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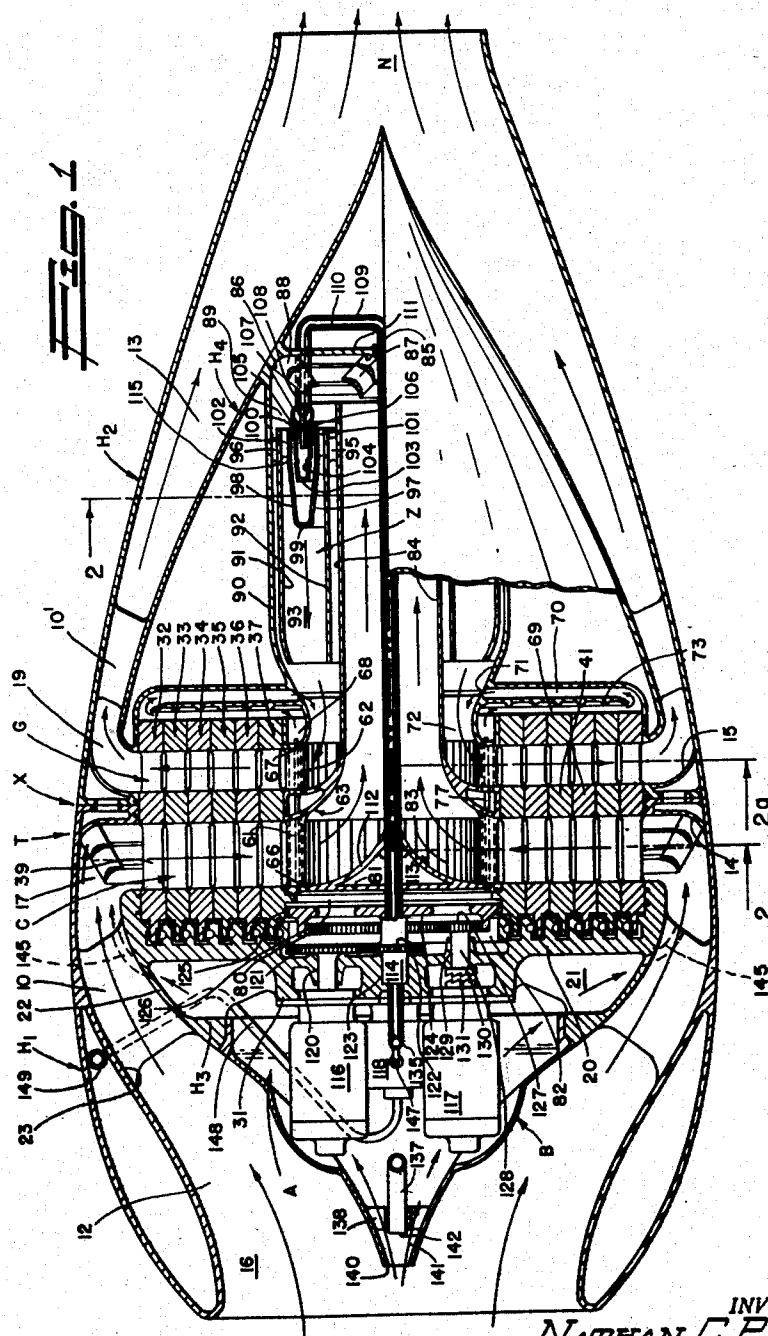
N. C. PRICE

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REACTIVE PROPULSION POWER PLANT HAVING RADIAL
FLOW COMPRESSOR AND TURBINE MEANS

Filed Feb. 14, 1944

4 Sheets-Sheet 1



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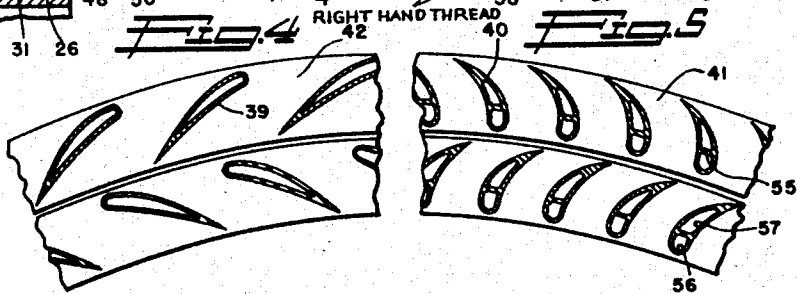
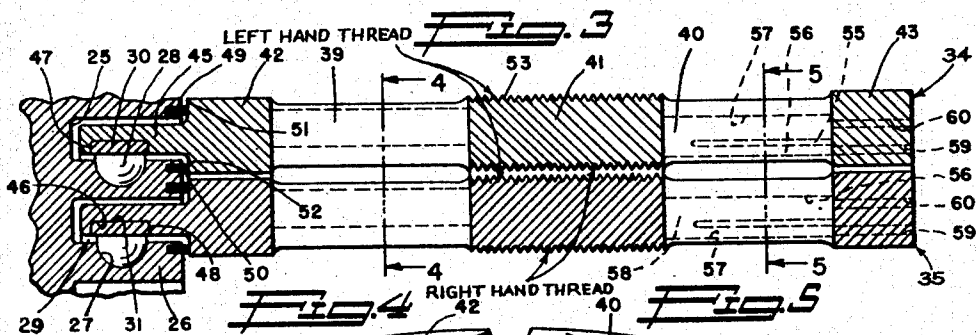
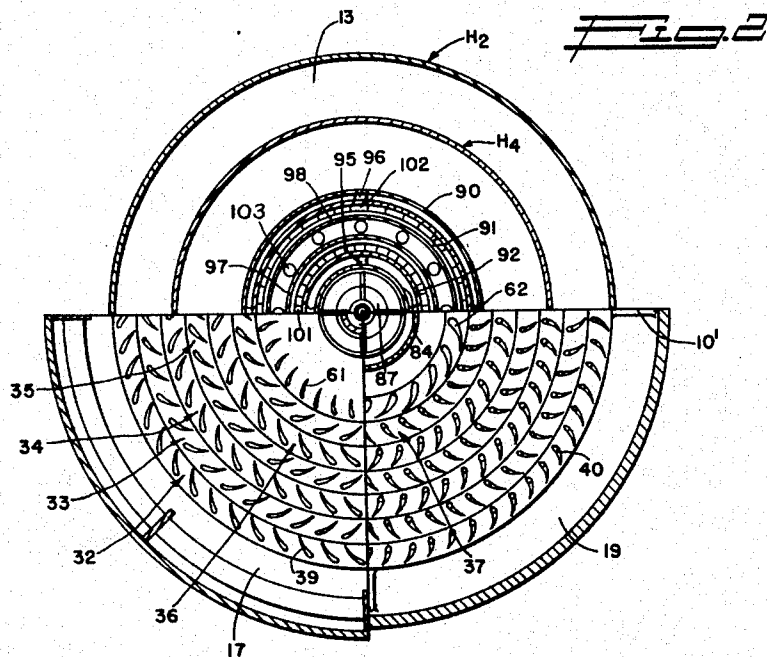
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4 Sheets-Sheet 2



