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COMBUSTION STABILIZATION MEANS FOR HIGH-VELOCITY
AIR STREAMS HAVING A PILOT BURNER AND
A STREAMLINE IGNITER GRILL
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FIG. 1

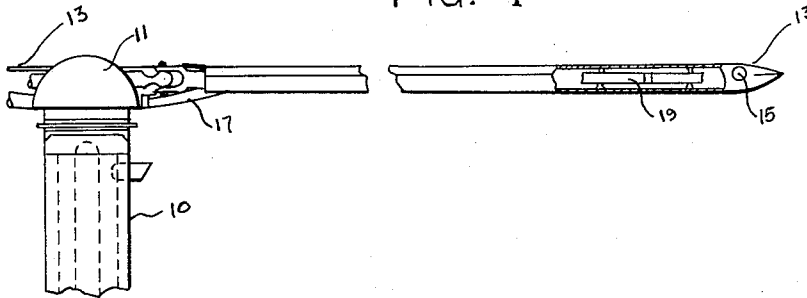


FIG. 2

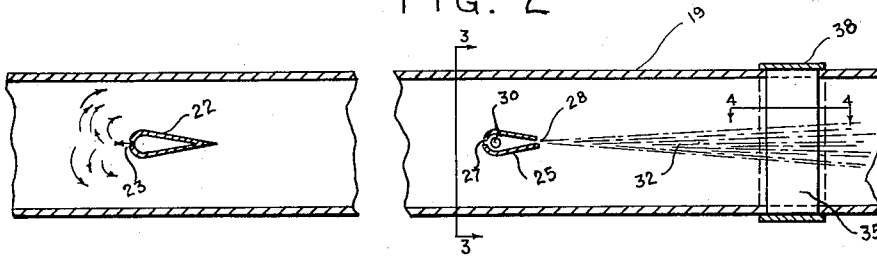


FIG. 3

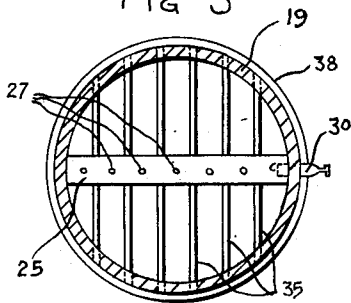


FIG. 4

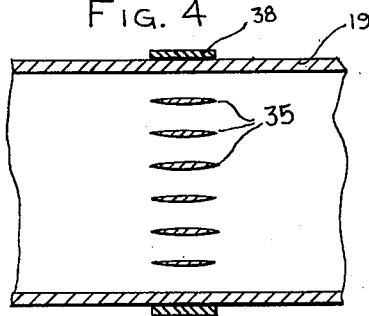


FIG. 5

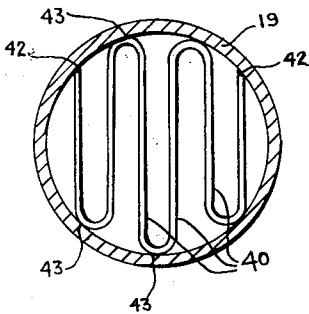


FIG. 6

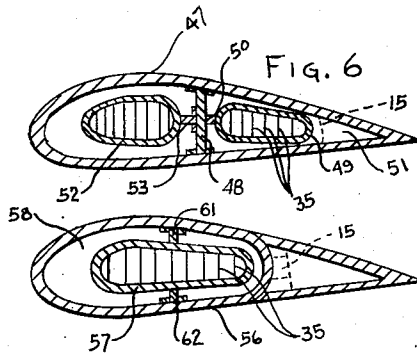
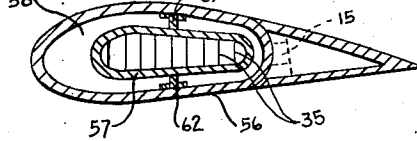


FIG. 7



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COMBUSTION STABILIZATION MEANS FOR
HIGH-VELOCITY AIR STREAMS HAVING
A PILOT BURNER AND A STREAMLINE
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4 Claims. (Cl. 60—39.72)

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This invention relates to heating apparatus, and to the heating of an air stream moving at any selected velocity, even though the velocity is greater than the rate of flame propagation through an air-fuel mixture used to heat the stream.

