Low-Density, Creep-Resistant Single-Crystal Superalloys

Weights of aircraft turbine rotors could be reduced significantly.

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Several recently formulated nickel-base superalloys have been developed with excellent high-temperature creep resistance, at lower densities than those of currently used nickel-base superalloys. These alloys are the latest products of a continuing effort to develop alloys that have even greater strength-to-weight ratios, suitable for use in turbine blades of aircraft engines. Mass densities of turbine blades exert a significant effect on the overall weight of aircraft. For a given aircraft, a reduction in the density of turbine blades enables design reductions in the weight of other parts throughout the turbine rotor, including the disk, hub, and shaft, as well as supporting structures in the engine. The resulting total reduction in weight can be 8 to 10 times that of the reduction in weight of the turbine blades.

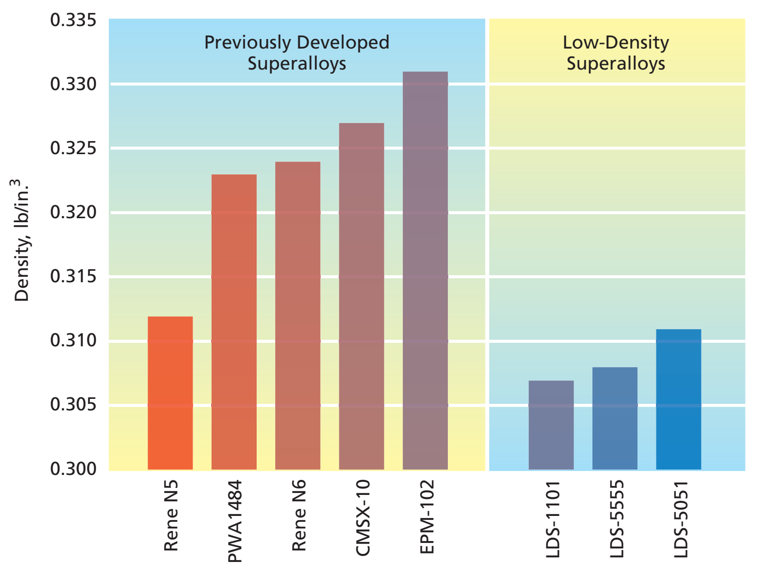

Figure 1. **Measured Densities of Low-Density Superalloys** are compared to previously developed superalloys.

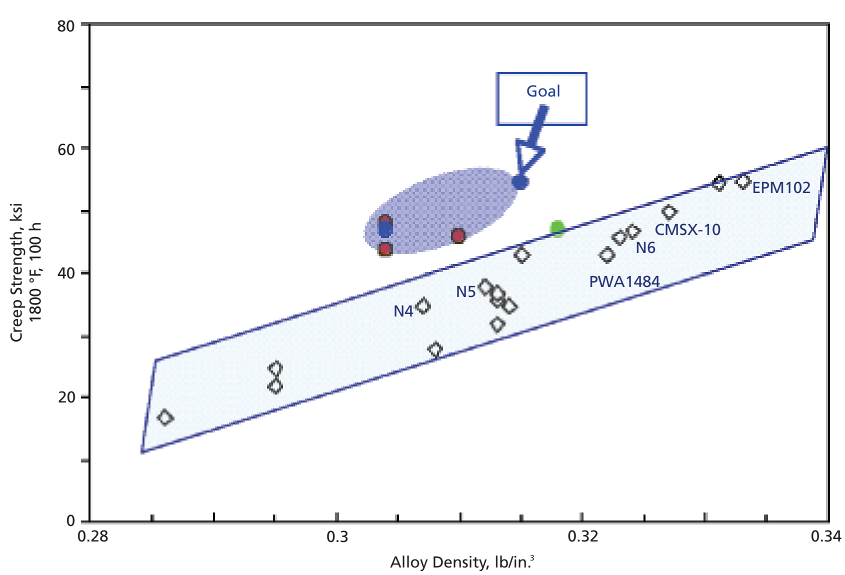

Figure 2. **Past Development Approaches** for first generation (Rene N4), second generation (Rene N5 and PWA1484), third generation (Rene N6 and CMSX-10), and fourth generation (EPM 102) superalloys increased alloy density with creep strength through the use of dense refractory element additions. The NASA GRC goal was to increase creep strength without concurrent increases in alloy density.

The approach followed in formulating these alloys involved several strategies for identifying key alloying elements and the range of concentration of each element to study. To minimize the number of alloys needed to be cast, a design-of-experiments methodology was adopted. A statistics-based computer program that models the effects of varying compositions of four elements, including effects of two-way interactions between elements, was used to test all possible alloys within the design space. The starting points for the computational analysis were three alloy compositions mandated by engineering consensus. After likewise identification of key alloying elements to vary and the allowed ranges of concentrations, the computer program then selects a minimum number of alloys within the design space to allow determination of effects for all four elements and their interactions.

On the basis of the results of the computational analysis, thirteen alloys were cast for determination of density and microstructural stability. Of these alloys, eight were cast into larger heats of single crystals and subjected to creep rupture tests at temperatures of 1,800 and 2,000 °F (982 and 1,093 °C, respectively). As shown in Figure 1, the densities of the three strongest alloys based on creep rupture were significantly lower than the density of the best second-, third-, and fourth-generation superalloys currently in use. As seen in Figure 2, the creep strength as a function of density for these various low-density superalloys was found to exceed those of the current superalloys.

In a departure from previous alloy-design practices, a conscious decision was made to sacrifice some resistance to oxidation for the sake of further optimization with respect to density and strength. This strategy involves reliance on a robust coating system for resistance to oxidation. The widespread use of coated turbine blades in engines for more than 40 years indicates this is a quite reasonable strategy. Nevertheless, these low-density superalloys were found to be as oxidation-resistant as that of first-generation-superalloy single crystals. Further optimization with respect to density and strength can be achieved if resistance to oxidation is further sacrificed to an acceptable extent.

This work was done by Rebecca A. MacKay, Timothy P. Gabb, James L. Smialek, and Michael V. Nathal of **Glenn Research Center**. *Further information is contained in a TSP (see page 1).*

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