United States Patent

Strelshik

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[54] **COMPRESSOR BLADES**

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[52] **U.S. Cl.** **416/236**
[51] **Int. Cl.** **F01d 5/10**
[58] **Field of Search** ....416/236, 236 A, 194, 196; 415/DIG. 1

[56] **References Cited**

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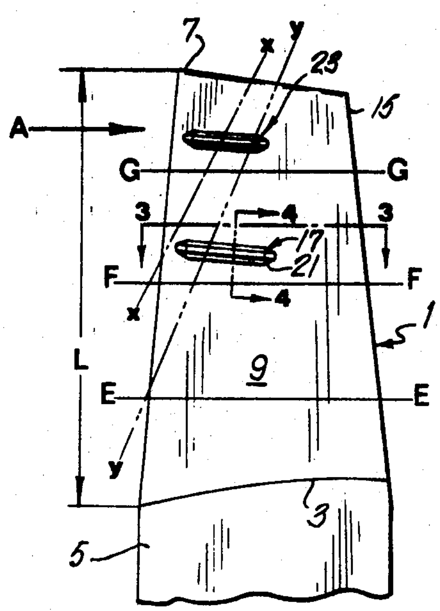
[57] **ABSTRACT**

An improved thin, plate-like, compressor blade having stiffening ribs on its airfoil surfaces extending from or adjacent the leading edge of the blade toward the trailing edge and being positioned on the blade to reduce the tendency of the blade to fail by buckling when the leading edge of the blade is struck by foreign objects.

5 Claims, 4 Drawing Figures



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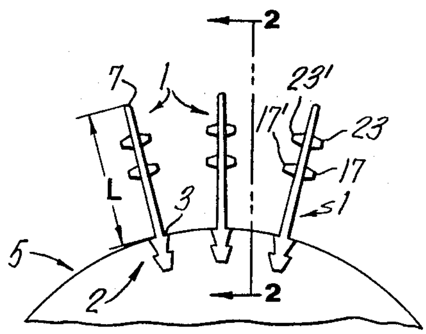

FIG. 1

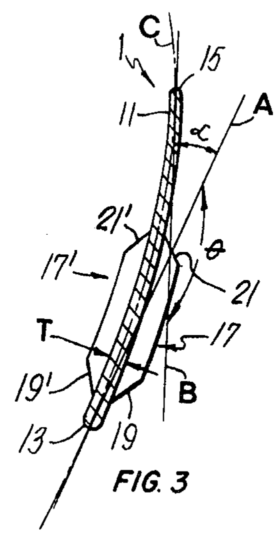

FIG. 3

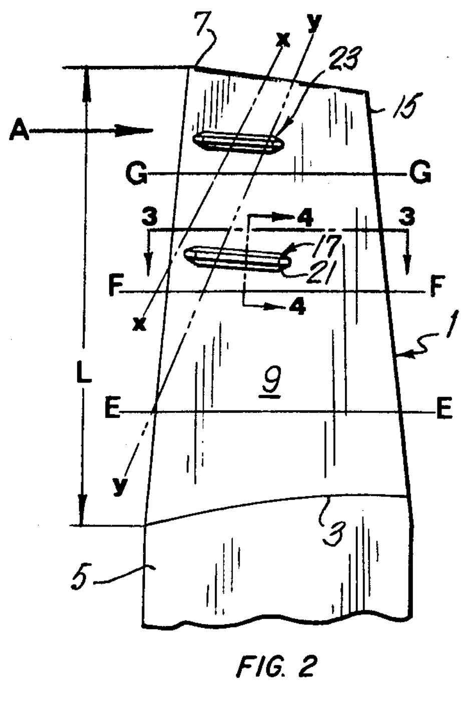

FIG. 2

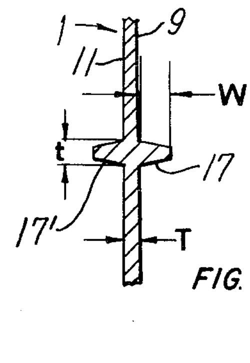

FIG. 4

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COMPRESSOR BLADES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improvements in compressor blades and compressor rotors incorporating the improved blades.

The invention is particularly directed to improvements in compressor blades, and compressor rotors incorporating the improved blades, used primarily in transonic and supersonic flow conditions. Blades used under these conditions normally are relatively thin with low camber areas and have a substantial width in comparison to their length. The blades have a dimensional configuration such that they act structurally, at least for a major portion of their length where the camber is low, as a plate member rather than as a beam member when impacted on an edge. Such blades, however, when used in the compressor rotor stage of a jet turbine engine, can be damaged by foreign objects, such as hail or birds, being ingested into the intake of the engine. The objects strike the leading edges of the blades and can cause the blades to fail by buckling and thus also cause possible failure of the compressor rotor itself.

