June 14, 1960 A. R. HOWELL 2,940,689

TURBINE-DRIVEN FANS

Filed April 6, 1956 3 Sheets-Sheet 1

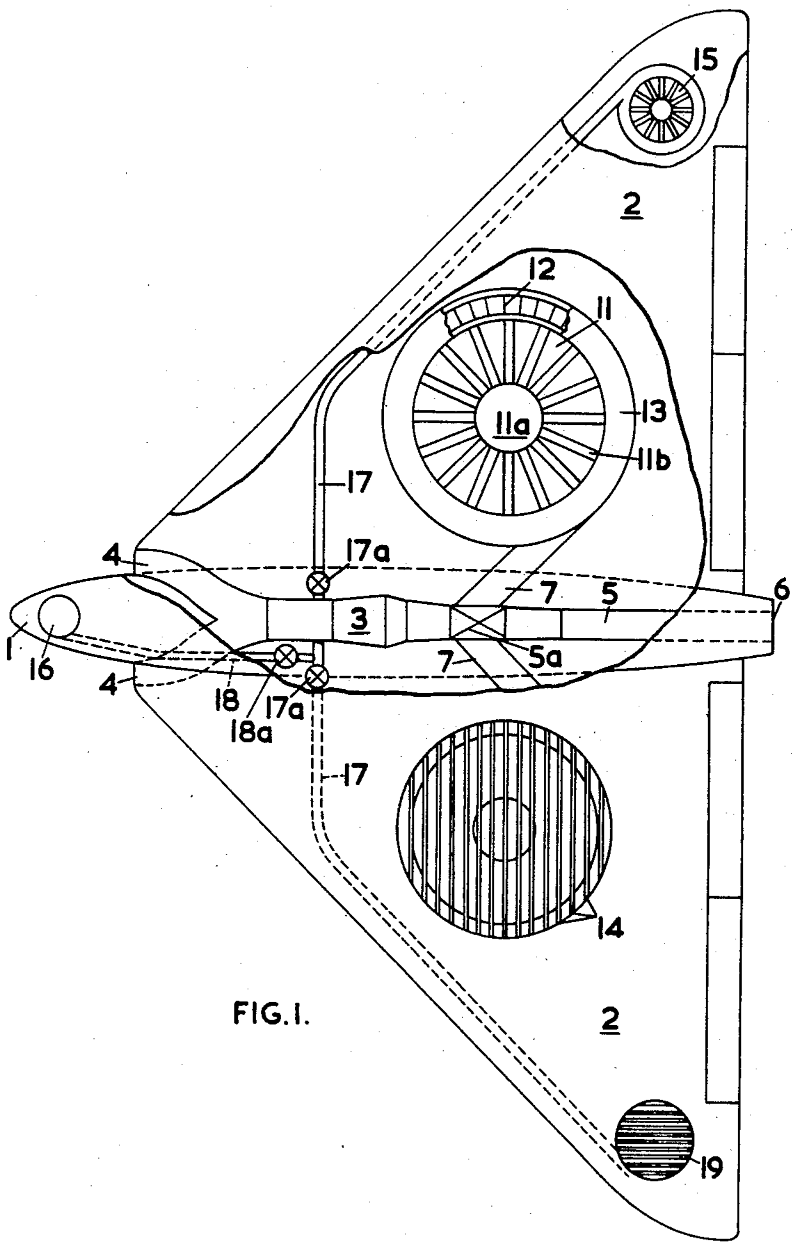

FIG. I.

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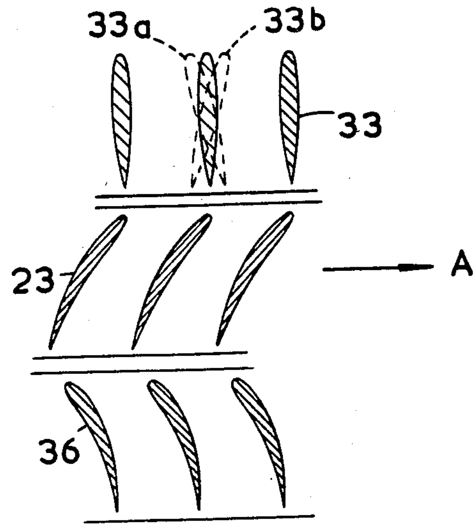

