Sept. 24, 1957 J. W. HOWLETT ET AL 2,807,435

TURBINE STATOR BLADE

Filed June 12, 1951

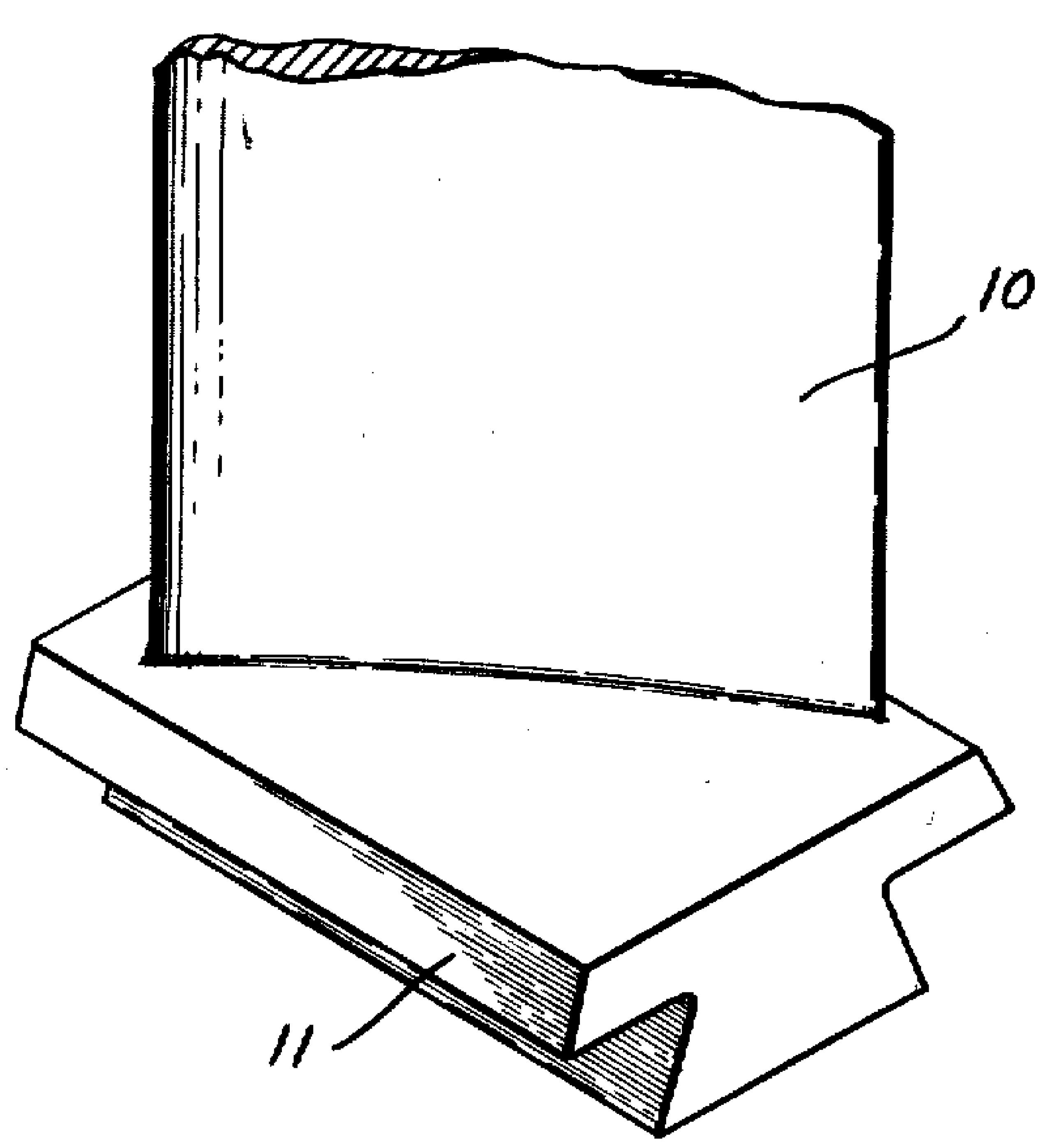

FIG. 1

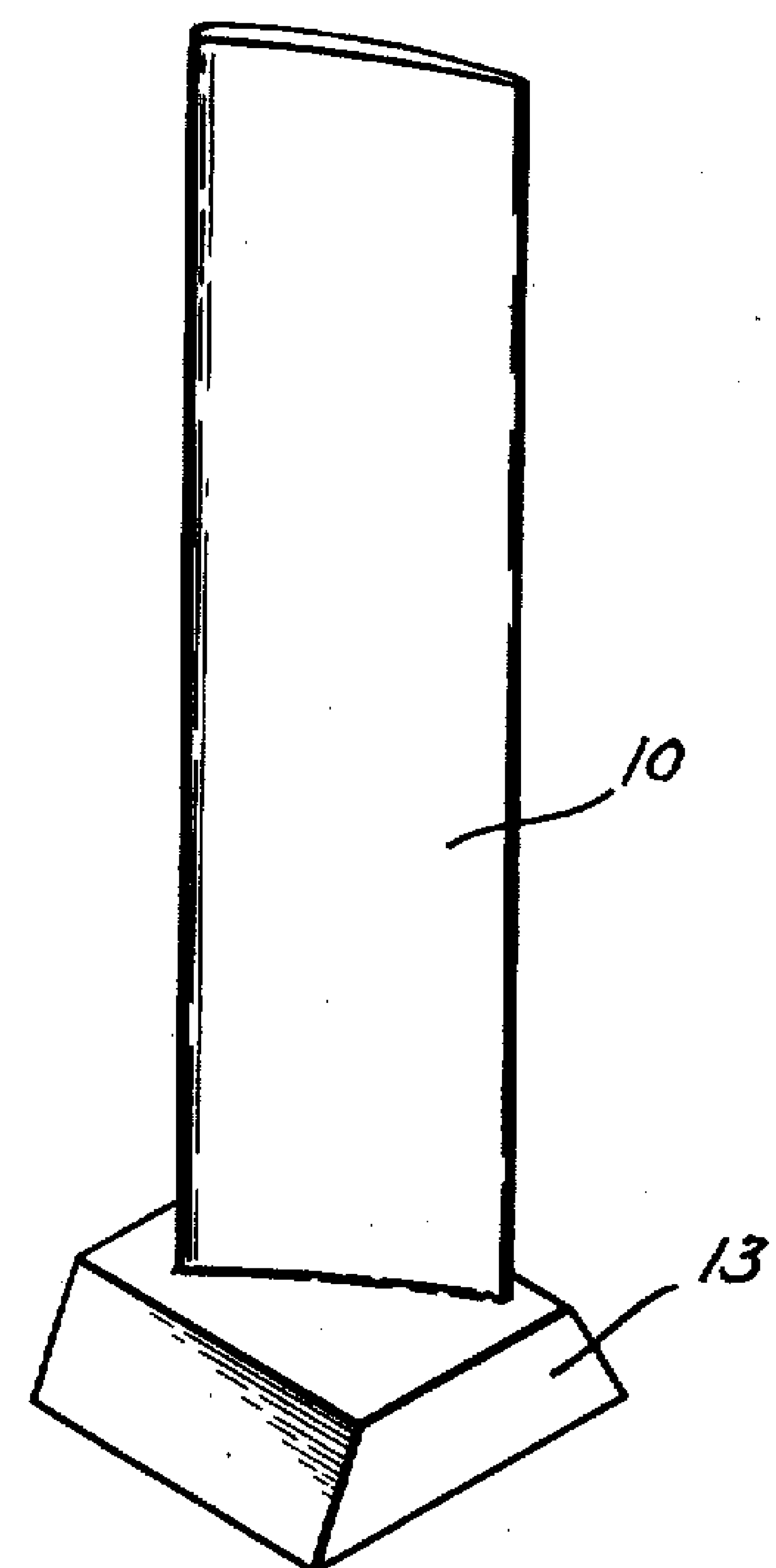

FIG. 2

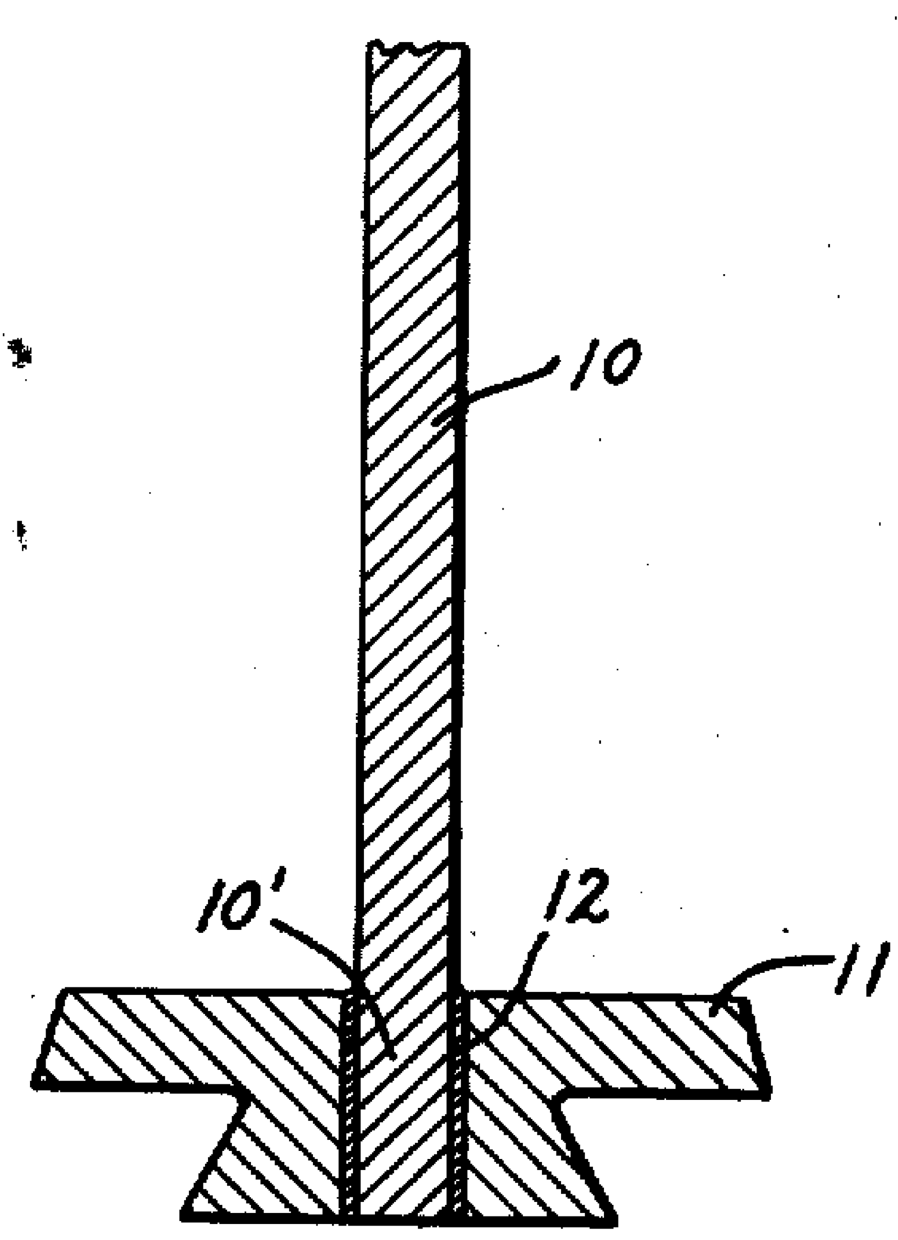

FIG. 3

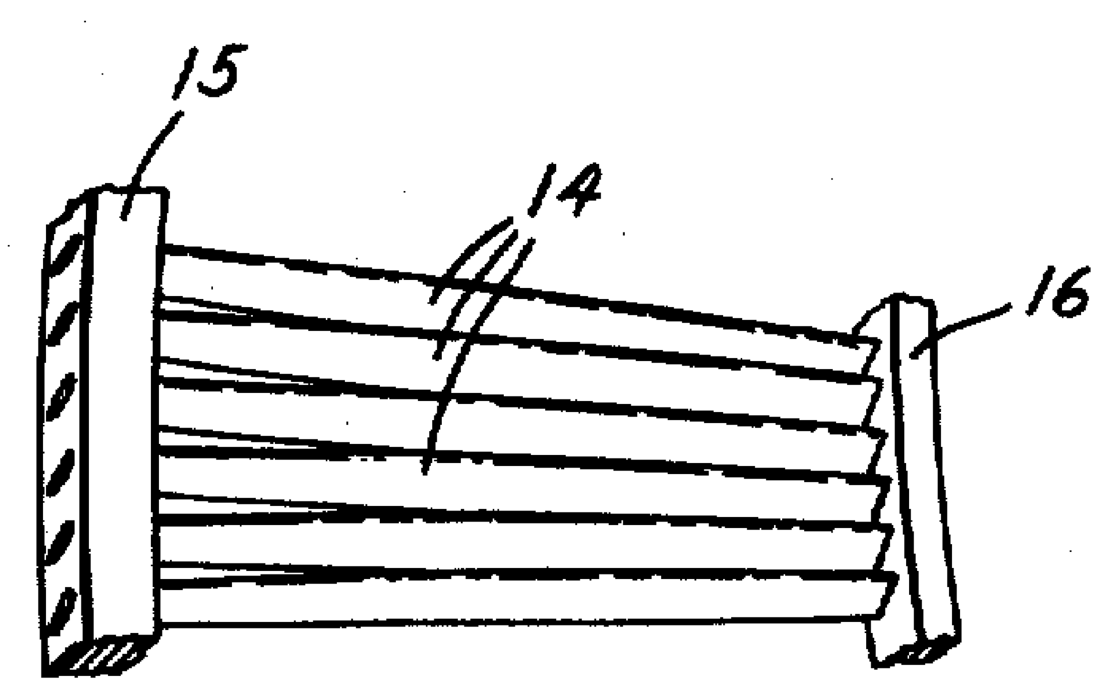

FIG. 4

INVENTORS

BY

ATTORNEYS

United States Patent Office

2,807,435

Patented Sept. 24, 1957

1

2,807,435

TURBINE STATOR BLADE

John W. Howlett and Sidney Bernard Dew, Lymington Hants, England, assignors to Fairchild Engine and Airplane Corporation, Farmingdale, N. Y., a corporation of Maryland

Application June 12, 1951, Serial No. 231,154

4 Claims. (Cl. 253—77)

This invention relates to turbine stator blades, and has particular reference to a composite stator blade for a gas turbine and to the method of making the same.

One of the major difficulties which confronts the manufacturer of gas turbines for aircraft propulsion and other purposes is the high cost and difficulty of fabrication of the compressor