

March 20, 1956

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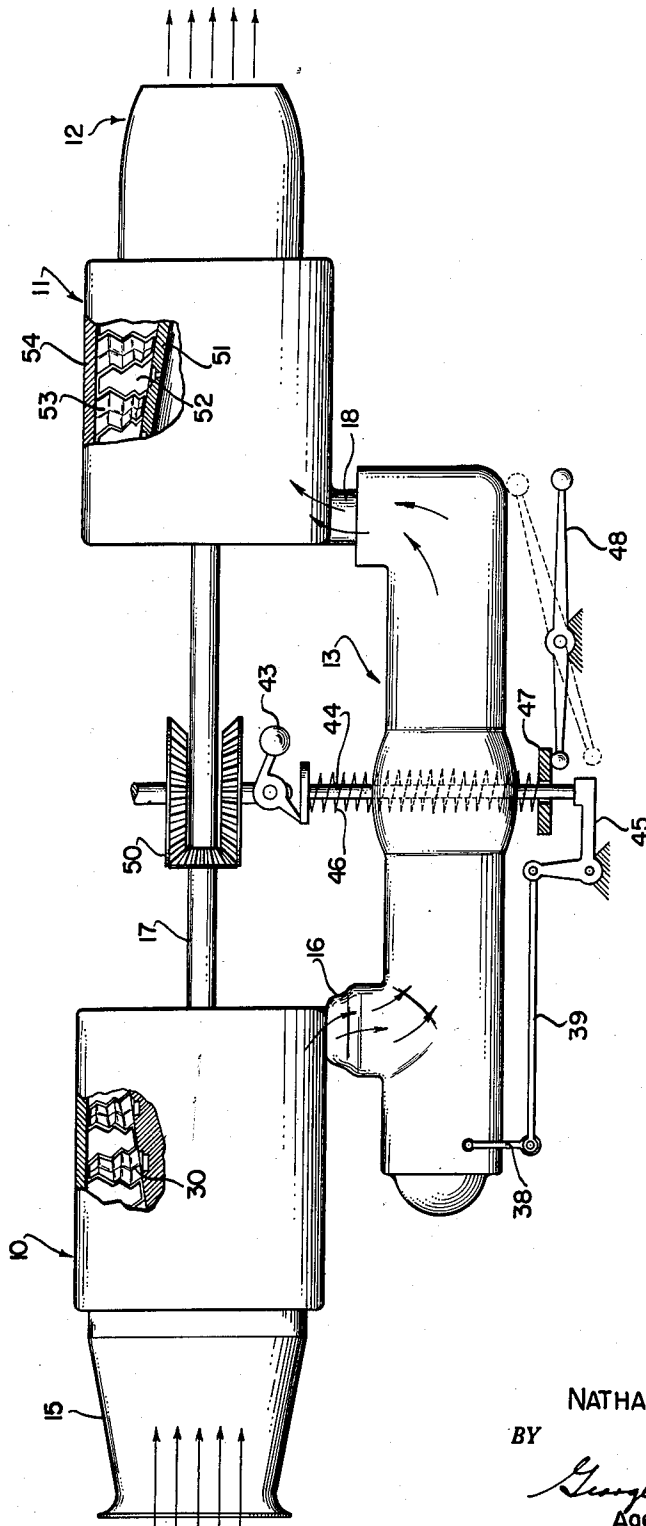
2,738,950

