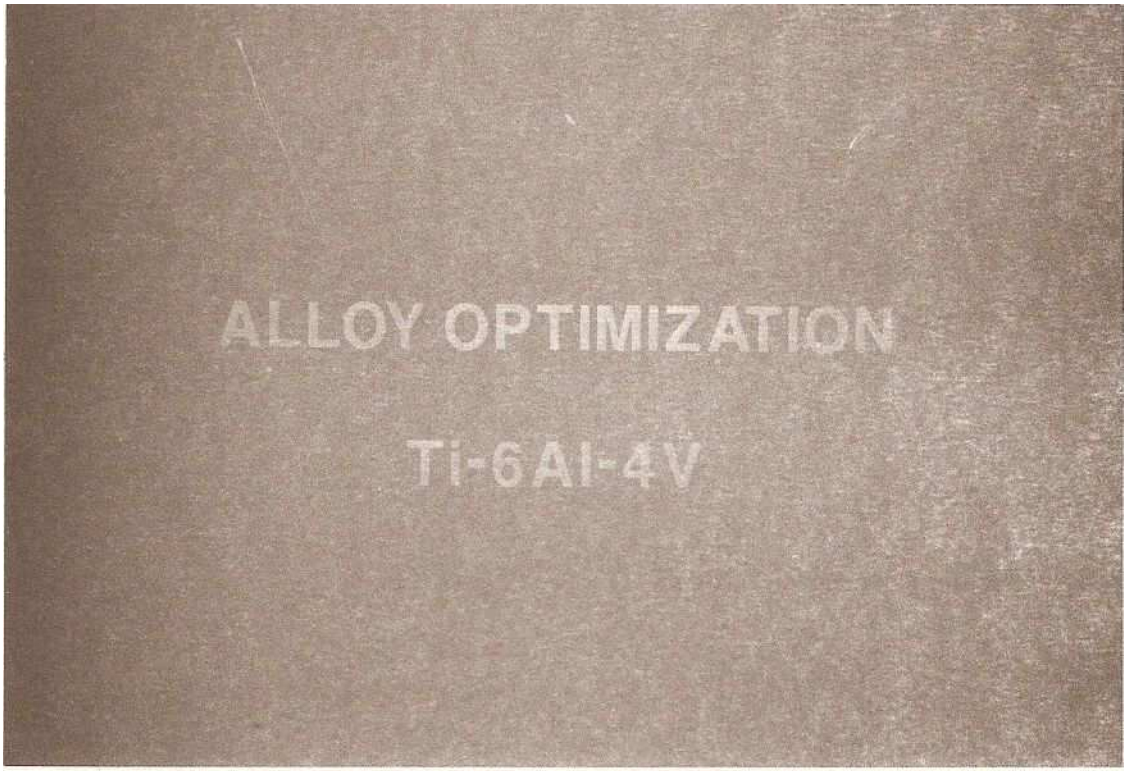
The second area of improvement in design (Slide No. 21) is merely optimizing older alloys to improve the characteristics of these alloys. I will just show you an example of a Ti-6Al-4V alloy. Slide No. 22 shows the