stator blades which not only are required in quantities up to several thousand blades for some types of turbines but also must be machined to fine machine tolerances. In order to meet physical requirements, the blades and their footings were initially machined from solid forgings at great expense, time and labor.

In accordance with the present invention, a stator blade particularly adapted for the compressors of gas turbines, and the method of making the same, are provided in which the blades are formed of metal strip stock having the required properties and shaped to airfoil sectional contour. The strip is severed into the required blade lengths and one or both ends of each blade bonded into a cast footing or footings which are then keyed into the stator frame and shroud ring in the proper predetermined relation.

More particularly, the invention comprises rolling, drawing or extruding a corrosion-resistant metal such as stainless steel, Monel metal, or the like, into a strip of the predetermined airfoil contour either of solid section or hollow section, as required. The strip is then accurately severed to the length required for the blade, plus the thickness of the footing at one or both ends. The footing and/or ends of the blade are coated with a thin film of molten aluminum or aluminum base alloy overlying a thin layer of an alloy of the blade metal and aluminum and, while the film of aluminum overlying the alloy is molten or plastic, the molten aluminum or aluminum base alloy of proper physical characteristics for the blade footing is cast around the aluminum-coated end of the blade to become integrally bonded to the blade through the alloy interface when the cast metal congeals. The same operation as is carried out of a footing is required for the opposite end of the blade and where more than one blade, such as a segment of the stator is desired to be formed as a unit, the ends of the several blades are cast into the plural footing, after the aforementioned pretreatment. Finish machining of the single or plural footing is then effected to complete the blade unit for assembly into the compressor of the turbine.

It will be seen that the composite turbine stator blade of this invention is readily fabricated in a simple, rapid manner and with the expenditure of a minimum of labor and time compared to the prior practice and that the blade unit is strong and corrosion resistant.

For a more complete understanding of the invention, reference may be had to the accompanying drawings, in which:

Figure 1 is a perspective view of a compressor stator blade embodying the invention and made according to the process thereof;

2

Fig. 2 is a perspective view of the stator blade before the footing blank is machined;

Fig. 3 is a perspective view of a stator blade segment structure formed integrally in one operation and embodying the invention; and

Fig. 4 is a fragmentary axial section through the root of the stator blade and the footing and shows the bond uniting them.