In order to maintain the combustion of gaseous fuel that moves in a stream away from its supply source at a velocity greater than the rate of flame propagation, it is necessary to have an igniter for maintaining combustion or repeatedly reigniting the stream in the vicinity of the igniter as the already-burning mass of gas is blown away by the high velocity of the stream.

It is an object of this invention to provide improved apparatus for burning fuel, and especially for burning fuel in a high-velocity stream. The apparatus includes means for burning the fuel at high velocity without producing a flame of excessive length.

Another object of the invention is to provide apparatus for controlling the length of the flame produced by the burning of a combustible gas stream. This control of the flame length makes it possible to burn the fuel within spaces of restricted length. For example, the invention is used for heating the air stream passing along a chamber within a blade of a jet-operated propeller or rotor of an airplane or helicopter.

Features of the invention relate to the heating of an air stream with a high velocity flame and without risk of overheating the walls of the conduit or housing through which the air stream passes. The invention may be used for heating the air stream in a hollow propeller blade without heating the material of the blade sufficiently to impair its strength.

Still other features of the invention relate to the combination of a heater with a hollow propeller blade or conduit, through which air flows; and to the thermal insulation of the heater from the walls of the blade or conduit so as to minimize the loss of heat to the walls. All heat absorbed by the walls represents a loss of energy from the air. One embodiment of the invention correlates the heater with the jet discharge opening of a propeller blade so that highly heated air is mixed with cooler air moving in a mass that surrounds the heated air in the region of the jet outlet so that little energy can escape into the walls of the blade or conduit before the air is discharged through the jet opening. The term "propeller" is used herein in a broad sense to include both helicopter rotors and airplane propellers.

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

The drawing, forming a part hereof, in which like reference characters indicate corresponding parts in all the views, illustrates the invention, by way of example, in its application to the rotor of a helicopter. In this drawing

Figure 1 is a fragmentary elevation, partly in section, showing the pylon, rotor hub, and a part of the rotor of a helicopter.

Figure 2 is a vertical sectional view through the heater shown in the rotor blade of Figure 1.

Figures 3 and 4 are enlarged sectional views on the lines 3—3 and 4—4 of Figure 2.

Figure 5 is a sectional view, showing a modified construction of the igniter grill.

Figure 6 is a sectional view, through a propeller or rotor blade, illustrating one way in which the heater apparatus of Figure 1 can be connected to the rotor.

Figure 7 is a sectional view, similar to Figure 6, showing a modified construction.

Figure 1 shows a pylon 10 of a helicopter. A rotor hub 11 rotatably connected with the upper end of the pylon and there are blades 13 extending radially from the hub 11. These blades are hollow, and air is blown through each blade for discharge from a jet orifice 15 at the trailing edge of the blade near the blade tip to produce a jet reaction for driving the rotor.

The air for the blade propelling jets is supplied from a compressor on the helicopter, or some other source not shown, and flows through the pylon 10 into the interior of the hub 11 from which the air is distributed to the respective propeller blades through tubes 17. In order to increase the energy of the jet that issues from the orifice 15, a heater tube 19 is located in the blade 13.

This tube 19 extends in the direction of flow of the air stream in the propeller blade; and the tube is open at both ends and has a cross section substantially less than the cross section of the blade chamber through which the air flows. Supporting means extending from the side walls of the blade chamber hold the tube 19 spaced from these walls so that there is a portion of the air stream between the tube and the side walls on all sides of the tube. This construction provides thermal insulation of the tube from the propeller blade, and the structure supporting the tube from the walls of the blade is preferably long enough, or made of low conductivity material, to prevent substantial flow of heat to the propeller blade.

