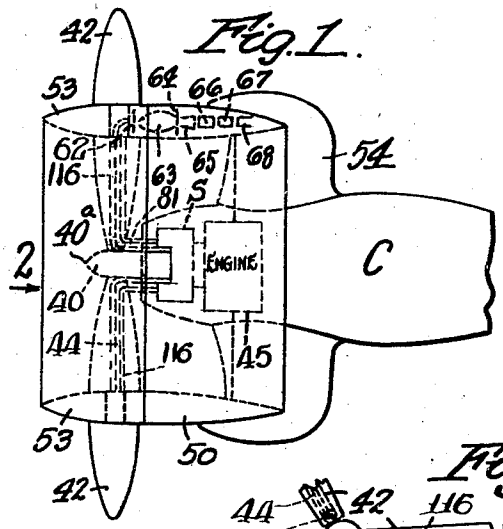
Feb. 26, 1946. R. H. GODDARD 2,395,404

AERIAL PROPULSION APPARATUS

Filed Oct. 18, 1939 4 Sheets-Sheet 1

Fig. 1.



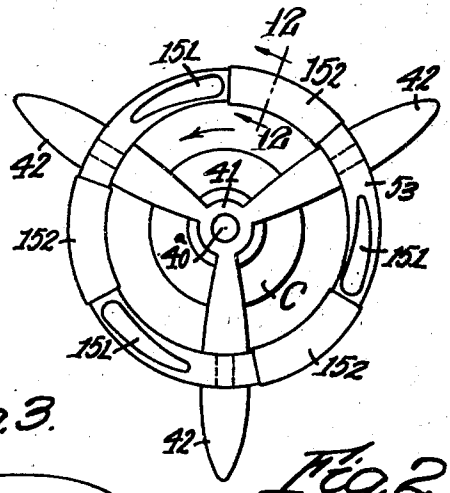
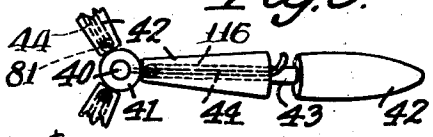


Fig. 2.

Fig. 3.



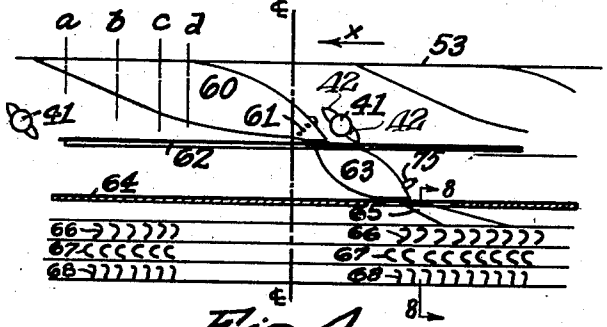


Fig. 4.

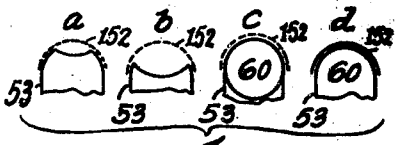


Fig. 5.

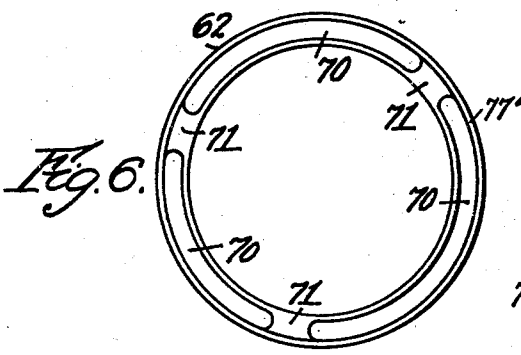


Fig. 6.

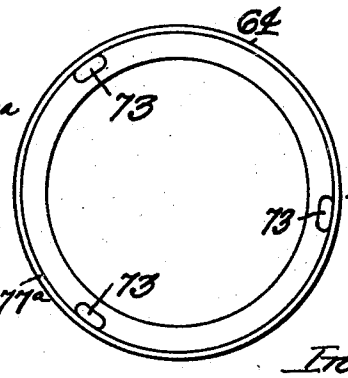


Fig. 7.

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Fig. 8.

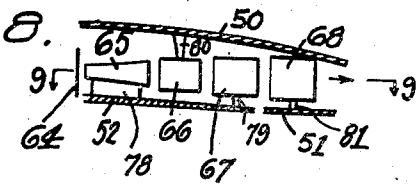


Fig. 9.

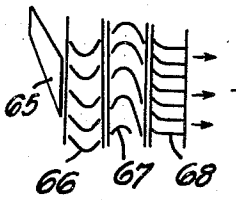


Fig. 10.

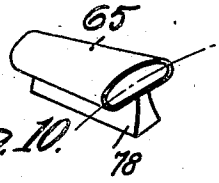


Fig. 11.

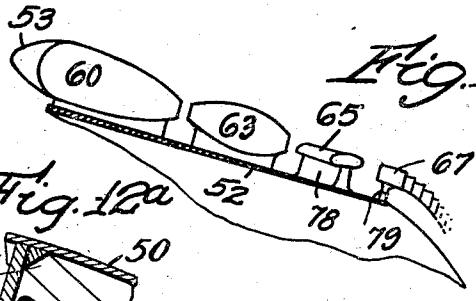


Fig. 12a

Fig. 13.

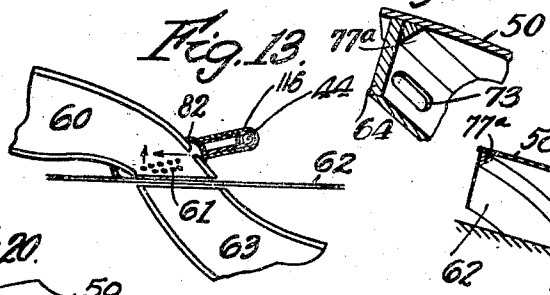


Fig. 12.

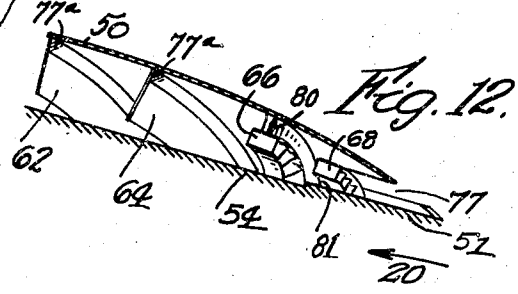


Fig. 20.