TURBINE MACHINE HAVING HIGH VELOCITY BLADING

Original Filed Dec. 13, 1945

2 Sheets-Sheet 1

FIG. 1



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2 Sheets-Sheet 2

FIG. 2

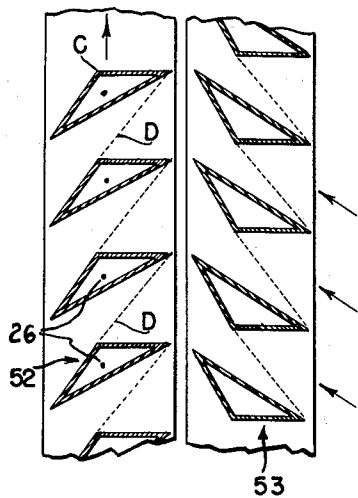


FIG. 3

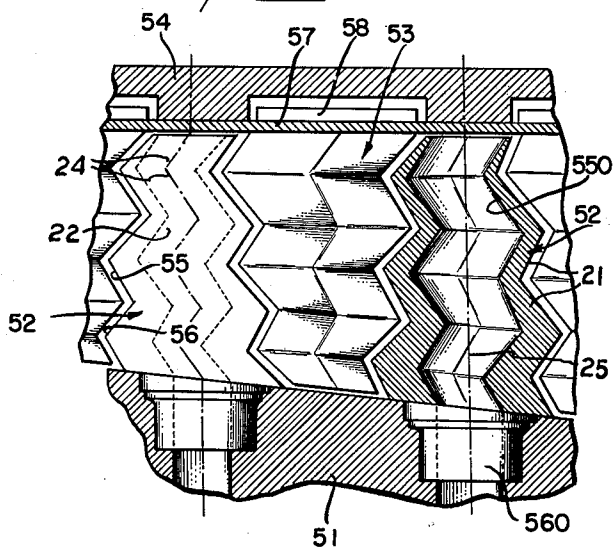
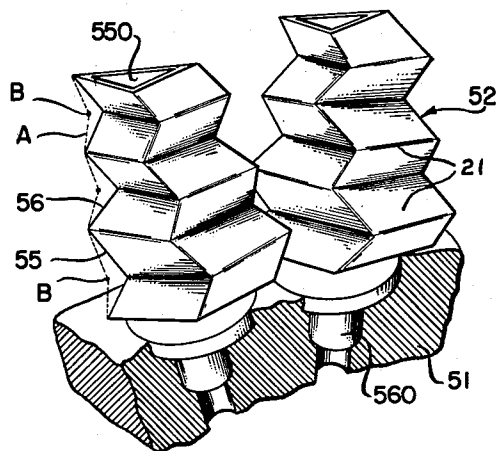


FIG. 4



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## TURBINE MACHINE HAVING HIGH VELOCITY BLADING

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Original application December 13, 1945, Serial No. 634,798. Divided and this application October 11, 1950, Serial No. 189,579

3 Claims. (Cl. 253—39.15)

This invention relates to turbo machines and relates more particularly to turbine powerplants having blading means for handling the working fluid at sonic, transonic and supersonic velocities.

This application is a division of my copending application, Serial Number 634,798, filed December 13, 1945, and now abandoned. In my copending application I have disclosed a turbine powerplant wherein the transmission of heat to the working fluid is obtained, to a large extent, by forced convection. In such situations the rate of heat transfer rises abruptly as the velocity of the working fluid reaches or exceeds the speed of sound and it is, therefore, desirable that the working fluid be conducted through the heat generator at these sonic or supersonic velocities. However, conventional compressor and turbine blading is not capable of effectively handling the working fluid at such velocities. For example, turbine blading of conventional design is not capable of effectively extracting energy from the gas or working fluid moving at such high velocities and as a consequence there is a marked loss of efficiency due to the development of serious shock phenomena, and the like, in the expansion region or zone of the turbine.

It is, therefore, an object of this invention to provide a turbo mechanism characterized by practical effective blading operable to efficiently utilize or handle working fluid at high velocities, that is, in the sonic, transonic and supersonic regions.

Another object of the invention is to provide a turbo powerplant characterized by compressor and/or turbine means designed to handle the working fluid at sonic, transonic and supersonic velocities with a minimum of loss as a result of shock wave effect. The compressor and turbine employ blading or vanes of such configuration that the propagation of heavy shock waves is eliminated or materially reduced when the working fluid is handled at sonic and supersonic through velocities. This permits the delivery of the working fluid to the heat generator at the supersonic velocities to obtain the most efficient transfer of heat to the fluid by forced convection and materially contributes to the overall efficiency of the powerplant.

A further object of the invention is to provide sonic and supersonic blading of the character above referred to that is hollow or tubular to reduce its weight and that has its internal passages designed to increase the cooling effect of the air or other cooling medium circulated through the blades.

Other objectives and features will be better understood from the following detailed description of a typical preferred embodiment of the invention in which:

Figure 1 is a more or less diagrammatic view of a turbo machine with the portions of the compressor and turbine broken away to illustrate the blading of the invention;

Figure 2 is a diagrammatic view of portions of adjacent rows of rotor and stator blading;

Figure 3 is an enlarged fragmentary longitudinal section

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of the turbine showing the blading thereof with one blade appearing in cross section; and

Figure 4 is a perspective view of two adjacent turbine rotor blades.

