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W. DOLL, JR., ET AL

2,746,672

COMPRESSOR BLADING

Filed July 27, 1950

FIG. 1

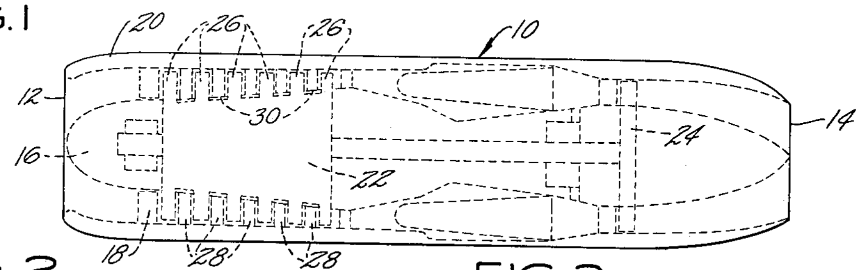


FIG. 2

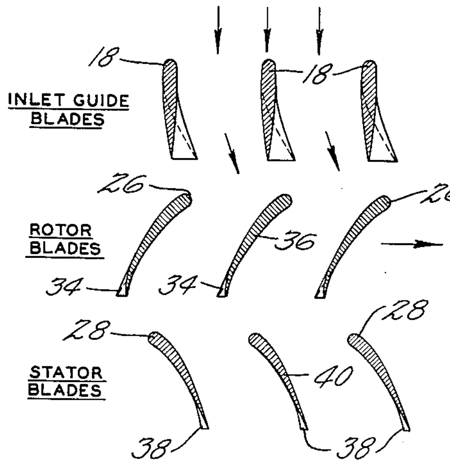


FIG. 3

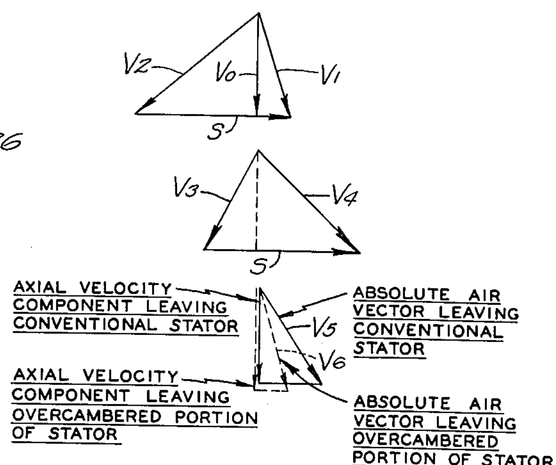


FIG. 5

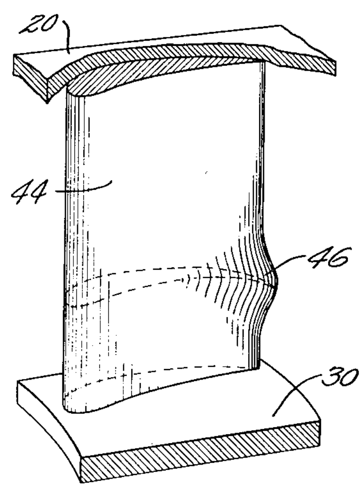
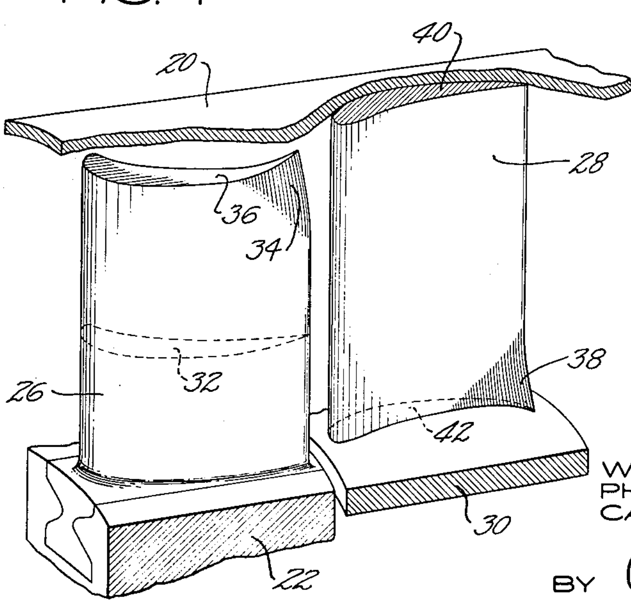