2. Description of the Prior Art

Attempts have been made to minimize this problem of buckling due to ingested objects striking the leading edge. The blades have been made of material providing greater compressive strength than is necessary for their normal use. However, this increases the cost and/or the weight of the blades. Attempts have also been made to use thicker blades, but again, this increases the cost and/or the weight and also reduces the efficiency of the blades. An obvious solution would be to use blades having more curvature or higher camber when viewed in cross-section along a line parallel to the axis of the compressor so as to impart more rigidity to the blade. However, such blades are not satisfactory for transonic or supersonic flow.

SUMMARY OF THE INVENTION

It is the purpose of the present invention to provide an improvement in jet engine compressor blades, particularly thin blades having low camber regions or areas over a major portion of their length and used primarily in transonic or supersonic operating conditions, which results in improved resistance to failure by buckling at little increase in cost or weight. The improvement resides in providing at least one stiffening rib on each airfoil surface of the blade in the area of low camber. Each rib is positioned to traverse a theoretical line on the blade in the area of low camber along which the blade, without a rib, is most likely to buckle when an object impacts the leading edge of the blade. More particularly, each rib is located to extend from or adjacent the leading edge of the blade toward the trailing edge, traversing the theoretical buckling line of the blade, and is located closer to the unsupported tip end of the blade than to the root end in the area of low camber. In order to minimize loss in aerodynamic efficiency, each rib is preferably dimensioned, at least in the region it traverses the buckling line, to have a width no greater than twice the maximum thickness of the blade and to have a thickness no greater than the' maximum thickness of the blade.

Blades as described above have been found, in testing, to provide a significant increased resistance to failure by buckling when impacted with foreign objects. The use of the stiffening ribs provides further advantages in that they can be used, by removing material from one rib or the other, to assist in the dynamic balancing of a rotor incorporating the blades, to assist in tuning the natural frequencies of the blade, and to provide an additional cutting action, over and above that provided by the blades, to foreign objects, such as birds, thus reducing the size of matter that is passed further downstream into the engine.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail having reference to the accompanying drawings, wherein:

FIG. 1 illustrates a portion of a compressor rotor having blades which incorporate the stiffening ribs;

FIG. 2 is a cross-section along line 2—2 of FIG. 1 showing one blade in detail;

FIG. 3 is a cross-section taken along line 3—3 of FIG. 2 showing a detail of the ribs; and

FIG. 4 is a cross-section taken along line 4—4 of FIG. 2 showing a further detail of the ribs.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention is particularly directed toward the blades used in the compression stage rotor of a jet turbine engine, such as a turbofan jet engine, for example, and a rotor incorporating the blades, handling transonic or supersonic flow. The blades **1**, as shown in FIG. **1**, are connected at their root end **3** by suitable connecting means **2**, such as, for example, a cooperating fir-tree member and slot, about the periphery of the compressor rotor **5**. The tip end **7** of the blade is unsupported. Each blade **1** has two major airfoil surfaces **9**, **11**, a leading edge **13**, facing generally in the direction of airflow shown by arrow A as shown in FIG. **2**, and a trailing edge **15**.

The blade **1** preferably is of the type having a dimensional configuration over at least a major portion of its length to act structurally, in theory, as a plate member rather than as a beam member. A blade, to act structurally as a plate member, can be defined as one which, when subjected to external and/or inertial loading, will deflect due to bending moments in the chord-wise direction. In other words, unlike a beam, the blade will deflect non-uniformly along the chord of the blade. Such blades are relatively thin and have, over a major portion of the length of the blade, spaced from the root end **3**, a low camber angle no greater than **30°**. The camber angle is defined by the complement angle α of the internal angle θ formed by the intersection of tangent lines A, B drawn from the mean line C of the blade at the leading and trailing edges **13**, **15** respectively, as shown in FIG. **3**. In blades manufactured to have varying camber, the area of minimum camber is between two-thirds and seven-eighths of the length L of the blade from the root end. Generally, the compressor blades **1** used in transonic or supersonic flow conditions have a high camber at the root end of about 60°. The camber is reduced to about 30° at a distance about one-fourth of the length L of the blade toward the tip end 7 at line E—E. The camber reduces to about 25° at a distance about one-half of the length of the blade toward the tip end at line F—F. The camber may then be reduced to a minimum of about 5° at a distance about three-fourths of the blade length from the root end at line G—G from where it increases slightly to about 10° at the tip end 7.

These blades can fail by buckling if an object is ingested into the intake of a jet engine and strikes the leading edge 13 of the blade, particularly along the leading edge of the blade in the area where the camber is 30° or less. Buckling will occur in these areas across a line Y—Y as shown in FIG. 2, the location of which can, for different blades, be determined analytically or experimentally.