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Fig. 6

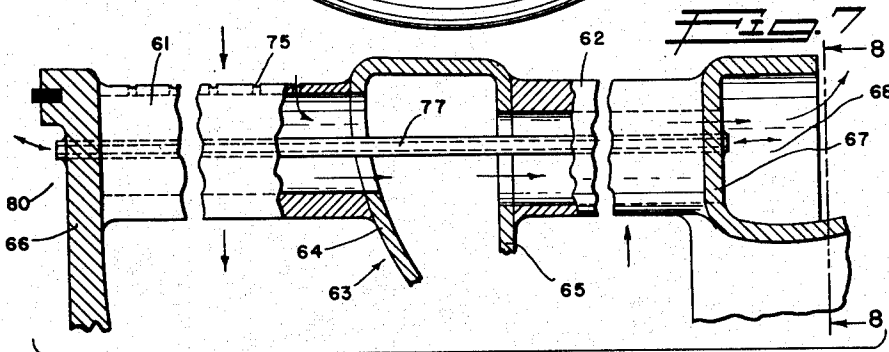
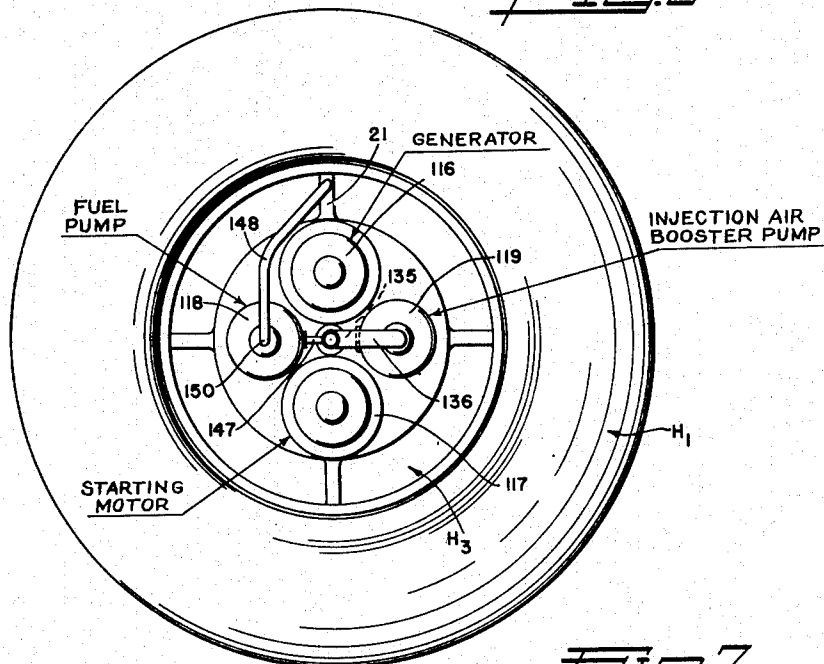


Fig. 8

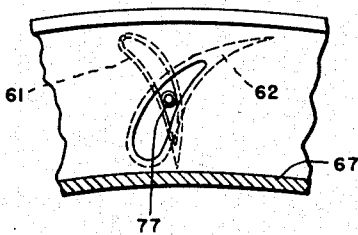
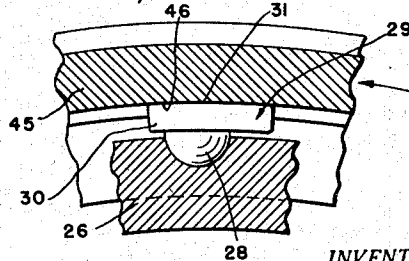


Fig. 9



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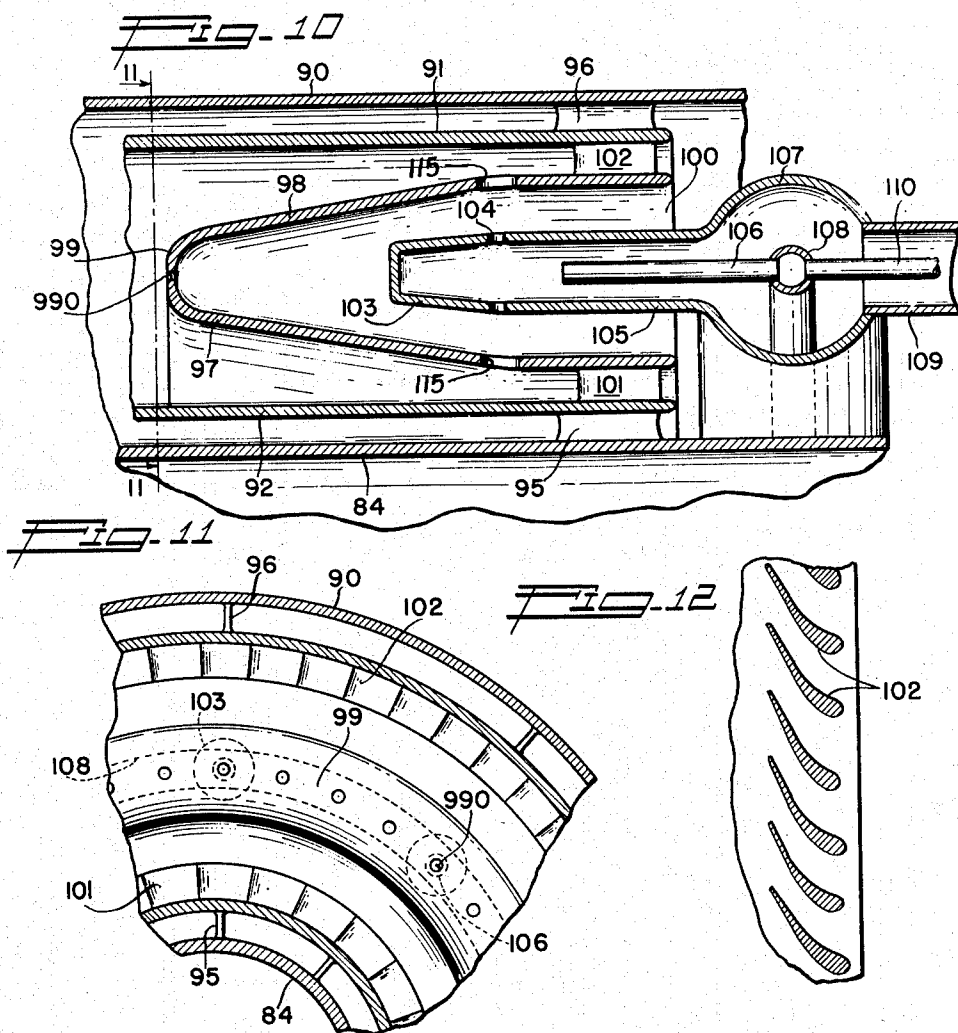
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4 Sheets-Sheet 4



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2,471,892

REACTIVE PROPULSION POWER PLANT HAVING RADIAL FLOW COMPRESSOR AND TURBINE MEANS

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Application February 14, 1944, Serial No. 522,342

21 Claims. (Cl. 60—35.6)

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This invention relates in general to prime movers of the fluid reaction type and more particularly to the type of internal combustion engines which function in accordance with the principle and in the manner commonly known as "jet propulsion."

