

Jan. 15, 1963

H. J. WOOD
VORTEX VENTURI

3,073,114

Filed April 6, 1959

2 Sheets-Sheet 1

FIG. 1

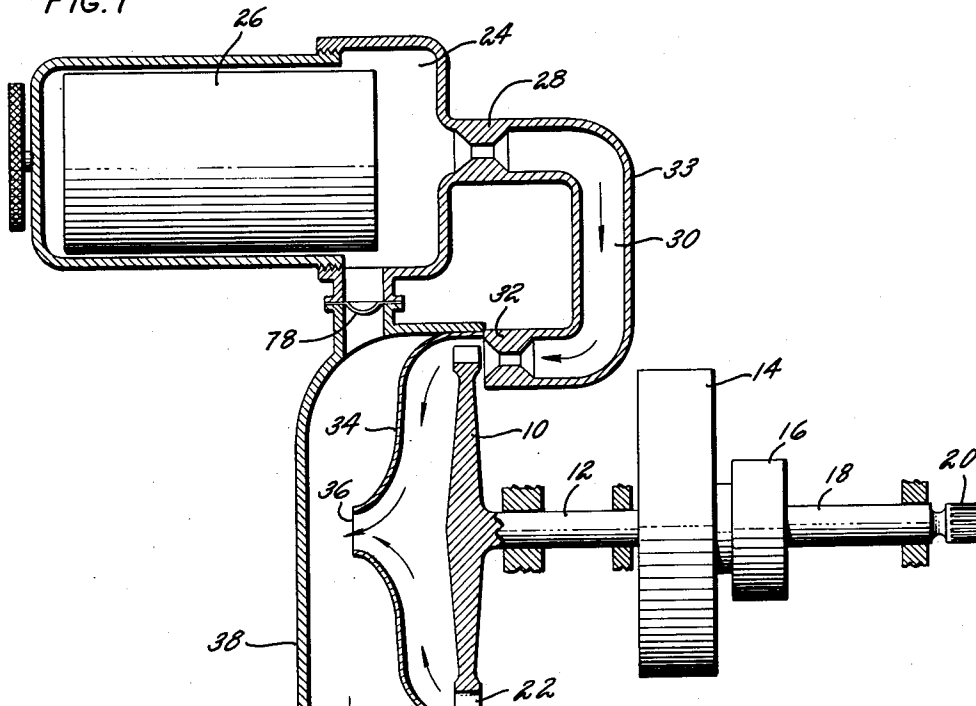
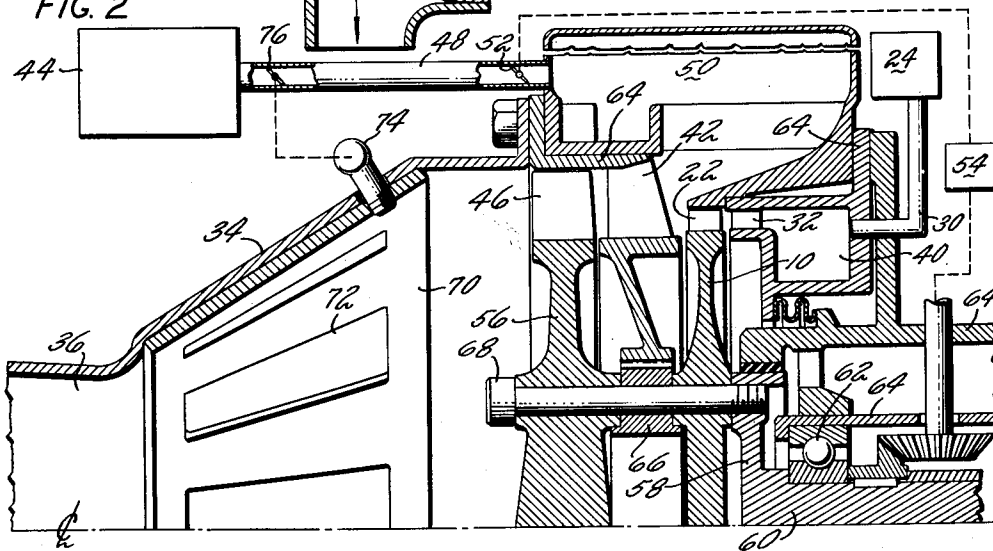