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The ratio of the cross section of the tube 19 to the cross section of the air stream chamber of the blade is so chosen as to cause a selected amount of the air stream to pass through the tube in which a burner is provided for heating the air. The energy supplied to the jet can be increased by using a larger tube 19 with provision for heating a substantial portion of the total air passing through the blade, but it is essential to prevent the temperature of the jet from becoming so high that it overheats the material of the propeller and impairs the strength of the propeller. The centrifugal force that propeller blades must withstand requires a high strength, and the temperature of the jet is kept within safe limits by having the heated air from the tube 19 mix with the other portion of the air stream before being discharged through the jet orifice.

Another important consideration is that all heat passing from the air to the walls of the propeller blade represents a loss of available energy. This loss is minimized, in the construction shown in Figure 1, by locating the discharge end of the tube 19 close to the jet orifice 15 through which the air stream is discharged. The hot stream of gas from the tube 19 is surrounded by cooler gas which is in contact with the sides of the propeller blade in the region immediately beyond the discharge end of the tube. The hot and cool gases mix as they approach the jet outlet 15 but with the gas stream moving at high velocity there is little time for loss of heat to the walls of the propeller blade in the short length of travel of these mixed gases in the blade.

Figure 2 shows the interior of the tube 19. Near the upstream end of this housing or tube 19 there is a fuel supply device 22 comprising a pipe, that is preferably streamlined in the direction of the air flow, and that has one or more discharge or spray openings 23 on its upstream side. Fuel is blown or sprayed from these openings 23 in a direction counter to the gas flow through the tube, and the countercurrents cause the fuel to be distributed throughout the full cross section of the tube as indicated by the arrows in Figure 2. The fuel used may be either gas or liquid. Gasoline or naphtha are particularly suitable.

In order to burn the air-fuel stream while it passes through the tube 19 at velocities higher than the rate of flame propagation through the mixture, a continuous burner is provided. This burner comprises a tube or shell 25 extending transversely across the interior of the tube 19. The shell 25 is streamlined in the direction of air flow and has a row of metering ports 27, in its upstream wall, for admitting some of the air-fuel mixture into the hollow interior of the shell. At the downstream edge of the shell 25 there are discharge openings 28 or a slot, for the escape of flame and products of combustions from within the shell.

The total cross section of the metering ports 27 is so chosen with respect to the volume of the chamber within the shell 25 that the air-fuel mixture passing through this chamber has a velocity below the rate of flame propagation. Means are provided for initially igniting the air-fuel mixture within the shell 25. Figure 3 shows a spark plug 30 extending through the side of the tube 19 and into one end of the chamber enclosed by the shell 25. After the air mixture has been ignited by the spark plug 30, it will continue to burn, and the flame or hot gases from the shell 25 continuously ignite the air-fuel stream that passes around the shell and close to the discharge openings 28, to produce a long flame 32 within the

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air-fuel stream beyond the shell. This flame 32 extends across the entire width of the tube 19 and increases in thickness as the flame front is propagated upward and downward through the air-fuel mixture.

In order to prevent the flame 32 from being of excessive length, an igniter grill, comprising webs 35, is provided in the path of the flame 32. The igniter webs 35 are shown as parallel, streamline elements extending for the full height of the tube 19 at spaced regions across the tube. The construction shown is advantageous because it provides a simple construction for holding the webs in place and offers little obstruction to the flow of the air-fuel stream.

In the construction shown in Figures 2 to 4, each of the webs 35 extends through openings in the wall of the tube 19, and the individual webs 35 are of such length that their opposite ends fit into these openings in the tube wall and are held against endwise displacement by a retainer ring 38 surrounding the outside of the tube.

Figure 5 shows a different construction for an igniter grill. In this construction a number of substantially parallel webs 40 are formed from a single piece of metal having reverse bends at such locations as to make the unit fit within the tube 19. The ends of the metal piece by which the webs 40 are formed are connected to the tube 19 by welds 42, and the bends at the ends of the webs 40 are preferably connected with the tube by welds 43. The webs can be circular or spiral in which cases the spacing is substantially radial in a transverse cross-sectional plane through the tube. The webs can be related in any design of grill for providing ignition sources at various regions across the air stream, but grills having substantially uniform spacing between the webs are preferred.