Referring to Fig. 1 of the drawings, the stator blade **10** preferably is formed of stainless steel or Monel metal, rolled, drawn or extruded in strip form to predetermined airfoil section, or it may be extruded to hollow airfoil section for interior cooling if desired. A suitable stainless steel is specification DTD .571 (0.2 C, 1.0 Mn, 0.05 S, 0.05 P, .020 Si, 7–12 Ni, Cu 16–20, 75.8 Fe+traces of W, Ti, Cu, V and Ta as stabilizers) or equivalent specification AMS 4292 stainless steel.

However it is formed, the strip stock is cut or cropped into proper lengths for the blades **10**, including the length to be incorporated in the footing **11** for the free end blade shown in Figs. 1 and 4 or for castings **15** and **16** at both ends of the structure shown in Fig. 4.

The mold for the footing blank **13** may be shaped as shown in Fig. 2, but is inverted for upward draft with the blade **10** projecting through the bottom of the mold and held therein at the proper pitch angle to the footing by means of a suitable fixture below or forming part of the mold.

Prior to insertion in the mold, the root **10'** of the blade **10** is heated to the temperature at which aluminum alloys with the metal of which the blade **10** is made, preferably by immersing the blade root **10'** in a bath of molten aluminum or aluminum base alloy for a sufficient period of time to reach the said temperature, whereupon the alloying action between the metal of the blade root **10'** and the molten aluminum takes place. Immediately upon formation of the alloy, which in the case of a steel blade **10**, is a ferro-aluminum alloy, the blade root **10'** is withdrawn from the aluminum bath and cooled or quenched sufficiently to decrease its temperature below the alloying temperature so as to arrest the continuation of the formation of the alloy and confine the thickness of the alloy to a dimension on the order of a thousandth of an inch or less. Although the alloying layer is necessary to molecular bond between the aluminum or aluminum alloy comprising the footing **11** and the metal constituting the blade **10**, the brittleness of such alloys, particularly ferro-aluminum alloy, requires that the alloy layer be held to a minimum thickness.

The blade **10**, while its root **10'** is heated to a temperature such that the surface film of aluminum overlying the alloy at the interface is molten or plastic, is then placed with the root **10'** in the mold and molten aluminum or aluminum base alloy selected for the footing **11** is cast around the blade root **10'** to form the footing blank **13** shown in Fig. 2. Any suitable aluminum or aluminum base alloy having the desired physical properties and corrosion resistance may be utilized. A suitable aluminum base alloy is specification BSS .2L .33 (0.1 Cu, 0.6 Fe, 10–13 Si, 0.5 Mn, 0.1 Zn, 0.2 Ti and 85–88 Fe) or equivalent specification AMS 4292 alloy.

Owing to the fusion union between the molten or plastic film of aluminum on the blade root **10'** and the molten casting metal of footing blank **13**, the aluminum or aluminum base alloy is homogeneous outwardly from the surface of the ferro-aluminum alloy layer or other alloy layer **12**, which accordingly constitutes the molecular bond between the aluminum or aluminum alloy footing blank **13** and the blade root **10'**. Further details of the general process for forming such bimetallic structures may be had upon reference to Patent No. 2,396,730, issued Mar. 19, 1946.

As is well known, gas turbine compressor stator blades are subjected to substantial vibration stresses and hence, proper root end fixity, resonance and flutter factors are essential to preclude failure, as well as proper damping and fatigue characteristics. For example, the total damping present in the blade support system is a vital property inasmuch as it determines the stress amplitude under resonance conditions for any given excitation force or energy supply. In the case of the composite blade structure shown in Figs. 1 and 4 in a compressor, the sources of damping in the order of their importance are: (1) support friction at the surfaces of the root **10'** which depends on the materials, surface condition, clamping force, and the like; (2) hysteresis losses in the bond **12** and the metal of the footing **11** as well as their form and (3) aerodynamic.

