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COMBUSTION CHAMBER

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2 Sheets—Sheet 1
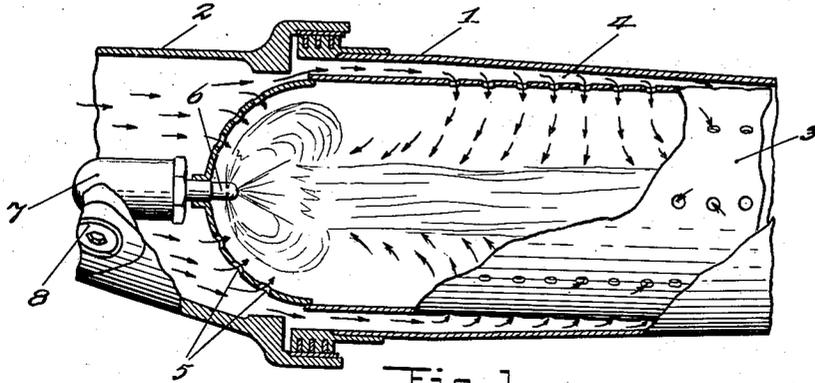
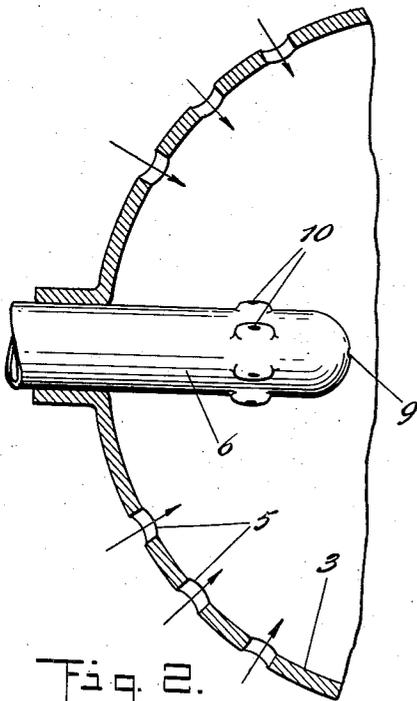Fig. 1.

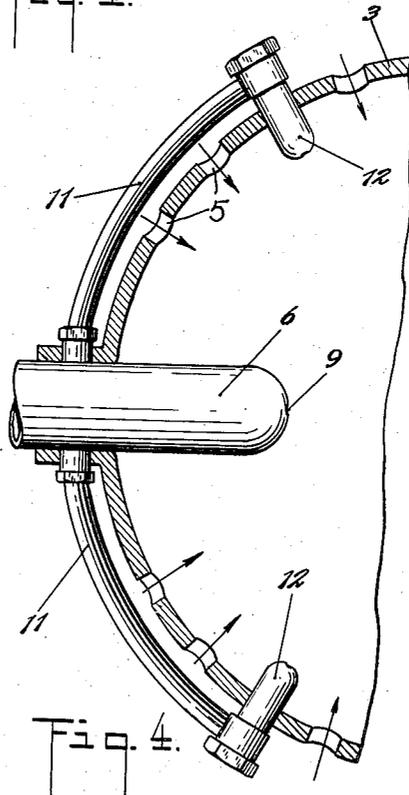Fig. 2.

Fig. 4.

Fig. 3.