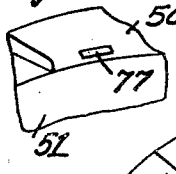
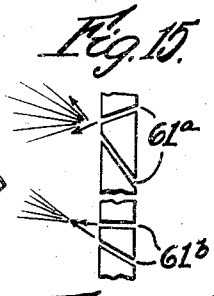


Fig. 15.



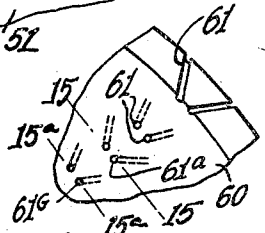


Fig. 14.

Fig. 15a

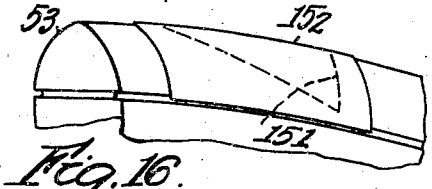


Fig. 16.

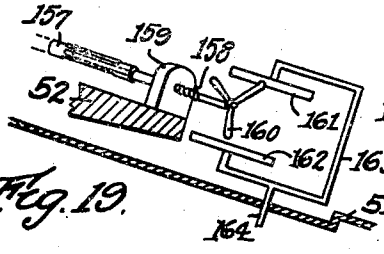


Fig. 19.

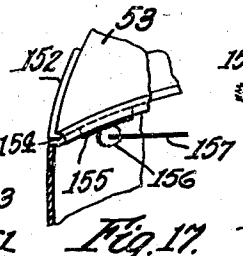
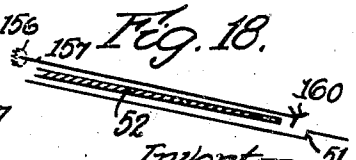


Fig. 17.

Fig. 18.

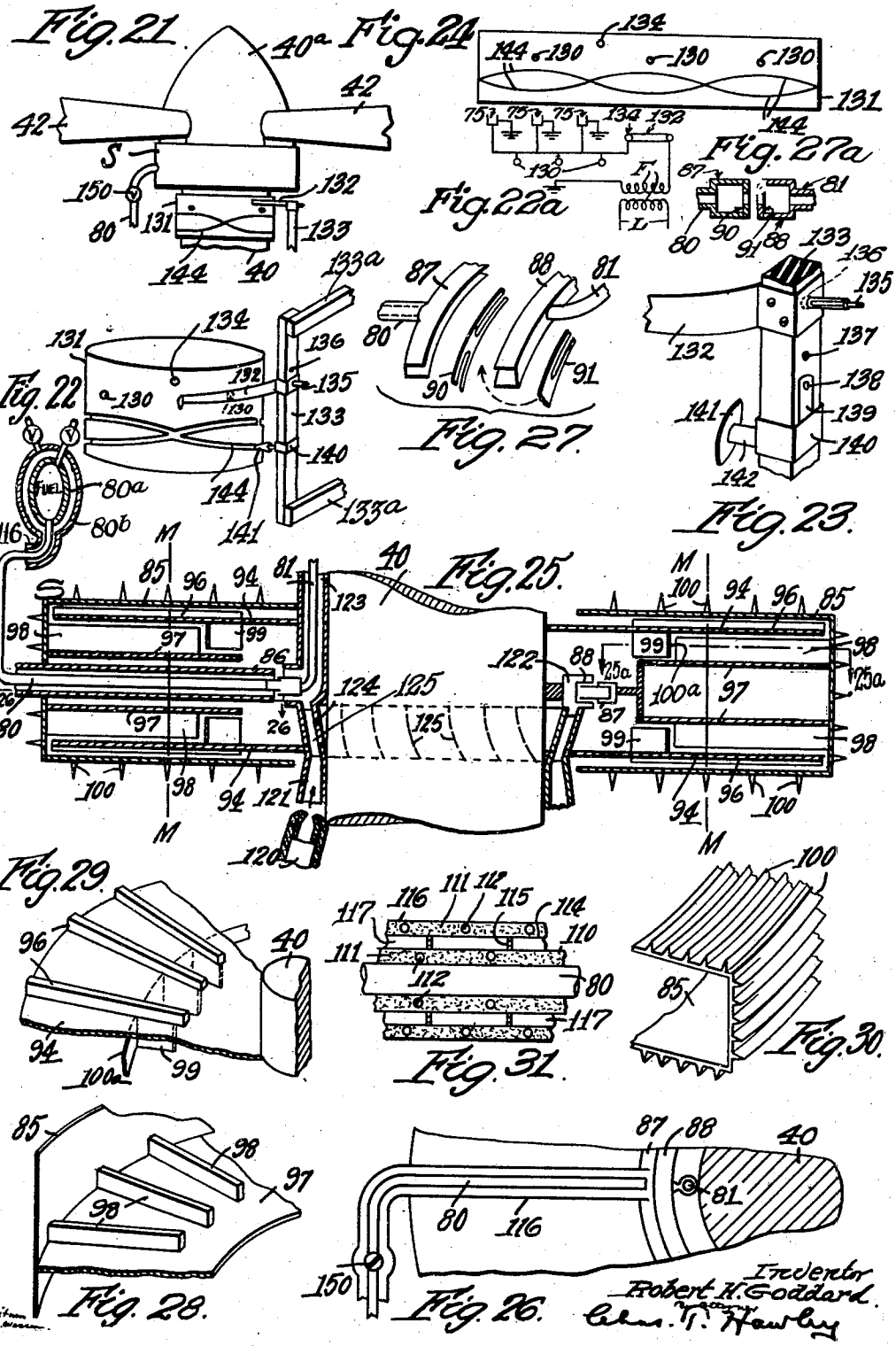


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AERIAL PROPULSION APPARATUS

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AERIAL PROPULSION APPARATUS

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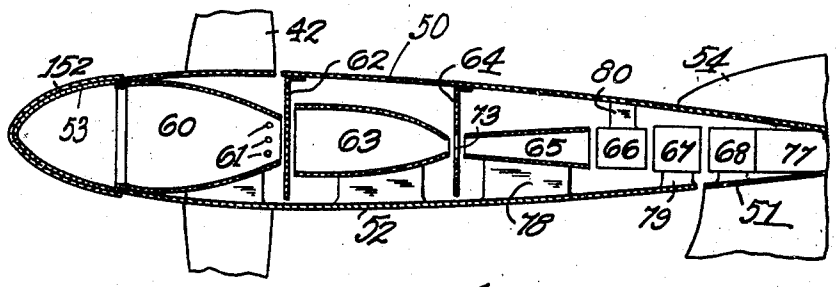


Fig. 32.