FIG. 4



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COMPRESSOR BLADING

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16 Claims. (Cl. 230—122)

This invention relates to a configuration of compressor blading; more specifically to rotating blades and stationary guide blades.

In flow machinery designed to convert kinetic energy into pressure rise, deviations from ideal design conditions always exist because of friction along the walls of the flow passage. Efficiency is lowered and changes in flow distribution result which may adversely affect subsequent bladed elements. In aircraft gas turbine power plants, where maximum compression per stage, high efficiency and wide operating range are necessary, design and operating limitations imposed by wall friction and boundary layer are very serious.

It has been found that the effect of wall friction and boundary layer can be reduced or minimized by modifying blading locally near the walls. Test results on a number of different axial flow compressors using the described blade modification showed a substantial increase in pressure rise, and probing runs showed a marked improvement in axial velocity distribution in subsequent stages. In some cases the efficiency of the compressor was improved.

This invention preferably is used with the inlet guide blading disclosed in co-pending application Serial No. 169,461, filed June 21, 1950, by Walter Doll, Jr.

A feature of this invention is the alteration or modification of compressor blading to minimize the detrimental effect of wall friction and boundary layer, and thus improve the overall performance of the compressor.

A feature of this invention is a compressor blade configuration which improves the distribution of gas velocities within the compressor.

Another feature of this invention is a compressor blade configuration which increases the pressure rise across the compressor.

Another feature of this invention is a compressor blade configuration which increases local pumping and forces gases through the casing boundary layer region.

Other features and advantages will be apparent from the specification and claims and from the accompanying drawing which illustrates an embodiment of the invention.

In the drawing:

Fig. 1 shows an axial flow gas turbine power plant having compressor blading incorporating this invention.

Fig. 2 is a section near the outer casing through the inlet guide blades, the first row of rotor blades and the first row of stator blades of the gas turbine power plant shown in Fig. 1.

Fig. 3 is a vector diagram of the gases entering and leaving the rows of blades shown in Fig. 2.

Fig. 4 is a fragmentary section of the power plant showing a rotor blade and a stator blade modified according to this invention.

Fig. 5 is a fragmentary section showing an alternate manner of modifying compressor blading.

An axial flow gas turbine power plant is indicated in Fig. 1 at **10**, the power plant having inlet **12** and outlet **14**

for the flow of gases therethrough. Inlet cone **16** defines an inner wall for the gases entering the power plant and supports a number of radially mounted inlet guide blades **18** which are supported at their outer tips by casing **20** defining an outer wall. An axial flow compressor rotor **22** is driven by turbine wheel **24**, the blades on the compressor rotor being indicated at **26**. Stationary guide blades, or stator blades **28** alternate with rows of compressor rotor blades. A shroud **30** connects the inner end of the stator blades and forms part of the inner wall.

Gases entering the power plant have an axial velocity V_0 as diagrammed in Fig. 3. These gases pass over inlet guide blades **18** which turn the gases from the axial direction through some predescribed pattern of turning, as can be seen in Fig. 2, leaving the blades in the direction indicated by the vector V_1. The turning pattern is designed to extend in a smooth and regular manner from wall to wall. Since the rotor blades **26** over which the gases next pass have a rotational velocity S, the velocity of the gases with respect to the rotor blades is V_2. The direction of the vector V_2 establishes the incidence angle of the blades **26**. As the gases pass over the rotor blades they are turned and are discharged in the direction of V_3. Since the gases also have a rotational velocity S, the resultant velocity with respect to the following row of stator blades **28** is V_4. This vector establishes the incidence angle of the leading edge of stator blades **28**. The gases leave the stator vanes in the direction of vector V_5 to pass through subsequent stages of the power plant in a pattern similar to that described.

