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(57) Abstract

A gas turbine engine combustor, eg of annular combustor configuration, has air inlets, typically in the dilution zone, which incorporate vortex generators operative to trip the inlet jet flow causing stabilizing vortex flow at the lateral edges of the jet. The vortex generators can comprise an inwardly directed abrupt change of section between forward and rearward parts of the air inlets. The rearward section of the air inlets can have a configuration operative to reinforce the jet stabilizing effect of the vortex flow. The combustor exhibits improved uniformity of jet and crossflow mixing.

GAS TURBINE ENGINE COMBUSTORS

This invention relates to gas turbine engine combustors
having improved arrangements for the provision of air to the
interior of the combustion chambers, especially improved
arrangements for the provision of that air required for the
5   cooling of the combustion products in the downstream zones
within the combustion chamber but not solely these.

The commercial drive for improved gas turbine engine
performance, especially in aircraft engines, renders desirable
an increase in turbine inlet temperatures for this would convey
10   an increase in cycle efficiency. The scope for increasing
engine efficiency by increase in turbine inlet temperature
would seem to dwarf that which could be secured by improvements
in aerodynamic design in the compressor and turbine sections.
However in current generation engines, particularly advanced
15   military aircraft engines, turbine inlet temperatures are
already such as to impose a severe restriction on the useful
life of turbine section components despite the use of the best
of current generation materials and cooling arrangements within
the turbine section. Moreover, at the same time as there is a
20   drive for improved engine performance (as measured by specific
fuel consumption) there is a parallel drive for improved
component life both in current engines as well as those at the
development stage. It is obvious that these two goals will be
mutually incompatible unless there is some considerable
25   improvement in engine materials or engine design.

One way in which significant improvements might be achieved without revolutionary change to engine designs or step advances in materials, is by providing a more uniform temperature within the turbine entry flow through improvement

5 in the combustor. Certainly, it has been recognised for some time by those in the art that current generation engines (especially those of the annular combustor design) convey to the turbine a flow of gases having significant variations of temperature from point to point within the turbine entry. A

10 consequence of this is that either the temperature capability of turbine section components, or their endurance, is not utilized to the full but wasted by local hotspots or the like which do not contribute in any way to cycle efficiency. Even when the mean turbine entry temperature is not excessive,

15 stationary hot spots can damage individual turbine guide vanes and a poor radial temperature profile (ie across the annulus) can cause uneven degradation of aerodynamic components from root to tip. Considerable progress has already been made in the area of combustion chamber design having regard to those

20 features of earlier designs which produced traceable and detrimental results. Despite these improvements made to date it would be typical for a current generation aircraft engine of the annular combustor type to exhibit an overall temperature distribution factor (OTDF) of say 25%. OTDF is a measure of

25 the highest point temperature less the mean of point temperatures. A figure of 25% obviously means there is still room for improvement in this regard. It is likely however that a new approach to this aspect of performance will be required if any significant reduction of the 25% figure is to be

30 secured.

It has been noticed in the art that in addition to those irregularities in temperature within the turbine entry flow of an annular combustor engine which are traceable to particular known origins within the combustor and can be avoided – such as

35 problems caused by disruption of boundary layers – there is a signficant degree of variation which has not been ascribed to

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any known origin. The term 'randomness' has been coined to describe these variations. It is known for example that a particular engine might produce a hot spot (or spots) within the turbine entry field which is consistent in location from

5   engine run to engine run and yet another engine made to the same construction might have its own peculiar hot spots different in location or intensity to the first. It has been suggested that one of the main sources of these assymetries within an engines turbine entry field is irregularities within

10 the primary zone of the combustion chamber. However, even in experiments with carefully controlled primary zone exit conditions the effect has persisted and this has led to the suspicion that the assymetries are created within the dilution zone of the combustion chamber.

15   Before giving further consideration to the source of the problem addressed in this specification, some discussion of the arrangements found in a conventional gas turbine engine combustor is warranted in order to elucidate the background to the problem and to clarify the terminology used herein. In a

20 typical present day gas turbine combustor there is a combustion liner which may be considered as comprising two or three distinct regions each with its own typical configuration. At the forward end of the combustion chamber (ie that end adjacent the compressor outlet) there is a region known as the primary

25 zone in which the primary combustion takes place. The primary zone has arrangements for supplying atomised or vaporised fuel and arrangements for supplying air such that a stabilized recirculatory flow is established for the purposes of maintaining the continuous ignition of new reactants on a