FIG. 5

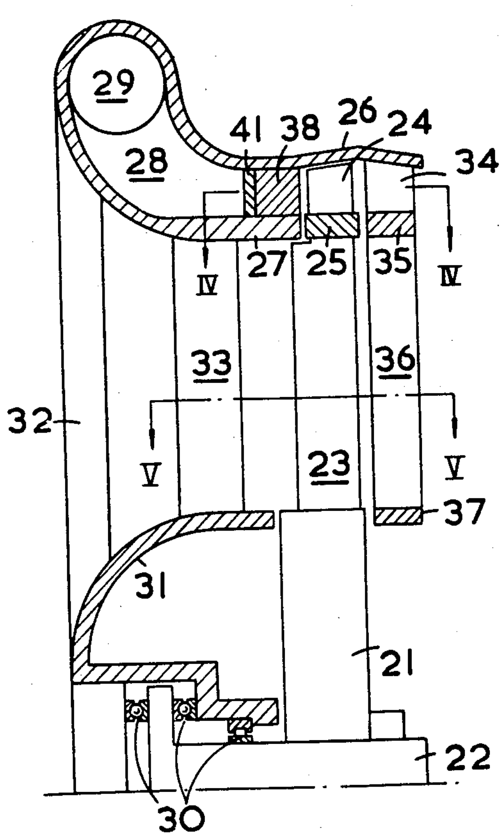

FIG. 2

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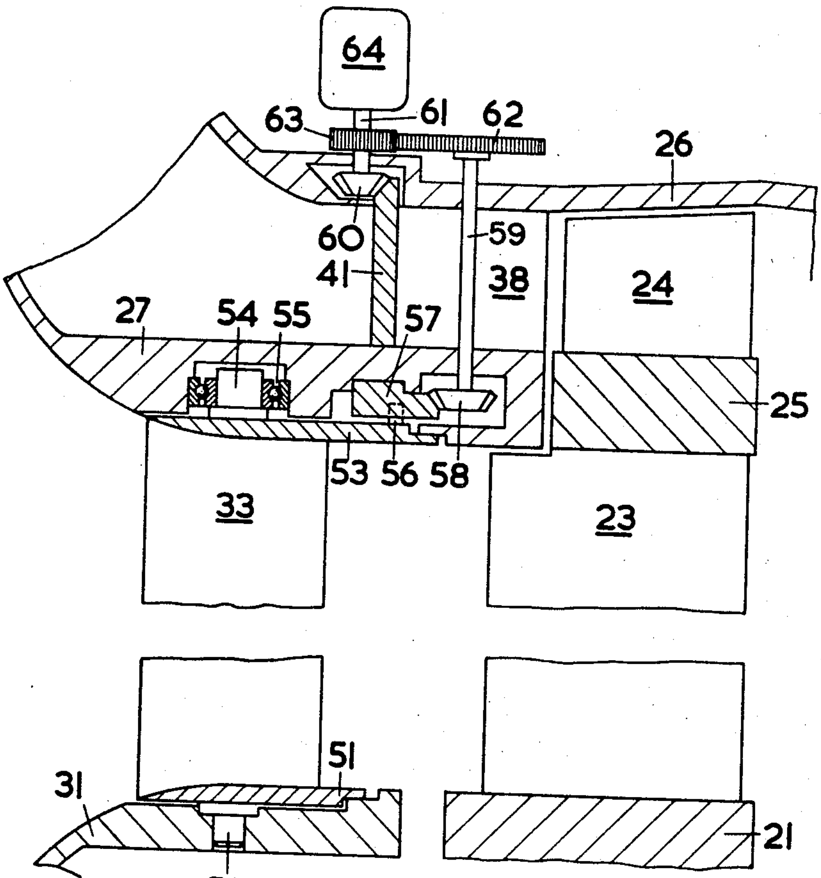