The vibration displacement of an impulse-excited damped blade may be expressed by an equation of the form:

$$y=y_0e^{-\delta ft}\cdot \cos 2\pi ft. \qquad (1)$$

wherein

y_0=initial maximum displacement at which t is chosen=0.
$\delta=\log(yn/yn+1)=\Delta y/y$, the logarithmic decrement
f=frequency of damped blade
t=time in seconds after y_0

Comparative damping measurements were made on the new composite blade and on the equivalent solid or one-piece blade under identical clamping conditions after being excited in the 1st flexural mode by a simple ballistic method. It was found that the sounding time for any given blade showed negligible dependance on exciting impulse magnitude providing this magnitude exceeded a certain point. Hence, assuming that each blade starts with identical amplitude and it is heard until this value falls to a specific value y_0, then if t is the time taken, equation (1) indicates that:

$$\delta_1 f_1 t_1=\delta 2f2t2=\delta 3f3t3$$

Hence

$$\frac{\delta c\text{ (for composite blades)}}{\delta a\text{ (for unitary blades)}}=\frac{f_a t_a}{f_c t_c} \qquad (2)$$

The results of the comparative measurements on the composite blade of this invention and the solid one-piece blade show that frequency (f) of the latter was 605 C. P. S. and time (t) was 3¼ seconds, whereas for the composite blade f was 423 C. P. S. and t 2¼ seconds and ran as low as 401 C. P. S. for f and 2 seconds for (t).

The tests also indicated that the use of a plain bond shown in Fig. 3 provides more damping than that provided by a root **10'** keyed into the aluminum footing **11** or slotted or pierced to afford a bridge of aluminum extending through the root **10'**. Also, the root size does not appear to have any well defined effect. Hence, in view of the increased damping, plain or unslotted blade forms are advantageous, quite apart from production cost considerations which also support such a choice.

The influence of damping on the natural frequency of a blade is given by the expression:

$$\frac{f_d}{f_0}=\sqrt{1-\left(\frac{c}{c_c}\right)^2}=\sqrt{1-\left\{\frac{\delta}{2\pi}\right\}^2} \qquad (3)$$

because

$$\delta=\frac{2\pi c}{c_c} \qquad (4)$$

where

f_d=natural frequency of blade with actual total damping.
f_0=natural frequency of blade with zero total damping.
c=damping const. in equivalent systems D. E.: $m\ddot{x}+c\dot{x}+kx=0$. (5)
$c_c=2\sqrt{mk}-4\pi mf_0$, the critical damping value of c for blade. (6)

From (3) it can be shown that the condition necessary in order to make f_d 1% less than f_0 is $\delta=0.895$ i. e., $c=0.1425\ c_c$.

The natural frequency of a blade form depends on the shape and size, etc. of the form and also on the root end fixity conditions. The root end fixity condition may be expressed as a factor by which the normal equation relating to perfectly rigid termination of a blade form must be multiplied in order to get the actual frequency, under the conditions to be described. So far as the new composite blades are concerned, the main factors determining the root end fixity condition are the stiffness of the footing and the clamping condition at the bond **12**. The magnitude of the latter is very large so that the infinite inertia condition implied by "perfectly rigid fixing" is practically met. The root clamping condition is comprised of the materials of root **10'** and footing **11**, their surface condition and clamping magnitude at bond **12**.

Another way of regarding root end fixity effects is to consider the equivalent increase of blade form length which gives the correct frequency when substituted in the equation referred to above. The expression used for estimating the frequency of a uniform blade supported perfectly rigidly at one end and free at the other end was:

$$f_c=\frac{1}{2\pi}\left(\frac{1.875}{lm}\right)^2\sqrt{\frac{EIg}{\rho a}}\text{ C. P. S.} \qquad (7)$$

Where l_m=mean length in inches, measured from upper surface of blade footing **11**.
g=386 inches/sec.^{2}.
$E=29\times 106$ lbs./in.^{2}.
ρ=.27914 lbs./in.^{3}.
$I=8.823\times 10^{-6}$ in.^{4}.
a=.317 in.^{2}.

Since f is proportional to l_2, it is apparent that the effective increment of length of a blade form produced by given root end fixity conditions would be represented by

$$\Delta l=\{\sqrt{f_c/f_0}-1\}lm\text{ ins.} \qquad (8)$$

where f_c and f_0=calculated and observed values respectively.

An examination of the blade frequencies in connection with the foregoing leads to the following conclusions as to design of the composite blades having a desired 1st flexural frequency:

(1) The end fixity constant f_0/f_c lies between 0.831 and 0.875 for all types of root termination, and the shorter axial length for root **10'** gives a higher value.

(2) The effective length of the blade form is

$$\sqrt{f_0/f_c}$$

times the measured length and lies between 1.069 and 1.097 for all types of root termination.