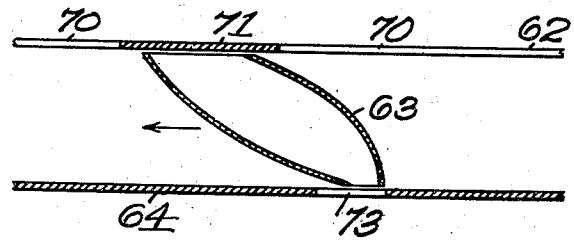


Fig. 33

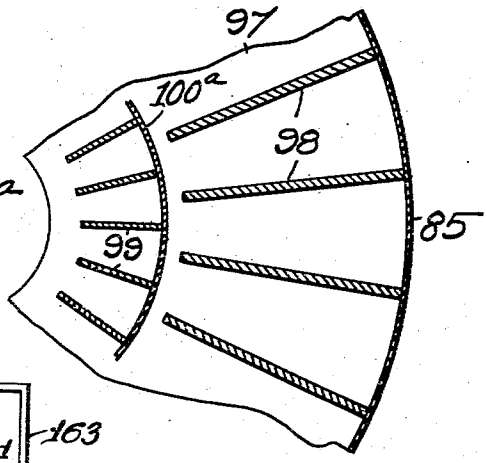
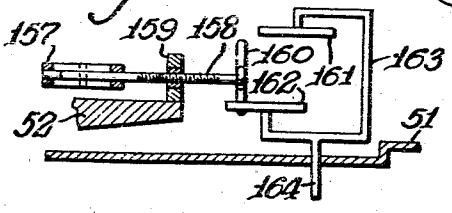


Fig. 25a

Fig. 34



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Patented Feb. 26, 1946 2,395,404

UNITED STATES PATENT OFFICE

2,395,404

AERIAL PROPULSION APPARATUS

Robert H. Goddard, Roswell, N. Mex.; Esther C. Goddard, executrix of said Robert H. Goddard, deceased, assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y., a corporation of New York

Application October 18, 1939, Serial No. 300,027

11 Claims. (Cl. 60—41)

This invention relates to rocket type propulsion apparatus for aircraft which is provided with one or more bladed propellers.

It is the general object of my present invention to provide improved devices to render such propellers more efficient and to supply auxiliary power to the propellers as occasion demands.

A further object of my invention is to provide improved means by which gases discharged from rocket-type combustion apparatus may be directly utilized in the rotation of aircraft propellers, whether or not said propellers are normally driven from some other source of power.

An important feature of the invention relates to the utilization of combustion gases from rocket-type apparatus in a turbine associated with an aircraft propeller. I also provide rocket-type combustion apparatus which is directly associated with and rotatable with the propeller of an aircraft.

My invention further relates to arrangements and combinations of parts which will be hereinafter described and more particularly pointed out in the appended claims.

A preferred form of the invention is shown in the drawings, in which

Fig. 1 is a plan view of the forward portion of an airplane having my improvements embodied therein;

Fig. 2 is a front elevation, looking in the direction of the arrow 2 in Fig. 1;

Fig. 3 is a perspective view of a propeller blade;

Fig. 4 is a diagrammatic view illustrating the operation of my invention;

Fig. 5 comprises a series of partial sectional elevations, taken along the lines *a*, *b*, *c* and *d* respectively in Fig. 4;

Figs. 6 and 7 are front elevations of certain fixed valve or shut-off members to be described;

Fig. 8 is a diagrammatic sectional view, taken substantially along the line 8—8 in Fig. 4;

Fig. 9 is a sectional plan view, taken along the line 9—9 in Fig. 8;

Fig. 10 is a perspective view of a nozzle to be described;

Fig. 11 is an enlarged sectional perspective view of the rotating parts of my improved propulsion apparatus;

Fig. 12 is an enlarged sectional perspective view of the non-rotating parts of the propulsion apparatus, the section being taken along the line 12—12 in Fig. 2;

Fig. 12ª is an enlarged detail sectional view of certain parts appearing in Fig. 12;

Fig. 13 is an enlarged sectional view of portions of the air-collecting and combustion chambers and associated parts;

Fig. 14 is a fragmental side elevation showing the fuel inlets in a portion of the casing appearing in Fig. 13;

Figs. 15 and 15ª are detail sectional views, taken substantially along the lines 15—15 and 15ª—15ª respectively in Fig. 14;

Fig. 16 is a perspective view of a front casing portion to be described;

Figs. 17, 18 and 19 are sectional views, partly in perspective, showing devices for adjusting certain cowling covers to be described;

Fig. 20 is a detail perspective view, looking in the direction of the arrow 20 in Fig. 12;

Fig. 21 is a plan view of certain sealing and firing devices to be described;

Fig. 22 is an enlarged perspective view of the firing devices shown in Fig. 21;

Fig. 22ª is a diagrammatic view of an electrical firing circuit to be described;

Fig. 23 is a further enlarged perspective view of certain details shown in Fig. 22;

Fig. 24 is a diagrammatic lay-out of certain cam and firing details;

Fig. 25 is a sectional elevation of the fuel feeding and liquid sealing devices;

Fig. 25ª is a partial transverse sectional view of a sealing member, taken along the line 25ª—25ª in Fig. 25;

Fig. 26 is an enlarged sectional detail, taken along the line 26—26 in Fig. 25;

Fig. 27 is an exploded view of certain parts of the sealing devices to be described;

Fig. 27ª is a transverse sectional view showing the assembled relation of the parts shown in Fig. 27;

Figs. 28, 29 and 30 are perspective views of additional details of the sealing devices;

Fig. 31 is an enlarged sectional view of certain parts shown in Fig. 26;

Fig. 32 is an enlarged partial and approximately longitudinal sectional view of one unit of my improved propulsion apparatus;

Fig. 33 is a diagrammatic sectional view showing the relation of one of the combustion chambers 63 to the valve plates 62 and 64, and

Fig. 34 is a front elevation of the parts shown in perspective in Fig. 19.

Before describing the details of construction of my improved propulsion apparatus, I will state briefly the general construction and method of operation thereof.