FIG. 3

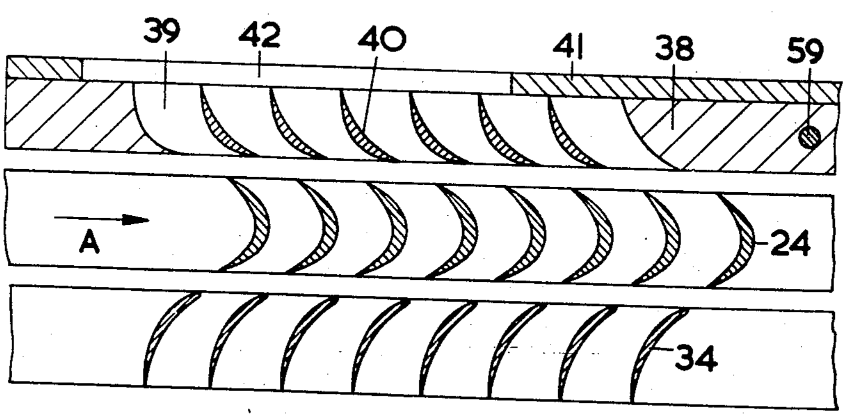

FIG. 4

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TURBINE-DRIVEN FANS

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8 Claims. (Cl. 244—12)

This invention relates to turbine driven fans of the type comprising a rotor carrying a row of axial flow fan rotor blades and a row of axial flow turbine rotor blades mounted radially outside the fan blades whereby the rotor is driven.

The invention is more particularly though not exclusively concerned with fans of the type indicated above in which the mass flow of air or other gaseous fluid through the fan blades is greatly in excess of the mass flow of working fluid through the turbine blades, while the pressure and velocity of the turbine working fluid is greater than that of the air passing through the fan.

One application of fans of the type referred is to control an aircraft in hovering flight. An aircraft may have a number of such fans mounted to discharge streams of air in such directions as to exert turning moments on the aircraft, one such aircraft being described in copending application No. 26,576/54. In hovering flight, it is essential that the control shall be immediate, and so the fans must be such that their outputs are variable over their working range substantially instantaneously. Delay in the fan adjusting itself to a change of output is primarily due to the inertia of the rotor and so it is desirable that the rotational velocity of the rotor shall be substantially constant throughout its working range.

Accordingly the present invention provides a turbine driven fan comprising a rotor carrying a row of axial flow fan rotor blades and a row of axial flow turbine rotor blades mounted radially outside the fan rotor blades, a variable area turbine nozzle for supplying working fluid to the turbine rotor blades, and a further row of axial flow fan blades arranged in series flow relationship with the fan rotor blades, wherein the blades of one of the rows of fan blades are angularly adjustable and are operatively linked to the variable area turbine nozzle in such a way that, for given conditions of temperature and pressure at the turbine inlet, the rotor speed is maintained at a substantially constant value over a range of output of the fan.

Preferably the further row of fan blades is a row of angularly adjustable axial flow fan inlet guide blades upstream of the fan rotor blades, and the linkage may then be such that when the turbine nozzle area and hence the mass flow through the turbine is increased, the guide blades are turned in a sense to increase the air inlet angle to the fan blades.

To get the maximum work out of the turbine it is desirable that the turbine shall be of the impulse type. The variable area nozzle is then of the partial admission type with the outlet static pressure equal to ambient pressure, and the rotor blades are shaped so that there is no static pressure drop across them.

In some circumstances it may be desired that working fluid discharged from the turbine shall constitute part of the total output of the fan. If the rotor peripheral velocity is low, the fluid discharged from the impulse turbine rotor blades necessarily has a large whirl component, and to reduce losses, there may be a row of tur-

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bine stator blades downstream of the rotor blades which are shaped to discharge the fluid in an axial direction. These blades are similar to compressor blades in cross-section, but to obviate reverse flow in the turbine, the height of the flow passage between them decreases in a downstream direction in such a way as to maintain the static pressure constant and equal to ambient pressure.

One embodiment of the invention will now be described by way of example with reference to the accompanying drawings, of which:

Figure 1 is a diagrammatic plan view of an aircraft provided with fans for giving vertical lift and with further fans for control, in hovering flight, part of the upper surface of the aircraft being shown as broken away to show the interior construction.

Figure 2 is a half-sectional view of one of the control fans.

Figure 3 is a view of the fan on a larger scale.

Figures 4 and 5 are developed sectional views on the lines IV—IV and V—V in Figure 2 of the turbine and compressor blading respectively.