The webs 35 or 40 extend in a direction substantially at right angles to the width of the flame 32 so that this flame strikes the middle portions of each of the webs. The flame heats the webs to a temperature above the ignition temperature of the air-fuel stream and the portions of the webs heated directly by the flame 32 transfer heat by conduction to the adjacent portions of the webs just beyond the flame. These portions of the webs ignite the air-fuel stream passing between them and broaden the flame.

The burning air-fuel mixture between the webs 35 heats the webs further so that they eventually spread the ignition of the mixture and cause a flame to issue from the downstream side of the webs across the full cross section of the tube. The length of this flame depends upon the velocity of the stream, the spacing of the igniter webs 35, and the turbulence of the air-fuel stream. The flame is controlled and limited to any desired maximum length by the choice of spacing for the igniter webs. If the apparatus is to be used with an air-fuel stream velocity equal to V ft. per second, and the velocity of flame propagation through the air-fuel mixture v ft. per second, then the web spacing in inches, for a flame having a length less than L inches, is equal to $2L$ multiplied by the ratio v/V . The degree of turbulence in the stream determines how much less than L the actual flame will be in practice.

The webs 35 may be made of a ceramic material capable of withstanding high temperatures, but are preferably made of metal. Stainless steel has been found suitable. Tungsten can be used.

Although the webs 35 are heated over a portion of their length by the flame 32, the heat produced by the mixture burning between the webs

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35 is also necessary in order to keep the webs at fuel-igniting temperature. In order to absorb enough heat from the fuel burning between them, it is necessary that the webs extend for some distance in the direction of the air flow. The webs must absorb enough heat to compensate for the cooling effect of the high-velocity stream of cool air-fuel mixture that strikes the upstream ends of the webs.

The actual lengths of the webs, in the direction of the air-fuel flow, and the ratio of this length to the width of the web sections exposed to the cooling blast of the air-fuel stream, depends upon the velocity of the stream and the material of the web. Higher velocity of the air-fuel stream requires a greater extent of the webs in the direction of gas flow for two reasons. The first is that the faster moving stream exerts a greater cooling effect, and the second is that there is less combustion for a given length of web when the stream is moving at higher velocity.

When using a fuel-gas mixture with gasoline and naphtha as the fuel, and with a stream velocity of the order of 150 ft. per second, stainless steel webs having a length, in the direction of gas flow, equal to between five and ten times their width have been found satisfactory when a flame, such as the flame 32, is maintained continuously against the center portions of the webs.

The webs must be mechanically strong enough to resist the force of the air-fuel blast when the webs are at white heat. The webs can be designed so that after being initially heated they absorb enough heat from the combustion between them to maintain them at fuel-igniting temperature if the flame 32 is discontinued.

In the illustrated embodiment of the invention the igniter webs 35 are heated by the burner 25 which uses a portion of the fuel-air mixture to heat the webs. Other methods of heating can be employed. For example, metal webs can be heated by passing a heavy electric current through them, and if so heated, it is not necessary to have their length, in the direction of gas flow, greater than their width; and hot wires of circular cross section can be used.

It has been found that the amount of current required, because of the cooling effect of the air-fuel stream, is extremely high and makes such heating very expensive when a short flame is wanted and the webs 35 have to be close together.

Figure 6 shows the blade 47 with a structural partition 48 extending between the upper and lower walls of the blade for a portion of the length of the blade. The two air passages formed by this partition meet again ahead of the jet outlet at the blade tip. A tube 49 is attached to the partition 48 by a connector 50 and this connector holds the tube 49 spaced on all sides from the walls of the chamber 51 through which the air stream flows through the propeller blade. In this construction shown in Figure 6, a second tube 52 is connected with the partition wall 48, on the other side of the partition wall, by a connector 53. The tubes 49 and 52 correspond to the tube 19 of Figure 1 but are shaped to conform generally to the cross section of the chambers in which they are located. The advantage of this shaping of the tubes is to more nearly equalize the width of the air stream on different sides of the tubes.

Figure 7 shows a section of another propeller 56 in which a single heater tube 57 is supported within an air-stream chamber 58 by connectors 75

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61 and 62 located both above and below the tube 57. All of the tubes 49, 52 and 57 are shown with igniter webs 35.