FIG. 2



INVENTOR
HOMER J. WOOD
BY *Harris G. Luther*
ATTORNEY

Jan. 15, 1963

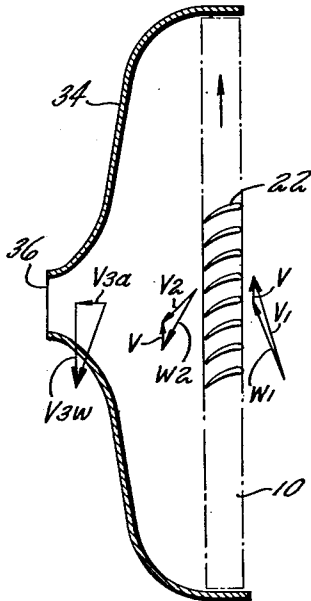
H. J. WOOD
VORTEX VENTURI

3,073,114

Filed April 6, 1959

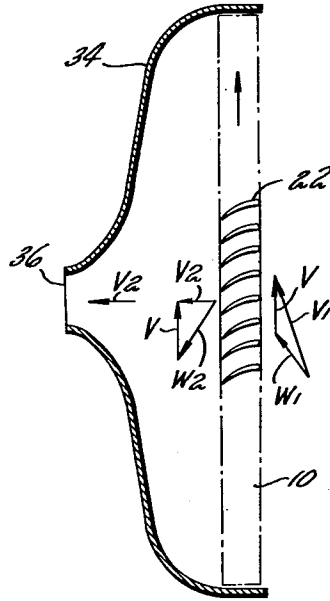
2 Sheets-Sheet 2

FIG. 3



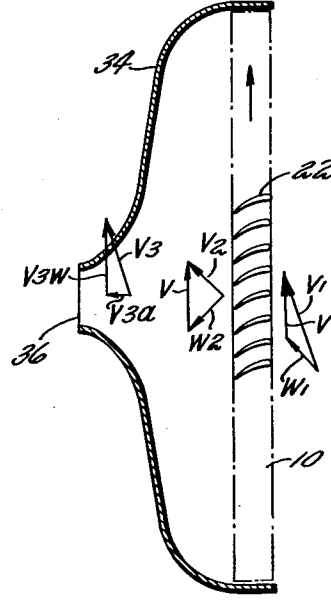
UNDERSPEED

FIG. 4



ONSPEED

FIG.5



OVERSPEED

FIG. 6

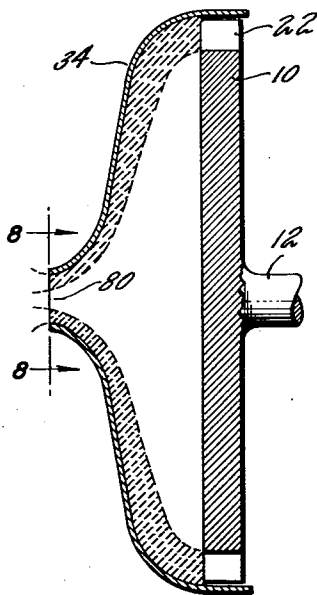


FIG. 7

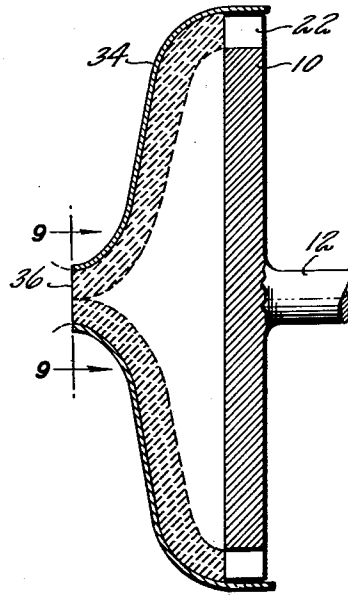


FIG. 8

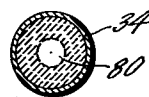
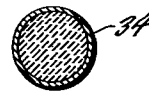


FIG. 9



INVENTOR
HOMER J. WOOD
BY *Harris E. Luther*
ATTORNEY

1

3,073,114

VORTEX VENTURI

Homer J. Wood, Sherman Oaks, Calif., assignor to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware

Filed Apr. 6, 1959, Ser. No. 804,183

4 Claims. (Cl. 60—39.14)

This invention relates to turbine construction and particularly to a speed control for a turbine utilizing a source of compressible fluid as a driving means.

An object of this invention is structure which will prevent overspeeding of a turbine by automatically controlling the turbine back pressure.

Another object is a simple speed limiting device which requires no moving parts.