Figure 1 shows a small high speed aircraft, as described in copending application No. 26,576/54, comprising a fuselage **1** and wings **2** of delta configuration and powered by a gas turbine jet propulsion engine **3** of known type mounted centrally within the fuselage. The engine **3** draws in air through air intakes **4** in the wing roots and discharges the exhaust gases rearwardly as a propulsive jet stream through a jet pipe **5** extending along the centre line of the fuselage **1** and terminating in a jet nozzle **6** at its rearward extremity. The jet pipe is circular in internal cross-section immediately rearwardly of the engine and at the nozzle but comprises an intermediate portion *5a* which is rectangular in cross-section, the circular and rectangular portions being joined by connecting portions which progressively change in shape without substantial change of cross-sectional area. The rectangular portion *5a* is provided with two branch pipes **7**, one on each side thereof, which intersect the jet pipe at an acute angle so that the entries to the branches face upstream relative to the jet stream. Means are provided for diverting the exhaust gas stream from the jet pipe **51** into these branch pipes **7** when required.

The aircraft is further provided with two fans **11** symmetrically arranged on each side of the centre line of the aircraft, one being mounted in each wing with its rotor axis substantially vertical and arranged to draw in air from atmosphere through an opening in the upper surface of the wing and to discharge it downwardly through an opening in the under surface of the wing so as to impart an upthrust to the aircraft. The fan rotors rotate in opposite directions, thus balancing out gyroscopic effects. Each fan rotor comprises a hub **11*a***, a row of axial flow fan rotor blades **11*b*** extending outwardly therefrom and a row of axial flow turbine rotor blades **12** mounted around the outside of the fan blades **12*a***. Exhaust gases diverted from the jet pipe **5** are supplied to these turbine rotor blades **12** through a turbine inlet volute **13** mounted immediately above the fan. Each volute **13** has a tangential inlet connected to one of the branch pipes **7** and a downwardly facing annular outlet provided with turbine nozzle vanes co-operating with the turbine rotor blades **12**.

For normal forward flight, the entries to the branch pipes **7** are closed while the exhaust gas stream is discharged rearwardly through the jet nozzle **6** as a propulsive jet stream. For take-off and landing, and in hovering flight, the exhaust gases are diverted into the branch pipe **7** and flow through the turbine inlet volutes **13** to drive the turbine rotor blades **12** which thereby drive the fans **11**.

Means are provided for closing the air inlet and outlet openings in the surfaces of the wings when the fans are not in use. Thus the openings in the wing upper surfaces are provided with cascades of pivoted vanes **14** which are pivotal between a position in which they lie edge on to the air flow through the openings as shown in Figure 1 to one in which they lie flush with the surface of the wing to close the openings.

In order to control the movements of the aircraft at low speed and in hovering flight, additional fans are provided, arranged to discharge streams of air in directions such as to exert turning moments or side forces on the aircraft in a sense to exercise the desired control. Thus there are fans **15** mounted in the aircraft wing tips with their axes vertical so as to exert moments about a longitudinal axis, and a further fan **16** is mounted with its axis vertical in the extreme nose of the aircraft so as to exert a moment about a transverse axes. In addition there may be a fan mounted in the fin of the aircraft with its axis extending horizontally and transversely of the centre line of the aircraft so as to exert a moment in the yawing plane. These fans **15**, **16** are smaller than the fans **11** for giving upthrust but are provided with turbine rotor blades for driving them in a like manner. The turbine blades for these fans are driven by compressed air at a pressure of several times atmospheric bled off from the compressor of the main gas turbine jet propulsion engine 3 and led to the fans through pipes 17, 18 provided with control valves **17a**, **18a**.

Each fan draws in air at substantially atmospheric pressure. The flow through the fan and turbine blading is in the same axial direction, and the concentric streams of air from the fan and the turbine blading together constitute the air stream for exerting a turning moment on the aircraft. The mass flow through the fan blading is greatly in excess of the mass flow through the turbine blading. The fan apertures are provided with rows of vanes **19** for closing them when not in use.

As shown in Figure 2, each fan comprises a rotor disc **21** mounted on a shaft **22** and carrying on its periphery a row of axial flow fan blades **23** and at row of axial flow turbine blades **24** mounted on the tips of the fan blades. The turbine blade height is only a small fraction of the fan height. Various forms of construction may be used. Thus as shown the tips of the fan blades **23** may be interconnected by a continuous shroud ring **25** having sockets or seatings in which the roots of the turbine blades **24** engage. Alternatively each fan blade **23** may be formed integrally with a tip shroud and one or more turbine blades **24**, the shrouds abutting circumferentially to form a continuous shroud ring.