The features of this invention may have numerous applications but they find their principal application in prime movers for aircraft and the like high speed vehicles, particularly for the propulsion of airplanes at high velocity.

The constant pressure fluid reaction type of internal combustion units heretofore known have usually been constructed along the general lines of the larger stationary types of prime movers used for generating power. The gas turbines and compressors of such units have been widely separated from one another and interconnected by means of relatively long shafts and more or less complicated transmission gearings with their attendant relatively low mechanical efficiency and heat dissipation problems. The prior art units usually employ axial flow turbines or when employing radial flow turbines the movable blade rows have all been carried on a common rotor and thus all rotated at the same angular speed. Where all of the blades are carried on a common rotor, conditions of maximum efficiency can not be maintained at all radial regions within the expansion or compression zone, as the case may be, because of the difference in velocity of the blade elements at such different zones. The best construction under such conditions must necessarily be a compromise which is not so efficient as could be desired. Additionally, in such conventional practice the radial fluid channel is varied in width and blades of correspondingly varying length employed resulting in losses of efficiency and complicating the construction.

It is accordingly an object of this invention to provide an improved propulsion unit in which the beforementioned blade speed and efficiency limitations inherent in the conventional propeller type of drive apparatus has been eliminated.

It is a further object of this invention to provide a gas turbine and compressor combination of improved and novel design wherein the thermal and mechanical efficiency is substantially improved by the elimination of substantially all of the transmission shafting and gearing of the type heretofore employed in connection with turbo-compressor units of this type employed for the production of a reactive fluid jet.

It is a still further object of this invention to provide a simplified form of turbo-compressor

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rotor and blading which lends itself to simple and inexpensive production methods.

The objects of the invention are also attained by a compact supercharger compressor rotor arrangement wherein a plurality of concentrically positioned radially interconnecting squirrel-cage type rotors carrying a plurality of peripherally spaced, longitudinally positioned impeller blades, are arranged for radial flow of the propulsive gases therethrough, each of such squirrel-cage rotors being freely and independently rotatable counter to one another.

It is a still further object of this invention to provide a turbo-compressor in which the blade velocities of each stage may vary independent of one another whereby the most efficient blade angles of incidence may be employed throughout the several stages, the compression ratio maintained substantially linear throughout the stages and blades of equal length throughout the several stages may be employed, all of which contributes to the improved efficiency of operation and simplification of construction of the machine. It is likewise apparent that the suitability of blades of equal length, and the suitability of squirrel-cage rotor blades which do not require twist from one end of the blade with respect to the other to attain correct angles of incidence, greatly facilitates ease of manufacture and reduces cost. Furthermore, the elimination of requirement of blade twist relieves the difficulty of initial development of suitable blade forms, since the prediction of pressure distribution and angle of incidence spanwise along the blade does not vary. Unlike conventional constructions, entailing twisted blades, the same airfoil section may be employed along the entire blade length.

The objects of this invention are attained, in general, by providing a power plant employing a turbo-compressor unit of high efficiency and extreme compactness in which substantially all shafting and gearing have been eliminated, and the structure in general simplified and which produces propulsive force and work wholly by means of the reaction of a high velocity expandable fluid jet. The attainment of the objects and advantages of this invention are realized largely by an improved design of the turbo-supercharger combination wherein each of the pluralities of supercharger compressor cascades is individually and directly coupled to and driven from each of the plurality of turbine cascades and each such individual turbo-supercharger cascade combination is independently rotatable. Such an arrangement of turbo supercharger cas-

acades directly driven and independently rotatable results in improved thermal and mechanical efficiency and weight reducing and power saving elimination of inter-coupling drive mechanisms and other associated mechanical equipment heretofore thought to be indispensable.

These and other objects and features of novelty will become evident hereinafter in the description which, together with the following drawings illustrate the preferred embodiment of the invention.

Figure 1 is a longitudinal sectional elevation of the power plant assembly.

Figure 2 is a frontal view in part section and part elevation taken on line 2—2 and 2—2a of Figure 1.

Figure 3 is an enlarged typical fragmentary cross-sectional view of a number of the turbo-compressor rotors shown in Figure 1.

Figure 4 is a typical fragmentary cross-sectional view of the compressor blades taken on line 4—4 of Figure 3.

Figure 5 is a typical fragmentary cross-sectional view of the turbine blades taken on line 5—5 of Figure 3.

Figure 6 is a front end elevation of the unit with the accessory compartment cover removed.

Figure 7 is a partial enlarged cross-sectional view of the compressor discharge and turbine inlet nozzle assembly shown in Figure 1.

Figure 8 is an enlarged fragmentary cross-sectional view taken on line 8—8 of Figure 7.

Figure 9 is an enlarged fragmentary detail of a turbo-compressor rotor bearing.

Figure 10 is an enlarged fragmentary longitudinal section of a portion of the combustion chamber illustrating the fuel jet and nozzle means.

Figure 11 is a fragmentary transverse sectional view taken as indicated by line 11—11 on Figure 10.

Figure 12 is a fragmentary stretch-out view of the swirl vanes shown in Figures 10 and 11.

Referring now to the drawings, in which like reference numerals refer to corresponding parts throughout the several figures, the apparatus of the invention is as follows:

The power plant assembly as shown in the drawings comprises nine main components, namely: an outer streamline housing having a forward portion H₁ and a rearward portion H₂ joined at X; an inner streamline housing having a frontal supporting structure portion H₃, and a rearward enclosing portion H₄, supported coaxially together substantially concentrically within the outer housing, and within the inner housing, a turbo-compressor T having a radial flow compressor section C, and a radial flow gas turbine section G, a centrally located combustion chamber Z interconnecting the compressor and turbine sections, and a forwardly located accessory compartment A enclosed by the conical cover B.

The inner streamlined housing H₃—H₄ which contains the principal components of the apparatus is concentrically supported within the outer housing H₁ as before stated, at the forward end by means of a plurality of interconnecting streamlined struts 10 extending between said outer housing H₁ and said inner housing portion H₃ and at the rearward end by means of a plurality of interconnecting streamline struts 10', forming therebetween forwardly located and rearwardly located annular shaped passages 12 and 13 respectively, separated endwise from one another by curved intervening circumferential

walls 14 and 15 which are coupled together at the outer housing joint X. The forward annular passage 12 leads from the forwardly directed inlet 16 rearwardly to the space 17 which forms a peripheral inlet of the compressor C. The rearward annular passageway 13 similarly formed between the rearward portion of the outer housing H₂ and the rearward portion of the inner housing H₄, leads from the peripheral outlet or exhaust receiving space 19 of the gas turbine G rearwardly and inwardly to the axial propulsive discharge nozzle N. The housing H₁ may be fabricated from chromium steel sheet, while the housings H₂ and H₃ may be formed from chromium-nickel-iron sheet which is heat resistant.