The blading means of the invention may be incorporated in turbo powerplants of different types having different intended uses or applications and, of course, may be modified to adapt it for incorporation in given mechanisms or powerplants. In the drawings, I have shown the invention embodied in one of the powerplants disclosed in my copending application, above identified, it being understood that this is only one specific application of the invention. The unit is primarily adapted for the propulsion of aircraft and other high velocity vehicles and produces power in the form of a reactive gas jet or thrust, although it may be designed for the production of shaft horsepower instead of or in addition to the reactive thrust power. The powerplant may be said to comprise, generally, a compressor 10, a gas turbine 11 driving the compressor and provided with a reactive discharge nozzle 12 and a heat generator 13 interposed between the compressor 10 and the turbine 11.

The compressor 10 serves to receive a relatively large volume of atmospheric air, compress the same and deliver it to the heat generator 13 for flow therethrough to the turbine 11. Where the powerplant is incorporated in an aircraft or other vehicle, the compressor 10 receives ram air to effect an increased compression ratio with respect to the ambient atmosphere. The compressor 10, as diagrammatically illustrated, has a cylindrical housing provided at its forward end with an inlet spigot 15 of large capacity. The spigot 15 is of rearwardly increasing capacity and its forward end is open and unobstructed for the reception of the ram air. This ram air inlet spigot 15 will usually extend to the leading edge of the fuselage or of the airplane wing and faces forwardly into the air stream so that the intake air is received and initially compressed in the ram or inlet by reason of the high velocity of the aircraft with respect to the relative air stream. Accordingly, there is an initial stage of compression before the air reaches the several stages of mechanical compression contained within the housing of the compressor 10. In the powerplant, as schematically illustrated, the compressor 10 has a single lateral outlet 16 discharging into the heat generator 13. The shaft 17 for operating the compressor 10 is driven by the turbine 11 and extends forwardly from the turbine into the compressor.

In accordance with the present invention the heat generator 13 may be of any selected, desired or required type, the invention not being primarily concerned with the specific details of this unit or element. Accordingly, the heat generator 13 is illustrated in a more or less diagrammatic manner as an elongate unit offset from the compressor 10 and turbine 11 and designed to conduct the air or other working fluid from the lateral outlet 16 of the compressor 10 to the lateral inlet 18 of the turbine 11, it being understood that the generator 13 contains or embodies heating means for heating the compressed air or for transferring heat to the working fluid as it flows from the compressor to the turbine. The heat generator 13 may, of course, be controlled manually by a direct or remote control or may be controlled automatically as by a temperature and/or speed responsive means. In the case illustrated, there is a lever 38 entering the generator 13 and may be considered an operating or control lever for a valve or other regulating device of the generator. A link 39 extends from the lever 38 to a bell crank 45. A speed responsive governor means operates the bell crank 45 and comprises a gear set 50 driven by the turbine shaft 17 and in turn driving a fly ball governor 43. The governor 43 operates a push rod 44 which is operatively connected with the bell crank 45. A spring 46 is

arranged under compression between the governor engaging head of the push rod 44 and a slidable sleeve 47. A manually operable lever 48 cooperates with the sleeve 47 and is movable to vary the compression in the spring 46 and thus control or adjust the governor 43. The control lever 48 may have a number of designated positions representing given turbine speeds and may be moved through a range of movement to vary the thrust power output of the powerplant. It will be seen that upon an increase in turbine speed the governor 43 operates through the linkage just described to move the valve lever 38 in one direction and upon a decrease in turbine speed the lever 38 is moved in the other direction.

The turbine 11 receives the compressed heated air or working fluid from the heat generator 13 and extracts therefrom the energy for driving the compressor 10. The turbine 11, like the compressor 10, may be of any preferred or selected construction. However, where the heat generator 13 provides for the transmission or transfer of heat to the working fluid by forced convection in whole or in substantial part, the rate of such heat transfer rises abruptly as the speed of sound is reached or exceeded. In such a case, it is desirable that the stream of working fluid be conducted through the heat generator 13 at sonic or supersonic velocities and where such velocities are employed, it is important that the blading of the compressor 10 and turbine 11 be constructed to avoid serious shock losses. The present invention provides a type of blading designed for embodiment in a powerplant of this general class where the working fluid is handled at sonic or supersonic velocities. While the blading illustrated in detail in the drawings and described below are incorporated in the turbine 11, it is to be understood that similar or corresponding compressor blading may be employed in the compressor 10.