My improved apparatus, while capable of somewhat general application, is particularly designed to supply auxiliary power to a propeller in an aircraft at such times as more power is necessary or desirable. Accordingly, the propulsion apparatus herein shown is commonly used as auxiliary or additional to the regular supply of power by which the propeller is normally rotated.

To the accomplishment of this result, I provide rocket apparatus having certain points of similarity to the apparatus shown in my prior Patent No. 1,960,266, issued November 13, 1934, but dif-

fering largely therefrom both in construction and application.

My improved propulsion apparatus is mounted in a streamlined annular casing, positioned at the front of an aircraft cowling and supported by and rotatable with the aircraft propeller.

As the rate of discharge of the combustion gases from rocket apparatus is much too high for direct and efficient application to propeller blades, I provide successive series of non-rotating turbine blades and turbine blades associated with the propeller, by the coaction of which the energy of the combustion gases may be more effectively applied to increase the speed or power of said propeller.

Auxiliary power may be supplied to the propeller continuously or for such periods of time as may be desirable, and provision is made for closing off the air intakes and thus minimizing the air resistance when the apparatus is not in use, it being understood that my auxiliary propulsion apparatus rotates with the propeller, whether or not it is in use to develop additional power.

Referring to Figs. 1 and 2, I have shown the front end portion of the casing or cowling C of an aircraft having a propeller shaft 40 provided with a propeller 41 having blades 42 and normally rotated by a suitable engine or motor, indicated at 45 (Fig. 1). The front end of the shaft 40 has the usual streamlined casing 40a. Each of the blades 42 is of the usual flattened oval or elliptical cross section, and is provided with a portion 43 of circular cross section intermediate its ends. This circular section permits a blade to be swiveled about its longitudinal axis to vary the pitch, while at the same time the blades may provide support for the rotatable auxiliary propulsion apparatus.

An axial passage 44 (Fig. 3) is provided in each propeller blade 42 for delivery of liquid fuel to the propulsion apparatus, all as will be hereinafter set forth.

The propulsion apparatus is mounted within an annular casing which comprises a non-rotating outer portion 50 (Figs. 1, 12 and 32), a short rear non-rotating inner portion 51, a rotated annular cylindrical ring or band 52 (Fig. 11) forming the inner side of the casing, and a rotated annular streamlined front casing portion 53. These casing parts are all made of a light strong alloy and the part 52 will preferably be reduced in thickness toward its rear edge to prevent distortion, as shown in Fig. 11. The non-rotating parts of the casing are mounted on streamlined arms or brackets 54 (Fig. 1) fixed to the cowling C, and the rotated parts have supporting bearings on the propeller blade portions 43.

Combustion apparatus

My improved rocket type combustion apparatus is shown diagrammatically in Fig. 4, in section in Fig. 32, and in greater detail on Sheet 2 of the drawings. The axis of the propeller shaft 40 is indicated by the dot-and-dash center line in Fig. 4. Each combustion unit comprises a rotating air-collecting chamber 60 (Figs. 4 and 32) having fuel inlets 61, a non-rotating annular valve or shut-off plate 62, a rotating combustion chamber 63, a second non-rotating valve or shut-off plate 64, a rotating discharge nozzle 65, a series of non-rotating turbine blades 66, a series of rotating turbine blades 67, and a second series of non-rotating turbine blades 68.

The number of such combustion units is preferably equal to the number of propeller blades, with an air-collecting chamber 60 provided in the rotated front casing portion 53 between each two adjacent propeller blades 42, as indicated in Fig. 4. Single valve plates 62 and 64 serve all of the combustion units.

Each collecting chamber 60 is disposed at an angle in the front casing 53. In order to provide streamlined air entrance to the chamber, the forward part of the chamber 60 is formed with the successive cross sections shown at *a*, *b*, *c* and *d* in Fig. 5, these sections being taken along the lines *a*, *b*, *c* and *d* in Fig. 4 respectively.

The inner or rear end of the air-collecting chamber 60 (Fig. 33) rotates closely adjacent the non-rotating valve or shut-off plate 62 (Fig. 6) which is provided with elongated slots 70 and with relatively short shut-off portions 71. The air-collecting chamber 60 is open into the combustion chamber 63 so long as a slot 70 is interposed between the chambers, and the entrance end of the combustion chamber is closed when a shut-off portion 71 is interposed between the chambers.

Liquid fuel, preferably hydrogen, is injected in spray form through the openings 61 near the contracted rear end of each air-collecting chamber 60 and adjacent its connection to its associated combustion chamber 63.

The non-rotating shut-off plate 64 is positioned at the rear or exit end of each of the combustion chambers 63 and is provided with relatively short slots or openings 73 (Fig. 7) corresponding with the short valve or shut-off portions 71 of the plate 62. The valve plates 62 and 64 are so related angularly that the openings between the chambers 60 and 63 are opened and closed simultaneously but reversely with the openings between the chambers 63 and the nozzles 65, as clearly shown in Fig. 33.

The rapid motion of my propulsion apparatus through the air, due both to rotation of the apparatus and to forward progress of the aircraft, together with the described operation of the shut-off plates 62 and 64, causes surging of the air in the chambers 60 and 63 and strong oscillations of pressure, all as explained in detail in my prior Patent No. 1,980,266 above cited. The parts are so timed that when the compression of the mixture of air and liquid fuel within the combustion chambers has substantially reached its maximum, the intake openings will be closed, the passages to the nozzles will be opened, and the charges will be fired by spark-plugs 75 (Fig. 4). Ordinarily, each combustion unit will provide three explosions for each revolution of the propeller 41, but I have also provided mechanism to be described by which the explosions in each unit per revolution may be reduced to two or even one.

The combustion gases from each nozzle 65 escape at very high speed and provide a reaction impulse partly in the direction of the arrow *x* or to the left in Fig. 4 and also partly rearward. As the gases leave the nozzle 65, they encounter the series of non-rotating blades 66 by which they are redirected in the direction of rotation of the propeller. The gases then encounter the series of rotating blades 67, thus giving a further forward impulse to the propeller with which they rotate. On leaving the rotating blades 67, the gases encounter the second series of non-rotating blades 68 by which they are directed rearward as indicated in Fig. 9, after which they es-

cape from the non-rotated outer casing member 50 (Figs. 12 and 20) through openings 77.

The described combination of rocket discharge with fixed and rotating turbine blades greatly increases the efficiency of the rocket apparatus, as the gases when leaving the nozzles have a much greater velocity than the rotational velocity of the propeller blades, even at their extreme outer ends, and the actual velocity of the gases discharged from the nozzles, being this high relative velocity less the speed of the propeller, is nevertheless still very high.