Within the forward inner housing H₃ and integral therewith a primary structure is provided for rotationally supporting the elements of the compressor and turbine, for carrying the various accessories and tying together the several housing components of the unit assembly. The structure of the compressor and turbine will be more fully described hereinafter. The inner primary supporting structure comprises a longitudinal disc or diaphragm like member 20 of such material as chromium-nickel-manganese steel heat treated to a tensile strength of 160,000 pounds per square inch, having a plurality of radially extending integral stiffening webs 21 formed as inward radial extensions of the supporting vanes 10. The diaphragm 20 together with the stiffening webs 21 which join with or may be formed integrally with the curved surface of the housing H₃ at 22 is thus supported by the plurality of radial interconnecting struts 10 which struts are in turn suitably attached at their outer extremities at 23 to the inner wall of the outer housing structure H₁. The inner diaphragm 20 is thus supported as a solid unit by means of the supporting vanes 10, webs 21, and the inner and outer surfaces 22 and 23 of the housings H₃ and H₁.

The rearward face of the diaphragm 20 carries a plurality of circular recesses as best shown at 25 in Figure 3 forming thereby a plurality of concentric ring shape tracks 26 for rotationally supporting the concentric turbine blade rings or cages which are hereinafter more fully described. Each turbine-ring-supporting-track 26 carries in its outwardly facing cylindrical surface a plurality of spherical seats 27 in each of which is seated the spherical supporting pedestal 28 of a pivotable slipper-type bearing 29 as best shown in Figures 3 and 9. Pivotaly carried by the spherical supporting pedestal 28, is a segmental bearing element 30 having an outer cylindrical bearing surface 31 conforming to and adapted to support the inner cylindrical bearing surface of the turbo-compressor cage runner as hereinafter more fully described.

The turbo compressor portion T of the unit, rotationally supported by means of the diaphragm 20 comprises a plurality of concentric, radially interconnecting, rotors 32 to 37. Each rotor comprises a plurality of circumferentially spaced airfoil shaped compressor impeller blades 38 and airfoil shaped turbine blades 40 axially positioned and coaxially joined end to end by means of an intermediate ring or separator 41. The outer end of the compressor impeller blade 38 and the turbine blades 40 terminate in end rings 42 and 43 respectively. The unitary structure formed by the end rings 42 and 43 and the intermediate ring 41 joined together by the plurality of compressor and turbine blades 38 and 40 respectively forms a squirrel-cage like structure having cylin-

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dricul rows of impeller and compressor blades as best shown in Figures 3, 4 and 5. The impeller blades in alternate concentric rows have opposite angles of incidence as best shown in Figures 2, 4 and 5 adapting alternate rows thereof for counter-rotation with respect to one another. The size and positioning of blading of the several concentric rotors are preferably constructed so that their solidities throughout are substantially equal, that is the solidities of the rotors from the innermost to the outermost one is substantially constant. By the term solidity is meant the ratio of the chord length of the impeller blade to its circumferential arc spacing center to center or leading edge to leading edge approximately.

The forward faces of each of the rotor rings 42 adjacent the supporting diaphragm 20 is provided with a unitary annular runner 45 carrying on its inner cylindrical surface a high polished annular groove or recess 46 of such a width and depth as to adapt it to receive the segmental bearing elements 30 of the slipper bearings as shown at 29. Both axial and radial forces may thus be taken by the segments 30 of the bearings 29 acting against the bottom and the sides 47 and 48 of the groove or recess formed in the runner member 45. The segmental bearing elements 30 are generally composed of a mixture of bronze and iron powder molded under high hydraulic pressure to have microscopic pores for retaining oil. A very light lubricant of approximately 70 Saybolt seconds viscosity is suitable for these bearings which are designed to operate at high rubbing speed. Annular packings 49 and 50 are provided in suitable grooves of the faces of the bearing supporting track members 26 and are adapted to make a sliding gas tight seal with the adjacent shoulders 51 and 52 of the rotor rings which shoulders are formed on either side of the annular rotor supporting runner 45 as best shown in Figure 3. The packings 49 are generally composed of a mixture of carbon and silver powder molded under high hydraulic pressure to form a heat resistant material with a very low coefficient of friction. The adjacent cylindrical surfaces of the concentric central rings 41 of the turbine rotors are provided with a plurality of circumferential serrations or threads 53 which are adapted to impede or control longitudinal flow of gases through the clearances between the rings, from the compressor section to the turbine section or vice versa, depending upon the pressure gradient. Threaded serrations are preferably employed with adjacent threads on opposite rotor rings having pitches of opposite hand and having leads with respect to the direction of rotation such as to tend to move the gases therein counter-current to the leakage pressure gradient. For example, in Figure 3 it is assumed that the leakage pressure gradient is from the turbine toward the compressor in which case the thread-like serrations are pitched as indicated by the legends in that figure.

The compressor impeller blades 39 and the turbine impeller blades 40 are made hollow for lightness. The rotors and blading may be constructed of an alloy high in nickel, chromium and cobalt with small additions of other metals such as tungsten, columbium, copper and aluminum. Such alloy has very high yield strength and favorable creep characteristics through a wide temperature range. The hollows of each of the turbine impeller blades 40, as shown in Figure 3, are provided with a transverse baffle or partition 55 which divides the hollow into parallel channels

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56 and 57 joined at their inner ends at 58. Communicating with the channels 56 and 57 in the hollow of the turbine impeller 40 are a pair of vent holes 59 and 60 drilled longitudinally through the end rings 43.

Adjacent the innermost turbo-compressor rotor 37 of the plurality of concentric turbo-compressor rotors 32 to 37 is an inner cage-like nozzle assembly comprising the compressor section outlet nozzle vanes 61, the turbine section inlet nozzle vanes 62 joined end to end by means of the intermediate hollow separator 63 formed by the bifurcating walls 64 and 65 thereof and terminating at their forward and rearward ends in the forward and rearward chamber walls 66 and 67 respectively. The compressor discharge nozzle vanes 61 and the turbine inlet nozzle vanes 62 are hollow as best shown in Figures 7 and 8 and the hollows of these blades or vanes are interconnected through 63 and communicate with the annular space 68 which is in turn in communication with the annular channel 69. The channel 69 is connected at its outer extremity with a return annular channel 70 which leads to a forwardly directed annular slot 71 formed through the wall of the combustion chamber discharge passage 72. The compressor discharge nozzle vanes 61 are provided with a plurality of longitudinally spaced perforations 75 as best shown in Figure 7, said perforations being in the leading edge or stagnation point of said vanes and adapted to form intercommunication between the compressor discharge and the compressor discharge vane hollows. Compressed air may thus enter the perforations 75 and flow through the hollows of the vanes 61 and 62 into the annular chamber 68 and thence circulate through the passageways 69 and 70 to discharge through the slot 71 into the combustion chamber discharge passage 72.

A tube 77 passes substantially axially through the hollows of the interconnected compressor discharge vanes and the turbine inlet nozzle vanes through the hollow 63 and serves to interconnect the air passage chamber 68 with the forward annular space 80 ahead of the wall 81 which in turn is in communication with the accessory transmission chamber 82 and the plurality of annular and cylindrical clearance spaces surrounding the bearing supported, forward end of the turbine rotor rings. The tube 77 thus serves for axial pressure equalization between the forward and rearward ends of the plurality of concentric turbine rotors. End thrust on the turbine rotors due to external pressure unbalance is thus substantially eliminated.

The inward radial discharge of the compressor section C leads through the beforementioned discharge nozzle vanes 61 through a curved passage 83 to a central, axially extending conduit defined by a coaxial cylindrical wall 84 which passage in turn communicates by way of bends 85 and 86 containing a plurality of Frey bend vanes or staggered turning vanes as shown at 87 and 88, with an annular inlet channel 89 formed at the inlet end of the annular combustion chamber Z.