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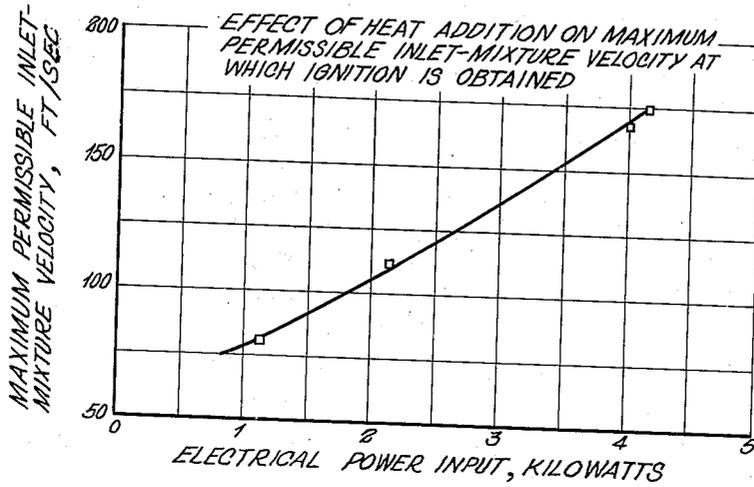
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Fig. 5.
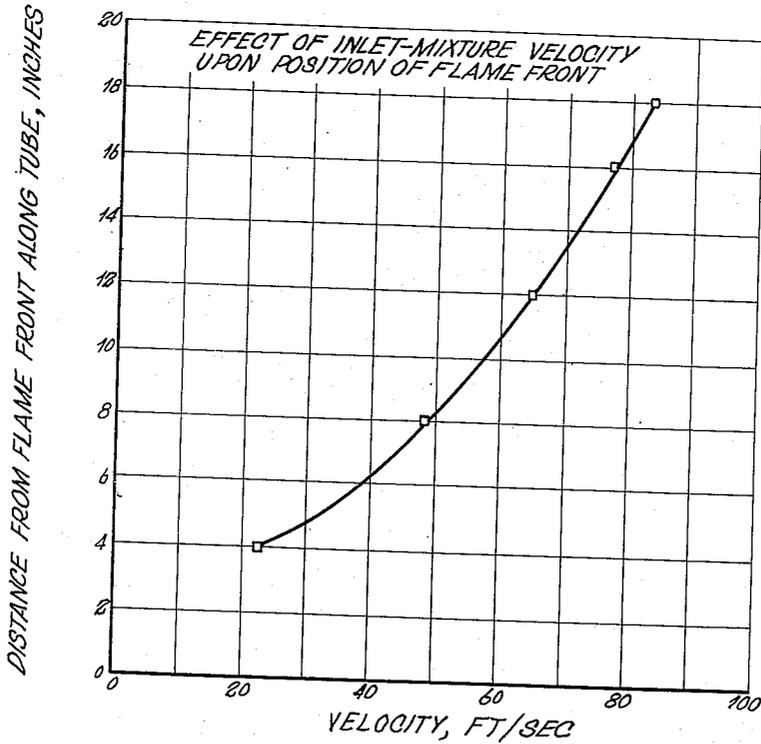
Fig. 6.

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This invention relates to improvements in combustion chambers for use with gas turbines, jet aircraft, and the like.

A broad object of this invention is to provide an improved construction for a combustion chamber in that a higher combustion efficiency and a greater flame stability are secured, especially at high altitudes when compared with similar prior art devices.

In accordance with this object a more specific object of the invention is to provide an apparatus in which means is provided for increasing the rate of heat transfer in the pre-combustion zone of such devices.

Another object of the invention is to provide means for rapidly bringing the main fuel-air mixture to the minimum temperature for ignition.

A subsidiary and resultant object of the invention is to cause the point of origination of the main flame to be closer to the fuel nozzle than in similar prior art structures.

A still more specific object of the invention is to provide in combination with the main fuel nozzle several secondary fuel nozzles and air orifices communicating with them to provide means for pre-heating the main fuel-air mixture.

A still more specific object of the invention is the provision of such secondary fuel nozzles in such relation to the main fuel nozzle that the heat from the secondary flames is directed into the pre-combustion zone of the main flame to provide a maximum rate of heat transfer to the main fuel and air stream.

Other and more detailed objects of the invention will be apparent from the following description of the embodiments thereof amplified herein for exemplary purposes.

This invention resides substantially in the combination, construction, arrangement and relative location of parts, all as will be hereinafter described.

In the accompanying drawings—

Figure 1 is an illustrative view of a combustion chamber in accordance with this invention in sufficient detail to understand the nature thereof with parts unnecessary to that purpose broken away;

Figure 2 is an enlarged detailed view of the nozzle structure of Figure 1, illustrating more clearly the improvement comprising this invention;

Figure 3 is a front elevational view of the nozzle structure;

Figure 4 is a view similar to Figure 3 of a modification of the invention; and

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Figures 5 and 6 are charts of operating characteristics of the subject matter herein disclosed.

One of the more serious problems encountered in the operation of modern aircraft gas turbines is that of maintaining combustion at high altitudes. Under these conditions high velocities of air entering the combustion chamber are often experienced which present a tendency for the continuous flame within the combustion chamber to be extinguished or be made unstable in that the flame becomes intermittent or oscillatory. Although complete loss of combustion is particularly undesirable it is almost equally undesirable to experience erratic or unstable operation. Various methods and structures have been resorted to in an effort to alleviate this problem. Some of these have succeeded in effecting partial improvement whereby the maximum altitude at which satisfactory combustion can be obtained has been materially increased. Mainly, these improvements have consisted of the relocation of air-inlet apertures and thereby a redistribution of the air admitted to the chamber. Nevertheless, these improved designs have introduced other limitations which seriously compromise the maximum efficiency of performance of jet aircraft.