With my turbine construction, there is a reduction of speed of the gases in passing through the rotating blades 67 equal to twice the propeller speed and there is a further reduction of the remaining velocity of the gases on passing through the fixed blades 68 equal to the forward motion of the aircraft. A marked increase in efficiency therefore results, as the energy utilised depends upon the difference of the squares of the initial and final velocities.

Each nozzle 65 (Figs. 8, 10 and 11) is mounted on a support 78 fixed to the rotating inner band or ring 52 and the rotating turbine blades 67 are provided with supports 79 similarly mounted on the band 52. The non-rotated blades 66 are secured to the fixed outer casing 50 by supports 80 (Fig. 12), and the non-rotated blades 68 are similarly mounted on the fixed inner rear casing portion 51 by supports 81.

The blades 66, 67 and 68 progressively increase in height and volume capacity, as indicated in Fig. 8, and the nozzles 65 are given the segmental and substantially elliptical section indicated in Fig. 10 to limit their height, so that the combustion gases may readily enter the comparatively narrow blades 66. The progressive increase in height of the blades in the successive series not only provides increased capacity for the expanding gases but also prevents the gases from directly engaging the shrouds or supports of succeeding blades.

The series of turbine blades 66, 67 and 68 are commonly not continuous around the band 52 and casing members 50 and 51, but are provided in separated sections as indicated in Fig. 4, spaced to correspond to the spacing of the nozzles 65 and positioned to be aligned with the nozzles at the times when the explosive charges are fired.

The various parts of the propulsion apparatus are shown separated in Figs. 11 and 12, with the rotating parts shown in Fig. 11 and the non-rotating parts shown in Fig. 12. The shut-off plates 62 and 64 are fixed to the non-rotated outer casing member 50 and are preferably provided with reenforcing fillets 77a (Fig. 12a).

Fuel feed

The preferred fuel for my improved propulsion apparatus is liquid hydrogen, which is extremely light for a given heat value and which also burns or explodes with great rapidity. This is an advantage in my present construction in which there are no relatively heavy moving parts to resist the quick force of the explosions.

The relatively light weight of this fuel is also advantageous on account of the comparatively small expenditure of energy necessary to give the mixed liquid and gaseous fuel its rapid forward or rotational speed as it is delivered to the combustion chambers which rotate with the propeller. The gases which pass through the turbine parts are largely a mixture of nitrogen from the intake air and steam formed by combustion of the hydrogen.

The liquid hydrogen is supplied from a suitable closed tank or storage receptacle 89a under a pressure which may be developed by its own evaporation. The hydrogen tank is preferably enclosed in an oxygen filled casing or jacket 89b to prevent evaporation of the hydrogen. The hydrogen is delivered through a pipe 88 (Figs. 21 and 25) to a sealing device S (Fig. 21) from which it is conducted through a pipe 91 (Fig. 25) alongside the propeller shaft 40 to the passages 44 (Fig. 3) extending axially through the propeller blades 42 to the reduced portions 43, where the passages 44 communicate with annular conduits 92 (Fig. 13) which surround the contracted inner ends of the air-collecting chambers 60 and which communicate with the fuel feed openings 61.

These openings 61 are preferably arranged in pairs, with certain openings at 61a (Fig. 15) disposed at a rather wide angle to produce a widely scattered spray and with other openings as 61b (Fig. 15a) disposed at a smaller angle to produce a narrower spray. Preferably the wide and narrow sprays are alternated around the contracted circumferential wall of the collecting chamber 60. A very even distribution and excellent atomization is thus secured, as the widely scattered sprays are largely taken up near the outer wall of the chamber, while the narrower sprays are more forcibly injected toward the middle of the contracted passage.

This method of introducing liquid fuel is of substantial advantage, as I thus avoid the serious losses which would be occasioned by any parts projecting into the air stream at the high air speeds and high densities encountered in the contracted part of the chamber 60.

Hydrogen seal

It has been indicated that liquid hydrogen, on account of its light weight and high heat value, is a particularly desirable fuel for my improved propulsion apparatus. However, liquid hydrogen is not only very light but is also extremely cold, so that it is impossible to use a sealing lubricant or a solid packing, either of which would immediately freeze. It is accordingly necessary to jacket all parts containing liquid hydrogen with liquid air or liquid oxygen but the liquid hydrogen cannot be directly exposed to the liquid air or oxygen as, being at much lower temperature, it will immediately freeze the jacketing liquid and itself evaporate if direct contact is permitted.

In order to overcome these difficulties, I provide a double mercury seal which balances the hydrogen pressure automatically and prevents leakage between two telescoping rings, one of which is fixed and the other supported by and rotating with the propeller shaft 40.

The sealing device S comprises a fixed housing 85 (Fig. 25) into which the hydrogen feed pipe 88 extends within a jacket or tube 86 supplied with liquid oxygen from any convenient source. At its inner end the hydrogen feed pipe 88 communicates with a fixed annular member 87 (Fig. 27) which has a loose sliding fit within a second annular member 88 which is fixed to and rotates with the propeller shaft 40 and communicates with the pipe 91 previously described. Both members 87 and 88 are of substantially U-shaped section.

The flow of hydrogen from the pipe 88 to the pipe 91 is controlled by annular slotted valve

members 90 and 91 (Fig. 27), one of which is fixed inside of the member 87 (Fig. 27ª) while the other rotates with the member 88. The slots in the valve members 90 and 91 normally coincide so that free hydrogen flow takes place, except at such times as the shut-off plate 62 closes the passage between the air-collecting chambers 60 and the combustion chambers 63.

Discs 94 (Figs. 25 and 29) are fixed to the rotating propeller shaft 40 and extend outward within the sealing casing 85. These discs are provided with radial vanes 96 on their outer sides, which vanes run closely adjacent the inner end faces of the fixed casing 85. Additional discs 97 (Figs. 25 and 28) are fixed to the fixed outer casing 86 and are provided with radial vanes 98 which are preferably somewhat wider than the fixed vanes 96. The outer edges of the vanes 98 are closely adjacent the rotating discs 94.

Additional short vanes 99 (Fig. 29) are secured to the inner sides of the rotating discs 94 and rotate adjacent the inner ends of the fixed vanes 98 and extend closely adjacent the outer sides of the fixed discs 97. The housing or casing 85 is to be partially filled with a heavy liquid M, preferably mercury, which is caused by centrifugal force to occupy the annular space outside of the lines M—M in Fig. 25 when the apparatus is operating at normal speed.