The rotor 51 of the turbine carries one or more rows of blades 52 operating between countervanes or stator blades 53 projecting inwardly from the wall of the compressor casing 54. The rotor 51 is conoidal, and its external surface diminishes in diameter in the direction of flow of the working fluid. The wall of the turbine casing 54 is substantially cylindrical so that the turbine blading 52 operates in an expansion chamber of rearwardly increasing fluid capacity. The several blades 52 of the rotor 51 may be similar in shape, although the blades of the successive rows are progressively longer in conformance with the increase in capacity of the expansion chamber. The rotor blades 52 are of zigzag configuration so that their leading edges present a series of angular or oblique edges 55 and 56 joining at apices. While in some instances it may be practical to employ short rotor blades, each having a single oblique leading edge, the centrifugal forces in a machine of this character require that the centers of mass of the blade sections be maintained in close proximity to lines perpendicular to the axis of rotation of the rotor. By making the blades 52 of zigzag configuration, as illustrated in Figures 3 and 4, this required location of the centers of mass of the blades is obtained, and the leading edges of the blades have pluralities of angularly related edges 55 and 56 to produce an obliquity of the shock waves in the spanwise direction. In Figures 2 and 4 the base surfaces of the triangular blades 52 are designated 22 and it will be observed that the chords of the blades are at these base surfaces. The blades 52 are zigzagged longitudinally to comprise series of contiguous triangular segments 21 each of which has a base surface portion or chord and the blades are zigzagged in a direction substantially parallel with a surface 22 generated by these chords. Because of this arrangement or configuration the leading edges of the blades 52 are made up of the oblique oppositely pitched edges 55 and 56 and the longitudinal axes 24 of the contiguous blade segments 21 are in zig-zagged relation as shown in Figure 3. The central longitudinal axis of a blade 52 is

represented by the line 25 in the same figure while the neutral axes of several blades 52 appear at 26 in Figure 2, these neutral axes being generally parallel with the plane occupied by the chords or bases of the triangular blade segments. The spanwise obliquity of the shock waves at the zigzagged leading edges of the blades is symmetrical so that the waves meet and die out substantially midway between each pair of adjoining angular edges 55 and 56. The broken lines A of Figure 4 illustrate the shock waves at the leading edges of one blade 52 and show the manner in which they converge and die out, or are reduced in intensity, at the points B. This suppression of intensity or elimination of the shock waves A, where the through flow velocity is of sonic or supersonic values, raises the critical Mach number of the blades to an appreciable degree. A three dimensional wave front defined by A and D, is formed, which is relatively weak, and, therefore, conducive to suppression of shock losses, as compared to the shocks which would be produced in conventional blading exposed to sonic or supersonic flow. In order to maintain a chordwise symmetry of the blades 52, their trailing edges are serrated or zigzagged in substantial conformance to the leading edges.

The rotor blades 52 are also designed or shaped to prevent the propagation of serious shock waves at the regions of maximum blade thickness. As best illustrated in Figures 2 and 4, the blades 52 are polygonal in transverse cross section, and in the invention, as illustrated, the blades are triangular, each having a plane surface facing in the direction of rotation and two angular rear surfaces joining at an apex C. The reaction type of blades 52 are arranged at a suitable angle of incidence, the blades of a given row being equally spaced and correspondingly positioned. The shock wave from the leading edge of one blade approaches or impinges upon the apex C of an adjacent blade, this being illustrated by the broken lines D in Figure 2. Since the aforesaid wave meets the adjacent blade at the point where the surface of the blade changes direction, or recedes away from the channel proper, no reflection wave is formed, thereby increasing thermo-dynamic efficiency by eliminating a shock loss. A shock wave from the leading edge of said adjacent blade travels along its rear surface and joins or sets up interference with the shock wave D at the apex C and the shock waves die out in this region. Thus the triangular configuration of the blades 52 prevents the propagation of strong rearwardly traveling shock waves which would otherwise occur when the velocities are of sonic or supersonic values. The rotor buckets or blades 52 are preferably tapered longitudinally to be of greater width or chord at their roots, and are preferably twisted or curved about their long axes, the curvature increasing toward the blade tips. Further, it is preferred to make the blades 52 hollow for cooling purposes and to reduce their weight. As illustrated at the right hand side of Figure 3, the wall thickness of the hollow blades 52 gradually increases from the blade tips to the blade roots. This increases the cooling surface area at the interiors of the blades and reduces the blade weight toward the tips. The cavities or cooling passages 550 of the blades 52 are preferably open at the blade tips and communicate with the interior of the rotor 51. The blades 52 may be secured to the rotor 51 in any approved or selected manner. In Figures 3 and 4 the blades 52 have shouldered roots or shanks 560 secured in recesses in the rotor 51, as by welding.

