Oct. 1, 1968 L. J. STOFFER 3,403,893

AXIAL FLOW COMPRESSOR BLADES

Original Filed Dec. 1, 1966

Fig 1

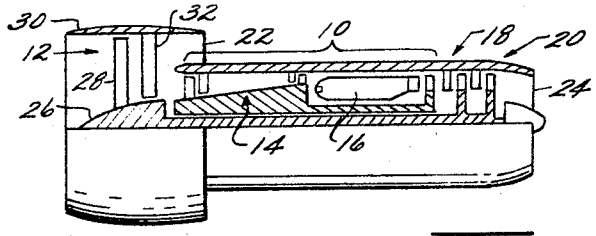


Fig 2

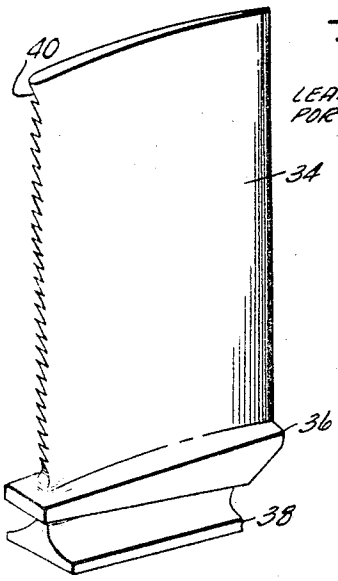


Fig 3

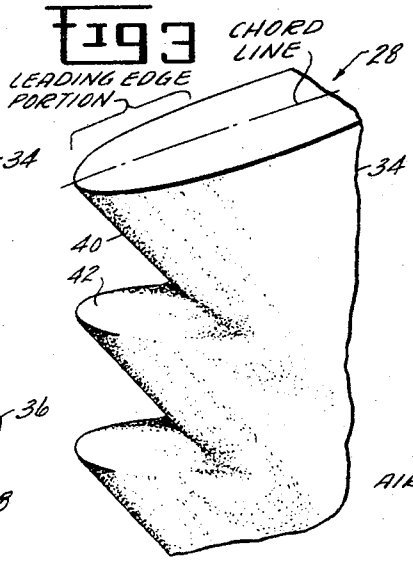


Fig 4

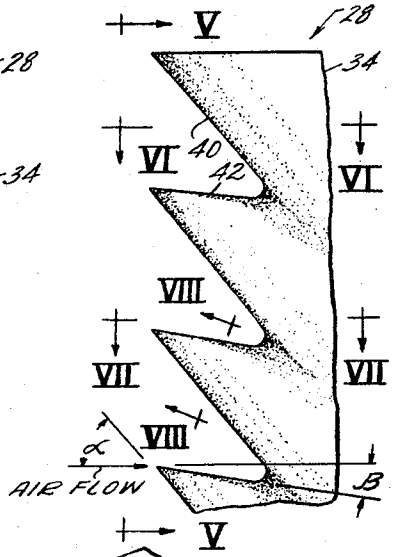


Fig 5

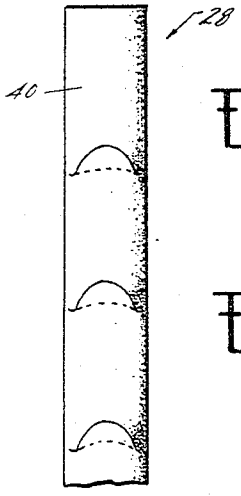


Fig 6

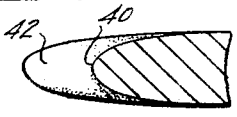


Fig 7

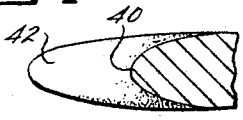


Fig 8



Fig 9

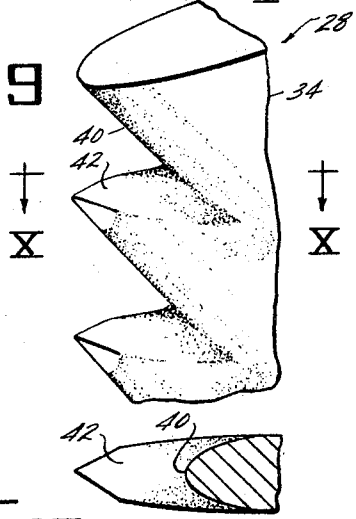


Fig 10

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AXIAL FLOW COMPRESSOR BLADES