As the axis of the propeller shaft 40 is normally horizontal, the mercury will collect in the bottom of the casing 85 when the propeller shaft is at rest, most of it being between the relatively wide fixed vanes 98. When the propeller is rapidly rotated, the mercury will move outward under centrifugal force produced by the rotating vanes 96, but will not move inward toward the rings 87 and 88, due to the action of the short vanes 99. A ring 100ª (Fig. 29) connecting the outer ends of the short vanes 99 prevents loss of energy by eddies between moving and stationary portions of mercury.

This is due to the fact that two streams of liquid moving in contact but in opposite directions tend to intermingle and thus produce a large energy loss by the formation of eddies. The ring 100ª prevents this loss as the liquid moving in one direction is on one side of the ring and the liquid moving in the opposite direction is on the other side of the ring. Consequently, the two currents of liquid cannot intermingle and thus produce eddies.

When hydrogen is supplied under pressure, some of the liquid hydrogen will escape between the sealing rings 87 and 88 and will evaporate, exerting gas pressure which forces some of the mercury around the outer edges of the discs 94 and between the moving vanes 96. A balance of pressure on the inner and outer sides of the sealing rings 87 and 88 will thus be automatically attained, with just sufficient mercury forced out around the discs 94 to balance the hydrogen gas pressure. It will be noted that the hydrogen, if any, which escapes from the casing 85 will be in the form of gas and will have been sufficiently warmed in its passage through the casing 85 so that there will be no danger of freezing the surrounding atmosphere.

The use of mercury for a liquid seal is of advantage, as it is over 190 times as heavy as liquid hydrogen and consequently a liquid seal of very greatly reduced diameter can be used. Furthermore, it is unnecessary to jacket the casing 85 as would be necessary if liquid hydrogen were used in the seal.

The fixed plates 98 retard the mercury on the inner sides of the discs 94, so that there is a difference in the speed of rotation of the mercury on the two sides of each disc 94 and a corresponding excess in radial pressure or centrifugal force at the outside of each disc. This unbalanced excess centrifugal force prevents outflow of hydrogen gas around the periphery of the disc 94.

Preferably fins 100 (Fig. 25) are provided on the exterior of the casing 85, so that the liquid hydrogen as it evaporates will not freeze the mercury. As soon as the liquid hydrogen has evaporated sufficiently to provide working pressure, this pressure will remain substantially constant and no more evaporation will take place. If hydrogen at extremely high pressure is used, the sealing device S may be enlarged axially, and additional discs and sets of vanes may be employed.

Jacket construction

It is necessary not only to provide effective sealing between non-rotating and rotating parts conveying liquid hydrogen, but also to carefully jacket all parts through which liquid hydrogen is conducted.

In Fig. 31 I have shown the preferred construction for jacketing the hydrogen feed pipe 80. For this purpose, I surround the pipe 80 with a tube 110 spaced from the pipe and having the intervening annular passage filled with a suitable light-weight heat-insulating material 111, thereby avoiding large air spaces. The pipe 80 and tube 110 may be held in spaced relation by solid balls or other devices 112 embedded in spaced relation in the material 111.

A second tube 114 surrounds the tube 110 and is spaced therefrom by perforated rings 115, and a third tube 116 surrounds the tube 114 and is spaced therefrom by additional insulating material 111 and balls 112. The space 117 (Fig. 31) between the tubes 110 and 114 is to be filled with liquid oxygen, which thus jackets the hydrogen conveying pipe 80.

The insulating material 111 between the pipe 80 and the tube 110 prevents contact of the pipe and tube, with resultant boiling of the hydrogen, and the insulating material 111 between the tubes 114 and 116 likewise prevents boiling of the oxygen. Similar jacketing should be provided for all parts conveying liquid oxygen.

Special means is provided to supply liquid oxygen to the jacket spaces of the rotating parts. For this purpose, liquid oxygen is supplied under moderate pressure to a heat-insulated nozzle 120 (Fig. 25) by which the oxygen is delivered to an annular receiving member 121 which connects to the space 122 surrounding the rotating sealing ring 88 and also to the jacket spaces 123 surrounding the pipes 81 extending to the combustion chambers.

It will be noted that a portion 124 of the annular member 121 extends outward away from the axis of the shaft 40 as it approaches the space 122. Centrifugal force thus assists the flow of the liquid oxygen axially along the annular passage. Vanes 125 (Fig. 25) may be provided in the member 121 to increase the centrifugal effect.

Centrifugal force also causes the oxygen to flow outward through all of the jacket spaces in the tubes 116 surrounding the hydrogen passages 44 up to their connection with the annular passages 82 (Fig. 13) surrounding the contracted portions

of the collecting chambers 60. Desired circulation of the liquid oxygen is thus secured without the use of mechanical pumps or other circulating devices.

Centrifugal force in the radial passages 44 (Figs. 1 and 3) develops low pressure in the pipes 81 (Fig. 25) so that direct flow from the passage 80 will take place and there will be no tendency for liquid hydrogen to escape to higher pressure areas outside of the pipes 81.

Firing mechanism

The explosive charges in the combustion chambers are fired by closing electric circuits through the spark-plugs 75 by mechanism shown in detail in Figs. 21 to 24.

One side of each spark-plug is grounded as usual, and the other side of all of the plugs is jointly connected to three terminals 130 in a cylindrical structure 131 mounted on and rotating with the propeller shaft 40. Contact with the terminals 130 is made by a resilient arm 132 mounted on a non-conducting rod 133 positioned by supports 133a (Fig. 22) alongside the propeller shaft 40 but non-rotatable therewith. The arm 132 is connected to the non-grounded side of a suitable electric circuit such as is shown in Fig. 22a.

A single contact 134 is also provided in the member 131, which contact is connected to each of the three spark-plugs 75 but is out of circumferential alignment with the contacts or terminals 130.

Three sparkplugs 75 for three combustion chambers 63 are shown in Fig. 22a as wired to the secondary of a transformer F the primary of which may be connected to lir. wires L. The contact arm 132 may be selectively aligned with the single contact 134 in the sparkplug circuit or with the three contacts 130.

The arm 132 is provided with a plunger 135 adapted to engage either one of two holes 136 (Fig. 22) or 137 (Fig. 23). When the plunger 135 is in the hole 137, as shown in Fig. 22, the arm 132 will engage the three contacts 130 at each revolution of the propeller shaft and at each engagement will fire the three explosive charges, thus giving nine impulses per revolution of the shaft.