The aforementioned stator blades 53 are arranged in rows disposed between the rows of rotor blades 52. The blades 53 project inwardly from the lining 57 of the compressor casing, having buttons or shanks 58 secured to the wall of the casing or its lining. The intermediates or stator blades 53 are of the same configuration as the rotor blades 52, being zigzagged in the direction of their long axes and being of triangular transverse cross sectional configuration. The relation between the rotor blades 52

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and stator blades 53 is clearly illustrated in Figures 1 and 3. The blades 52 and 53 are constructed of high strength heat resistant material such as tantalum coated by chromium, cobalt steel, or the like, and are preferably precision cast.

From the foregoing detailed description it will be seen that I have provided novel, effective blading for incorporation in turbo type powerplants that effectively handles the working fluid at sonic, transonic and supersonic velocities. It will be observed that the cooling passages 550 have walls or surfaces which follow generally the external configuration of the blades 52 to present greatly increased areas for contact by the cooling air or other coolant, thus obtaining maximum cooling of the blades. The zigzag shape of the internal cooling passages 550 increases turbulence of the coolant to promote cooling effectiveness. Further, the gradually tapering or increasing wall thickness of the blades increases the cooling surface areas of the blades as above described. It has already been described how the oblique edges 55 and 56 of the turbine blades 52 avoid the propagation of shock waves which would otherwise produce severe losses when the working fluid is handled at the sonic and supersonic velocities. The action of the triangular sectioned blades in eliminating the shock waves D has also been described. The specially constructed or shaped blades of the invention adapt the powerplant for the efficient utilization of working fluid moving at sonic or supersonic velocities in obtaining shaft power for driving the compressor 10 as well as any auxiliary shafts that may be included in the powerplant and makes possible the discharge of an extremely high velocity reaction jet from the nozzle 12. When the powerplant is designed for handling the working fluid at sonic or supersonic velocities in the turbine it is preferred to employ blades 30 in the compressor 10 of the same general configuration as the turbine blades 52 above described, with appropriate variations to suit them for the compression of the working air.

Having described only a typical form of the invention I do not wish to be limited to the specific details herein set forth, but wish to reserve to myself any variations or modifications that may appear to those skilled in the art and fall within the scope of the following claims.

I claim:

1. In a turbo machine having a case for handling fluid at sonic and super-sonic velocities and a rotor in the case the combination of: spaced rows of blades on the rotor of triangular transverse cross section, the base surfaces of the triangular blade sections constituting the chord lines of the blades and the blades presenting sharp knife like leading edges defined by the intersection of said base surfaces and contiguous surfaces of the triangular sections, the blades each being zigzagged longitudinally as a whole to each comprise a series of blade segments of triangular cross section each having a chord line, said zigzagging being in a direction generally parallel with a surface generated by said chord lines of the segments, said chord lines of the segments of each blade being so disposed that all of the same are intersected by a single straight line and the longitudinal center lines of the contiguous blade segments lying in a surface substantially parallel with said surface generated by said chord lines, and stator blades on the case projecting inwardly between the first named blades.

2. In a turbo machine having a case for handling fluid at sonic and super-sonic velocities and a rotor in the case the combination of: spaced rows of blades on the rotor of triangular transverse cross section, the base surfaces of the triangular blade sections constituting the chord lines of the blades and the blades presenting sharp knife like leading edges defined by the intersection of said base surfaces and contiguous surfaces of the triangular sections, the blades each being zigzagged longitudinally as a whole to each comprise a series of blade segments of triangular

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cross section each having a chord line, said zigzagging being in a direction generally parallel with a surface generated by said chord lines of the segments, said chord lines of the segments of each blade being so disposed that all of the same are intersected by a single straight line and the longitudinal center lines of the contiguous blade segments lying in a surface substantially parallel with said surface generated by said chord lines, and stator blades of triangular cross section and longitudinally zigzagged configuration on the case projecting inwardly between the first named blades.