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Continuation of application Ser. No. 598,428, Dec. 1, 1966. This application Dec. 5, 1967, Ser. No. 695,818
4 Claims. (Cl. 253—77)

ABSTRACT OF THE DISCLOSURE

A compressor blade is shown having incremental, inclined airfoil-shaped portions along its leading edge, which portions are interconnected by other portions of the blade. The inclined and interconnecting portions are disposed on angles within specified limits. The teeth so formed are effective in reducing blade erosion, while maintaining desired aerodynamic characteristics.

The present application is a continuation of copending application Ser. No. 598,428, filed Dec. 1, 1966, now abandoned.

The present invention relates to improvements in gas turbine engines having axial flow compressors and more particularly to improved blades for such compressors.

One approach to increasing the performance of gas turbine engines, used for the propulsion of aircraft, has been to increase the diameter and/or the rate of rotation of the rotor of such compressors. The result has been that the tangential velocity of the blade tips becomes extremely high and often supersonic. Under these conditions of high tip speed, serious problems are encountered as a result of erosion caused by rain entrained in the air entering the compressor. Rain erosion, as well as erosion from dust particles, can seriously reduce the efficiency and operating life of compressor blades even though normally the duration of aircraft operation, under conditions where rain ingestion could occur, is relatively short under such conditions.

Compressor baldes are ordinarily made of high strength metal. Much effort in recent years has been expended in perfecting compressors which are fabricated from various laminates, particularly those employing plastic resins reinforced with glass fibers. Such laminated constructions provide great savings in weight but are even more vulnerable to erosion from rain or dust particles entrained in the air entering and passing through such a compressor.

A somewhat similar erosion problem exists in steam turbines, and in U.S. Patent 1,862,827, it is taught that slots should be provided in the convex surface of a turbine bucket and extend through the leading edge thereof to minimize the erosion effect of condensate particles in a vacuum turbine. This teaching, however, is not applicable to compressor blades and particularly for compressors employed in gas turbine engines where a high degree of efficiency is required in order to obtain necessary weight and fuel consumption requirements.

Accordingly, it is an object of the invention to provide significant reductions in the erosive effect of rain or other particles entrained in an air entering and passing through a compressor and at the same time maintain a high level of efficiency in the operation of the compressor.

These ends are attained in a gas turbine engine having an axial flow compressor which includes a bladed rotor

driven to compressor air, which may be used to support combustion or provide a propulsive force. The blades of the rotor are arranged in at least one circumferential row. It is also usual practice to provide a circumferential row of fixed blades immediately downstream of the rotating row of blades.

Each blade has an aerodynamic airfoil portion extending radially of the axis of rotation of the rotor with leading and trailing edges relative to the flow of air therepast. The leading edge portion of each blade has a theoretical optimum curvature through approximately and usually slightly less than 180° to opposite sides of the blade which are equidistant from chord extending between the leading and trailing edges of the blade. In accordance with this invention, the leading edges of at least the first row of rotor blades, and optionally the stator blades, have small, lengthwise, incremental portions inclined at an angle between 30° and 75° relative to the gas flow path approaching the blade. These inclined portions are interconnected by portions which are disposed on an angle of 0°–30° relative to the gas flow path and are inclined in the same direction relative thereto as the incremental inclined portions. The inclined leading edge portions and the interconnecting portions form teeth having crotches protected by their tips from rain or the like entrained in the air stream. By inclining incremental portions of the leading edge in the fashion described, a high resistance to erosion is obtained with little or no adverse effect on the aerodynamic characteristics of the blade, thus providing an efficiency in operation which approaches, if not equals, that of the conventional, theoretical design.