A further object of the invention is mechanism utilizing swirl in the turbine exhaust fluid to create a strong vortex and consequent back pressure which will reduce the pressure drop through said turbine and control the turbine speed.

A still further object is an engine starter utilizing an uncontrolled-pressure compressible fluid source, such as a combustion cartridge supplying pressure fluid to a turbine, and utilizing the exhaust stream for automatically preventing overspeeding of the turbine.

A still further object is an engine-starter turbine having a regulated-pressure compressible fluid source and an unregulated-pressure compressible fluid source including mechanism responsive to turbine speed controlling the supply of regulated pressure fluid and means responsive to an exhaust gas condition controlling the turbine speed when operated by the unregulated pressure fluid source.

Other objects and advantages will be apparent from the following specification and the attached drawings in which:

FIG. 1 is a schematic side view showing the pressure source, the turbine starter and the exhaust shroud;

FIG. 2 is a partially schematic vertical cross-section showing the invention applied to a combined combustion gas and controlled gas turbine starter;

FIGS. 3 to 5 are diagrammatic showings including vector diagrams of the effect of the swirl in the exhaust duct;

FIG. 6 is a schematic showing of the path of swirling exhaust fluid from the turbine;

FIG. 7 is a schematic showing of the path of exhaust fluid without swirl; and

FIGS. 8 and 9 are sections on lines 8—8 and 9—9, respectively.

The speed controlling devices described herein are applicable to turbine speed regulation for many purposes in addition to the specific application to engine starters described herein. A starter is used only as a convenient embodiment for explaining the invention.

One of the problems in connection with the use of combustion turbine starters for engines and particularly with combustion starters utilizing a cartridge of solid propellant which will continue to produce a stream of high pressure fluid until completion of the combustion, is overspeeding of the turbine driving the starter when the load on the starter is relieved as by starting of the engine or failure of the drive mechanism; although the load on the starter has been relieved, the stream of hot gases continues to be supplied until the combustion cartridge has burned out. This continued supply of uncontrolled gas will cause the turbine of the starter to overspeed unless some means are provided for preventing such overspeeding. It is well known that conventional turbines which drive starters, when overspeeding, will produce a swirl in the exhaust gases, and this invention provides a means

2

whereby this swirl can be utilized to create a build-up in the back pressure on the downstream side of the turbine and thus reduce the effective pressure ratio across the turbine to such an extent that the torque produced by the turbine is reduced to zero or controlled to such an extent that overspeeding is prevented; although the quantity of gas being fed through the turbine may be substantially unaltered.

As shown in FIG. 1, a starter having a turbine rotor 10 mounted on a shaft 12 drives a reduction gear 14 and may be connected by a clutch 16 to a shaft 18 having a spline portion 20 adapted to connect with a portion of the engine to be started. The turbine rotor 10 has buckets or vanes 22. Gas may be supplied from any suitable source but in the embodiment shown, is generated in the combustion chamber 24 by burning of combustion cartridge 26 and is led through a restricting nozzle 28, a conduit 30 and through directing or inlet nozzles 32 which are supported by turbine casing 33 and direct the combustion gases so that they will impinge on the blades or vanes 22 of the turbine and provide the propulsive force for driving the turbine rotor 10. The turbine may be of any well known type, either reaction or impulse, but it has been found that a turbine having reaction buckets or vanes operates satisfactorily. The combustion gases, after passing between the turbine blades 22, are directed radially inward by an exhaust shroud or duct 34 and are discharged through an opening 36 which may be substantially concentric with the axis of the turbine 10. After discharge through the orifice 36, the exhaust gases are led through a pipe 38 to any convenient point of discharge.

A somewhat similar turbine, but utilizing both controlled and uncontrolled gas source, is shown in FIG. 2. In this figure, the gases produced in the combustion chamber 24, upon firing of the cartridge, are led through a pipe 30 to a manifold 40 having nozzles 32 directing the combustion gases between the blades 22 of the turbine rotor 10 in substantially the same way as described in connection with FIG. 1.

In the device shown in FIG. 2, however, additional nozzles 42 are provided for directing fluid from any suitable source such as a chamber 44, which may be a portion of a jet engine, between turbine blades 46 into an exhaust duct 34 having an opening or orifice 36 in the form of a venturi. The gases from the pressure source or chamber 44 are led through a pipe 48 to a manifold 50 which delivers the gases to the nozzles 42. The pipe 48 is provided with a valve 52 controlled by a governor 54 driven in any suitable manner such as by beveled gears from the turbine rotor 56 to provide a speed responsive control for the gases from the chamber 44. The turbine rotor of FIG. 2 is a built-up structure supported on a flange formed on the end of a shaft 60 mounted on bearings 62 in a housing 64. The built-up turbine rotor comprises the rotor 10, adapted to be driven by the combustion gases of chamber 24, a spacer ring 66 and the rotor 56 which are held in assembled relation on the flange 58 by bolts, one of which is shown at 68. The nozzles 32 and 42 are stationary and are supported from and secured to the housing 64 of the turbine assembly.