Around the outside of the rotor is a stator casing **26** which extends upstream and downstream of the rotor. Within this casing on the upstream side of the rotor is an inner annular wall **27** aligned with the shroud ring **25** between the fan and turbine rotor blades and defining with the casing an annular nozzle passage leading to the turbine rotor blades 24. These two walls are connected at their upstream ends to an annular manifold **28** which has a tangential inlet **29** receiving the compressed air from pipes **17** or **18** for driving the turbine.

The rotor shaft **22** is mounted in bearings **30** carried in a fairing **31** on the upstream side of the rotor. This fairing **31** with the above mentioned inner wall **27** defines an annular air inlet from atmosphere to the fan rotor blades **23**, and is supported from the inner wall **27** by streamline struts **32** extending across the inlet. Oil for the rotor shaft bearings **30** may be supplied through these struts. Also extending across the fan inlet is a row of inlet guide blades **33** lying immediately upstream of the fan motor blades **23**, these blades being angularly adjustable, each being mounted for pivotal movement about a longitudinal radially extending axis.

Mounted on the inner wall of the casing **26** immediately downstream of the turbine rotor blades **24** is a row of inwardly extending turbine stator blades **34**, the inner extremities of which are connected by a shroud ring **35** aligned with the shroud ring **25** between the fan and turbine rotor blades. The inner surface of the shroud ring **35** carries a row of inwardly extending fan stator blades **36** lying immediately downstream of the fan rotor blades **23** and connected at their inner extremities by a shroud ring **37** aligned with the surface of the rotor disc **21**. These turbine and fan stator blades may be constructed in a similar manner to the rotor blades.

Extending across the annular nozzle passage immediately upstream of the turbine rotor blades **24** is a diaphragm **38** formed with one or more sector shaped openings **39** (see Figure 4) provided with flow-directing inlet nozzle vanes **40** and constituting a partial admission nozzle for the turbine. Immediately upstream of the diaphragm **38** is an annular nozzle plate **41** having sector shaped openings **42** corresponding to the nozzle openings in the diaphragm. This plate **41** is circumferentially rotatable so as to cover or uncover part of the turbine nozzle openings and so vary the nozzle area and the mass flow through the turbine. The turbine inlet nozzle vanes **40** are so designed that the static pressure at the nozzle outlet is equal to ambient pressure.

The turbine rotor blades **24** are of the known impulse type. The height of the flow passage between them increases from inlet to outlet as shown in Figures 2 and 3 to ensure that the static pressure is constant. The blades are symmetrical with respect to a line normal to and bisecting their chord lines, and their inlet and outlet angles are such as to produce a large deflection of the air flowing therethrough. The air discharged therefrom thus has a large whirl component.

The turbine stator blades **34** are in cross-section similar to conventional compressor blades, and have their trailing edges shaped to discharge the air axially without whirl. The flow path between these blades however is such that it decreases in height in the direction of flow so that the static pressure through the blade row remains constant and substantially equal to the ambient pressure. This serves to prevent reverse flow through the turbine. To achieve this condition, the casing **26** is tapered to give the required reduction in flow area. Alternatively or in addition the outer surface of the shroud ring **35** may be appropriately tapered.

Instead of shaping the geometrical flow path to correspond to the aerodynamic flow path through the turbine as described above, it may be left parallel and the air allowed to follow its own path.

The turbine blade angles are such that the peripheral direction of the air at the turbine nozzle outlet and rotor inlet is opposite to that at the rotor outlet and stator inlet as shown in Figure 4, the direction of rotor being indicated by the arrow A. In order to get the maximum work out of the turbine, the air velocities are quite high, and may be supersonic at the nozzle outlet.

The fan rotor and stator blades **23**, **36** are of conventional compressor cross-section, being cambered and oppositely staggered as shown in Figure 5. The trailing edges of the stator blades **36** are shaped to discharge the air axially without whirl. The guide blades **33** are uncambered and are angularly adjustable so as to vary the air inlet angle to the fan rotor blades. In this way the rotor velocity can be maintained at a substantially constant value over the range of output of the fan. In the particular embodiment described the guide blade incidence is zero at the design output. For lower outputs the blades are adjusted so that they are staggered oppositely to the rotor blades as indicated at **33a** and the outlet air flow has a component in the direction of rotation of the rotor (indicated by the arrow A), and for higher outputs, they are adjusted so that their stagger is in the same sense as the rotor blades as indicated at **33b**, and the outlet airflow has a component opposite to the direction of rotation of the rotor. Thus for increasing output, the air outlet angle from the guide blades is decreased from a positive value at minimum output to zero at design output, and then to a negative value for minimum output, the air inlet angle to the rotor blades being correspondingly increased.