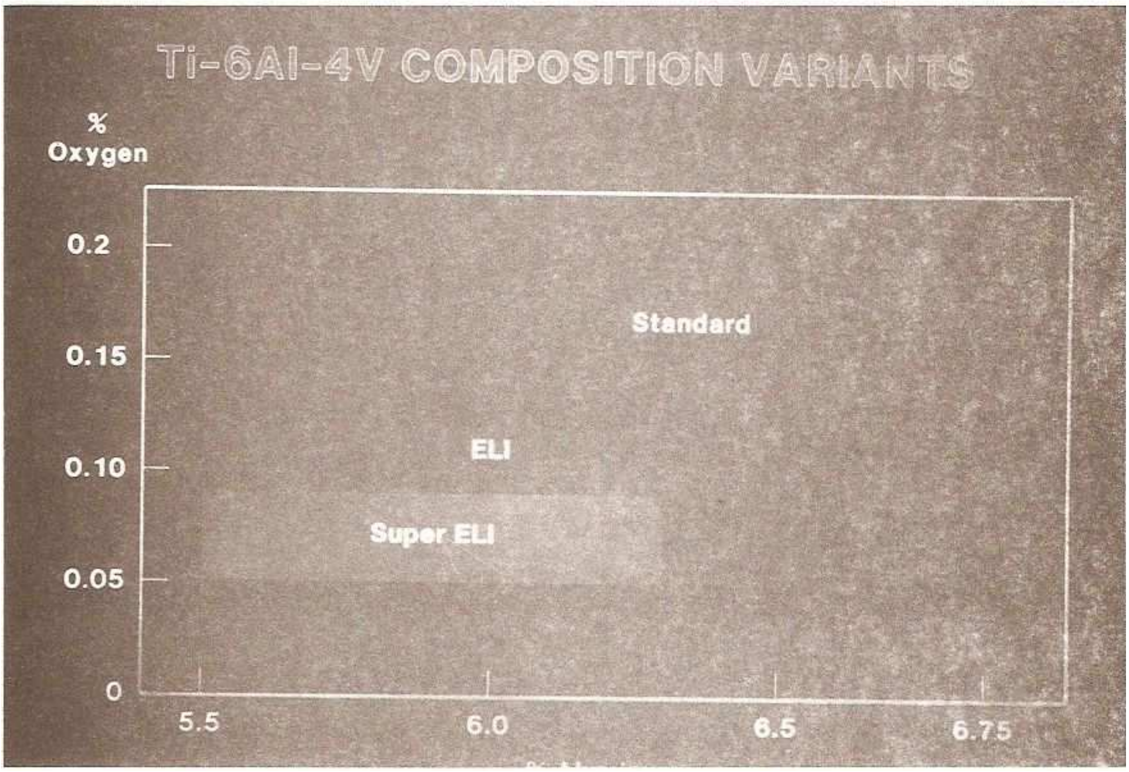
Slide No. 19



Slide No. 20

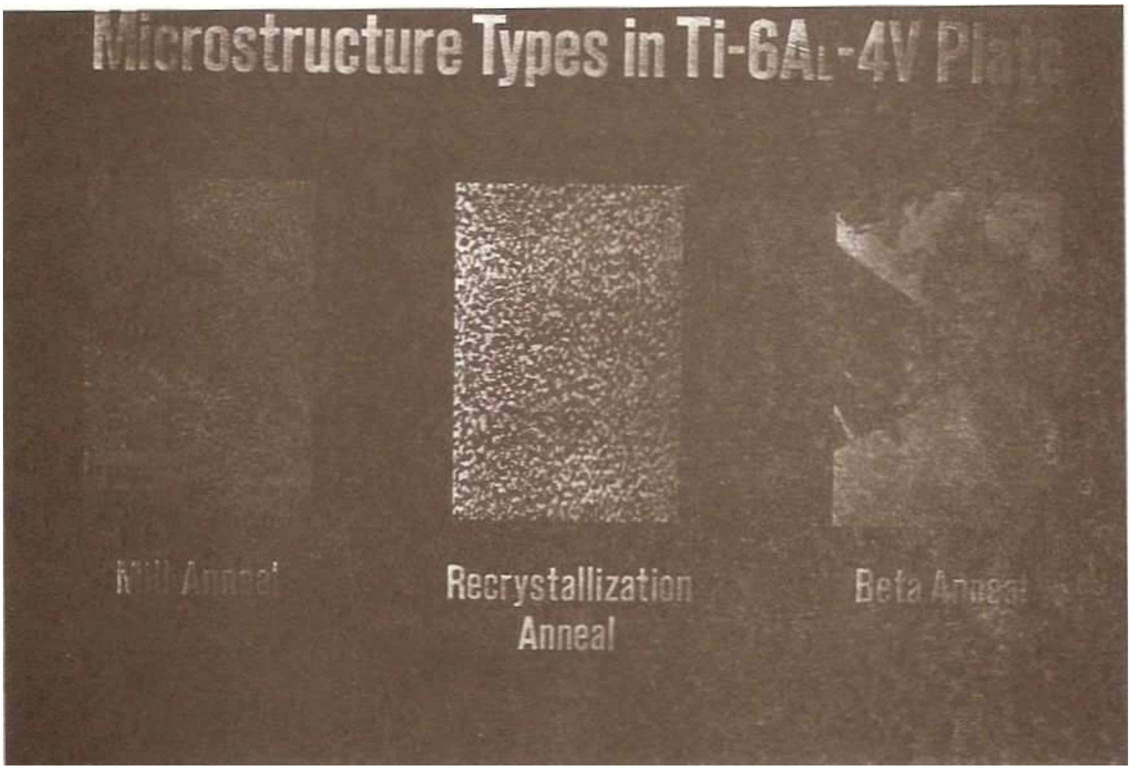


Slide No. 21

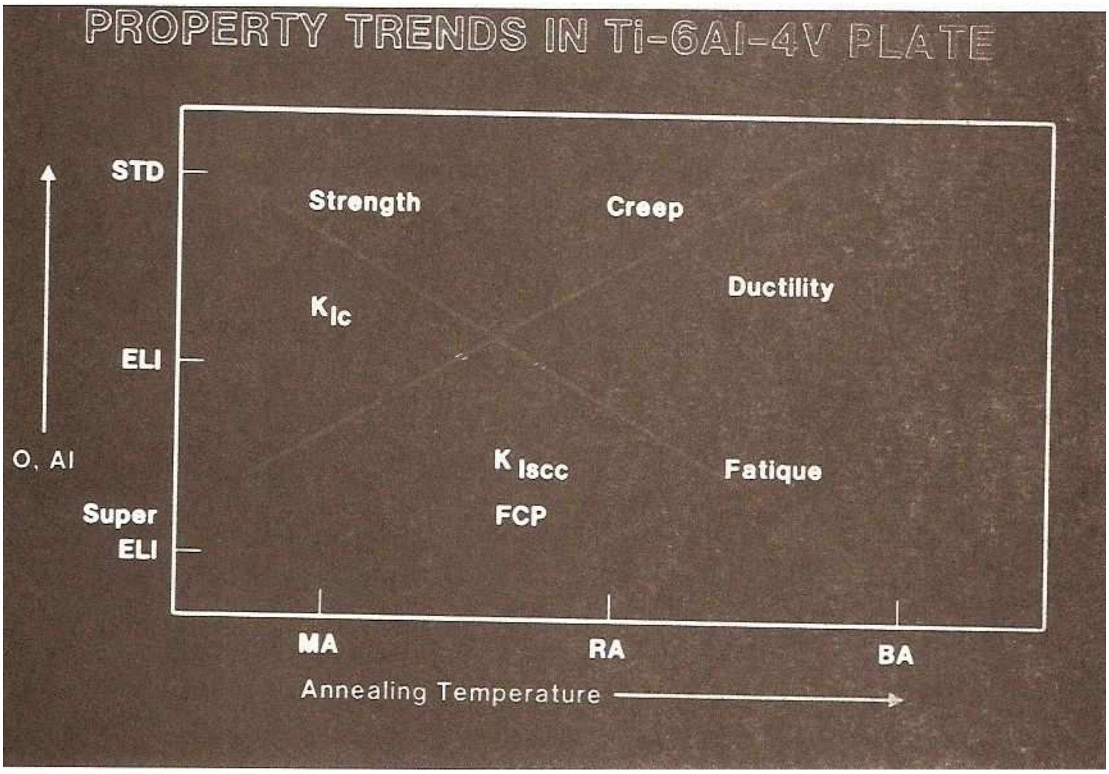


Slide No. 22

various compositions of the Ti-6AI-4V. The aluminum content in the specifications can range from 6.5 to 6.75% aluminum and the oxygen can range up to 0.2%. The Titanium producers now control these compositions very accurately, and as a result we have several 6-4 alloys: a standard grade, an ELI, which means extra low innerstitial, and a super ELI. So we have three different 6 Aluminum 4 Vanadium alloys. We add to this chemical control our ability to manipulate microstructure as shown in the next slide (No. 23). For any one of those compositions, we can obtain microstructures through low-temperature annealing, by moderately high-temperature annealing or by a very high-temperature annealing. As a result, as shown in the next slide (No. 24), by manipulating the annealing temperature and the composition, we can adjust properties. Unfortunately we do not optimize all the properties with one composition or one annealing treatment, so it is always a compromise. I have indicated trends in this slide as we increase annealing temperature and change composition. Different properties can be achieved for special applications such as helicopter, rotor hubs, and bomber airframes. Today, we can produce at least nine different versions of 6-4, depending on the design requirements.