The annular combustion chamber Z is defined by and contained within an outer cylindrical casing 90 and the beforementioned inner cylindrical conduit 84. Within the combustion chamber Z are a pair of concentrically positioned annular shaped shroud members 91 and 92, spaced a short distance from the inner surface of the cylindrical walls 84 and 90 respectively to form narrow

annular air passages therebetween and to enclose an annular combustion zone 93. The shroud members 91 and 92 are both preferably fabricated from a heat resistant material such as nickel-chromium-iron alloy. The combustion Z converges slightly at the forward outlet portion at the entrance to the channel 72 which leads to the turbine inlet nozzle ring and the nozzle inlet vanes 62.

The beforementioned inner and outer annular shroud members 91 and 92 are supported from the inner and outer surfaces 84 and 90 of combustion chamber Z by means of a plurality of circumferentially spaced positioning lugs or struts as shown in Figure 1 at 95 and 96. Within the forward inlet portion of the combustion zone centrally located between the shroud members 91 and 92 is a relatively short annular member formed with two converging walls 97 and 98 joined in an apex at the forward edge at 99 and opening rearwardly as shown at 100 to form a fuel spray nozzle housing. The said walls 97 and 98 of the fuel nozzle housing are supported between and join the inner rearward surfaces of the shrouds 91 and 92 by means of inner and outer concentric sets of a plurality of circumferentially interconnecting swirl vanes 101 and 102. These swirl vanes have an exit angle of about 25° to the tangent and form at the entrance of the combustion zone on either side of the fuel nozzle housing 97-98 between the shrouds 91 and 92, two vaned concentric annular inlet passages which are adapted to impart a spiral flow to fluid flowing to the combustion zone.

A plurality of fuel spray jets extend into the rearward opening portion of the central annular nozzle housing formed between the beforementioned converging walls 97 and 98 and each spray jet carries at the inner end a spray head 103 provided with a pair of laterally directed orifices 104. Each said spray head is supported by and adapted to be supplied with a mixture of liquid fuel and injection air by means of a pair of concentric pipe nipples 105 and 106 which make connection with concentrically arranged circular pipe manifolds 107 and 108 which are contained within the annular entrance space 89 of the combustion chamber Z. The exterior circular manifold 107 is adapted to be supplied with air under suitable pressure through a lead-in pipe 109 and the interior manifold 108 is adapted to be supplied with liquid fuel under pressure through a lead-in pipe 110. Both the air pipe 109 and the liquid fuel pipe 110 enter the forward end of the combustion zone through the wall 111 which defines the rearward end of the air conduit 84 and the entrance channel 89 of the combustion chamber Z. The lead-in or supply pipes 109 and 110 are supported and passed axially forward through the axis of the conduit 84, through the forward curved walls 112 and 113 and coaxially through the bore of the hollow gear hub 114 into the accessory compartment A where it makes connection with a compressed air booster pump as more fully described hereinafter.

The beforementioned converging walls 97 and 98 of the nozzle housing between which the fuel spray jets extend are provided with apertures 115 registering with each of the beforementioned laterally directed jet head orifices 104 whereby an atomized mixture of fuel and air may be projected laterally into the adjacent space in the contracted portion of the air passages which lead

into the combustion zone 93. A plurality of perforations 990 are provided in the apex 99 of the nozzle housing 97-98 for flow therethrough of a relatively small quantity of cooling air.

Under the forward cover B and within the accessory compartment A and supported on the forwardly extending face 31 of the diaphragm 20 are a number of accessories namely a generator 116, a starter motor 117, a liquid fuel pump 118, and an injection air booster pump 119. The fuel pump 118, generator 116 and injection air pump 119 are gear-driven through a suitable train of gears by the innermost turbo-compressor rotor 37. The shafts of the fuel pump 118, generator 116, and air booster pump 119, pass through the central portion of the diaphragm 20 through suitable bearings at 120 in the manner shown in connection with the generator 116 in Figure 1. All of these shafts carry on the inner end thereof, gears as shown at 121 which mesh with a single central pinion 122 which is in turn carried upon the beforementioned central shaft or hub 114 journaled in a central bearing at 123 located at the center of the diaphragm 20. The said hub 114 carries an integral disc member 124 which has formed on its outer periphery a plurality of teeth which are adapted to mesh with a plurality of mating teeth carried on the inner forward surface of the forward turbo-compressor ring at 125 to form a splined connection therewith. The hub 114 and disc 124 are thus rotatably coupled with the innermost turbo-compressor rotor 37 yet the splined connection prevents the normal hoop stretch of the rotor 37 from being transmitted to the disc member 127. The disc 124, before mentioned, carries an internal gear 126 which is adapted to mesh with and be driven by a pinion 127 which is fixed to the inner end of a starter drive shaft 128 rotatably journaled in bearing 129. The forward end of the starter shaft 128 carries a toothed clutch member 130. The tooth clutch member 130 is adapted to couple with a corresponding tooth clutch member 131 which is carried on the extending end of the starter motor shaft. The turbo-supercharger is thus adapted to be started by initially rotating the innermost turbo-supercharger rotor by means of the starter motor 117 acting through the clutch 130-131, the gearing 126 and 127 and the spline 125. Upon actuation of the starter motor 117 the clutch members 130 and 131 are automatically brought into engagement by conventional means, not shown.

The injection air pipe 109 which enters centrally into the accessory chamber A makes connection with the discharge of the booster air pump 119 through a lateral connection 135. The air inlet to the booster pump 119 makes connection through connecting piping 136 to a forwardly directed inlet conduit 137 which is centrally supported within the open, forwardly directed apex of the accessory compartment cover B by means of a plurality of radial supporting webs as shown at 138. The forwardmost tip of the apex of the accessory compartment cover B is provided with a central opening as shown at 140 adapted to allow rammed air to flow into the accessory compartment in the manner illustrated by arrows 141 and also to flow into the forwardly directed open end 142 of the beforementioned conduit 137.

Air entering the accessory compartment A through the forward opening 140 is provided with a means of escape through a plurality of channels 145 which pass outward through the supporting webs 21 and 10 and discharge through

suitable apertures in the trailing edges thereof into the annular channel 17 leading to the peripheral inlet to the compressor section C. The air entering at 140 and circulating through the accessory compartment A and issuing therefrom through the channels 145 serves to withdraw heat from the turbo-compressor bearings support 20 from the required bearing lubricant used therein and from the accessories and prevents the accumulation of fumes.

The liquid fuel pipe 110 contained concentrically within the air pipe 109 passes therewith into the accessory compartment A and makes connection with the discharge of the fuel pump 118 through a lateral connection 147 passing through the wall of the said air pipe 109. Liquid fuel is supplied under suitable pressure to the fuel pump 118 by means of a pipe 148-149 which enters the accessory compartment through one of the struts 10-21 and makes connection with the inlet 150 of the fuel pump 118.

