Our invention relates to jet propulsion and includes among its objects and advantages the union in a single thrust unit of simplicity approaching that of a ram jet combined with effectiveness at sub-sonic speeds substantially equal to that of a turbo-jet.

In the accompanying drawings:

Figure 1 is a side elevation of a jet unit of substantially the proportions suitable for a small jet to be mounted on the tip of a helicopter blade;

Figure 2 is a partial section through the axis of the jet of Figure 1;

Figure 3 is a section similar to Figure 2 showing a modified form suitable for higher speed range;

Figure 4 is a plan view of a helicopter rotor indicating the assembly of units according to Figure 1;

Figure 5 is a partial section of the unit of Figure 1 at the rear end;

Figure 6 is a diagrammatic section of the shroud and driven fan blades as on line 6—6 of Figure 2;

Figure 7 is a similar section of the shroud and driving fan blades as on line 7—7 of Figure 2; and

Figure 8 is a longitudinal section of the front end of a unit designed for maximum speed range.

In the embodiment selected to illustrate the invention, the main draft tube 10 may be of generally conventional configuration. It is telescoped inside an outer housing 12, and the tube 10 and housing 12 together define a reverse draft, or return, passage 14 through which power generated by suction at the rear end of the return passage 14 can be transmitted back to the front end to contribute to the energy of the entering main stream.

In the embodiment of Figure 2, which is the preferred embodiment for use on the tip of a helicopter blade, this power is transferred mechanically to a segregated fraction of the entering stream. This segregated fraction receives three increments of power.

The first increment is its own kinetic energy, which is changed to compression energy by slowing it down to about one-tenth of its entering speed. The second increment is delivered mechanically by fan blades carried by a small propeller by the stream entering the return passage 14. The third increment is added to the doubly compressed segregated stream by combustion in the stream itself. The total is finally reconverted into kinetic energy and delivered in the main throat where it functions to aspirate the stream in the main throat.

For speeds far enough below sonic speeds to permit a driven helicopter blade to function with good efficiency, the construction indicated in Figure 2 carries the return passage 14 in just a little at 16, and the main throat is defined by a short tubular portion 18 joined to the tube 10 by the cone 20. At the front end, between the tube 10 and the parts 18 and 20 there remains a storage space, or plenum and expansion chamber, 22.

At the extreme front we provide a fixed shroud in the nature of an annular septum 23 fixedly connected by shroud blades 24 to the lip 25 of the outer tube 12. The shroud also includes inner blades 26 positioned in front of the entry to the plenum chamber 22. Beside the shroud blades 24 we position the driven blades 28 of a spinner having radial spider arms 30. The spider arms 30 carry an outer annulus 32 on which the driven blades 28 are mounted, and a closely adjacent annulus 34 on which the driving blades 36 are mounted. The front end of the tube 10 is curved inwardly at 38 and ends in a conical septum 40 extending forward between the blades 28 and 36 and segregating the air stream entering the return passage 14 and the air stream entering the plenum chamber 22 from each other, while the sleeve 18 segregates the plenum chamber from the main stream.

Because there is high suction in the return passage 14 the blades 28 are designed with relatively open outletlets. The shroud blades 24 impart a helical movement at approximately 30 degrees to the incoming stream, and the blades 28 are shaped to let the air leave them with a movement that is either parallel to the tube axis or slightly helical in the reverse sense.

The stream entering the plenum chamber must eventually find its exit from the accelerating nozzle 42, fixed by the front end 43 of the throat 18 and a gently tapered reverse cone 44 which, with the parts 43, 18 and the main cone 20, defines the inner wall of the plenum chamber. The dimensions of the nozzle 42 are such that the air stream in the plenum chamber 22 is slowed down to about one-tenth of the speed with which the jet is traveling through the air. We provide combustion means indicated at 46 for injecting into the air in the plenum chamber substantially enough fuel for complete combustion. We also provide conventional ignition means indicated at 48 in the outer wall of the plenum chamber.

Because the speed of the gases around the burner 46 is very low, the problem of keeping the flame lit is negligible.

