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COMBUSTION DEVICES

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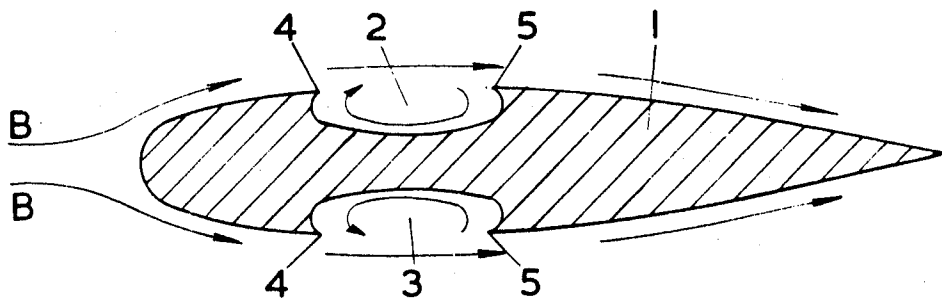


FIG. 1.

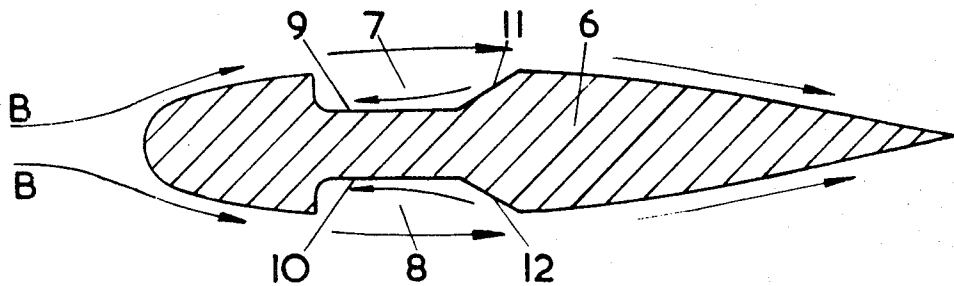


FIG. 2.

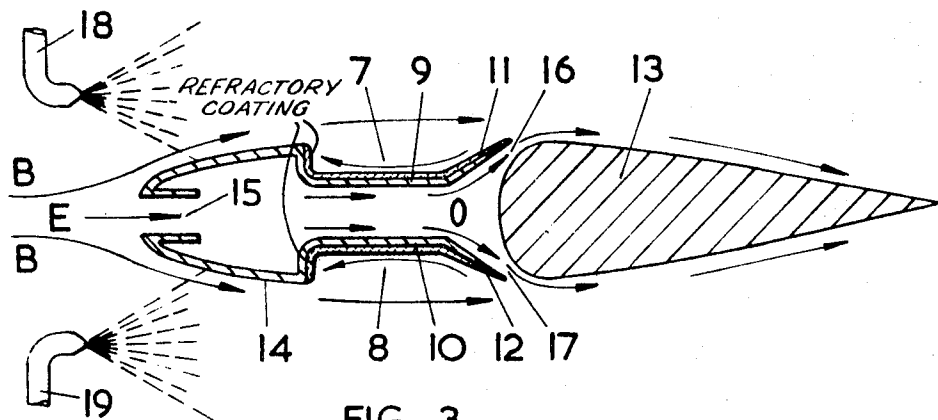


FIG. 3.

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## COMBUSTION DEVICES

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14 Claims

### ABSTRACT OF THE DISCLOSURE

The vane of aerofoil section has recesses of generally elliptical shape in its side surfaces. Separation of flow round the vane occurs at the resultant discontinuities and causes recirculation within the recesses, the length of which ensures reduction in velocity compared with free stream flow to allow adequate mixing between unburnt fuel/air mixture and combustion gases. In one arrangement, an inlet is provided in the leading edge of the vane for gas which is discharged from slots positioned rearwardly of the recesses as a cooling film over the downstream surfaces of the vane. The surfaces of the recesses may be of ceramic (e.g., silicon nitride) or other refractory material.

The present invention relates to combustion devices wherein a flame stabilisation zone is formed in a swiftly moving gas stream by the separation of flow from the surface of a body disposed within the stream.

In aircraft gas turbine jet propulsion engines, extra power can be developed by burning additional fuel in an afterburner. It has long been the practice in such installations to use fixed baffles to produce stable turbulent (or recirculation) zones in their wakes wherein flames will maintain themselves. Such baffles offer undesirable resistance to flow during such time as afterburning is not in operation. One of the more common forms of fixed baffle is a V-shaped gutter having its apex pointing upstream of the flow, the extreme simplicity of the arrangement tending to outweigh adverse considerations. By setting the arms to an included angle of the order of 45°, or slightly less according to flow velocity, a reasonable optimum between resistance and the provision of an adequate recirculation zone can be obtained.