It is further preferred that the inclined, incremental edge portions have a cross section (relative to the lengthwise direction of the blade) approximating that of said theoretical curvature. It is further preferred that the interconnecting portions are substantially flat at the tips of the teeth and are progressively crowned toward the crotches so that the crotches may be formed on a curvature which blends with the curvature of the inclined portions.

The above and other related objects and features of the invention will be apparent from a reading of the following description of the disclosure found in the accompanying drawing and the novelty thereof pointed out in the appended claims.

In the drawing:

FIGURE 1 is a diagrammatic view of a gas turbine engine;

FIGURE 2 is a compressor blade which would be used in such an engine;

FIGURE 3 is an enlarged fragmentary perspective view of the upper leading edge portion of this blade;

FIGURE 4 is an elevation of the leading edge portion of the blade, looking at the concave surface of the blade;

FIGURE 5 is a view taken on line V—V in FIGURE 4;

FIGURE 6 is a section taken on line VI—VI in FIGURE 4;

FIGURE 7 is a line taken on line VII—VII in FIGURE 4;

FIGURE 8 is a section taken on line VIII—VIII in FIGURE 4;

FIGURE 9 is a fragmentary perspective view of the upper leading edge portion of a modified blade; and

FIGURE 10 is a section taken on line X—X in FIGURE 9.

FIGURE 1 illustrates the gas turbine engine environment of the present invention. The engine illustrated is of the turbofan type, comprising a core engine **10** and a fan or low compressor **12**. The core engine includes a high pressure compressor **14**, a combustor **16**, and a turbine **18**. Air is pressurized by the compressor **14** to support combustion of fuel in the combustor **16** to thereby generate a hot gas stream which passes through the turbine **18**. The rotor of the compressor **14** is connected to the turbine **18** and driven thereby. The hot gas stream then passes through a second compressor **20** which is connected to the rotor **26** of the fan **12** to drive the latter.

Part of the air pressurized by the fan **12** is discharged through a bypass nozzle **22** to provide a propulsive force. The remainder of this pressurized air enters the compressor **14** for the generation of a hot gas stream, as above described. The hot gas stream, after passing through the fan turbine **20**, is then discharged through an exit nozzle **24** to provide an additional propulsive force.

The fan **12** comprises a rotor **26** having a single, circumferential row of airfoil-shaped blades **28** rotating within a shroud **30**. Air passes from the blades **28** to a row of stators **32**, which properly direct the pressurized air towards the nozzle **22** and the core engine **10**.

FIGURES 2–8 illustrate in detail one of the blades **28**. The blade itself has an airfoil-shaped portion **34** which terminates at its inner end in a platform **36**. The platforms of adjacent blades are closely spaced in abutting relation to define the inner flow path of the air passing through the fan. A tang **38** is provided at the base of the blade **28** for mounting it in the usual fashion on the rotor **26**.

As is evident from the drawing, the blade **28** projects radially from the axis of rotation of the rotor **26** and has an aerodynamic airfoil cross section relative to its length. Design of such aerodynamic cross sections is a highly refined art, dependent upon several parameters such as speed, length, desired pressure ratio, etc. For any given compressor there will be a theoretical optimum curvature of the sides of the blade and, particularly for the leading edge portion wherein there is a relatively sharp curvature usually through somewhat less than 180° to the opposite sides of the blade. The opposite sides of the blade are spaced equidistant from a chord extending between the leading and trailing edges of the blade. These relationships are illustrated in FIGURE 3.

The leading edge of the blade **28** is characterized by incremental, lengthwise portions **40** being inclined relative to the air flow path and connected by portions **42** to form teeth having tips which overlie curved crotches at the inner convergence of the surfaces **40** and **42**.

Assuming that the teeth at their tips have the theoretically desired leading edge curvature, it will be seen from FIGURES 6 and 7 that the inclined portions **40** substantially throughout their length approximate this desired curvature. The surface **42** is preferably flat at the outer ends of the teeth and is progressively crowned (FIGURE 8) toward the crotch so that the curved crotch may be in the form of a saddle blended with the curvature of the inclined portion **40**.