Of course in other embodiments of the invention the design incidence of the guide blades may be other than zero.

The fan inlet guide blades 33 and stator blades 36 are of constant section and untwisted. The rotor blades 23 may be twisted to suit the condition of equal work done along the height of blade with constant axial velocity in known manner. In the present embodiment of the invention however, it is not essential to have constant axial velocity at all radii, and so constant section untwisted rotor blades may be used with little loss of efficiency.

The adjustable guide blades 33 are linked to the nozzle plate 41 for varying the turbine nozzle area in such a way that when the nozzle area is increased to increase the mass flow through the turbine, and so increase the fan output, the guide blades are adjusted in a sense to maintain the rotor at substantially constant speed, i.e. the air inlet angle to the fan rotor blades is increased. The linkage may be of any conventional form and one arrangement is shown in Figure 3. Each guide blade 33 has an inner shroud 51 and an inner spindle 52 supported in a plain bearing in the fairing 31 and an outer shroud 53 and an outer spindle 54 supported in a ball bearing 55 in the inner wall 27. The shroud 53 extends downstream of the blade and has a pin 56 fixed to its outer surface engaging in a recess in an operating ring 57 which is rotatable in a circumferential sense in an inwardly facing groove in the wall 27.

The ring 57 is formed with bevel gear teeth which engage with a bevel gear 58 carried within a cavity in the wall 27 on the end of a shaft 59 extending radially through the turbine diaphragm 38. Thus rotation of shaft 59 causes the ring 57 to turn and so the blades 33 can be rotated in unison about radially extending axes.

The nozzle plate 41 for varying the turbine nozzle area extends into a recess in the outer casing 26 and is formed with bevel gear teeth engaging with a bevel gear 60 mounted on a shaft 61. The shafts 59 and 61 are linked by spur gears 62, 63 and are driven by an electric motor 64. Thus the plate 61 can be rotated circumferentially and the blades 33 turned about their axis simultaneously, the gear ratio of gears 62 and 63 being chosen to give the desired relation between the movements of the plate and blades to ensure substantially constant rotational speed of the rotor. As the movement of the operating ring 57 will normally be small compared with that of the plate 41, the gear 62 is considerably larger than the gear 63 to give the required speed reduction.

The above described embodiment gives a linear relationship between the angular position of the blades and the turbine nozzle area which may in some cases be satisfactory to produce constant speed conditions over the working range of the fan. In some circumstances some departure from constant speed conditions may be permissible to obviate the necessity for a more complicated linkage. Thus there might be a continuous small variation of speed over the working range of the fan, or the linkage might be such as to give the same rotational speed at minimum, design and maximum outputs while permitting some departure from this value at intermediate output.

If precisely constant speed conditions are required over the whole working range of the fan and the design is such that a simple mechanism such as that described above will not suffice, other more complicated arrangements may be used. For example, the shafts 59, 61 may carry spur gears each meshing with a rack formed on a push rod actuated by a cam, the cams being driven by a common motor and being shaped to impart the required movements to the plate 41 and guide blades 23.

Any other equivalent mechanism to those described above may be used. For example, the guide blades and nozzle plate may be operated by hydraulic cylinders or other fluid pressure operated means controlled by servo-mechanisms giving the required ratio of speeds.

Instead of the fan rotor blades 23 described above, a row of high reaction fan rotor blades from which the air is discharged axially may be used. In this case the row of fan stator blades 36 downstream of the fan rotor blades may be dispensed with, and normally the guide vanes 33 will be cambered.

In alternative arrangements, the fan rotor blades 23 or the fan stator blades 36 may be angularly adjustable to give the required rotor speed. In either case the adjustable blades will be linked to the plate 41 in such a way that when the nozzle area is increased, the stagger of the blades is decreased, that is, the blades 23 are turned in an anticlockwise sense (as shown in Figure 1) or the blades 36 are turned in a clockwise sense as the case may be.