Slide No. 23

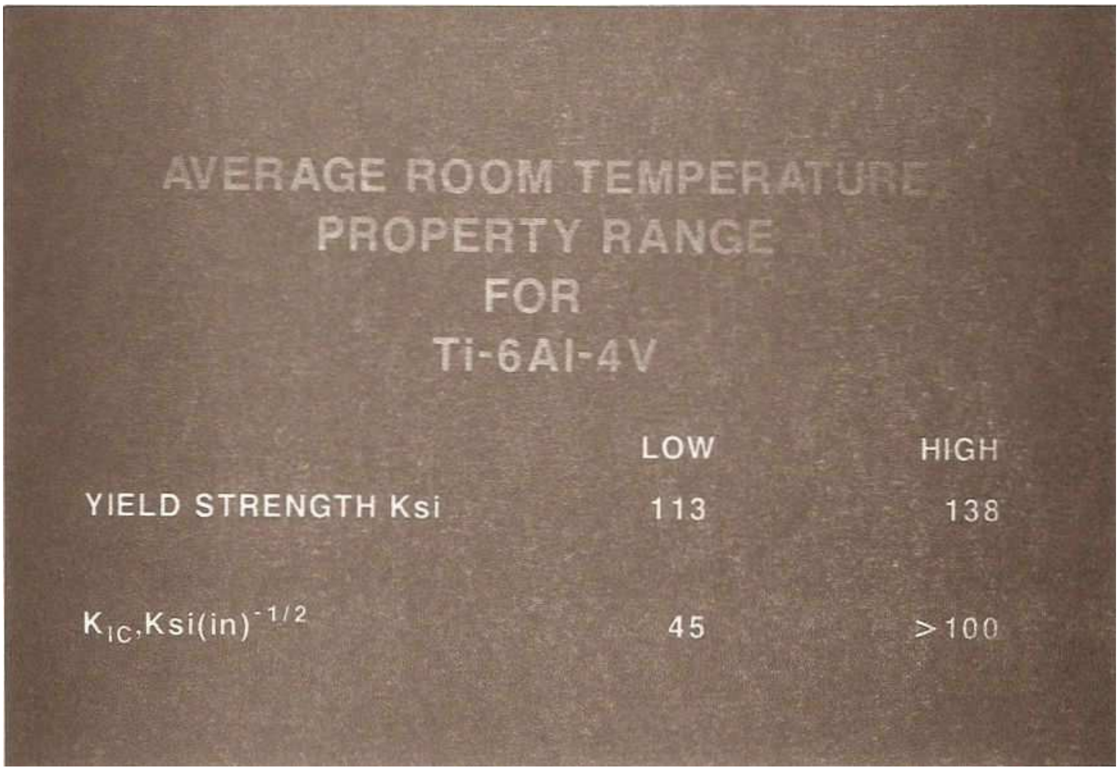


Slide No. 24

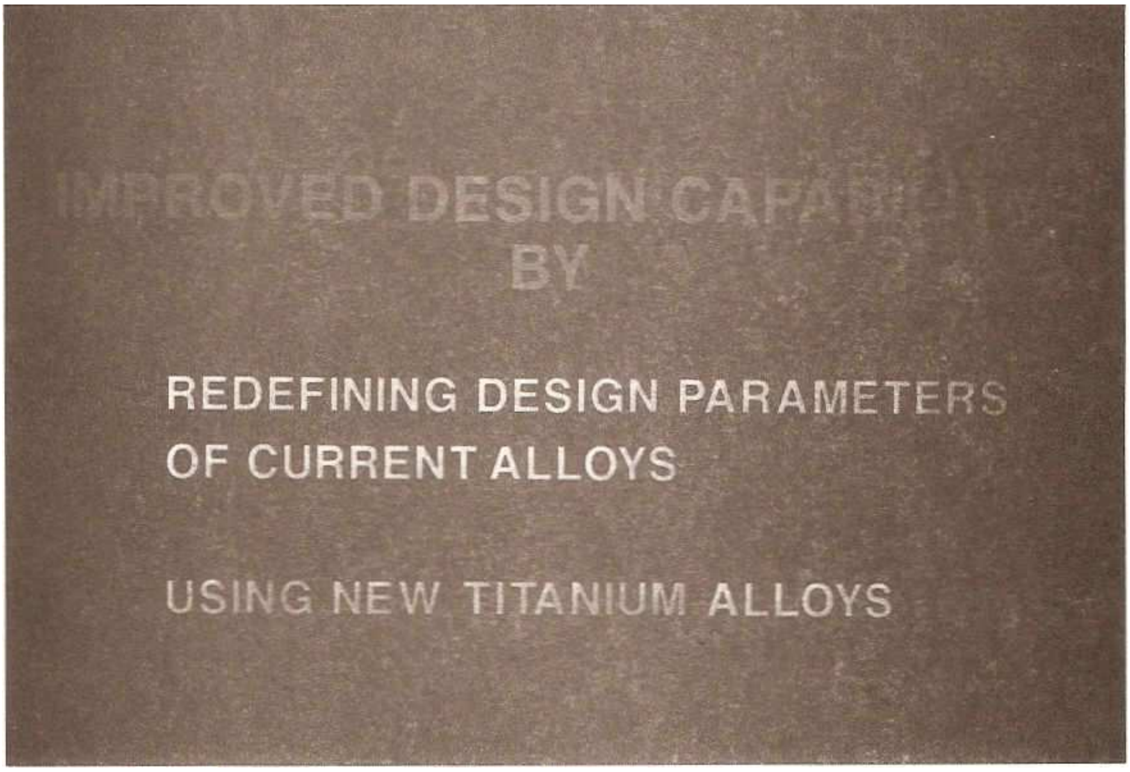
Slide No. 25 shows the range of properties that can be achieved by manipulation of composition and structure, Strength could be as low as a 113 KSI to as high as 138. Fracture toughness from 45, to 90 ksi in. Unfortunately, we cannot have high toughness with the high strength. A compromise is always necessary.

In summary (Slide No. 26), the designer has available improved design possibilities by utilizing the ability to more accurately control microstructure and composition of existing alloys. In addition there is a whole host of new Titanium alloys which offer the designer improved characteristics in strength as well as in toughness. Now let's review the Titanium trends that I discussed earlier, and see where this leads us.