Actually, a fluid boundary layer exists adjacent to the inner and outer casings which by virtue of its reduced kinetic energy is not imparted as great a pressure rise in the compressor blading as experienced by the major portion of the gas flow. As a result, conditions within the compressor are not conducive to best operation, separation of flow from the compressor walls occurring in severe cases.

In accordance with the invention taught in the co-pending application Serial No. 169,461, filed June 22, 1950, by Walter Doll, Jr., the span of inlet guide blades **18** is modified so that the portions of the gases flowing through the compressor adjacent to the casing walls are not turned in the direction V_1 but have an axial velocity component substantially in the direction of V_0. A high energy level in the gases in the boundary layer thus is maintained so that tendency for wall separation is retarded or eliminated at the compressor inlet. This modification to the blades improves the velocity distribution at succeeding stages and tends to overcome a faulty inlet condition at rotor blades **26** resulting from wall separation which may occur under conditions of high blade loading and off-design operation.

It has been discovered that by overcambering portions of the span of rotor blades **26** and stator blades **28**, thereby increasing local pumping, wall flow separation adjacent to these blades is retarded or eliminated and the useful operating range of the blading is extended. In Fig. 4, rotor blade **26** having an airfoil cross-section substantially as shown at **32** has its tip area **34** overcambered relative to the remainder of the blade span in accordance with this invention. The blade tip, where the overcambering is greatest, can be seen at **36**. The modified portion blends with the remainder of the span to form a smooth and continuous surface. Stator blade **28** following rotor blade **26** has a portion **38** of its span near shroud **30** overcambered in a similar manner. The unmodified cross-section of this blade can be seen at **40**, and a modified section can be seen at **42**.

The principle involved consists of increasing the aerodynamic loading of the ends of rotating blades by increasing the incidence angle at which gases approach the blades, by increasing the turning in the blades, or a combination of both. A stronger pumping action results near the walls which in turn permits the boundary layer fluid to flow against higher pressure gradients as produced by the mid-passage portion of the blading. The main effect of changing the stator blade angle near the wall appears to be an increase in loading of the corresponding section of the subsequent rotating blades which increases the axial component of force imparted to the fluid by the blades, thus increasing the kinetic energy of the fluid near the walls.

When properly designed, the blade end modifications generally result in a higher gas velocity near the walls than would exist with conventional blade design. The higher velocity near the walls is beneficial in stabilizing and controlling blade end flow conditions which affect blading performance, efficiency, stable operating range, and permissible loading.

Overcambering turns the gases passing over the modified section of the blades so that they leave the blades in a more nearly axial direction than the gases leaving the unmodified portions of the blades. This is illustrated in Fig. 3 where the vector V_5 indicates the direction of the gases leaving the unmodified portion of stator blades **28**. V_6 is substantially the velocity vector of the gases leaving the modified or overcambered portion **38** of stator blades **28**, and, as can be seen from the diagram, the axial component of V_6 is greater than the axial component of V_5. In the case of rotor blades **26**, the gases leaving the overcambered portion **34** have a larger axial component than do the gases leaving the unmodified portion. By increasing the axial component, the axial force on the gas flow is maintained at a high level, tending to inhibit or eliminate wall separation and stabilize the flow distribution.

Overcambering can be performed at any spanwise location, the particular area at which it is done being determined by design and operating conditions. It can be performed at more than one location on any one blade, and it can be done to any number of rows of rotor and stator blades. It might be confined only to stator rows, or to rotor rows, or a combination of both, but the final decision is determined by the particular installation. Fig. 4 illustrates application to the rotor blade tip and the inner end of the stator blade.