The operation is as follows:

If the unit is stationary and thus no rammed air is available for entrance through the forward inlet 16 to flow through the annular channel 12 into the peripheral inlet of compressor C, the starter motor 117 is actuated to bring the clutch 130-131 into engagement and to drive the innermost turbine rotor 37 to about 10% of full operating speed. The resultant inflow of air radially through the impeller blades of the compressor section C will induce a corresponding rotation of all of the concentric freely rotating turbo-compressor rotors 32 to 37. Sufficient combustion air pressure will thus be built up within the air conduit 84 for flow through the combustion chamber Z to allow initiation of fuel injection through the nozzle 103 and ignition of the resultant fuel and air mixture. The ignition of the combustible mixture may be made by means of a spark plug or glow plug entering the combustion zone in the manner shown and described in connection with my copending application, Serial No. 488,029, now Patent No. 2,468,461. The resultant heated combustion gases are discharged from the combustion chamber Z through the annular channel 72 and the inlet nozzle ring 62 and flow outward radially through the turbine impeller vanes of the plurality of turbo-compressor rings 32-37. The partially spent gases exhausted from the turbine at 19 are discharged rearwardly through the annular passage 13 formed between the outer and inner housings H₂ and H₄ respectively and are finally discharged rearwardly in the form of a comparatively high velocity propulsive jet expanded to a relatively low temperature by virtue of the high inherent efficiency of the turbo-compressor elements in the construction shown, through the nozzle N. As soon as the initial combustible mixture formed in the combustion chamber Z is ignited and commences to flow through the turbine G, as before described, the turbo-compressor rotors 32 to 37 are soon thereafter brought up to full operating speed. Under normal operating conditions the tangential velocities of the several turbo-compressor rotors are substantially equal and in the neighborhood of 800 feet per second, the speed of the innermost rotor being approximately 13,000 and the outermost rotor being approximately 6,500 revolutions per minute. Under normal operating conditions the air discharged from the compressor C and entering the combustion zone is maintained at a pressure of approximately 75 pounds per square inch absolute,

When the unit has a relatively high forward air speed, rammed air enters the forward opening 16 and thereby undergoes a measure of initial compression prior to entrance into the compressor C.

Referring again to the combustion chamber Z and the associated burner construction, the compressed air entering the combustion chamber through the annular entrance space 89, is divided several ways, a major portion thereof flowing through the two concentric annular inlet passageways containing the swirl vanes 101 and 102 formed between the shrouds 91 and 92 and located on either side of the fuel spray nozzle housing 97-98 and thence through the Venturi shaped passageway into the combustion zone 93. These swirl vanes may have an angular position with respect to the axial inlet flow of the air of approximately 25°. Another portion of the air from the entrance 89 passes between the combustion zone shrouds 91 and 92 and the inner surface of the combustion zone walls 84 and 90 for the purpose of cooling them. Still another minor portion of the air passes around the manifold piping 107-108 and through the passageway formed within the spray nozzle housing 97-98 and thence through the end perforations at 99 into the combustion zone 93.

Under normal operating conditions liquid fuel such as, for example, gasoline, kerosene, or the like, introduced into pipe 110 under pressure from the fuel pump 118, issues from the orifices 104 together with atomizing air introduced into pipe 109 and into the manifold 106 under pressure and passes laterally out through the registering apertures 104 in the form of a spray into the beforementioned Venturi shaped air passages where it meets and mixes with the flowing air stream, and the resulting fuel-air mixture passes forward into the combustion zone 93 where combustion takes place. As before stated combustion may be initiated by a spark plug or glow plug in the manner described in my copending application Serial No. 488,029. The beforementioned swirl vanes 101 and 102 at the entrance to the Venturi shaped air passages leading to the combustion zone 93 impart a spiral flow pattern to the burning atomized fuel air mixture flowing through the annular space of the combustion zone. A more thorough mixing of the fuel and combustion air is thus effected by the added turbulence of the spiral flow and at the same time the effective length of the combustion chamber is increased by the greater length of the spiral combustion flame the combustion zone is thereby able to accommodate. This arrangement thus permits, in effect, a shorter length of combustion chamber for a given degree of mixing and heat generating capacity than would otherwise be possible. The resultant heated products of combustion and excess air under the combustion zone pressure of about 75 pounds per square inch absolute are discharged from the combustion chamber through the channel 72 and outward through the nozzle vanes 62 and thence pass substantially radially outward through the expansion zone of the gas turbine G where independent counter-rotative impulsion is given to the adjacent rotors of the plurality of concentric turbo-compressor rotors 32 to 37 as before mentioned. The partially expanded gases exhausted from the gas turbine at 19 after passing through the annular channel 13 formed between the inner and outer housing members H₂ and H₄ are finally

discharged rearwardly from the nozzle N in the form of a reactive jet.

A portion of the compressed air being discharged from the compressor C enters the apertures 75 in the leading edge of the discharge nozzle vane 60 and passes axially under pressure through the interconnecting space, turbine nozzle vanes 62, and into the annular space 68 adjacent the inner turbine ring 37. The air thus entering the space 68 under pressure passes outwardly substantially radially through the space 69 formed between the rear faces of the rear end rings of the turbine rotors and the annular baffle 73 for the purpose of cooling these rings. A portion of the air thus flowing outward through the space 69 enters the vent holes 59 and 60 as shown in Figure 5 leading into the hollows of each of the turbine blades. A portion of the air thus flowing outward through the space 69 enters each of the innermost vent holes 60 leading through the rings into the hollows of the turbine impeller blades, flows through the channels 56 and 57 formed on either side of the baffles 55 and outward therefrom through the outermost vent holes 59. This flow is induced mainly by the centrifugal force of the air contained within the hollows of the turbine impeller blades under the high rotative speeds which they normally maintain. The cooling air thus having extracted heat from the turbine impeller blades and rings passes around the outer edge of the baffle to return inwardly through the annular channel 70 and from there to discharge forwardly through the slots 71 into the channel 72 leading from the combustion zone Z to the turbine inlet.

Each of the plurality of individual rows of compressor impeller blades being attached to and carried by independently journaled rotors are thus independently free to select rotational velocities which are determined by the local conditions therein, thus any variations in airplane speeds, altitude or atmospheric temperature will automatically result in optimum adjustment of the ratio of the relative rotative speeds of each adjacent concentric stage or cascade rotor to produce the highest internal turbo-compressor efficiency of the power plant in the presence of such external variable conditions. While the tangential speeds of the impeller blades of the several concentric rotors ordinarily maintain themselves at approximately 800 feet per second under the conditions herein described, it may be advantageous to allow the innermost rotors to operate at a tangential speed slightly higher than that of the outermost rotor, but generally not to exceed about 10% greater speed, because in the compressor and turbine flow passages the air and combustion gas temperatures are greatest at the innermost rotors. Under such conditions slightly higher speeds of the inner impeller blades in the higher temperature region may be maintained, and yet remain safely within the allowable Mach number or critical speed which produces compressibility effects, which effects are a function of fluid temperature. The pressure ratio through each compressor stage can thus be maintained at a maximum value. This operating condition serves to permit almost identical angles of incidence of the blading to exist in all of the rotors when the solidity of the blading and the lengths of the blades in all of the rotors is substantially identical.