Considering for the sake of convenience, a condition of zero ram (zero air speed) at the entrance to the compressor which supplies air to the combustion chamber, the Q/N (volume flow divided by R. P. M.) value for the compressor will remain approximately constant regardless of altitude, except for the effects of temperature lapse rate at altitude on both the critical Mach number of the compressor blading and on frictional losses. For the purpose of this discussion the effect of temperature and friction on volume flow at any given R. P. M. of the compressor will be neglected, whereby it may be said for approximate treatment that the mass flow of air at constant R. P. M. will decrease with altitude because of the reduction in ambient air density while the volume flow will be relatively constant. With a reduction in mass flow, however, there will be a proportional reduction in fuel flow. This, in essence, will mean a smaller fuel spray at altitude. The effect of a smaller fuel spray and flame and a relatively higher velocity of air flow will be to increase the tendency of the flame to extinguish or at least to become erratic and unstable.

One reason for this is associated with transient effects of turbulence, gas stratification, and general dynamic stability of combustion. These have proven difficult to treat mathematically and although extensively explored experimentally no

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satisfactory empirical methods of performance of the engine as it may be effected by them are known to have been developed.

Additional reasons for a tendency of the flame to be extinguished are associated with mixture inflammability, surface-volume ratio of the combustion chamber, rate of heat transfer within the combustion chamber, the minimum temperature rise required for ignition to take place within the full (or some fixed) length of the combustion chamber as well as others.

The mixture will ignite and appreciable combustion will take place when its temperature has been raised to the minimum value for ignition. Under many conditions, the temperature will be such that combustion will not occur immediately upon admission of the fuel into the combustion chamber but some finite time later, at some point farther along in the combustion chamber. This length of penetration of the fuel into the chamber prior to combustion is defined herein as the "pre-combustion zone."

If the inlet temperature is reduced while all other factors (fuel-air ratio, rate of heat transfer, velocity of the fuel spray, and so forth) are held constant, in order to arrive at the same minimum ignition temperature, it will be necessary for the pre-combustion zone to increase in axial length, thereby moving the flame farther along the chamber. This effect will be aggravated also by an increase in inlet-air velocity at a constant mass air flow and fuel-air ratio, such as would be experienced for higher altitudes with a reduction in ambient air density. The chart of Figure 6 indicates the relationship of the distance of the flame from the nozzle (i. e., pre-combustion zone) to the inlet air velocity. It is of course apparent that instability of combustion and the probability of an interruption in combustion both will increase as the flame migrates away from the nozzle, that is, the pre-combustion zone increases in length. In addition, there is a strong probability that under some conditions only incomplete combustion will result by the time the flame and gases have reached the end of the combustion chamber. While this may impose the disadvantage of a serious loss in efficiency of combustion it may also exert a detrimental effect in possibly damaging the turbine which is located at the exit of the combustion chamber by virtue of bringing it into closer proximity with the excessively hot gases or by causing severe temperature gradients which in turn cause uneven stresses to occur.

In accordance with this invention, the solution proposed is to provide for increasing the rate of heat transfer in the pre-combustion zone whereby the main fuel-air mixture would more rapidly reach the minimum temperature for ignition. The result is to reduce the axial length of the pre-combustion zone and originate the main flame at a point closer to the source of main fuel admission. In accordance with the disclosure herein, the means provided for increasing the rate of heat transfer in the combustion zone also provide that the method be in effect self-regulating for changes in the amount of air entering the combustion chamber with the result that the transfer of heat is substantially proportional to the amount of air to be heated.

In accordance with this invention, it has been found that the maximum permissible air velocity increases as a function of the amount of heat which is added to the fuel-air charge in a given time. This was established by tests wherein an

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electric heating element was inserted in the combustion chamber of the test apparatus and positioned so as to supply heat to the pre-combustion zone. The amount of power supply to the heater was varied while the maximum inlet-air velocity at which the mixture was ignited was measured. While these tests did not provide an exactly quantitative indication, they did provide a sufficiently general indication of the improvement which can be expected by the addition of heat. Results of one of these tests are illustrated in Figure 5 from which it will be seen that an increase of over 150% was achieved in the inlet-air velocity over the range of heat input investigated. With some qualification the curve of Figure 5 may be regarded as indicative of the improvement which can be expected with the addition of heat to the pre-combustion zone. The question of whether the maximum permissible inlet-air velocity is regarded as that at which ignition will occur within the full length of the chamber, or within some fixed portion thereof, constitutes only one of agreement on the definition of what is satisfactory. It is known that the heat transfer rate for tubes is a function of the mixture velocity, the rate of heat input, and the hydraulic radius of the tube. The heat transfer rate under turbulent flow conditions is reported to increase with approximately the 0.8 power of the velocity. If the source of heat transfer has approximately fixed dimensions then the time during which the incoming air flow or the fuel-air mixture will come in contact with the source or heat will be reduced in direct proportion to the increase in inlet-air or fuel and air velocity. Together, these factors will produce a temperature rise in the pre-combustion zone assuming that heat transger will take place, which is an inverse function of the 0.2 power of the velocity.