Fig. 5 illustrates another of the ways in which compressor blading can be modified. Here, the blade **44** is overcambered only through a local section of the span as at **46**. The modified area does not extend to the nearest wall, having unmodified sections of the blade span on either side. The nature and extent of overcambering is, as stated above, determined by design and operating conditions.

It is to be understood that the invention is not limited to the specific improvements herein illustrated and described but may be used in other ways without departure from their spirit as defined by the following claims.

We claim:

1. A blade for use in flow machinery designed to convert kinetic energy into pressure rise, said blade having an operative span for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with its intended use so that gases passing thereover are turned through a predetermined pattern of turning, at least one end of said span being overcambered to a degree beyond that normally required by its intended use to turn the gases flowing thereover substantially more than they normally would be turned, said trailing edge being a warped line as a result of overcambering said end.

2. A rotor blade for a compressor, said blade having a root and an operative span designed to increase the pressure of gases passing thereover, said span having a leading edge and a trailing edge and being cambered in accordance with its intended use so that gases passing thereover

are turned through a predetermined pattern of turning, the end of said span remote from said root being overcambered to a degree beyond that normally required by its intended use to turn the gases flowing thereover substantially more than they normally would be turned, said trailing edge being a warped line as a result of overcambering said end.

3. A stator blade to be used in combination with a compressor rotor, said blade having an operative span for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with its intended use so that gases passing thereover are turned through a predetermined pattern of turning, at least one end of said span being overcambered to a degree beyond that normally required by its intended use to turn the gases flowing thereover substantially more than they normally would be turned, said trailing edge being a warped line as a result of overcambering said end.

4. A stator blade to be used in combination with a compressor rotor, said blade having an operative span for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with its intended use so that gases passing thereover are turned through a predetermined pattern of turning, the end of said span nearest the rotational axis of said compressor rotor being overcambered to a degree beyond that normally required by its intended use to turn the gases flowing thereover substantially more than they normally would be turned, said trailing edge being a warped line as a result of overcambering said end.

5. In gas flow machinery designed to convert kinetic energy into pressure rise, guide blades mounted within the inlet of said machinery and designed to turn gases entering said machinery through a predetermined pattern of turning, at least one end of said inlet guide blades being modified to maintain substantially the original direction of said gases, a rotor downstream of said inlet guide blades and having a plurality of rows of blades thereon with a row of stator blades upstream of at least one row of rotor blades, said rotor and stator blades having an operative span for the flow of gases thereover and being cambered in accordance with the intended use of the blades so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, at least one row of rotor and at least one row of stator blades being modified by overcambering at least one end of said blade span to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of boundary layer is minimized.

6. In a compressor including inner and outer walls defining a flow passage, a rotor with at least one row of blades thereon and a row of stator blades adjacent to at least one row of rotor blades, each of said rotor and stator blades having an operative span extending substantially across said flow passage for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, at least one end of said span in at least one row of said blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of wall friction is minimized.

7. In a compressor including inner and outer walls defining a flow passage, a rotor with at least one row of blades thereon and a row of stator blades adjacent to at least one row of rotor blades, each of said rotor and stator blades having an operative span extending substantially across said flow passage for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with the intended use of

the blade so that the gases leave said span at a predetermined angle with respect to the axis of the rotor, at least one end of said span in at least one row of said rotor blades and in at least one row of said stator blades being overcambered to a degree beyond that normally required by the intended use of the blades to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of wall friction is minimized.

8. In a compressor including inner and outer walls defining a flow passage, a rotor with at least one row of blades thereon, said blades having an operative span extending substantially across said flow passage for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, the end of said span adjacent the outer wall of said flow passage in at least one row of blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of wall friction is minimized.

9. In a compressor including inner and outer walls defining a flow passage, a rotor with a plurality of rows of blades thereon and a row of stator blades immediately upstream of at least one row of rotor blades, said stator blades having an operative span extending substantially across said flow passage for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, at least one end of said span in at least one row of stator blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of wall friction is minimized.