The preferred embodiments of this invention have been illustrated and described, but changes and modifications can be made, and features of the invention can be used in different combinations without departing from the invention as defined in the claims.

I claim as my invention:

1. Apparatus for heating air including in combination a tube through which an air stream passes at high velocity, a fuel-supply device comprising a conduit extending into the air stream in the tube and having a streamline contour in the direction of the air flow, said fuel-supply device having a spray opening at its upstream end for projecting fuel into the high-velocity air stream in a direction counter to the direction of air-stream flow, a burner in the tube at a substantial distance downstream from the fuel-supply device, said burner comprising a shell extending across the entire width of said tube and having a streamline cross section in the direction of the air flow, and having metering ports at spaced locations across the width of said tube for admitting a limited quantity of the air-fuel mixture into the interior of said shell for combustion within said shell at low velocity, a lighter for initiating combustion within said shell, and a discharge outlet at the trailing edge of said shell for the escape of flame and products of combustion from within said shell, a plurality of substantially parallel webs extending across the interior of said tube in directions substantially at right angles to the transverse extent of said shell, said webs being streamlined in the direction of air flow and being located downstream from said shell to be heated by the products of combustion from the shell to a temperature above the ignition temperature of the air-fuel mixture.

2. A heater for heating air moving at high velocity, said heater comprising: a substantially straight tube through which the air passes; a streamline device for mixing fuel with the air stream disposed in said tube; a streamline burner for continuously igniting a portion of the air-fuel mixture disposed downstream from said mixing device centrally within said tube; and an igniter grill comprising a plurality of streamline webs having one cross-sectional dimension longer than the other each extending completely across said tube in the path of the ignited and the unignited portions of the air-fuel mixture for receiving heat from the ignited portion of the air-fuel mixture and conveying such heat to the unignited portion of the air-fuel mixture to spread and shorten the flame within said tube, the longest cross-sectional dimension of each web of said grill extending in the direction of the air-fuel mixture flow; whereby the entire air-fuel mixture passes completely through said igniter grill in substantially turbulence-free condition.

3. A heater for heating air moving at high velocity, said heater comprising: a substantially straight tube of substantially unchanging cross-sectional dimension through which the air passes; a streamline device for mixing fuel with the air stream disposed in said tube; a streamline burner for continuously igniting a portion of the air-fuel mixture disposed downstream from said mixing device centrally of said tube; and an igniter grill comprising a plurality of parallel streamline webs having one cross-sectional dimension longer than the other each extending

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completely across said tube in the path of the ignited and the unignited portions of the air-fuel mixture for receiving heat from the ignited portion of the air-fuel mixture and conveying such heat to the unignited portion of the air-fuel mixture to spread and shorten the flame within said tube, the longest cross-sectional dimension of each web of said grill extending in the direction of the air-fuel mixture flow; whereby the entire air-fuel mixture passes completely through said igniter grill in substantially turbulence-free condition.

4. A heater for heating air moving at high velocity, said heater comprising: a substantially straight tube of substantially unchanging cross-sectional dimension through which the air passes; a streamline device for mixing fuel with the air stream disposed in said tube; a burner for continuously igniting a portion of the air-fuel mixture disposed downstream from said mixing device centrally of said tube, said burner comprising a shell streamlined in the direction of air flow having a row of metering parts in its upstream wall for admitting some of the air-fuel mixture into its interior and slot for escape of flame from within said burner at its downstream edge; and an igniter grill comprising a plurality of parallel streamline webs having one cross-sectional dimension longer than the other each extending completely across said tube in the path of the ignited and the unignited portions of the air-fuel mixture for receiving heat from the ignited portion of the air-fuel mixture and conveying such heat to the unignited portion of the

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air-fuel mixture to spread and shorten the flame within said tube, the longest cross-sectional dimension of each web of said grill extending in the direction of the air-fuel mixture flow; whereby the entire air-fuel mixture passes completely through said igniter grill in substantially turbulence-free condition.

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