The structure herein disclosed is based upon these principles and will be described first in connection with Figures 1, 2 and 3. Sufficient structure of a combustion chamber is illustrated for the purposes herein of this disclosure. As shown, it comprises an outer shell **1** having an air-inlet extension **2** which will be open to the source of air supply such as the outlet of a compressor commonly used for the purpose. Within the housing **1** is a metal shell **3** of smaller diameter so as to form an annular space **4** between it and the housing **1**. The shell **3** is provided with a series of air-inlet openings **5** at the flame end as well as throughout its circumferential area. The main fuel nozzle **6** is connected to a suitable coupling and supporting structure **7** to which in turn the fuel supply pipe is connected at the port **8**. This part of the structure is similar to prior art devices and the improvement consists of supplying secondary fuel nozzles so positioned that the heat from the secondary flames will be delivered to the pre-combustion zone of the main flame. In this form of the device the secondary nozzles **10** are arranged circumferentially around the main nozzle **6** and in back of the nozzle orifice **9** thereof.

A known design main fuel nozzle is provided with an open orifice whose output is approximately proportional to the 0.5 power of the pressure differential across it. The secondary nozzles **10**, if of the open orifice type as shown, will deliver a greater fuel flow simultaneously with the main nozzle if both are supplied as shown with the same source of fuel pressure which in this case will be through the connection **8**. Under

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conditions of constant inlet-air density (constant altitude and aircraft velocity) and constant fuel-air ratio, the delivery of the nozzles will increase in proportion to the increase in mass air flow. Since the mass air flow will increase in direct proportion to the increase in inlet-air velocity at constant ambient air density it follows that the amount of heat available through the secondary nozzles will increase with increases in the velocity of the total inflowing air. Thus, there is provided automatic compensation for the previously mentioned tendency of the temperature rise in the pre-combustion zone to decrease as a function of the 0.2 power of the velocity. As indicated in the drawings, the heat of the flames from the secondary nozzles will be released in the pre-combustion zone pre-heating the fuel-air mixture from the main nozzle to the point of ignition more quickly than if the secondary nozzles are not used. Thus, the main flame is brought closer to the main nozzle, that is the pre-combustion zone is shortened.

The arrangement of Figure 4 illustrates an alternative construction wherein the secondary nozzles 12 comprise a series of independent units connected by means of conduits 11 to the main fuel nozzle 6. In this arrangement the secondary flames are directed toward the pre-combustion zone, which will also shorten the pre-combustion zone to attain the main objects of the invention.

From the above description of structures by means of which the invention can be accomplished, it will be seen that they have the virtue of simplicity with all its advantages.

It will be appreciated by those skilled in the art that this invention is to be distinguished from regenerative arrangements now used where part of the heat output of the combustion chamber is led through conduits to a point in advance or near the combustion chamber to increase the thermal efficiency of the engine. These methods serve the disadvantage of increasing the dimensions of the engine as well as its weight.

From the above description it will be apparent to those skilled in the art that the subject matter of this invention is capable of considerable variation. As the embodiments herein disclosed are for illustrative purposes only it is preferred to be limited by the claims granted me.

What is claimed is:

1. In a combustion engine of the type described, the combination comprising a shell forming a combustion chamber including a precombustion zone and a combustion zone axially aligned, said combustion chamber having a closed arcuate end, said precombustion zone being an air envelope around the inside of said combustion chamber, said combustion zone being

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a central axial combustion core within the combustion chamber, a housing around said shell providing the air supply to said combustion zone, orifices in the shell which form said combustion chamber, said orifices providing access for air to the precombustion zone, and combustion zone, a main fuel nozzle for providing fuel to said combustion chamber, said nozzle being axially aligned with said combustion chamber and extending through the arcuate end wall thereof, and auxiliary fuel nozzles in said combustion chamber located upstream from said main fuel nozzle to maintain an auxiliary flame within the envelope of said precombustion zone inside the combustion chamber in direct contact with air in said precombustion zone, said air being supplied from the precombustion zone to the combustion zone.

2. Apparatus in accordance with claim 1 in which the auxiliary nozzles are upstream on the same stem with the main nozzle and are directed radially outwardly with respect to the axis of the main nozzle stem.

3. Apparatus in accordance with claim 1 in which the auxiliary nozzles are in the arcuate end wall of the combustion chamber and are fed from the same fuel line feeding the main nozzle, the said auxiliary nozzles being located axially behind the main nozzle and being directed into the combustion chamber in a direction radial with the curvature of the end of the combustion chamber.

4. Apparatus in accordance with claim 1 in which the auxiliary nozzles are in the arcuate end wall of the combustion chamber, the said auxiliary nozzles being located axially behind the main nozzle and being directed into the combustion chamber.

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