This invention relates to helicopters which have their rotors driven by jets discharged from nozzles at the trailing edge of each blade near the tip of the blade. Air for the jets is obtained from a compressor or blower driven by an engine in the helicopter. Power in excess of that supplied by the engine can be obtained for hovering, or vertical ascent, or other peak loads, by heating the compressed air stream in the rotor blades before it is discharged from the jet nozzles. The stream is heated by mixing fuel with the air and burning the mixture in the blade as the mixture travels toward the jet nozzle. The jet discharged from the blade contains substantial quantities of carbon dioxide and water vapor produced by the combustion, but the jets will be referred to herein as “air” jets, it being understood that the term “air” is used in a broad sense to include jets of air and gaseous products of combustion resulting from the burning of fuel, preferably hydrocarbon fuel, in air.

For aerodynamic reasons, the cross-section of the rotor blades is quite limited, and in order to develop substantial power it is necessary to pass a large amount of air through the blades to the jet nozzles. These circumstances make the velocity of the air stream in the blades so high that ignition is difficult to obtain and special precautions have to be taken to insure mixing of the air and fuel and to obtain propagation of the flame throughout the full cross-section of the stream, within the extremely short time required for the air to reach the nozzle at the blade tips.

It is an object of this invention to provide a helicopter with improved apparatus for obtaining mixing of the fuel and air, ignition and combustion of the air-fuel mixture inside of the blades of the helicopter rotor. The invention reduces the velocity of the air-fuel stream or shuts it off entirely for temporary periods by means of an adjustable velocity controller, in order to expedite the ignition of the air-fuel mixture, particularly when starting in cold weather.

Another object is to heat the air supplied for the air-fuel mixture so that the fuel will volatilize for starting in cold weather. This heating is accomplished in a simple and efficient manner by using centrifugal compressor or blower to supply the air, and shutting off the air from the blower, by closing the outlet of the blower, so that air which is contained within the blower is raised to a higher temperature by the agitation produced by the rotor of the blower. Experience has shown that atmospheric air below 30°F. can be heated within about one-half minute to a temperature of the order of 75° by merely shutting off the air conduit of the blower. When the conduit is reopened, this heated air passes into the rotor blades and mixes with the fuel and volatilizes the fuel to produce a combustible mixture.

There is also an advantage in shutting off the air from the blower when starting the engine which drives the blower. In the preferred construction of the invention, the blower is driven at a speed of the order of ten times the engine speed. This high gear ratio makes starting of the engine difficult if the blower is not unclutched from the engine and can deliver air when first started. If the air conduit of the blower is closed and the blower can deliver no air, the engine can be started with considerably less effort, and no clutch is necessary between the blower and the engine.

Another object of the invention is to provide apparatus for reducing the velocity of the air streams in the blades of a jet helicopter without decreasing the speed of the helicopter engine.

For reasons of safety, it is desirable to maintain a certain minimum engine speed whenever the helicopter is in use. One reason for maintaining the engine speed is to obtain adequate cooling of the engine, and another is to prevent stalling and backfiring, particularly with high compression engines.

The adjustable velocity controller of this invention is preferably an obstruction, such as a butterfly valve, in the air stream, and movable into different positions to reduce or shut off the air stream from a blower that is directly connected with the helicopter engine, without reducing the blower or engine speed.

Another object is to provide an improved cooling system for the engine, particularly for the engine oil, which cools the bearings and various parts of the engine. It is a feature of this cooling system that it increases its cooling effect in proportion to the load on the engine and is independent of the speed of the helicopter through the air. This is an important advantage in a helicopter which has its engine under maximum load when hovering and in vertical ascent, at which times there is no speed of translation to provide a strong flow of air over the engine as in automobile and airplane practice.

Other objects, features and advantages of the invention will appear or be pointed out as the description proceeds.

In the drawing forming a part hereof, in which
like reference characters indicate corresponding parts in all the views.

Fig. 1 is a diagrammatic side view, mostly in section, of an auxiliary aspirator cooling structure shown in Fig. 1. Fig. 2 is an enlarged view, mostly in section, of a portion of the rotor of the helicopter shown in Fig. 1. Fig. 3 is an enlarged diagrammatic plan view of the auxiliary aspirator cooling structure shown in Fig. 1. Fig. 4 is a greatly enlarged sectional view, on the line 4—4 of Fig. 2, through the end of the rotor blade. Figs. 5 and 6 are sectional views taken on the lines 5—5 and 6—6, respectively, of Fig. 4. Fig. 7 is a greatly enlarged rearward end view of one of the fuel nozzles shown in Fig. 4. Fig. 8 is a side elevation of the fuel nozzle shown in Fig. 7. Fig. 9 is a sectional view taken on the line 9—9 of Fig. 7. Fig. 10 is a sectional view on line 10—10 of Fig. 9, with the nozzle insert in elevation. Fig. 11 is a front view of a modified form of nozzle insert.