In order to minimize the tendency of the blade to buckle and to distribute the impact load to the rest of the blade, when struck by a foreign object on its leading edge, at least one rib **17**, **17'**, is provided, one on each major airfoil surface **9**, **11** of the blade as shown in FIG. 1. Each rib **17**, **17'** extends from or adjacent the leading edge **13** of the blade toward the trailing edge **15** and is generally positioned to extend in a direction substantially parallel to the direction of the airflow past the blade, as shown by arrow A, to minimize any reduction in aerodynamic efficiency of the blade. The ribs **17**, **17'** on the airfoil surfaces are opposite to one another to minimize unbalancing of the blade. The ribs **17**, **17'** traverse the buckling line Y—Y and are centrally located with respect to the buckling line to extend substantially the same distance to either side of the buckling line. Generally, each rib **17**, **17'** is located closer to the tip end of the blade rather than to the root end edge, since buckling is more likely to occur in the upper half of the blade where the camber is at a minimum, but are spaced from the tip end so as to be positioned approximately midway of the buckling line Y—Y length. The ribs **17**, **17'** are preferably located in the area of minimum camber. To minimize aerodynamic loss in efficiency of the blades, the ribs preferably should have a width w no greater than twice the maximum thickness T of the blade and a thickness t no greater than the maximum thickness T of the blade.

The ribs **17**, **17'** can be of any suitable shape in cross-section, such as, for example, rectangular or trapezoidal, and are integrally formed with the blade when the blade is being cast or otherwise manufactured.

The front **19**, **19'** and back **21**, **21'** edges of the ribs are preferably tapered to merge smoothly into the airfoil surfaces of the blade and reduce airflow resistance as shown in FIG. 3.

If the blades **1** are relatively long, an additional pair of opposed ribs **23**, **23'**, as shown in FIGS. **1** and **2**, can be provided on the airfoil surfaces **9**, **11** of the blade to improve the resistance of the blade to buckling. If additional ribs **23**, **23'** are used, they are generally spaced midway between a secondary line of buckling X—X which is developed after using a first pair of ribs **17**, **17'**. The ribs **23**, **23'** have substantially the same dimensions as the ribs **17**, **17'**.

Tests of rotors having blades with low camber portions incorporating the stiffening ribs have shown that such blades have a greatly improved resistance to failure by buckling, as compared to similar low camber blades with no ribs, when foreign objects strike the leading edge of the blade.

I claim:

1. A thin, plate-like, compressor blade, said blade having a leading edge, a trailing edge, a tip end edge, a root end edge having means permitting connection of the blade to a rotor, and two opposed airfoil surfaces bounded by said edges, the blade having a decreasing camber toward the tip and becoming substantially flat adjacent the tip, said blade having a buckling line in the substantially flat portion adjacent the tip, at least one pair of elongate stiffening ribs positioned on the plate-like blade in a low camber region of the blade to strengthen it against buckling by impact of foreign objects on the leading edge, the ribs being located on the opposite airfoil surfaces in directly opposite relation to one another, each rib extending from a point adjacent the leading edge of the blade and extending toward the trailing edge, each rib being located in the tip end edge area of the blade but spaced from the tip end edge, and said region of the blade has a camber of less than 30°, this area of the blade including the location of the buckling line, the ribs on adjacent blades being substantially spaced circumferentially from one another.

2. A compressor blade as claimed in claim **1**, wherein each stiffening rib projects from its airfoil surface a distance no greater than twice the maximum thickness of the blade.

3. A compressor blade as claimed in claim **2**, wherein each stiffening rib has a maximum thickness no greater than the maximum thickness of the blade.

4. A compressor blade as claimed in claim **1**, including an additional pair of stiffening ribs on the blade, one rib of the additional pair being located on one of the airfoil surfaces, and the other rib of the additional pair being located opposite to said one rib of the additional pair on the other airfoil surface, said additional pair of ribs being located closer to the tip end of the blade than the root end, each rib of said additional pair extending from or adjacent the leading edge of the blade toward the trailing edge, said additional pair of ribs being spaced from the first pair of ribs toward the tip end.

5. A compressor rotor, a plurality of thin, plate-like, blades mounted about the periphery of the rotor, each blade having a leading edge, a trailing edge, a tip end edge, a root end edge, and two airfoil surfaces bounded by said edges, each blade being relatively thin and decreasing in camber toward the blade tip to a substantially flat configuration forming a region subject to buckling, cooperating means on the root end edge of each blade and the periphery of the rotor permitting connection of each blade to the periphery of the rotor, at least one pair of stiffening ribs positioned on each plate-like blade to strengthen it against buckling due to impact of foreign objects on its leading edge, one rib being located on one airfoil surface and the other rib being located on the other airfoil surface opposite to said one rib, each rib extending only from a point adjacent the leading edge of the blade toward the trailing edge, each rib being located in the tip end area of the blade but spaced from the tip end, in a region of the blade where the camber is less than 30°, and in the buckling region.

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