If changes occur in operating conditions such as air density, plane speed, or period of surgings or oscillations in the chambers 60 and 63, it may be desirable to reduce the number of explosions per shaft revolution. In this case the arm 132 may be moved to the position shown in Fig. 23, in which position it will engage the single contact 134 during each shaft revolution, so that three impulses only instead of nine will be given per revolution.

The fuel feed valve 150 (Fig. 21) will be manually adjusted to provide the correct amount of fuel for the slower rate of firing.

If an intermediate rate of firing is desired, the plunger 135 is inserted in a hole 138 in a lug 139 extending upward from a sleeve 140 slidable on the rod 133. A switch block 141 is mounted on a stud 142 carried by the sleeve 140 and projects into a double cam groove 144 (Fig. 22) in the cylindrical member 131. The lay-out of the cam groove is shown diagrammatically in Fig. 24, from which it will be seen that the contact arm 132 will be axially shifted to engage each alternate terminal 130 and to skip the intervening terminals. Consequently all three cylinders will be fired three times in each two revolutions, instead of three times in each revolution when the plunger 135 is in the hole 137, or once in each revolution when the plunger is in the hole 136.

It should be understood that the timing control adjustments are so selected manually that firing will take place in each chamber only when the pressure has risen to a desired maximum. The pressure maxima are produced by resonance or surging as the craft passes through the air, and hence the interval between these pressure maxima varies according to existing operating conditions and this interval determines the desirable manual setting of the timing control. The rate of fuel feed is then manually adjusted so that the proper air and fuel mixture will be provided in the combustion chamber by the time each pressure maximum occurs. A very sharp rise of pressure while the valve 73 is open (due to the detonating nature of the fuel used) is followed immediately by a low pressure due to condensation of the combustion product. The chamber thereafter becomes substantially filled with a fresh supply of air and fuel, while the ports 70 are open.

The flow-resistance in the parts rearward of the combustion chamber 63 is such that no substantial out-flow of combustion mixture from the chamber 63 will occur, even with the ports in the exhaust valve 64 momentarily uncovered, unless an explosion in the chamber 63 has developed very high pressure in the chamber. The pressure of the combustion mixture and the proportion of fuel therein continues to build up by surging between ignitions until the required efficient operative maximum pressure is attained.

The time required for building up this desired pressure varies as previously stated under different operating conditions, and particularly in different atmospheric densities and for different rates of movement of the aircraft.

Intake coverage

A valve 150 (Fig. 21) in the hydrogen feed pipe 80 may be manually operated to shut off the flow of hydrogen fuel when desired. In this event, the intake openings 151 (Fig. 2) in the front casing member 53 which lead to the air-collecting chambers 60 should be closed to reduce air resistance.

For this purpose I provide segmental covers 152 (Figs. 2 and 16) circumferentially slidable on the annular front casing member 53 and each provided with inwardly projecting guiding flanges 154 (Fig. 17) and with a depending rack member 155 engaged by a pinion 156. Each pinion 156 is mounted on a shaft 157 extending axially rearward along the rotating ring or band 52 and supported in bearings thereon.

A threaded rod 158 (Figs. 19 and 34) forms an extension of the shaft 157, in which it telescopes and with which it has a pin and slot connection. The rod 158 is mounted in a threaded bearing 159, so that rotation of the rod in either direction also causes axial movement thereof. A star wheel 160 (Fig. 19) is mounted on the outer end of each rod 158 and is selectively engageable by a plate 161 or a plate 162, both mounted on a frame 163 which is manually adjustable relative to the star wheel 160 by a hand rod 164. The plates 161 and 162 are staggered axially of the rod 158 as clearly shown in Fig. 34.

When the covers 152 are to be moved from the open position of Fig. 2 to the closed position in Fig. 16, the frame 163 will be moved so that the plate 162 engages each star wheel 160 at each revolution of the propeller shaft and its asso-

ciated propulsion apparatus, which revolution moves the star wheels past the relatively fixed plate 162.

This causes the star wheels to be advanced one tooth for each revolution of the propeller shaft and associated mechanism, thereby gradually closing the covers 152. The star wheels are simultaneously moved toward the right in Fig. 19 by the threaded bearings thereof, so that the teeth of the star wheels will eventually clear the right-hand end of the plate 162, and the covers 152 will remain in adjusted closed position.

When it is thereafter desired to open the covers 152 for further operation of the propulsion apparatus, the frame 163 is shifted in the opposite direction to bring the plate 161 to position to engage the star wheels and intermittently rotate the same in the opposite direction to slide the covers 152 to the open position of Fig. 2.

Operation

The general operation of my improved propulsion apparatus has been quite fully indicated in the detailed description but may be briefly summarized as follows:

When it is desired to use the auxiliary apparatus, the frame 163 (Fig. 19) is shifted to cause the covers 152 to be removed from the intake openings 151 (Fig. 2) of the air-collecting chambers 60. The valve 150 (Fig. 21) is also opened to permit liquid hydrgoen fuel to flow to the spray openings 61 (Figs. 13 and 14) at the contracted rear portion of the air-collecting chamber.

As the apparatus then rotates with the propeller, the valve or shut-off plates 62 and 64 alternately close the air-collecting chambers 60 and the combustion chambers 63, and the explosive charges are fired when the combustion chambers are closed at their intake ends and open at their discharge ends to the nozzles 65. The discharge gases pass successively through the fixed turbine blades 66, the rotating blades 67, and the fixed discharge plates 68, thus supplying power to the ring or band 52 (Fig. 11) and to the propeller on which said band is mounted.

The power supplied may be varied by the setting of the valve 150 which regulates the flow of fuel to the combustion chambers. The frequency of the explosions is determined by the setting of the contact arm 132 (Figs. 22 and 23) as described, and may provide either one, one and one-half, or three explosions per revolution for each combustion chamber.

It should be particularly noted that I have to a very great extent avoided use of relatively moving parts in my improved apparatus. In particular, the operation of the valve plates 62 and 64 depend solely upon rotation of the propeller and not upon additional mechanical connections.

By the provision of turbine blades to be used in connection with the discharge gases of rocket apparatus, I greatly improve the efficiency of such apparatus and provide a practical means to utilize such rocket apparatus for supplementing the power of a rotating propeller.