Nevertheless, baffle resistance can be critical in determining the total amount of afterburning which can be employed, and an afterburner system having a lower pressure loss when in the non-operating condition is desirable, provided that the penalties arising out of other considerations are not too severe. The present invention is concerned with means directed towards this end, as are prior co-pending U.S. patent application Ser. No. 780,085, filed on Aug. 5, 1968, by L. D. Wigg, now U.S. Pat. No. 3,504,491, and co-pending U.S. patent applications Ser. Nos. 830,259 and 830,394, filed coincidentally herewith by the present applicant.

Fluid flowing over a surface in which there is a discontinuity will separate from the surface and turbulence will result. If the discontinuity is in the form of a recess in the surface, the turbulence can, by suitable shaping of the recess, be contained within the recess or substantially so to give a stable recirculation zone, the flow over the surface becoming re-attached downstream of the recess. One such arrangement is the so-called "vortex bearing" in which a near circular recess is formed in a surface with two opposed cusp portions spaced from one another in the direction of flow, a zone of rotating fluid forming in the recess so that part of its periphery defines a

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boundary for fluid flowing along the surface which takes the place of a solid boundary wall at the discontinuity. Neglecting friction and boundary layer effects, there will be no velocity discontinuity at the separation point and hence the flow will re-attach downstream of the cusp recess without significant wake.

With such an arrangement, velocities at the periphery of the recess would be of the same order as the free-stream velocity which will be too high to allow for complete combustion of fuel/air mixtures in the recirculation zone. However, by lengthening the recess so that it becomes substantially elliptical, the peripheral velocities are reduced which incidentally improves the mixing characteristics. Further improvement can be obtained by varying the shape of the junctions between the recess and the surface.

Since the surface downstream of the recess will almost certainly be exposed to hot gases, it would be advantageous to provide cooling means in this region.

A combustion device according to the invention comprises a body having an aerodynamic surface and a recess formed in the surface, the recess being arranged to sustain a recirculating flow and shaped to induce a gas flow over the surface to separate therefrom and mix at least in part with the recirculating flow.

Preferably, the recirculating flow is contained partially within the recess which is dimensioned to maintain the peripheral velocity of the recirculating flow at less than the free-stream velocity of the gas flow over the surface.

Preferably also, the body is a vane of symmetrical aerofoil section having recesses in its opposite surfaces in the region of maximum thickness of the vane.

According to a feature of the invention, a cooling stream may be introduced into the vane and discharged as thin films over the surfaces of the vane downstream of the recesses.

Some embodiments of the invention will now be described by way of example with reference to the accompanying diagrammatic drawings of which:

FIG. 1 is an axial section through an aerofoil section vane,

FIG. 2 is a similar view of another vane, and

FIG. 3 shows a modification to the vane of FIG. 2.

FIG. 1 shows a vane 1 of symmetrical aerofoil section which is intended to be mounted, for example, in an afterburner duct extending between the exhaust of a gas turbine and a propulsion nozzle, the direction of gas flow over the vane being indicated by the arrows B.

The opposite surfaces of the vane are cut away in the region of maximum vane thickness to form recesses 2, 3 of part elliptical section as shown in the drawing, the edges of the recesses extending along the vane transversely of the direction of gas flow and being undercut to define opposed cusp portions 4, 5 spaced from one another in the direction of gas flow. Flow over the vane surfaces will separate at the upstream cusp portions 4 and re-attach in the vicinities of the downstream cusp portions 5, the profile of the after portion of the vane being such that little or no wake will result. As a result of flow separation, recirculation will occur within the recesses and, with a ratio between major and minor axes of the order of 3/1 or greater, the velocity of the recirculation flow at the periphery of the recess will be less than that of the free-stream flow over the vane. If a fuel/air mixture is introduced into the flow and ignited by conventional means, flame stabilisation zones will be set up in the recesses and the difference in the peripheral and free-stream flows will enable mixing to take place between incoming unburned mixture and the hot burnt products from the recirculation zone.

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FIG. 2 shows a vane 6 having recesses 7, 8 in its opposite surfaces in which the upstream cusp portions have been omitted to give a bluff body type of separation point with consequent increase in turbulence and thus improved mixing. The inner surfaces 9, 10 of the recesses are substantially flat while the downstream cusp portions of the previous vane are replaced by inclined surfaces 11, 12 subtending an angle of 30° with the inner surfaces 9, 10. For best performance the stagnation point of the re-attaching flow should be at or near the downstream corners of the faces 11, 12 and to achieve this, the vane thickness increases steadily from the leading edge to the upstream steps of the recesses 7, 8.