The helicopter comprises a fuselage 10 which has wheels 14 and 15 for supporting it when on the ground. A pylon 17 secured to the top of the fuselage connects the fuselage with a rotor 18 comprising blades 20 extending from the opposite sides of a rotor hub 21.

The rotor hub 21 is connected with the pylon 17, but is rotatable on the pylon as will be more fully explained in connection with Fig. 2. There are preferably two blades 20, and these blades have sufficient lift to support the helicopter during flight.

The rotor 18 is driven by air jets which are discharged through jet orifices 23, there being at least one such jet orifice at the trailing edge of each blade 20 near the outer tip of the blade. The air which discharges through the jet orifices 23 is supplied by a blower 25 located in the fuselage 10. This blower takes air from the atmosphere through an inlet 27 and discharges the air, under some compression, through a blower outlet and through a discharge conduit 29 which passes through the rotor outlet upward through the pylon 17 and to the inner ends of the rotor blades 20 in the hub 21. The blades 20 are hollow, and the air from the conduit 29 is discharged through the hollow blades 20 to the jet orifices 23. The jets drive the rotor at a speed which is usually controlled automatically. As the speed rises, the blades are turned to increase their pitch, and vice versa.

The blower 25 is shown as a centrifugal blower, but other types of blowers may be used, such as axial flow compressors in which blades move the air parallel to their axis of rotation and impart some increase in pressure to the air for subsequent delivery through an outlet located on the downstream side of the rotor blades. Several stages of compression can be employed, usually with a reduction in the cross section of the air passages proportional to the reduction in volume of the air resulting from the compression. The term “blower” is used herein to designate any non-positive displacement air pump, that is, an air pump in which the load on the pump is not affected substantially by a partial or complete blockage of the air outlet passages of the pump.

The blower 25 is driven from a gear box 31 by a power shaft 32. The gear box 31 transmits power to the blower from an engine 34 which is preferably an internal combustion engine.

Experience has shown that the engine 34 should always operate above a predetermined minimum speed. This speed is different for different types and models of engines, but with any internal combustion engine, particularly when the engine is cold, it is dangerous to reduce the speed below a certain minimum number of revolutions per minute because there is danger of a backfire and of having the engine stall. Even though the engine is equipped with a starter, there are many situations where it is dangerous to have the engine stall because power cannot safely be dispensed with for the length of time necessary to use the starter and to get the engine back into reliable running operation.

It is both a convenience and a safety precaution to provide means for reducing the air output from the blower 25 without reducing the speed of the engine 34, and without resorting to clutches or other mechanisms for connecting and disconnecting the blower 25 and the engine. In the preferred construction of this invention, the blower 25 is permanently connected with the engine 34, and the speed of the blower varies directly with the speed of the engine. The air delivered by the blower 25 is regulated by obstructing the air flow of the blower either at the inlet 27 or beyond the outlet 28, preferably the latter.

When extra power is necessary, as for hovering, or for vertical ascent, the helicopter can develop power in excess to that supplied by the motor 34. This extra power is developed by passing the air streams through burners or combustion chambers in the blades 20, and heating the air streams to a high temperature before they are discharged at the jet orifices 23. Fuel which may be gas, but is more frequently vaporized liquid, is mixed with the air stream in the blades 20 at the upstream ends of the combustion chambers, and the air-fuel mixture burns as it passes through the combustion chambers on its way to the jet orifices 23.

The combustion should be complete before the air-fuel mixture is discharged from the jet orifices 23, and the amount of excess air should be kept as low as possible, in order to develop the highest efficiency from the fuel burned in the blades. This introduces a problem because the velocity of the air stream through the blades is extremely high, and the mixing of the air and fuel, as well as the propagation of the flame through the mixture, must be very rapid in order both to mix and burn the mixture within the length of the combustion chambers.

The high velocity of the air stream introduces an even greater problem in ignition. When the pilot of the helicopter wants to obtain greater jet thrust by using the heaters in the rotor blades, he operates a switch 38 located adjacent to the pilot’s seat 39 at the cabin of the helicopter. This switch supplies power to an electric igniter, which will be described in connection with Fig. 2, and he also operates a manually-actuated control 41, located adjacent to the seat 39, for reducing the velocity of the air stream so that the air-fuel mixture can be more easily ignited.