To save weight, the row of turbine stator blades 34 may in some cases be omitted. In a still further alternative arrangement, the turbine nozzle may be provided with angularly adjustable inlet nozzle vanes for varying the turbine nozzle area.

The fans may be driven by exhaust gases bled off from the jet pipe 5 instead of by compressed air from the compressor.

The invention may be applied to the main fans 11 of the aircraft. It might also be applied to fans for use in wind tunnels or for ventilation.

I claim:

1. A turbine driven fan comprising a rotor; a row of axial flow fan rotor blades mounted thereon; a row of axial flow turbine rotor blades mounted on the rotor radially outside said fan rotor blades; a turbine nozzle arranged to supply working fluid to said turbine rotor blades; means for varying the area of said nozzle; a row of axial flow fan blades in series of flow relationship with said fan rotor blades; means mounting the blades of one of said rows of fan blades for angular adjustment; means for angularly adjusting said last-mentioned row of fan blades; and means operatively linking said means for varying the area of the turbine nozzle and the means for angularly adjusting said fan blades in such a way that, for given conditions of temperature and pressure at the turbine inlet, the rotor speed is maintained at a substantially constant value over the range of output of the fan.

2. A turbine driven fan comprising a rotor; a row of axial flow fan rotor blades mounted thereon; a row of axial flow turbine rotor blades mounted on the rotor radially outside said fan rotor blades; a turbine nozzle arranged to supply working fluid to said turbine rotor blades; means for varying the area of said nozzle; a row of axial flow fan inlet guide vanes upstream of said row of fan rotor blades; means mounting said vanes for angular adjustment; means for angularly adjusting said vanes; and means operatively linking said means for varying the area of turbine nozzle and the means for angularly adjusting said vanes in such a way that, for given conditions of temperature and pressure at the turbine inlet, the rotor speed is maintained at a substantially constant value over the range of output of the fan.

3. A turbine driven fan comprising a rotor; a row of axial flow fan rotor blades mounted thereon; a row of axial flow turbine rotor blades mounted on the rotor radially outside said fan rotor blades; a turbine nozzle arranged to supply working fluid to said turbine rotor blades; means for varying the area of said nozzle; a row of axial flow fan inlet guide vanes upstream of said row of fan rotor blades; means mounting said vanes for angular adjustment; means for angularly adjusting said vanes; and means operatively linking said means for varying the area of turbine nozzle and the means for angularly adjusting said vanes in such a way that when the turbine nozzle area is increased, the guide vanes are

turned in a sense to increase the fluid inlet angle to the fan rotor blades.

4. A fan according to claim 3 further comprising a row of fan stator blades downstream of said row of fan rotor blades, said stator blades being shaped to cause the fluid to be discharged in an axial direction.

5. A fan according to claim 3 wherein said turbine rotor blades are of the impulse type and said turbine nozzle is of the variable area partial admission type.

6. A fan according to claim 5 further comprising a row of turbine stator blades downstream of said row of turbine rotor blades, said stator blades being shaped to cause the working fluid to be discharged in an axial direction.

7. A fan according to claim 6 including means to decrease the height of the flow passage between said turbine stator blades in a downstream direction in such a manner as to maintain the static pressure constant and equal to ambient pressure.

8. An aircraft having mounted therein a turbine driven fan arranged to discharge a stream of air in such a direction as to exert a turning moment in the aircraft, said fan including means to vary the mass flow through said fan without changing the rotational velocity of said fan whereby the output of said fan may be changed substantially instantaneously, said fan comprising a rotor; a row of axial flow fan rotor blades mounted thereon; a row of axial flow turbine rotor blades mounted on the rotor radially outside said fan rotor blades; a turbine nozzle arranged to supply working fluid to said turbine rotor blades; means for varying the area of said nozzle; a row of axial flow fan blades in series flow relationship with said fan rotor blades; means mounting the blades of one of said rows of fan blades for angular adjustment; means for angularly adjusting said last-mentioned row of fan blades; and means operatively linking said means for varying the area of the turbine nozzle and the means for angularly adjusting said fan blades in such a way that, for given conditions of temperature and pressure at the turbine inlet, the rotor speed is maintained at a substantially constant value over the range of output of the fan.

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