3. In a turbo machine having a rotor; a row of spaced blades of triangular transverse cross section on the rotor, the base surfaces of the triangular sections of the blades constituting the chord lines of the blades and said base surfaces intersecting contiguous surfaces of the triangular sections at sharp edges, said sharp edges constituting the leading edges of the blades, each blade being zigzagged longitudinally to comprise a series of blade segments of triangular cross section each having a chord line, the zigzagging being in a direction generally parallel with a surface generated by said chord lines of the segments so that said leading edges of the blades are each comprised of a series of oblique portions, said chord lines of each blade being disposed so that all of the same are intersected by a single straight line, the longitudinal center lines of the blade segments of each blade lying in a surface substantially parallel with said surface generated by said chord lines.

4. In a turbo machine having a rotor; a row of spaced blades of triangular transverse cross section on the rotor, the base surfaces of the triangular sections of the blades constituting the chord lines of the blades and said base surfaces intersecting contiguous surfaces of the triangular sections at sharp edges, said sharp edges constituting the leading edges of the blades, each blade being zigzagged longitudinally to comprise a series of blade segments of triangular cross section each having a chord line, the zigzagging being in a direction generally parallel with a surface generated by said chord lines of the segments so that said leading edges of the blades are each comprised of a series of oblique portions, said chord lines of each blade being disposed so that all of the same are intersected by a single straight line, the longitudinal center lines of the blade segments of each blade lying in a surface substantially parallel with said surface generated by said chord lines, each blade being twisted about said single straight line.

5. In a turbo machine having a rotor; a row of spaced blades of triangular transverse cross section on the rotor, the base surfaces of the triangular sections of the blades constituting the chord lines of the blades and said base surfaces intersecting contiguous surfaces of the triangular sections at sharp edges, said sharp edges constituting the leading edges of the blades, each blade being zigzagged longitudinally to comprise a series of blade segments of triangular cross section each having a chord line, the zigzagging being in a direction generally parallel with a surface generated by said chord lines of the segments so that said leading edges of the blades are each comprised of a series of oblique portions, said chord lines of each blade being disposed so that all of the same are intersected by a single straight line, the longitudinal center lines of the blade segments of each blade lying in a surface substantially parallel with said surface generated by said chord lines, the blades having longitudinal internal passages of triangular cross section and zigzagged longitudinally to have walls substantially paralleling the surfaces of said segments.

6. In a turbo machine having a rotor; a row of spaced blades of triangular transverse cross section on the rotor, the base surfaces of the triangular sections of the blades constituting the chord lines of the blades and said base surfaces intersecting contiguous surfaces of the triangular sections at sharp edges, said sharp edges constituting the

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leading edges of the blades, each blade being zigzagged longitudinally to comprise a series of blade segments of triangular cross section each having a chord line, the zigzagging being in a direction generally parallel with a surface generated by said chord lines of the segments so that said leading edges of the blades are each comprised of a series of oblique portions, said chord lines of each blade being disposed so that all of the same are intersected by a single straight line, the longitudinal center lines of the blade segments of each blade lying in a surface substantially parallel with said surface generated by said chord lines, the blades having longitudinal internal passages of triangular cross section and zigzagged longitudinally to have walls substantially paralleling the surfaces of said segments, said passages continuing through the outer ends of the blades and increasing in capacity toward the outer ends of the blades.

7. In a turbo machine; an elongate blade of triangular transverse cross section, the base surface of the triangular section constituting the basic chord line of the blade and said base surface intersecting a contiguous surface of the triangular section at a sharp edge to constitute the leading edge of the blade, the blade being zigzagged longitudinally to have a series of blade segments of triangular cross section each having a chord line, the zigzagging of the blade being in a direction generally parallel with a surface generated by said chord lines of the segments so that said leading edge is comprised of a series of oblique edge portions, said chord lines of the several segments being intersected by a single straight line and the central longitudinal axes of the several segments lying in a surface generally parallel with said surface generated by the chord lines of the segments.

8. In a turbo machine; an elongate blade of triangular

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transverse cross section, the base surface of the triangular section constituting the basic chord line of the blade and said base surface intersecting a contiguous surface of the triangular section at a sharp edge to constitute the leading edge of the blade, the blade being zigzagged longitudinally to have a series of blade segments of triangular cross section each having a chord line, the zigzagging of the blade being in a direction generally parallel with a surface generated by said chord lines of the segments so that said leading edge is comprised of a series of oblique edge portions, said chord lines of the several segments being intersected by a single straight line and the central longitudinal axes of the several segments lying in a surface generally parallel with said surface generated by the chord lines of the segments, said blade being twisted about said single straight line.

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