The control 41 is connected by a link 42 with a crank arm 43 secured to a baffle comprising a butterfly valve 44 in the conduit 29 of the blower. This butterfly valve 44 comprises an obstruction in the air stream, and the valve 44 is preferably large enough to block substantially the entire cross section of the conduit 29 when
turned into a position extending transversely of the air stream. Since the obstruction of the conduit 29 by the butterfly valve 44 reduces the load on the blower 25, the engine speed 24 will actually increase approximately 10% to 15% when the air from the blower is shut off. The temperature of the air delivered by the blower is raised when the flow is obstructed or partially obstructed, as previously explained.

The degree to which the velocity of the air stream must be reduced in order to obtain ignition of the air-fuel mixture in the blades 20 depends upon various considerations, but experience has shown that a substantially lower velocity is necessary to obtain ignition in cold weather. By reducing the velocity of the air stream sufficiently low, the pilot can be sure of obtaining ignition promptly in the combustion chambers of the rotor blades, and at times when the extra power of the blade heaters is necessary, it may be important to insure operation quickly and reliably. This is particularly true because of the fact that the reduction of jet velocity reduces the power of the rotor 18 and it may be essential that this power reduction be limited to only a short period.

Fig. 2 shows the construction of the rotor hub 21 and the connection of the blades 20 to the hub. These blades can be turned about their axes for changing their pitch, and the upper portion of the hub, to which the blades are connected, has universal movement with respect to the lower portion of the hub 21 and the pylon 17 in order to effect forward flight, rearward flight and to maneuver the helicopter. The construction that makes such movements possible, and the controls for obtaining it, are not illustrated in the diaagramatic drawing because these details are not necessary for a complete understanding of this invention. For purposes of this invention, it is sufficient to understand that the hub 21 is connected with the pylon 17 by a thrust bearing 46 which permits rotation of the hub about the axis of the pylon, but prevents axial movement of the hub with respect to the pylon.

The hollow interiors of the blades 20 communicate with the hollow interior of the pylon through elbows 58. There is an expansion joint connecting the elbows 58 with the lower portion of the hub. This is necessary because of the tilting of the upper portion of the rotor hub with respect to the lower portion when maneuvering the helicopter in flight. The interior of the pylon comprises a portion of the conduit 23 through which air is delivered from the blower.

A fuel supply line 53 extends upward along the axial direction of the rotor hub 21 and there is a T connection 54 at the upper end of the fuel supply pipe 52. Branch piping 55 extends in opposite directions from the T fitting 53 and connects with tubing 55 that carries the fuel outward along the blade 20 to a nozzle 57 located in the blade near the upstream end of the combustion chamber 58. The fuel supply pipe 52 is fixed with respect to the pylon 17, and the T fitting 53 is notable about an axis of the pipe 52 so that the branch pipes 55 can be connected to and rotate with the rotor hub 21. The supply of fuel through the pipe 52 is controlled by the operator and can be actuated by electric valve mechanism connected in the circuit with the ignition switch 38, though ordinarily a separate fuel controller 39 is desirable because the electrical ignition is not necessary after the combustion has been started in the blades.

The switch 38 supplies current to the igniters 5 in the blades 20 through conductors 53 secured to the pylon 17 and connected with brushes 54 that bear against a slip ring 56 on the lower portion of the rotor hub 21. Wires 61 lead from the slip rings 56 outward along the blades 20 to an igniter 70 located along the combustion chamber 58 downstream from the fuel nozzle 57.

The combustion chamber 58 comprises a sleeve that is spaced from the inside surface of the blade but that is of only slightly less height than the interior of the blade. There are two combustion chambers in each blade, as will be explained more fully in connection with Figs. 4-6, but a description of one of them is sufficient, since they are similar except in cross section. The cross sections are shaped to fit the parts of the blades in which they are located.

The sleeve or combustion chamber 60 is open at both ends and most of the air that passes through the blade travels through the combustion chamber 60, or the other combustion chamber immediately behind it. There are small boundary layers of air that travel through the clearance between the outside face of the combustion chamber sleeve and the inside surface of the rotor blade. This clearance insulates the skin of the rotor from the combustion chamber heat.

The fuel nozzle 57 faces in a direction to discharge a spray of liquid fuel against the current of the air stream. This produces a violent atomizing of the liquid fuel and a rapid evaporation of the fuel as it mixes intimately with the air.

During normal forward flight of the helicopter, the combustion in the blades is ordinarily not used, since it is necessary only for vertical ascent or for hovering. The power of the engine 34, without assistance from combustion in the blades, is sufficient for forward flight. When the helicopter is hovering, or in vertical ascent, the engine operates under a heavy load supplying large quantities of air for the combustion in the blades, and additional cooling of the engine is required. This invention makes special provision for cooling the engine in proportion to its load.