(3) The results indicated by (2) are further reflected by the values shown for effective length increment and show that the effective length changes with mean blade length.

The fatigue strength of the new composite blade was compared with that of the one-piece blade and footing, where the blade **10** was of the same material, contour and dimensions as the one-piece blade. Considering that the fatigue strength of a blade is expressed as the maximum alternating stress in any part which it can withstand indefinitely, the resonant strength of a blade is a reliable measure of the energy it can absorb or the exciting force it can withstand under resonance conditions. Failure of the one-piece blade occurred at 463,480

C. P. S. and of the new composite blade at 2,268,350 C. P. S., which represent the average failure cycles of a comparable number of resonance tests of both types of blade units. In each case failure occurred at the root fillet of the blade, and the nucleus of the failure was near the center of the convex side of the airfoil section. In no case of failure of the new composite blade was there any sign of loosening of the blade root **10'** in the footing **11**, the bond **12** remaining sound. In view of the location of the fracture, it is apparent that such factors as root size or special fixing like a slotted root, would not appreciably affect the fatigue strength of the blade form. The fatigue strength of the composite blade is about ± 20 ton/in.^{2}, to break in 10^7 cycles, that of the one-piece blade is about ± 8.3 and 7.0 tons/in.^{2} to break in 10^7 and 10^8 cycles respectively. The fatigue strength of the blade **10** itself is little short of that of the material for the composite blade, which cannot be said for the one-piece blades. The resonant strength of the plain fixing composite blade of Figs. 1 and 4 exceeds appreciably the value of 40 times that of the one-piece blades.

The foregoing test results were based on stainless steel blades of the specification given, including a Young's modulus on the order of 29×10^6 lbs./in.^{2}, which is characteristic of suitable stainless steels, but Monel metal blades were found to have comparable properties in the composite structure including a Young's modulus on the order of 25 to 26×10^6 lbs./in.^{2}, and Monel metal has the additional advantage of ease of working, which offset the mild disadvantage in some instances of higher specific gravity although the natural frequencies of Monel metal blades, having the same dimensions and contour of stainless steel blades, are approximately 0.85 of the values of the latter. It has been found that corrosion resistant alloys of the stainless steel and Monel metal classification having a Young's modulus of between about 25 and about 30×10^6 lbs./in.^{2} are suitable for service as the blade material in the composite stator blade unit of this invention.

The summary of the tests of the composite blade unit of this invention shows that (1) the damping constant of the composite blade is approximately 2½ times the value of the equivalent one-piece blade, (2) the fatigue strength of the composite blade is greater than 7 times that of the equivalent one-piece blade, (3) the resonant strength of the composite blade is at least about 40 times that of the one-piece blade, (4) root end fixity of the composite blade is approximately 0.86, (5) root retention of the blade by an aluminum bridge or link through a perforation or slot in the blade root is unnecessary and plain fixing by the bond gives improved results, particularly damping, (6) fatigue failure of the blade is characterized by local fracture at the fillet between the blade and the footing surface, but is not accompanied by any loosening of the blade root in the footing, and (7) the fabrication cost of the composite blade unit is materially lower than the cost of manufacture of the one-piece blade unit.

Similar advantages are obtainable plus still lower manufacturing costs by casting one end of a group of stator blades **14** in a segmented plural footing **15** according to the aforementioned molecular bonding method and similarly and preferably simultaneously casting the other end of the group of stator blades **14** in a plural shroud ring segment **16**, to form the segmented stator section shown in Fig. 3. Various ways may be utilized for simultaneously casting the aluminum alloy segments **15** and **16** after the aforementioned pre-treatment of the ends of the blades **14** for obtaining the requisite bond between the aluminum and the blades **14**. One method of holding the blades at proper pitch and spacing in a jig, sand coring the blade center portions and casting the metal in segmental fixed molds into which the blade ends project, is generally described in Dimberg Patent No. 1,621,001 and may be employed to form the unit shown in Fig. 3, it being understood that the blade ends are pre-treated before casting as specified herein. Alternatively, the ends of the blades **14** may be individually cast with blocks of the aluminum alloy selected for the segments **15** and **16**, in a manner similar to that described in connection with Fig. 2, and the preheated cast blocks **13** aligned in a segmental mold to be united by casting the aluminum alloy around them to complete the segments **15** and **16**.