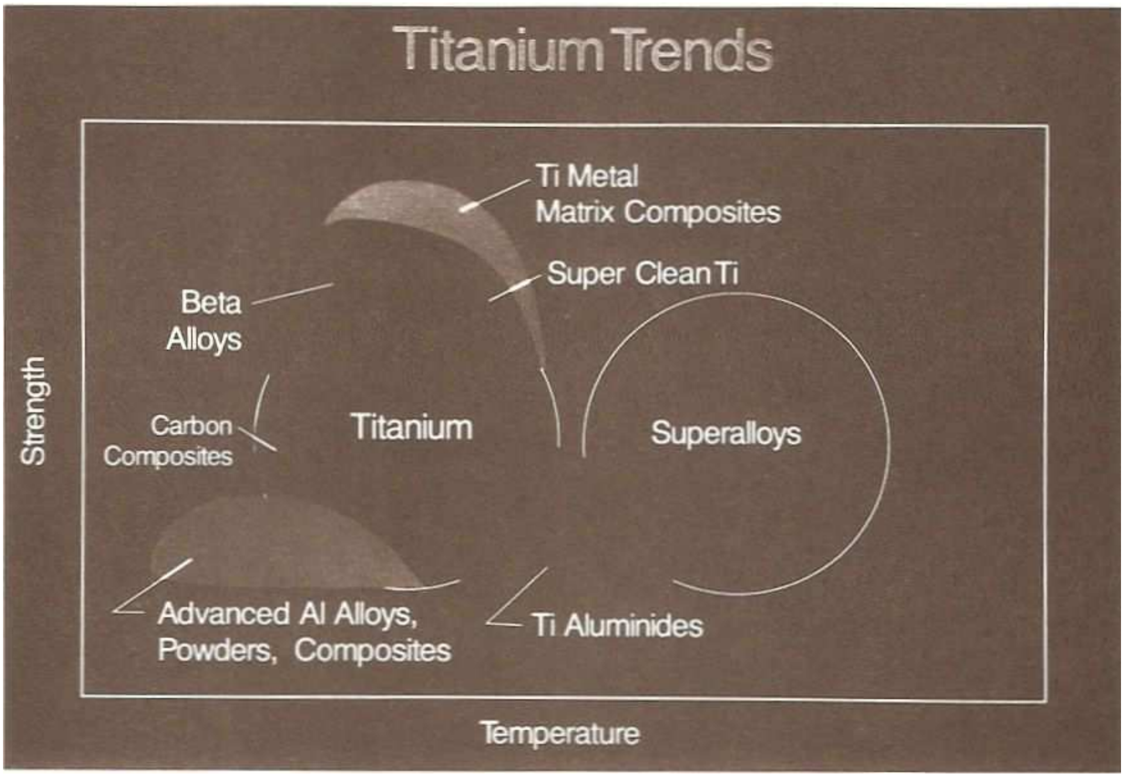
Slide No. 27 is similar to an earlier slide. Titanium is used at moderate temperatures slightly lower than super alloys. Because of the development of Titanium Aluminides, we anticipate Titanium being used at higher temperatures, but in the low stress area. We expect the threat of carbon composites at the low temperature area. In addition, we see the possibility of advanced aluminum alloys, powders and composites, in the low-strength side, low temperature side. However we expect to extend the usefullness of Titanium through newer high strength alloys and through new developments in Super Clean



Slide No. 25



Slide No. 26


Titanium Trends
Ti Metal
Matrix Composites
Super Clean Ti
Beta
Alloys
Strength
Carbon
Composites
Titanium
Superalloys
Advanced Al Alloys,
Powders, Composites
Ti Aluminides
Temperature

Slide No. 27

Titanium where a defect-free material alloys the designer to utilize higher stresses. Current development work occurring in Titanium-Metal-Matrix composites offers even further improvements in strength. I have attempted to provide a background in design requirements and the competitive environment for Titanium alloys in aerospace applications. Today Titanium has been very successfully utilized in this application; and we expect continued applications in the future as a result of improved alloys and improved processes to produce these alloys. Thank you.