Referring to Figs. 1 and 3, the engine is equipped with a cooling fan 72, driven from the engine and located in position to direct a strong blast of air forward over the cylinders of the engine 34. The cooling of the engine bearings is effected by forced circulation of oil to the bearings in accordance with the usual automotive practice. There are oil coolers 74 in the circuit with the oil that cools the bearings. At least one of these oil coolers 74 is located in an air duct 76 through which some of the air from the fan 72 is deflected by a baffle 77. The flow of air is indicated by arrows in Fig. 1.

The amount of air blown into the air duct 75 by operation of the fan 72 would be proportional to the engine speed but not to the load. In order to make the air flow through the duct 75 by cooler 74 proportional to the engine load, an exhaust pipe 79 from the engine 34 extends into a suction duct 80 at the discharge end of the air duct 75. The flow of gas from the exhaust pipe 79 exerts an aspiratory action which reduces the back pressure in the duct 75 and thereby increases the flow of air from the fan 72.
through the air duct 78 proportional to the load on the engine 54. The exhaust pipe 79 is surrounded with asbestos insulation 81 where it enters the suction duct 80; and there is another asbestos insulation 81 in the duct to prevent the exhaust gas from heating the duct.

Figures 4, 5 and 6 are detail views showing the combustion chambers in the rotor blades. In order to provide the necessary strength for the blade 29, there is a central spar 83 extending lengthwise of the blade. This structural element makes it necessary to use two combustion chambers in the blade, one on each side of the spar 83. The combustion chamber 80 is located rearwardly of the spar and another combustion chamber 85 is located forward of the spar 83, the only difference in these combustion chambers 80 and 85 being that they are differently shaped to conform to the cross section of the portion of the rotor blade in which they are located. Pairing 81 attached to the rotor blade and forming the trailing edge of the blade, provides a housing through which the fuel tubing 55 and the electric conductors for the igniter 76 extend.

The nozzle 57 is connected to a header 88 which extends through the spar 83 and across one or both of the combustion chambers 80 and 85. This header is supplied with liquid fuel through the tubing 55. Just beyond the header there is an obstruction comprising a hollow post 89 which preferably has a number of spaced openings on its upstream side, and slot openings on its downstream side. The spark plug or igniter device 70 preferably has its operative end located within the post 89.

Part of the air-fuel mixture enters the post through the upstream openings, and this mixture travels through the inside of the post at reduced velocity, and is ignited in the post by the park plug or igniter 76. Flame from the burning mixture flows out through the downstream slots in the hollow post and ignites the air-fuel mixture outside the post, particularly in the location immediately downstream from the post where the air-fuel stream eddies because of the obstruction provided by the hollow post. The eddy currents prevent the flame from being blown away from the post 89 which serves as an anchor flange holder within the combustion chamber. From this region of low velocity, the flames propagate into the high velocity stream on both sides of the hollow post and across the entire width of the combustion chamber.

Although the post or flame holder provides an anchor for the flame at all times, it is of particular importance when first igniting the air-fuel mixture in the blade. It provides an obstruction in the air-fuel stream and reduces the velocity of the stream locally in the region of the ignition device 70 to facilitate the original ignition such that the heaters in the rotor blades are put into operation. This localized reduction in velocity is in co-operation with and adds to the overall reduction in velocity by the valve in the blower conduit.

A similar nozzle 80 is connected to the header and located in the combustion chamber 85. Each of these nozzles 57 and 90 is located in position to spray a stream of atomized liquid fuel against the air stream through the rotor to promote rapid dispersion and evaporation of the fuel throughout the full cross section of the air stream. The detailed construction of the nozzles 57 and 90 will be explained more fully in connection with Figures 7-10, and for the present it is sufficient to understand that these nozzles direct flaring jets having small angles of divergence so that the particles of liquid fuel are vaporized before they come into contact with the side walls of the combustion chambers.

Ignition devices, here shown as spark plugs 70, are located in each of the combustion chambers 80 and 85 downstream from the header 88. The flames in the combustion chambers 80 and 85 pass into an elbow 92 at the end of the blade and the products of combustion are discharged from the jet outlet 23 at the end of the elbow 92.