Suitable sealing means are provided adjacent the turbine periphery and adjacent the turbine shaft to prevent leakage of gases from high to low pressure portions.

The combustion gases in FIG. 2, after passing between the blades 22 of the rotor 10, pass through the nozzles 42 and between the blades 46 of the rotors 56 into the turbine exhaust shroud 34. The exhaust shroud 34 in FIG. 2 has a sleeve 70 with ports 72 and may be manually moved by a handle 74 so that the ports 72 will line up with similar ports, not shown, in the shroud 34

or will block such ports in the shroud 34. The handle 74 may be operatively connected to a valve 76 in the outlet pipe 48 from the pressure chamber 44 so as to close the valve 76 when the ports 72 are closed and to open the valve 76 when the ports 72 are opened; thus providing an auxiliary outlet for the turbine exhaust when utilizing the controlled pressure source and limiting the exhaust from the turbine assembly to the venturi nozzle 36 when the controlled pressure source is blocked and combustion gas or an uncontrolled pressure source is utilized.

A manually controlled valve, in addition to the valve 76, may be inserted in the pipe 48 if desired. If desired and the pressure conditions warrant, the sleeve 70 and the ports in shroud 34 may be omitted and control of overspeed left to the effect of the exhaust shroud 34 and orifice 36 on the exhaust gases in the same manner as when the gas supply is from the combustion cartridge.

From the above structure, it will be appreciated that when the controlled pressure source is utilized, overspeeding may be prevented by the action of the governor 54 closing the valve 52 and limiting the supply of gas whenever the speed exceeds a preselected value. It will also be appreciated that, with the uncontrolled supply of combustion gases, no such control is possible. If such a control were attempted with a combustion gas supply, it would undoubtedly result in an excessive build-up of pressure in the combustion chamber 24 and a rupturing of the safety blow-out plug, requiring mechanical servicing of the unit, as well as additional mechanical structure and complications and hence, would not provide control without moving parts which is one of the objects of this invention.

It will be understood that the starter shown in FIG. 2 is provided with the reduction gear 14, clutch 16 and the engine connection 20 in the usual manner such as indicated in FIG. 1.

In order to control the turbine when utilizing the combustion gases, the turbine is designed so as to have a substantially axial discharge with substantially no swirl at the normal operating or design speed of the turbine as shown in FIGS. 4 and 7. Upon overspeed of the turbine, as shown in FIG. 5, a substantial swirl is imparted to the exhaust gases in addition to the axial flow as shown in FIGS. 5 and 6 and a similar action takes place upon underspeeding of the turbine as shown in FIG. 3.

In FIGS. 3, 4, and 5, the velocities and direction of the gases are shown vectorially and V_1 indicates the velocity and direction of the gases from the discharge nozzle 32 in FIG. 1 and 42 in FIG. 2. The size of the nozzles 32 in FIGS. 1 and 2 and the pressures created in the pipe 30 and the manifold 40 may be such that the nozzles are always choked; that is, the gases passing therethrough have reached sonic velocity so that changes in downstream pressure while the nozzles remain choked do not change the mass flow of gas through the nozzles. In other words, in the normal operating condition, the pressure drop across the nozzle 32 may be so far above the critical value (say a ratio of 20 to 1), that the pressure downstream of the nozzle may be materially increased without affecting the mass flow through the nozzle, and as the direction of discharge of the nozzle is fixed, V_1 will be a satisfactory representation of the velocity and direction of the nozzle discharge for all the working conditions of the turbine for the purposes of this disclosure.

In practice, however, it is quite possible that changes in pressure downstream of the nozzle may change both the velocity and direction of the gases reaching the turbine buckets, but for the present consideration relating to the creation of a vortex in the exhaust, it will suffice to consider the direction and velocity of the nozzle discharge as fixed.