10. In a compressor including inner and outer walls defining a flow passage, a rotor with a plurality of rows of blades thereon and a row of stator blades immediately upstream of at least one row of rotor blades, said stator blades having an operative span extending substantially across said flow passage for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, the end of said span adjacent the inner wall of said flow passage in at least one row of stator blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of wall friction is minimized.

11. In a compressor including inner and outer walls defining a flow passage, a rotor with at least one row of blades thereon and a row of stator blades adjacent to at least one row of rotor blades, each of said rotor and stator blades having an operative span extending substantially across said flow passage for the flow of gases thereover, said span having a leading edge and a trailing edge and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, the end of said span adjacent the outer wall of said flow passage in at least one row of said rotor blades and the end of said span adjacent the inner wall of said flow passage in at least one row of said stator blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of wall friction is minimized.

12. In a gas flow machinery designed to convert kinetic energy into pressure rise, guide blades mounted within the inlet of said machinery and designed to turn gases entering said machinery through a predetermined pattern of turning, at least one end of said inlet guide blades being modified to maintain substantially the original direction of said gases, a rotor downstream of said inlet guide blades and having at least one row of blades thereon, said blades having an operative span for the flow of gases thereover and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, the end of said span remote from said axis in at least one row of blades being modified by overcambering to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of boundary layer is minimized.

13. In gas flow machinery designed to convert kinetic energy into pressure rise, guide blades mounted within the inlet of said machinery and designed to turn gases entering said machinery through a predetermined pattern of turning, at least one end of said inlet guide blades being modified to maintain substantially the original direction of said gases, a rotor downstream of said inlet guide blades and having a plurality of rows of blades thereon with a row of stator blades upstream of at least one row of rotor blades, said stator blades having an operative span for the flow of gases thereover and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, at least one end of said span in at least one row of stator blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of boundary layer is minimized.

14. In gas flow machinery designed to convert kinetic energy into pressure rise, guide blades radially mounted within the inlet of said machinery and designed to turn gases entering said machinery through a predetermined pattern of turning, the inner end of said inlet guide blades being modified to maintain substantially the original direction of said gases, a rotor downstream of said inlet guide blades and having a plurality of rows of blades thereon with a row of stator blades upstream of at least one row of rotor blades, said rotor and stator blades having an operative span for the flow of gases thereover and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with respect to the rotational axis of the rotor, the end of said span remote from said axis in at least one row of rotor blades and the end of said span nearest said axis in at least one row of stator blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of boundary layer is minimized.

15. In gas flow machinery designed to convert kinetic energy into pressure rise, guide blades radially mounted within the inlet of said machinery and designed to turn gases entering said machinery through a predetermined pattern of turning, the inner end of said inlet guide blades being modified to maintain substantially the original direction of said gases, a rotor downstream of said inlet guide blades and having at least one row of blades thereon, said blades having an operative span for the flow of gases thereover and being cambered in accordance with the intended use of the blade so that the gases leave said span

at a predetermined angle with respect to the rotational axis of the rotor, the end of said span remote from said axis in at least one row of blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially in axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of boundary layer is minimized.

16. In a gas flow machinery designed to convert kinetic energy into pressure rise, guide blades radially mounted within the inlet of said machinery and designed to turn gases entering said machinery through a predetermined pattern of turning, the inner end of said inlet guide blades being modified to maintain substantially the original direction of said gases, a rotor downstream of said inlet guide blades and having a plurality of rows of blades thereon with a row of stator blades upstream of at least one row of rotor blades, said stator blades having an operative span for the flow of gases thereover and being cambered in accordance with the intended use of the blade so that the gases leave said span at a predetermined angle with

respect to the rotational axis of the rotor, the end of said span nearest said axis in at least one row of stator blades being overcambered to a degree beyond that normally required by the intended use of the blade to impart substantially an axial direction with respect to said rotor axis to the gases flowing thereover with the result that the effect of boundary layer is minimized.

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