Figures 7 to 10 show the construction of the nozzle 57, which is the same as the nozzle 90. There is an outside shell 95 with a threaded end 97 that screws into the header. At its discharge end, the nozzle has a relatively small central and circular opening 99, the axis of which is preferably coincident with the longitudinal axes of the shell 95. A nipple 105 has threads 101 which screw into the rearward end of the shell 95. Forward of the threads 101, the nipple 100 is of reducer diameter and it has a frusto-conical end portion 103 which confronts a complementary inside wall of the shell 95.

There are longitudinal slots 105 extending across the threads 101 for admitting fuel into the interior of the nozzle shell 95. The fuel flows along the reducer diameter portion of the nipple 100 beyond the threads and into an annular slot 106. From this slot 106 the liquid fuel flows along converging slots 105 which are slightly eccentric so that the liquid discharged through the openings 99 is a swirling stream. The centrifugal force of the liquid particles as they are ejected from the nozzle 57 and atomized by the blast action of the nozzle against the air stream, causes these particles to move outward at a slight angle to the axis of the opening 99. With a liquid pressure of 300 pounds per square inch, produced principally by the centrifugal force of the rotating blade on the liquid in the tubing 55, an included angle of divergence of 7° has been found to give good results in a combustion chamber having a cross section 1½ inches by 2 inches.

This example is given by way of illustration. The angle of divergence of the fuel stream from the nozzle 57 can be changed by inserting into the nozzle a different nipple 100 in place of the nipple 100. A different nipple either increases or decreases the angle of divergence of the fuel stream, depending upon the eccentricity of the slots 108, which produce the whirling of the fuel stream and the resulting centrifugal force.

Figure 10 shows a modified type of nozzle 110 which has an outlet 112 of non-circular cross section. This nozzle is constructed in the manner of a paint spray nozzle, or in accordance with the nozzle shown in Figures 7 to 10, but with the outlet 112 having a width so proportioned to its height as to give a spray by which the width and height of the stream have substantially the same ratio as the width and height of the combustion space into which the atomized fuel is projected by the nozzle 110. This gives a greater cross-sectional area for the fuel spray, without having the atomized particles strike against the walls of the burner and condense before being vaporized.

The preferred embodiment of the invention has been illustrated and described, but changes and modifications can be made and some features can be used alone or in different combinations without departing from the invention as defined in the claims.
I claim as my invention:

1. A jet helicopter comprising a rotor, an air supply conduit through which air flows to the rotor, a blower in the air supply conduit, an engine for driving the blower, said engine having an air and fuel supply which is independent of the blower, motion-transmitting connections by which the engine is permanently connected with the blower, said connections including a speed-increasing transmission, a fuselage by which the engine, air supply conduit and blower are carried, the rotor being operably connected with the fuselage and having blades that lift the helicopter for flight, combustion chambers within the blades and through which air from the conduit passes, means for igniting an air-fuel mixture in the combustion chambers, branch passages through which air from the air supply conduit is discharged to the rotor blades, the supply conduit downstream from the blower being arranged to receive substantially all of the air discharged from the blower and leading directly to said branch passages, apparatus for reducing the load on the engine when starting or idling the engine and for increasing the temperature of the air by friction to vaporize fuel for starting the ignition in the combustion chambers, said apparatus including an obstruction located in the conduit and adjustable into different positions to obstruct different amounts of the cross-section of the conduit, the adjustable obstruction being movable into one position in which it substantially closes the conduit and stops flow of air through the blower so that air within the blower is heated by friction for vaporizing the fuel when the air is subsequently pumped to the combustion chambers, said adjustable obstruction, in all positions, being at a substantial distance upstream from the branch passages so that it affects the flow to all passages substantially equally and simultaneously, and said obstruction being movable into other positions in which it serves as a baffle for reducing the velocity of the air discharged from the blower to the rotor blades while the engine speed remains above a predetermined minimum.

2. In a jet operated helicopter having a fuselage and a rotor operably connected to the fuselage, said rotor having blades that support the helicopter during flight, each of said blades being hollow and having a jet orifice near its outer end for the discharge of a jet of gas, an air supply conduit, a blower in the conduit for pumping air through said supply conduit, said conduit being arranged to receive substantially all of the air discharged from said blower, an engine in the fuselage, said engine having an air and fuel supply which is independent of the blower, motion-transmitting connections between the engine and the blower for driving the blower, branch passages through which air from the air supply conduit is delivered through the rotor blades to the jet orifices, combustion chambers in the rotor blades and through which at least a portion of the air passes, means for mixing fuel in the air stream in the combustion chambers, an ignition device in each combustion chamber, apparatus for controlling the temperature and velocity of the air prior to ignition, said apparatus including an obstruction for reducing the velocity of the air stream to the branch passages and through the combustion chambers, said obstruction being located in the conduit and adjustable into differ-