The gases entering the plenum chamber are first deflected helically to an angle of about thirty degrees by the shroud blades 26 and then receive power from the compression blades 36, which are designed to work in air that is slowed down by the time it leaves the blades to a very small fraction of its entering speed. Accordingly, the pressure throughout the plenum chamber may be from three to ten or fifteen times the pressure developed by slowing down the entering air stream, and the subsequent expansion in the nozzle 42 will accelerate the gases to a speed much greater than the speed of the air entering the main throat. This high velocity exerts a powerful aspiration action that sucks the gases in through the throat 18. It will be noted that the blades 26 are not united at their inner edges. The spaces between these blades remain open in a radial inward direction so that the suction in the throat 18 can draw in a cone of air moving diagonally over the blades 26, to increase the intake into the throat 18. The inlet cone 44 is a unitary structure with the cone 50, which defines a tapering outlet from the plenum chamber, leading to the nozzle 42.

In normal operation the gases leaving the accelerating nozzle 42 will still be incandescent or at least much above the temperature of ignition of the fuel used. Downstream from the nozzle 42 we position an annular fuel supply pipe 52 carrying a series of fuel injection heads 54 which may be of conventional design. At least a substantial portion of the fuel sprayed from the end of the device 54, as indicated by the radiating lines at 56, impinges on the jet issuing from the nozzle 42 so that gases that are still much above the ignition temperature and in which the final stages of chemical combustion may still be going on, provide powerful and effective ignition.
means in an envelope completely encircling the main fuel supply. Thus the normal propagation of flame in the gas in the tube 10 only needs to travel radially in the wedge of half the distance to the axis by the time the gases in the tube 10 have reached the rear end of the jet.

The spider arms 30 of the spinner carry no torque but merely guide the movement of the blades 28 which receive power from the blades 36 which deliver power. The arms 30 are united in a central hub 58, pivoted behind the stationary, tapered point 60. For purposes of simplicity, the hub 58 is illustrated with a plain bearing. The threaded extension 66, seated in the point 60 has a cylindrical portion, or stud, 67 to maintain the moving parts centered. At the base of the stud 67 there is a device to receive the light axial thrust of the air stream, and the rear end of the point 60 provides an opposite abutment.

The point 60 may be supported by three or four stationary spider arms 62 radiating out to join the outer lip 25 of the outer tube 12.

To increase the promptness of combustion, or to permit cheaper or slower burning fuels to be used in relatively short jets, we extend the pivot for the spinner rearwardly in the form of a tube 64. The tube and pivot are supported at their front ends by the threaded extension 66 entering the stationary hub, and the tube 64 is open at its rear end. Near the front end of the tube 64 we fashion a plurality of windows 68. Because the windows 68 are in a zone of maximum suction, and the rear end of the tube 64 is far enough behind the throat to experience a materially higher pressure, there will be a rapid but small current of air entering the rear end of the tube and traveling forward, as indicated by forward directed arrows 70, to issue from the windows 68. The gas entering the tube 64 will include a substantial percentage of unconsented oxygen. We provide a small booster fuel inlet at 72 spaced rearwardly from the windows 68, and a conventional ignition device at 74 between the fuel jet 72 and the windows.

By delivering in the jet 72 a quantity of fuel of pilot light proportions compared with the fuel delivered by the main heads 54, we maintain a flame issuing continuously from the windows 68. This flame is swept rearwardly close to the tube by the main stream of entering air, and diluted by that stream, so that the process of combustion will be far advanced by the time the flame gets back to the rear end of the tube 64. The size of the flame remains insufficient to satisfy the available oxygen in the main stream, so that the portion of the gases in the tube 64 will still have enough available oxygen to initiate the process of combustion in the flame issuing through the windows 68.

At the same time, the bulk of the flame issuing from the windows 68 will continue beyond the tube 64 and ignite the fuel injected at 56 in a central core along the axis of the tube 10. This cuts in half the distance that the flame has to propagate itself radially to cause the entirety of the main stream to burn completely. A ceramic button 75, close behind the windows 68 will become incandescent as soon as the flow starts, and insure continuity in the flame from the windows 68.