It is of particular importance that the air for combustion is taken from the air stream produced by flight, as otherwise considerable power would be wasted in forcing the air forward and against the direction of flight to the combustion chambers.

My invention may be applied to standard types of aircraft with but little necessary modification.

The constricted part of the collecting chamber 60, where the spray orifices are located, is of advantage in several respects: it reduces the distance through which the sprays have to travel; it increases the speed of the air at this point, and hence produces increased atomization; and it further reduces the area, and consequently the force, over which the gases exert pressure on the valve plate 62 during the explosions.

Having thus described my invention and the advantages thereof, I do not wish to be limited to the details herein disclosed, otherwise than as set forth in the claims, but what I claim is:

1. In an aircraft, propulsion apparatus comprising a noted member, power means to rotate said member, an annular casing rotatable with said member, a plurality of rocket type combustion devices mounted in said casing and rotatable therewith in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, and means to apply the combustion gases escaping from said devices to the production of increased power to rotate said member, said casing having spaced air intake openings in its front portion directly exposed to the slip-stream of air about said craft when in flight, each combustion device having an air-collecting chamber coacting with an intake opening, valve means automatically controlling communication between said openings and said chambers during rotation and operation thereof, and additional means to open and close said air-intake openings for interrupting operation thereof while said casing and chambers are in rapid rotation.

2. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, an annular casing rotatable with said member, a plurality of rocket type combustion devices mounted in said casing and rotatable therewith in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, and means to apply the combustion gases escaping from said devices to the production of increased power to rotate said member, said casing having spaced air intake openings in its front portion directly exposed to the slip-stream of air about said craft when in flight, covers for said air-intake openings mounted on said casing for circumferential sliding movement thereon, and manually-controlled means to effect opening or closing circumferential movements of said covers while said casing is in rapid rotation.

3. The combination in an aircraft as set forth in claim 2, in which automatic means is provided to limit said opening and closing movements.

4. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, rocket-type combustion devices rotated with said member in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, means to directly utilize the combustion gases escaping from said devices to supply additional power to turn said member, each combustion device comprising a combustion chamber and an air-collecting chamber, both mounted at a substantial and common angle to their common path of rotation, and said collecting chamber being effective to directly collect air from the slip-stream in said chamber and said air being compressed in said collecting chamber by the high speed rotation of said chamber in said angular position, and fixed valve plates mounted at the exit ends of said air-collecting chambers and of said combustion

chambers respectively and having spaced circumferential slots and interposed shut-off portions, said plates being fixed in such angular relation that they simultaneously and reversely open and close the intake and discharge ends of each of said combustion chambers as said chambers rotate relative to said plates.

5. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, rocket-type combustion devices rotated with said member in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, and means to directly utilize the combustion gases escaping from said devices to supply additional power to turn said member, each combustion device comprising a combustion chamber and an air-collecting chamber, both mounted at a substantial and common angle to their common path of rotation, and said collecting chamber being effective to directly collect air from the slip-stream in said chamber and said air being compressed in said collecting chamber by the high speed rotation of said chamber in said angular position, each air-collecting chamber having means to produce fuel sprays substantially throughout the cross section between said air-collecting chamber and its coacting combustion chamber, and said means comprising alternately and circumferentially disposed wide-angle and narrow-angle pairs of spray openings for liquid fuel adjacent the rearward end of the air-collecting chamber.

6. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, an annular casing rotatable with said member, a plurality of rocket type combustion devices mounted in said casing and rotatable therewith in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, and means to apply the combustion gases escaping from said devices to the production of increased power to rotate said member, firing means for said devices, and manually selective means to vary the total number of ignitions per revolution of said rotated member, while maintaining an equal number of ignitions per revolution for each and every combustion device.

7. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, an annular casing rotatable with said member, a plurality of rocket type combustion devices mounted in said casing and rotatable therewith in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, means to apply the combustion gases escaping from said devices to the production of increased power to rotate said member, and manually selective means to fire each and every device either once or three times per revolution of said member.

8. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, an annular casing rotatable with said member, a plurality of rocket type combustion devices mounted in said casing and rotatable therewith in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, means to apply the combustion gases escaping from said devices to the production of increased power to rotate said member, and manually selective means to fire each and every device either once or three times per revolution of said member or three times during each two successive revolutions of said member.

9. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, rocket type combustion devices rotated with said member in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, means to directly utilize the combustion gases escaping from said devices to supply additional power to rotate said member, means to supply air to said devices, means including fixed and rotating parts to supply liquid fuel under pressure to said devices while said devices are in rapid rotation, and means to prevent escape of said liquid fuel in said supply means between the fixed and rotating parts thereof, said latter means including fixed and rotating adjacent discs, vanes on said discs, and a quantity of mercury interposed between said discs and vanes and sealing said fuel supply means.

10. In an aircraft, propulsion apparatus comprising a rotated member, power means to rotate said member, rocket type combustion devices rotated with said member in a path spaced radially and substantially outward from but concentric with the axis of rotation of said member, means to directly utilize the combustion gases escaping from said devices to supply additional power to rotate said member, means to supply air to said devices, means including fixed and rotating parts to supply liquid fuel under pressure to said devices while said devices are in rapid rotation, and means to prevent escape of said liquid fuel in said supply means between the fixed and rotating parts thereof, said latter means including fixed and rotating adjacent discs, relatively wide vanes on said fixed discs, relatively narrow vanes on said moving discs, and a quantity of a heavy liquid interposed between said discs and vanes and largely retained by said wide vanes when said rotated member is at rest with its axis approximately horizontal.

11. In an aircraft having propulsion apparatus comprising a rotated member, power means to rotate said member, an annular casing rotatable with said member and having spaced air-intake openings in its front portion which are directly exposed to the slip-stream of air about said craft when in flight, a plurality of rocket type combustion devices mounted in said casing and rotatable therewith in a path spaced radially and substantially outward from but concentric with the axis of rotation of said members and means to apply the combustion gases escaping from said devices to the production of increased power to rotate said member, that improvement which comprises an air-collecting chamber for each combustion device rotating therewith but spaced axially therefrom and coacting with an associated intake opening, a nozzle device rotating with each combustion chamber and associated therewith but spaced axially thererfom, and fixed valve means between said spaced parts which automatically control communication between associated air-collecting and combustion chambers and between each combustion chamber and its associated nozzle during rotation and operation thereof, whereby the gaseous content of each combustion chamber is successively compressed, ignited and released and in timed relation to the operation of the other combustion chambers.

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