For maximum effectiveness in resisting erosion with little or no adverse effect on aerodynamic characteristics, it is preferred that the inclined portion **40** be disposed on an angle α, relative to the direction of air flow, preferably between 30° and 75°. It is further preferred that the interconnecting portions **42** be inclined on an angle β between 0° and 20° relative to the direction of air flow. Both of the portions **40** and **42**, it will be noted, are inclined in the same direction relative to air flow, giving a swept sawtooth effect wherein the tips of the teeth protect the crotches as previously pointed out. It is preferred that the teeth be angled toward the outer end of the blade, as illustrated, to minimize stress concentrations.

FIGURES 9 and 10 illustrate a modified form of the invention wherein the tips of the teeth formed by the portions **40** and **42** are pointed at their outer ends. This illustrates that some small deviation from the theoretical airfoil curvature may be tolerated and, in fact, desirable for certain materials, as will be more apparent from the following discussion.

The provision of the incremental, inclined leading portions **40** has been found highly effective in preventing or minimizing erosion resulting from rain particles or the like entrained in air which passes by the compressor blades. The inclined portions provide an angle of incidence for the rain particles which minimizes the erosion effects. The angle may vary through fairly wide limits, as indicated by the preferred limits for the angle α given above. Further, the swept configuration of the resultant teeth insures that all portions of the leading edge will have such an inclined incidence surface. This is to say that the tips of the teeth protect the crotches from direct impingement of air particles thereon. Further, the cross section of the teeth (related to the lengthwise direction of the blade) approximates the optimum airfoil shape so that the aerodynamic characteristics of blades formed in accordance with the present invention will show little or no loss in efficiency and conceivably may show an increase in efficiency.

As was mentioned above, the angled incidence of rain particles on the blade is necessary and the pointed tips of FIGURES 9 and 10 may be required to provide increased angularity for certain materials, particularly the plastics mentioned above.

The use of incremental, inclined portions has been discussed in connection with the first row of fan blades where erosion conditions are usually most severe. However, the same feature can be used to advantage on stators as well and also straight turbojets. It will further be apparent that deviations from the precise configuration disclosed will fall within the present inventive teachings, the scope of which is therefore to be derived solely from the following claims.

Having thus described the invention, what is claimed as novel and desired to be secured by Letters Patent of the United States is:

1. In a gas turbine engine having an axial flow compressor which includes a rotor having radially projecting blades at the compressor inlet,

each of said blades having an aerodynamic, airfoil portion extending radially of the axis of the rotation of said rotor and having leading and trailing edges relative to the air flow therepast, said leading edge portion having a theoretical optimum curvature blending with the opposite sides of the blade which are equidistant from a median chord line extending between the leading and trailing edges of the blade,

characterized in that the leading edge, at least at its outer end portion, has relatively small, lengthwise incremental portions inclined at an angle α of 30° to 75° relative to the air flow path approaching said blade,

said inclined portions have said optimum curvature substantially throughout their lengths, and

said inclined portions are interconnected by edge portions which are inclined at least 30° relative to the air flow path therepast,

whereby said inclined portions have a high resistance to erosion and the blade, as a whole, has a high aerodynamic efficiency.

2. In a gas turbine engine as in claim **1** wherein,

said interconnecting portions are inclined at an angle β of 0°–30° relative to said gas flow path,

said interconnecting portions being inclined relative to said gas flow path in the same direction as the lengthwise incremental portions to form teeth having crotches protected by the tips thereof from rain or the like entrained in said air stream, while at the same time providing a leading edge which is resistant

to the corrosive effects of rain, or the like, with little or no adverse effect on the aerodynamic characteristic of the blade.

3. In a gas turbine engine as in claim 2 wherein, the interconnecting portions are substantially flat at the tips of the teeth and are progressively crowned toward the crotches, the curvature of said crown being blended with the curvature of said inclined portions at said crotches.

4. In a gas turbine engine as in claim 2 wherein, the extreme tips of said teeth are pointed.

References Cited

UNITED STATES PATENTS

1,862,827	6/1932	Parsons et al.	170—159
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EVERETTE A. POWELL, JR., *Primary Examiner.*