Referring now to Figures 1, 4, and 5, the tube 10 and envelope 12 may remain of full diameter until it becomes necessary to accelerate the burned gases, especially in jets of large power, which are often faiired into the contours of an air craft. However, for small jets to be mounted on the tip of a helicopter blade, we prefer to employ a shallower taper beginning about midway of the length of the tube, at the point identified by reference character 76 in Figure 1, so that the diameter at the elbow 78 has been reduced ten or twenty percent, with a corresponding gradual preliminary acceleration of the main stream. This acceleration would be from minimum to thirty-six percent if volumetric changes were not taking place at the same time, but in actual practice there should be a volumetric acceleration of much more than one hundred percent in the main tube.

At the rear end all the power in the main tube is transformed, so far as practicable, into kinetic energy by the cone 80 so that the main stream issuing from that cone has maximum of suction precisely at the exit from the cone 80. The envelope 12 has a similar cone 82 and the openings of the two cones are designed to transfer a substantial amount of power from the jet to the passage 14. At the same time the material flowing through the passage 14 and blending with the jet from the cone 80, increases the mass ejected rearwardly and contributes materially to the forward thrust developed by reaction.

In most conditions of operation, better efficiency can be obtained by blending the issuing jet with additional air entrained through a conventional diffuser 64. Since the best thrust development requires the entrainment of more air than the passage 14 could deliver, it will be obvious that the effective power lost in the passage 14 is limited to that dissipated in friction between the walls of the passage and the air flowing in it. Accordingly, the tail cones 80 and 82 are arranged to generate a maximum of suction with a relatively small volume of flow, leaving to the diffuser 64 the task of entraining the large volume of air desirable for full thrust.

In Figure 4 we have indicated conventional helicopter blades 94 pivoted at 96 and a unit according to Figure 1 positioned at 100 at the outer tip of each blade.

Referring now to Figure 3, the main tube 102 is associated with envelope 104 to function the same way as tube 10 and envelope 12, but the plenum chamber has been omitted.

The passageway 166 carries the suction generated at the rear, and the flow in this passage drives the driven spinner blades 168. The power thus transferred back to the front end travels radially inward on the spinner arms 110 and is delivered by the driving fan blades 112 in the main thrust 114.

As in Figure 2, the stationary pivot cone 116 is supported on spider arms 118 and carries the central return tube 120. Because there is no outer ignition for the main fuel jets from the heads 122, fed by the header 124, we prefer to move the heads 122 just a little more toward the center and to increase the volume of flame to be delivered from the window 125 to supply much more powerful ignition at the center. Accordingly, the pilot flame supply tube 128 and fuel jet 130 are designed to deliver five to ten or more times as much fuel as in the embodiment of Figure 2, which will be ignited by the igniter 132 so that the flame from the windows 126 is still flaming when it hits the fuel laden stream at approximately the point indicated at 134. The incandescent button 75 performs the same function as in Figure 2.

It will be obvious that in a unit according to Figure 3 the percentage of power that can be brought back to the front is a minor fraction of what can be delivered by the jet 42 of Figure 2. The construction of Figure 3, accordingly, can not be expected to pull efficiently until it is brought up to speeds much higher than the minimum speeds at which the jet of Figure 2 could function efficiently. In approximate terms it should have good efficiency over speeds from sixty percent of sonic up to perhaps somewhat below sonic speeds, a range which extends down far enough to include the desirable speeds for helicopter blades.

Referring now to Figure 8 we have indicated a configuration for securing high efficiency at speeds beginning at or only a little below sonic speed and up to the highest speeds attainable. The plenum chamber has been retained, but the power transfer duct has been eliminated. The main tube 136 is flared outward slightly at its front end at 138 and approximately thirty percent of the air entering, at some such speed as six hundred to fourteen hundred miles an hour, is impounded in the plenum chamber 140 by means of a divider having a cutting edge at...
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142, an inwardly flaring wing 144, and an outwardly flaring wing 146.