The form of compressor and turbine blading afforded by the freely floating squirrel-cage rotors permits the solidity of blading in each rotor, that

is the ratio of chordal length of the blades to the circumferential spacing between adjacent blades to be greater without deleterious airfoil cascade interference effects. As a result the ratio of compression of each stage of the compressor may be much higher than in conventional machines without attendant loss of efficiency, which affords a more efficient operating cycle with fewer stages, and likewise in the turbine more favorable shapes can be obtained in the combustion gas flow channels defined by the impeller blades. The solidity as defined above may be maintained substantially constant from stage to stage which cannot be accomplished in a conventional machine without entailing other disadvantages well known to those skilled in the art.

It is to be understood that the foregoing is not to be limited but may include any and all forms of methods and apparatus which are included within the scope of the claims.

I claim:

1. In a turbine apparatus, a plurality of concentric rows of longitudinally positioned peripherally spaced impeller blades of substantially equal length, rings at the opposite ends of said rows, said rings defining a radial flow channel of substantially uniform axial width throughout, said blades of adjacent rows being formed for counter-rotation with respect to one another under the reactive force of radially outward fluid flow through said channel, a separate journal means for only one end ring of each row of blades cantilevering the respective row of blades and its end rings for rotation independently of each other row of blades, and means to pass fluid under pressure radially outward through said channel to drive said blading rows.

2. In a turbine apparatus, a plurality of concentric rows of longitudinally positioned peripherally spaced impeller blades of substantially equal length, rings at the opposite ends of said rows, said rings defining a radial flow channel of substantially uniform axial width throughout, said blades of adjacent rows being formed for counter-rotation with respect to one another under the reactive force of radially outward fluid flow through said channel, journal means supporting one end ring of each row of blades against both radial and axial thrusts, the other end rings of the rows of blades being without journals so that each row of blades is cantilevered from its said one ring, and means to pass fluid under pressure radially outward through said channel to drive said blading rows.

3. In a turbine apparatus, a plurality of concentric rows of longitudinally positioned peripherally spaced impeller blades of substantially equal length, rings at the opposite ends of said rows, said rings of the several rows defining a radial flow channel of substantially uniform axial width throughout, the blades of adjacent rows being formed for counter-rotation with respect to one another for reactive force upon fluid flowing radially inward through said flow channel, a separate bearing for one ring of each said rows of blades constituting the sole means for supporting the respective row of blades for rotation, each bearing being substantially axially aligned with its respective row of blades, and means to pass fluid substantially radially inward through said flow channel.

4. In a turbine apparatus, a plurality of independently journaled concentric rows of longitudinally positioned peripherally spaced impeller blades of substantially equal length, an annular

shaped flow channel of uniform width axially throughout the radial dimension thereof housing said rows of blades, the said blades of adjacent rows being formed for counter-rotation with respect to one another for reactive force upon fluid flowing radially inward therethrough, means to pass fluid under pressure substantially radially inward through said concentric rows of blades in said annular flow channel, and a separate bearing means at only one end of each row of blades for cantilevering the respective row of blades for independent rotation.

5. In a turbine apparatus, a plurality of concentric radially intercommunicating rotors each comprising an end ring and a plurality of peripherally spaced longitudinally positioned blades carried by the ring, the blades of adjacent rotors being formed for counter-rotation with respect to one another for reaction with fluid flowing radially through the rotors, a stationary diaphragm, and a separate bearing means supporting the end ring of each rotor on said diaphragm so that the respective rotor has cantilevered support for independent rotation.

6. In a turbo-compressor apparatus, a plurality of concentrically positioned radially intercommunicating squirrel-cage rotors in surrounding relation to one another, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller blades terminating in a common annular ring and bearing means associated with each of said rotor rings for rotationally supporting said rotors for independent rotation with respect to one another, each bearing means constituting the sole means for supporting its respective rotor whereby each rotor is cantilevered from its respective bearing.

7. In a turbo-compressor apparatus, a plurality of concentrically positioned radially intercommunicating squirrel-cage rotors in surrounding relation to one another, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller blades terminating in a common annular ring, said impeller blades in adjacent concentric rows having opposite angles of incidence for counter-rotation with respect to one another, and a single bearing means associated with each of said rotor rings for rotationally supporting each rotor for independent rotation.

8. In a turbo-compressor apparatus, a plurality of concentrically positioned radially intercommunicating squirrel-cage rotors, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller blades terminating in a common annular ring, said impeller blades in adjacent concentric rows having opposite angles of incidence for counter-rotation with respect to one another, means to conduct fluid substantially radially through said rotors, and a bearing means associated with each of said rotor rings for independently supporting the same so that each of said rotors is cantilevered for independent rotation.

9. In a turbine apparatus, a plurality of independently journaled concentric rows of longitudinally positioned peripherally spaced airfoil shaped impeller blades of substantially equal length, said impeller blades in each row terminating in common end rings to form unitary cage like rotors and an annular flow channel of substantially uniform width therethrough defined by said annular end rings, said blades of adjacent rows being formed for counter-rotation with respect to one another under the reactive

force of outward radial flow of fluid therethrough, means to pass fluid under pressure radially outward through said concentric rows of blades in said annular flow channel, and stator blades at an end of said flow channel, at least one stator blade having an axially extending duct for equalizing the fluid pressure on opposite external end surfaces of said end rings whereby axial thrust of said rotor is substantially eliminated.

10. In a turbo-compressor apparatus, a plurality of concentrically positioned radially intercommunicating rotors in surrounding relation to one another, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements and each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement, said blades terminating in common annular end rings to form a unitary squirrel-cage rotor, said blades in adjacent concentric rows having opposite angles of incidence for counter-rotation with respect to one another, means to conduct fluid substantially radially through said rotors, and a bearing means associated with a ring of each rotor cantilevering the rotor for independent rotation.

11. In a turbo-compressor apparatus, a plurality of rotors arranged in surrounding relation to one another to have radial intercommunication, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements joined in a common annular end ring to form a unitary squirrel-cage rotor for radial flow of fluid therethrough, and each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement, said blades in adjacent concentric rows having opposite angles of incidence for counter-rotation with respect to one another, means to conduct fluid substantially radially through said rotors, and a bearing means associated with the ring of each rotor for cantilevering the rotor for independent rotation with respect to the other rotors.

12. In a turbo-compressor apparatus, a plurality of rotors arranged in surrounding relation to one another to have radial intercommunication, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements terminating in a common annular end ring to form a unitary squirrel-cage rotor for radial flow of fluid therethrough, and each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement, said blades in adjacent concentric rotors having opposite angles of incidence for counter-rotation with respect to one another, and said turbine blade portion and said compressor blade portion of each of said elements having blades positioned for counter-current radial flow of fluid with respect to one another, means to conduct fluid substantially radially through said impeller elements carried by said rotors, and a bearing means at the ring of each rotor for cantilevering the rotor for independent rotation with respect to the other rotors.

13. In a gas reaction propulsive unit, an outer housing having a forward axial opening for the entrance of rammed air and a rearwardly directed outlet nozzle for the discharge of gases in the form of a propulsive jet, an inner housing supported within said outer housing, a diaphragm separating said inner housing into forward and rearward portions, a turbo-compressor in an intermediate portion of said inner housing at the

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rearward side of said diaphragm, said turbo-compressor having a compressor section and a turbine section, means for rotatably mounting the turbo-compressor on said diaphragm, a combustion chamber in the rearward portion of said inner housing interconnecting said compressor section with said turbine section, a channel connecting said forward axial opening with the inlet of said compressor section, a channel connecting the discharge of said turbine with said outlet nozzle, an accessory compartment in said forward portion of the inner housing and drive means interconnecting said turbo-compressor with said accessory compartment through said diaphragm.