The peripheral velocity of the turbine wheel is indicated by the vector V and is shown in FIGS 3 to 5 as varying in accordance with the underspeed, on-speed and

overspeed conditions of the turbine. The relative velocity of the gas discharge with respect to the turbine buckets 22 is represented by the vector W_1 which will indicate the angle and velocity at which the gases impinge upon the buckets. The direction of these gases is turned by the buckets 22 and the gases leave the buckets in a direction and at a value indicated by the vectors W_2 with respect to the buckets.

In FIG. 4, the velocity of the turbine wheel V , when vectorially subtracted from the velocity W_2 of the gas leaving the wheel, will give an absolute velocity V_2 of the gas with respect to the exhaust shroud 34 which is axially directed and does not have any circumferential component or swirl. This velocity is indicated by the vector V_2 adjacent the turbine buckets 22 and adjacent the shroud exit 36.

In FIG. 5, the component V of the turbine wheel when subtracted vectorially from the component W_2 , indicating the velocity and direction of the gases discharged from the turbine buckets, will result in a vector V_2 showing the direction and velocity of the gases with respect to the exhaust duct 34. It is apparent that these gases have a swirl or circumferential component as well as an axial component.

As will be indicated hereinafter, this circumferential or tangential component, or swirl, will increase in accordance with free vortex theory as the gas is forced radially inward and will take a direction and amount indicated by the vector V_{3W} . The axial velocity will be represented by the vector V_{3A} and the absolute velocity will be represented by the vector V_3 .

As shown in FIG. 3, a similar action takes place on underspeed conditions in which the wheel velocity vector V , when subtracted from the gas discharge vector W_2 , will result in the vector V_2 showing the absolute velocity of the gases with respect to the shroud 34. The tangential velocity which will increase adjacent the discharge opening 36, would be represented by the vector V_{3W} , the axial velocity by the vector V_{3A} and the absolute velocity with respect to the exhaust shroud by the vector V_3 . It will be noted that the swirl on underspeed is in the opposite direction from the swirl on overspeed, but the vortex effect is substantially the same.

As shown in FIG. 7, the gases discharged from the buckets 22 are directed by the shroud 34 radially inward from the turbine outer diameter to the discharge orifice 36. This stream of gas and the discharge orifice 36 have maximum effect when sized so that the discharge orifice, which may be of any desired shape such as a streamlined orifice as shown in FIGS. 1 and 3 to 9, inclusive, or a venturi as shown in FIG. 2, is choked or nearly choked, at the on-speed (zero swirl) condition; that is, the speed of the gases passing therethrough is Mach 1 so that an increase in pressure ratio across the nozzle will not result in an increase in axial velocity although the mass flow may be varied by changes in density.

When a tangential component of motion is imparted to the gases so as to create a swirl, as indicated in FIGS. 3 and 5, they will follow the laws of a free vortex in which the angular momentum of each particle remains substantially constant and, as this momentum is a function of velocity and the radius at which the particle is rotating about the vortex axis, it will be apparent that, as the radius is reduced, the velocity of the particle will be increased and hence, as the gases are forced radially inward toward the discharge orifice 36 along shroud 34, the tangential velocity is materially increased. The vortex thus formed produces a core of gas at substantially ambient pressure in which no axial flow takes place. This core is indicated in FIGS. 6 and 8 at 80 and its diameter depends on the tangential speed of the vortex and the ambient pressure at the discharge.

As shown in FIG. 9, the discharge under on-speed conditions utilizes the entire nozzle area but, when the swirl is imparted and the vortex formed in the exhaust

stream, the nozzle area is reduced by the size of the core of the vortex. As the axial speed of the flow through the nozzle is limited to Mach 1, it is necessary to increase the pressure in the gases upstream of the nozzle to thus increase the density of the gases in order that the same mass flow may be pushed through the nozzle with the vortex core as was pushed through the nozzle without the vortex core.

As indicated above, the mass flow of gases through the inlet nozzles 32 and 42 may be substantially constant because of their choked condition and the production of a substantially constant mass of gas by the burning cartridge. It is therefore necessary for the discharge orifice 36 to discharge that same fixed quantity of gas whether the discharge nozzle 36 contains a vortex core or not.

The build-up of pressure necessary to increase the gas density to force the same mass flow through the nozzle with the vortex core therein as without the core is reflected back to the discharge side of the turbine wheel blades 22 and rapidly reduces the pressure drop through the turbine and limits the torque developed by the turbine and thus limits the speed of the turbine. This back pressure on the downstream side of the turbine is further increased by a pressure necessary to overcome the centrifugal force resulting from the rotation of the gases and tending to maintain the gases at the larger diameter of the shroud, but the major cause of the rapid build-up of the back pressure is the formation of a vortex in the choked nozzle and the resultant necessary increase in pressure to force the required weight flow of gas through the nozzle. It is possible to use an annular substantially choked exit orifice in place of the simple choked orifice 36. In such cases, a core may not form, but the above centrifugal pressure gradient, which exists within the orifice too, and thus affects the gas density, also may have a prominent speed-limiting effect.