The main cone at 148 performs the conventional function of reducing the average velocity in the tube 136, and at its front end the reversely tapered cone 150 defines the accelerating nozzle 152. The nozzle 152 is so proportioned that the gases in the plenum chamber are reduced to speeds of the order of magnitude of less than ten percent and usually from three to five percent of the speed of the incoming stream. This very low velocity is naturally accompanied by a maximum pressure, but the criterion is not so much pressure as a slow enough velocity so that the fuel injector 154, after the fuel has once been started burning by a conventional igniter 156, is in no danger of having its flame blown out by the velocity of the air current. We prefer to adjust the fuel supply at 154 for substantially complete burning of the volume of gas that issues from the nozzle 152, and this sheet of flame exerts a strong aspirating action on the main throat and will still be substantially incandescent when it reaches the fuel injection heads 158 fed by the fuel header 160. Accordingly, the heads 158 deliver only the fuel needed to burn the gas that has come through the throat 144.

It will be seen that the entirety of the air passing through the tube 19 is first subdivided into a minor priming portion entering the expansion chamber 22 and a main, or major, portion. Then the minor portion receives a small increment of energy from the blades 36 and a large increment of energy from the flame at 46, and is returned to the main stream through the accelerating nozzle 42 before the main stream receives the main chamber of the expansion heads 54.

Others may readily adapt the invention for use under various conditions of service by employing one or more of the novel features involved or equivalents thereof. The transfer of power by the suction passages 14 cannot be nearly as great as can be accomplished by the driven blade and torque shaft of a conventional turbojet, but the multiplication of that power in the plenum chamber can result in the delivery of power in the jet at 42, up to amounts comparing favorably with such turbojets. The great speed of combustion caused by the jet at 42, and the simple light transfer spinner not exposed to flame temperatures, are outstanding advantages.

As at present advised, with respect to the apparent scope of our invention, we desire to claim the following subject matter:

1. Jet thrust means comprising, in combination: tubular shell walls defining: an open front end; an open axial throat extending back from said front end and having an intermediate waist of minimum diameter; an annular plenum chamber encircling said waist; said plenum chamber having an annular front inlet and a rearwardly directed annular outlet from said plenum chamber into said waist; and means for burning fuel in said plenum chamber, whereby said outlet delivers an annular flame into said waist encircling the stream coming through said waist.

2. Jet thrust means according to claim 1, in which said shell increases in diameter rearwardly of said throat to define a main combustion chamber; and additional main fuel jets in said main chamber, positioned to be bathed by the flame from said plenum chamber outlet; the rear end of said main chamber being rearwardly tapered to accelerate the products of combustion; said throat and main chamber being substantially straight, and open, and unobstructed from end to end, except for said main fuel jets.

3. Jet thrust means according to claim 2, in which said plenum chamber outlet is tapered and of minimum cross section at its mouth to accelerate the gases issuing therefrom.

4. Jet thrust means according to claim 3, in combination with a power source and means driven thereby for compressing the gases entering through said inlet to support combustion in said plenum chamber; and in which said outlet accelerates the products of combustion to a higher velocity than that of the stream through said waist.

5. Jet thrust means according to claim 4, in which said power source is a blade motor actuated by the oncoming air which by-passes said annular inlet, and a blade compressor in said inlet turning in unison with said motor.

6. Jet thrust means according to claim 4, in which said outer plenum chamber extends both forward and back, from the transverse plane of said outlet; the outer wall of said plenum chamber merging smoothly at its rear end with the outer wall of said main combustion chamber.

7. Jet thrust means according to claim 6, in which said plenum chamber is defined by a larger, outer, annular trough opening forward; and a smaller, inner, annular trough opening rearward; said troughs being partly telescoped axially, with the outer wall of the inner trough extending axially back outside the inner wall of the outer trough, and the inner wall of the inner trough defining said main throat back to the transverse plane of the mouth of said outlet; the inner wall of said outer trough extending forward beyond the mouth of said outlet, and, with the adjacent edge portion of the inner wall of said inner trough, defining said outlet.

8. Jet thrust means according to claim 7, in which said larger trough is positioned to receive air from said inlet moving rearwardly along its outer wall; said trough having a U-shaped bottom; whereby a vortex is maintained in said larger trough, with gases leaving said vortex in a forward direction to pass into said smaller trough.

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