Although several preferred embodiments of the composite stator blade unit and methods of making the same have been illustrated and described herein, it is to be understood that the invention is not limited thereto, but is susceptible to changes within the scope of the appended claims.

We claim:

1. A composite blade unit for a gas turbine, comprising a casting of a light metal of relatively low strength of the class consisting of aluminum and aluminum base alloys, a blade of a substantially higher strength ferrous metal projecting from said casting and having a root end partially embedded in said casting and projecting therefrom, and a film of an alloy including the aluminum of the casting and the ferrous metal of the blade interposed between abutting surfaces of the blade and the casting and bonding them together, said blade having a root end fixity of approximately 0.86 of that of a one-piece blade, a damping constant approximately two and one-half times the value of an equivalent one-piece blade and a fatigue strength about 7 times as great as said one-piece blade.

2. A composite blade unit for a gas turbine, comprising a casting of a light metal of relatively low strength of the class consisting of aluminum and aluminum base alloys, a blade of a substantially higher strength stainless steel projecting from said casting and having a root end partially embedded in said casting and projecting therefrom, and a film of an alloy including the aluminum of the casting and the steel of the blade interposed between abutting surfaces of the blade and the casting and bonding them together, said blade having a root end fixity of approximately 0.86 of that of a one-piece blade, a damping constant approximately two and one-half times the value of an equivalent one-piece blade and a fatigue strength about 7 times as great as said one-piece blade.

3. A composite blade unit for a gas turbine, comprising a casting of a light metal of relatively low strength of the class consisting of aluminum and aluminum base alloys, a blade of a substantially higher strength Monel metal projecting from said casting and having a root end partially embedded in said casting and projecting therefrom, and a film of an alloy including the aluminum of the casting and the Monel metal of the blade interposed between abutting surfaces of the blade and the casting and bonding them together, said blade having a root end fixity of approximately 0.86 of that of a one-piece blade, a damping constant approximately two and one-half times the value of an equivalent one-piece blade and a fatigue strength about 7 times as great as said one-piece blade.

4. A composite blade unit for a gas turbine, comprising a casting of a light metal of relatively low strength of the class consisting of aluminum and aluminum base alloys, a blade of a substantially higher strength corrosion resistant metal having a modulus of elasticity between about 25×10^6 and about 30×10^6 and projecting from said casting and having a root end partially embedded in said casting and projecting therefrom, and a film of an alloy including the aluminum of the casting and the metal of the blade interposed between abutting surfaces of the blade and the casting and bonding them together, said blade having a root end fixity of approximately 0.86 of that of a one-piece blade, a damping constant approxi-

mately two and one-half times the value of an equivalent one-piece blade and a fatigue strength about 7 times as great as said one-piece blade.

References Cited in the file of this patent

UNITED STATES PATENTS

2,000,692	Dimberg	May 7, 1935
2,019,329	Warren	Oct. 29, 1935
2,090,468	Brown	Aug. 17, 1937
2,285,811	Gay	June 9, 1942
2,382,273	Thielemann	Aug. 14, 1945
2,396,730	Whitfield et al.	Mar. 19, 1946
2,510,735	Bodger	June 6, 1950
2,620,530	Sulprizio	Dec. 9, 1952

FOREIGN PATENTS

500,425	France	Dec. 16, 1919

OTHER REFERENCES

"Stainless Iron and Steel" (Monypenny) Pub. 1931 by Chapman and Hall, London (pages 533–540.)

UNITED STATES PATENT OFFICE

Certificate of Correction

Patent No. 2,807,435 September 24, 1957

John W. Howlett et al.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 46, for "while" read —with—; line 47, for "alloy is" read alloy in a semi- —; line 48, after "plastic" insert —state—; line 53, after the syllable "ation" strike out "as"; column 2, line 52, for "is molten" read —is semi-molten—; column 3, line 43, after the equation insert —etc.—; column 4, line 42, for "a=.317 in.²." read —a=.0317 in.².—; line 43, for

$$l_2 \quad \text{read} \quad \frac{1}{l_2}$$

lines 68 and 69, strike out "where the blade 10 was of the same material, contour and dimensions as the one-piece blade" and insert instead —where the blade and footing were machined from a single block of metal to the contour and dimensions of the new composite blade—.

Signed and sealed this 18th day of March 1958.

[SEAL]

Attest:
KARL H. AXLINE,
Attesting Officer.

ROBERT C. WATSON,
Commissioner of Patents.