It will be appreciated that the size of the core 30 formed by the vortex will depend upon the tangential velocity of the gases which, in the overspeed condition, will materially increase with increases in overspeed. It will also be appreciated that in order to compress the gases sufficiently to force the necessary mass flow through the choked orifice with the vortex core, that there will be a very rapid increase in pressure which will be very effective in limiting the overspeed of the turbine.

It will also be appreciated that the pressure ratio across the turbine is a direct measure of the power which can be absorbed from the gases by the turbine wheel and that, by increasing the back pressure on the downstream side of the turbine wheel, the power which may be developed by the turbine is reduced substantially in proportion to the increase in this back pressure.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the disclosure of the preferred form has been made only by way of example and that changes in the details of the construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. In combination an axial flow turbine having a rotor and an exhaust duct and discharging fluid substantially axially into said duct at normal power and speed and at an angle to said axis, so as to create a swirl in the exhaust fluid, at overspeed, said duct having reducing transverse dimensions from the rotor to a discharge orifice at the small end of the duct, said orifice sized to discharge a coreless axially directed stream of fluid at substantially sonic velocity at normal power and speed of said turbine and to form an annulus of swirling fluid in said orifice, reducing the effective area of said orifice,

and increasing the back pressure of the fluid on said turbine, at overspeed.

2. In combination a choked turbine inlet nozzle, said nozzle having a pressure ratio materially greater than its critical pressure ratio, a turbine wheel receiving gases from said nozzle and constructed and arranged to discharge gases axially at normal turbine speed, an exhaust duct of reducing cross section receiving said discharged gases and having a discharge opening operating at normal turbine speed with substantially axial flow at substantially sonic velocity to produce a substantially choked discharge opening, said turbine wheel constructed and arranged to discharge gases tangentially at speeds above said normal speed and create a vortex in said substantially choked discharge opening increasing with speed to increase the back pressure on said turbine to limit the overspeed.

3. In an engine starter, a turbine having blades for supplying power to said starter, a combustion chamber, duct means and nozzle means connecting said chamber with said turbine blades to deliver the uncontrolled products of combustion to conducting passages running through said turbine and between the blades thereof, said blades constructed and arranged to direct said combustion products away from said blades substantially without swirl at normal speed of said turbine but to impart a substantial swirl to said combustion products upon overspeed of said turbine, a substantially funnel-shaped duct receiving said combustion products at the large end of the funnel and discharging said products at the small end of the funnel, said small end having an effective substantially choked fixed opening for said products without swirl at said normal speed, and due to the effect of said swirling fluid, a smaller effective opening for said swirling products at said overspeed.

4. In an engine starter, a turbine having blades for supplying power to said starter, a combustion chamber, duct means and nozzle means connecting said chamber with said turbine blades to deliver uncontrolled fluid products of combustion to conducting passages running through said turbine and between the blades thereof, a source of fluid pressure, duct means conducting fluid from said source to said passages, said blades constructed and arranged to direct fluid away from said blades substantially without swirl at normal speed of said turbine but to impart a substantial swirl to said fluid upon overspeed of said turbine, a reducing area duct receiving said fluid at the large end of said duct and discharging said fluid at the small end of the duct, said small end having an effective substantially choked opening for unswirling fluid and, due to the effect of the swirling fluid, a smaller effective opening for said swirling fluid and means selectively connecting said source of fluid pressure with said passages and simultaneously increasing the discharge area of said exhaust duct.

References Cited in the file of this patent

UNITED STATES PATENTS

2,403,388	Morey	July 2, 1946
2,714,802	Wosika	Aug. 9, 1955
2,806,351	Kent	Sept. 17, 1957
2,816,731	Dantowitz	Dec. 17, 1957
2,951,678	Cliborn	Sept. 6, 1960

FOREIGN PATENTS

200,731	Australia	Jan. 27, 1956
319,717	Switzerland	Apr. 15, 1957

OTHER REFERENCES

"Theory and Design of Gas Turbines and Jet Engines," Vincent, McGraw-Hill Book Co., New York, page 406.