14. In a gas reaction propulsive unit, a housing having a forward axial opening for the entrance of air and a rearwardly directed outlet nozzle for the discharging of gases in the form of a propulsive jet, a turbo-compressor in said housing, said turbo-compressor comprising a plurality of concentrically positioned radially intercommunicating rotors, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements, and each of said elements having a turbine blade portion and a compressor blade portion with all of the compressor blades of the same length and all of the turbine blades of the same length, forming thereby separate annular compressor and turbine flow channels of substantially uniform width throughout their radial dimensions, a combustion chamber substantially concentrically related to the axis of said rotors, an outer peripheral inlet to the compressor flow channel communicating with said forward inlet opening for flow of air radially inward through the concentric compressor blades in said compressor flow channel, an inwardly directed discharge from said compressor flow channel leading to said combustion chamber, an outwardly directed radial inlet to said turbine flow channel from said combustion chamber for expansive flow of gases radially outward through said turbine flow channel, and an annular passage leading from the periphery of said gas turbine flow channel and communicating with said rearwardly directed outlet nozzle.

15. In a gas reaction propulsive unit, a housing having a forward axial opening for the entrance of rammed air and a rearwardly directed outlet nozzle for the discharge of gases in the form of a propulsive jet, a turbo-compressor in an intermediate portion of said housing, said turbo-compressor comprising a plurality of concentrically positioned independently journaled radially intercommunicating rotors, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements, each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement and terminating in common annular rings which define separate annular shaped compressor and turbine flow channels of uniform width throughout their radial dimensions, a substantially centrally located combustion chamber, an outer peripheral inlet to the compressor flow channel communicating with said forward inlet opening for flow of air radially inward through the said compressor flow channel, an inwardly directed discharge from said compressor flow channel leading to said central combustion chamber, an outwardly directed radial inlet to said turbine flow channel from said combustion chamber for expansive flow of gas radially outward through said turbine flow channel, and an annular passage leading from the periphery

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of said gas turbine flow channel and communicating with said rearwardly directed outlet nozzle.

16. In a gas reaction propulsive unit, a housing having a forward axial opening for the entrance of rammed air and a rearwardly directed outlet nozzle for the discharge of gases in the form of a propulsive jet, a turbo-compressor in an intermediate portion of said housing, said turbo-compressor comprising a plurality of concentrically positioned independently journaled radially intercommunicating rotors, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements, each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement and terminating in common annular rings which define separate annular shaped compressor and turbine flow channels of uniform width throughout their radial dimensions, a substantially centrally located combustion chamber, an outer peripheral inlet to the compressor flow channel communicating with said forward inlet opening for flow of air radially inward through the said compressor flow channel, an inwardly directed discharge from said compressor flow channel, a centrally located conduit leading axially to said annular combustion chamber surrounding said conduit, an outwardly directed radial inlet to said turbine flow channel from said combustion chamber for expansive flow of gas radially outward through said turbine flow channel, and an annular passage leading from the periphery of said gas turbine flow channel and communicating with said rearwardly directed outlet nozzle.

17. In a gas reaction propulsive unit, an outer housing having a forward axial opening for the entrance of rammed air and a rearwardly directed outlet nozzle for the discharge of gases in the form of a propulsive jet, a turbo-compressor in an intermediate portion of said inner housing, said turbo-compressor comprising a plurality of concentrically positioned independently journaled radially intercommunicating rotors, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements, each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement and terminating in common annular rings which define separate annular shaped compressor and turbine flow channels of uniform width throughout their radial dimensions, a combustion chamber in said inner housing in substantially concentric relation to the axis of said rotors, an outer peripheral inlet to the compressor flow channel communicating with said forward inlet opening for flow of air radially inward through the said compressor flow channel, an inwardly directed discharge from said compressor flow channel, a centrally located conduit leading axially rearward to said combustion chamber, an outwardly directed radial inlet to said turbine flow channel, an annular conduit leading forward from said combustion chamber to said turbine inlet for expansive flow of gas radially outward through said turbine flow channel, and an annular passage formed between said inner and outer housings extending from the periphery of said gas turbine flow channel and communicating with said rearwardly directed outlet nozzle.

18. In a gas reaction propulsive unit, an outer housing having a forward axial opening for the entrance of rammed air and a rearwardly di-

rected outlet nozzle for the discharge of gases in the form of a propulsive jet, an inner housing within said outer housing, a turbo-compressor in an intermediate portion of said inner housing, said turbo-compressor comprising a plurality of concentrically positioned independently journaled radially intercommunicating rotors, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements, each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement and terminating in common annular rings which define separate annular shaped compressor and turbine flow channels of uniform width throughout their radial dimensions, a combustion chamber in said inner housing in substantially concentric relation to the axis of said rotors, an outer peripheral inlet to the compressor flow channel communicating through an annular passage formed between said inner and outer housings with said forward inlet opening for flow of air radially inward through the said compressor flow channel, an inwardly directed discharge from said compressor flow channel, a centrally located conduit leading axially rearward to said combustion chamber, an outwardly directed radial inlet to said turbine flow channel, an annular conduit leading forward from said combustion chamber to said turbine inlet for expansive flow of gas radially outward through said turbine flow channel, and an annular passage formed between said inner and outer housings extending from the periphery of said gas turbine flow channel and communicating with said rearwardly directed outlet nozzle.

19. In a gas reaction propulsive unit according to claim 16 and an accessory compartment in the said inner housing ahead of said turbo-compressor, and drive means extending from said turbo-compressor into said accessory compartment.

20. In a turbo-compressor apparatus according to claim 12 in which each bearing means comprises a track in the rotor ring and slipper bearings received in the track.

21. In a gas reaction propulsive unit, a housing having a forward axial opening for the entrance of rammed air and a rearwardly directed outlet nozzle for the discharge of gases in the form of a propulsive jet, a turbo-compressor in an intermediate portion of said housing, said turbo-compressor comprising a plurality of concentrically positioned independently journaled radially intercommunicating rotors, each of said rotors having a plurality of peripherally spaced longitudinally positioned impeller elements, each of said elements having a turbine blade portion and a compressor blade portion in unitary end to end arrangement and terminating in common annular rings which define separate annular shaped compressor and turbine flow channels of uniform width throughout their radial dimensions,

a substantially centrally located combustion chamber, an outer peripheral inlet to the compressor flow channel communicating with said forward inlet opening for flow of air radially inward through the said compressor flow channel, an inwardly directed discharge from said compressor flow channel leading to said central combustion chamber, an outwardly directed radial inlet to said turbine flow channel from said combustion chamber for expansive flow of gas radially outward through said turbine flow channel, a passage leading from the periphery of said gas turbine flow channel and communicating with said rearwardly directed nozzle, and means for facilitating initiation of operation of the propulsive unit including a starting motor, and a drive between the motor and one of said rotors whereby the motor is operable to drive said rotor to cause flow through said compressor and turbine flow channels.

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