In the foregoing embodiments, the surfaces of the recesses and the after parts of the vanes are exposed to hot gases and it may be desirable to provide for some cooling of these.

FIG. 3 shows a vane of composite construction having a solid afterbody 13 and a hollow nose portion 14. The nose portion is shaped to define recesses 7, 8 as in the embodiment last described and likewise has flat surfaces 9, 10 and inclined faces 11, 12. An upstream-facing opening 15 is provided in the leading edge of the nose section 14 and apertures 16, 17 are formed between the nose section and the afterbody 13. Gas will enter the nose section from the main flow through the opening 15 as indicated by the arrow E and pass over the inside surfaces of the recesses 7, 8 before passing through the apertures 16, 17, as indicated by the arrows O, to be discharged therefrom tangentially over the afterbody surfaces. Heat is thus drawn from the recesses and a cooling film is formed around the afterbody. Film cooling of the outer surfaces of the recesses is not a practicable proposition in view of the possibility of quenching the combustion taking place in the recirculation gases. Preferably, these surfaces are of ceramic (for example, silicon nitride), or other refractory material. Atomised fuel is preferably discharged into the main flow so that it impinges on the vane surfaces downstream of the opening 15 but upstream of the recesses 7, 8, as, for instance, by spray nozzles 18, 19. Alternatively, the opening 15 may be dispensed with and cooling flow introduced to the interior of the nose portion by connection to some suitable fuel-free point.

The performance of such a flame stabiliser would be comparable, from the combustion point of view, with that of a V-gutter of width equal to the combined depth of the recesses. The blockage of the duct will thus be of the order of 2 to 3 times that of the gutter but without the large wake resulting therefrom and the pressure loss when after-burning is not in operation will therefore be considerably lower.

Flame stabilisers as described herein are not restricted to use in afterburners, but may be used also, for example, in by-pass ducts of turbofan engines where it is desired to produce extra power intermittently by burning fuel in such ducts.

I claim:

1. A combustion device for producing a flame stabilization zone in a swiftly moving gas stream comprising a vane of symmetrical airfoil section with recesses formed in opposite surfaces of said vane in the region of maximum thickness thereof to sustain a recirculating flow, said recesses being shaped to induce gas flow over said vane surfaces to separate therefrom and mix at least in part with said recirculating flow, wherein each recess is substantially of part elliptical section with edges extending along said vane transversely of the direction of gas flow.

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2. A combination device for producing a flame stabilization zone in a swiftly moving gas stream comprising a vane of symmetrical airfoil section with recesses formed in opposite surfaces of said vane in the region of maximum thickness thereof to sustain a recirculating flow, said recesses being shaped to induce gas flow over said vane surfaces to separate therefrom and mix at least in part with said recirculating flow, wherein each recess includes a substantially flat surface of refractory material extending generally parallel to the direction of free-stream gas flow over said vane.

3. A combustion device according to claim 1, wherein said recesses are dimensioned to maintain the peripheral velocity of said recirculating flow at less than the free-stream velocity of the gas flow over said surface and to contain said recirculating flow partially within said recesses.

4. A combustion device according to claim 1, wherein said edges are undercut to define opposed cusp portions spaced from one another in the direction of intended gas flow over said vane.

5. A combustion device according to claim 2, wherein said substantially flat surface is connected at its downstream extremity to said vane surface by an inclined surface extending in a generally downstream direction.

6. A combustion device according to claim 5, wherein said inclined surface subtends an angle of the order of 30° with said substantially flat surface.

7. A combustion device according to claim 2, wherein said refractory material is a ceramic.

8. A combustion device according to claim 2, wherein said refractory material is silicon nitride.

9. A combustion device according to claim 2 including means within said body for extraction of heat from said recesses.

10. A combustion device according to claim 9 including a passage within said body for the flow of fluid coolant.

11. A combustion device according to claim 2, including a hollow portion embracing said region of maximum thickness and provided with openings for entry and exit of fluid coolant.

12. A combustion device according to claim 11 having an upstream-facing opening connected to the hollow portion, said exit openings being formed in the surface of said vane downstream of the recesses.

13. A combustion device according to claim 12 in which the exit openings are arranged to discharge fluid tangentially downstream over the vane surfaces.

14. A combustion device according to claim 2, wherein said recesses are dimensioned to maintain the peripheral velocity of said recirculating flow at less than the free-stream velocity of the gas flow over said surface and to contain said recirculating flow partially within said recesses.

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DOUGLAS HART, Primary Examiner

U.S. Cl. X.R.

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