30 localised or general level. At the rearward end of the combustion casing there is a region known as the dilution zone in which air is introduced to the interior entirely for the purpose of cooling and regulating the distribution of the hot gases resulting from combustion to a level tolerable by turbine

35 section components. Usually there is also a region

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intermediate the primary zone and the dilution zone which is
called the intermediate or secondary zone in which air is
introduced to the interior for the purpose of completing the
combustion process for avoidance of smoke and other emissions

5   and for the avoidance of dissociation loss. The boundary
between these three zones is more or less distinct according to
combustor design and the intermediate zone may not exist in all
combustors as a distinct recognisable zone. The combustion
liner sits within an air casing and a portion of the compressor

10   delivery air is funelled into the space between the combustion
liner and the air casing from whence it is fed to the
combustion chamber in the various zones.

        In the dilution zone this compressor delivery air is
introduced to the combustion chamber through relatively large

15   holes in the combustion liner with a view to achieving
sufficient cooling jet penetration into the crossflow from the
forward zones to secure a good temperature profile in the
outgoing flow which passes to the turbine entry. The source of
the air in these cooling jets is of course the compressor

20   delivery air which is flowing along the outside of the
combustion liner and within the air casing.

        The characteristics of a single jet, such as a dilution
jet, issuing transversely into a crossflow, (typically at 60°
say), such as the hot gases from the primary and intermediate

25   zones are well established. An analytical and descriptive text
covering this topic may be found at page 117 et seq of Gas
Turbine Combustion written by A H Lefebvre (published by the
McGraw Hill Book Company ISBN 0-07-037029-X) and also in a
paper presented by the inventors named in this application, at

30   the 23rd AIAA/SAE/ASME/ASEE Joint Propulsion Conference of
June 29-July 2 1987. This paper is available in reprint form
from the American Institute of Aeronautics and Astronautics
under reference AIAA-87-1827. Both these above works will be
mentioned further in this specification.

35   The single jet which issues from its source has momentum
which projects it into the crossflow causing an obstruction to

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that crossflow and consequent downstream deflection of the jet
from its initial trajectory. There is intensive mixing between
jet and crossflow which creates a turbulent shear layer around
the periphery of the jet. Gas within this shear layer has less
5   momentum in the direction of the jet than that within the core
and consequently it suffers more downsteam deflection than the
core flow at the sides of the jet where it is free to adopt a
different trajectory. This leads to a jet section, downsteam
of the inlet, which is kidney shaped with the lobes on the
10   inlet side of the jet. Within this overall kidney section
there is vortical flow in each lobe with the core gas being
swept downstream from the forward and lateral edges and
recirculating through the middle of the core.

    The situation in a real dilution zone where there are
15   multiple jets and interaction between individual jets is not so
clearly established. Generally the flow phenomenon will be
similar to that of the single jet. However, the jets present a
significant obstruction to the crossflow gases and this
blockage effect leads to the creation of a sympathetic pattern
20   of double vortex flow within the crossflow gases in the wake of
each jet. There are other complications as well as this one.
It has been known for some time that in certain circumstances
of adverse dilution zone geometry it is possible for vortex
flow to occur within the dilution jet at issue. In the
25   inventors above-referenced paper it was demonstrated that this
vortex flow can occur on a gross scale with respect to jet size
and with varying degrees of intensity. This is a different
phenomenon to that causing vortical flows within the jet and
its wake after it issues for it is not a consequence of
30   interaction between jet and crossflow being present within the
jet as it leaves the hole. This vortex flow within the jet at
issue can however effect that subsequent interaction and
various simplistic design rules exist for the avoidance of this
phenomenon, which are based on the geometry of the dilution
35   zone. A H Lefebvre at page 114 of the above referenced book
refers to two aspects of this in the following text:

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"If the pitch of the dilution holes is greater than the
annulus height, a vortex can form in the flow entering the
hole; this changes the penetration and mixing characteristics
of the dilution air jet. The strength of the vortex depends on
5   the ratio of annulus area, as measured in the plane of the
holes, to the hole area". In Lefebvre's terminology the
annulus is the space between the combustion liner and the
surrounding air casing and annulus height is the radial
distance between one and the other. Lefebvre reports also (at
10   the same page) that: "Vortex formation, which can occur on
both tubular and annular liners, may be eliminated or subdued
by fitting a longitudinal splitter plate across (longitudinally
with respect to the liner) each dilution hole. The plate.....
is effective when used in conjunction with spectacle plate or
15   dam" (behind the dilution hole within the annulus). The above
given quotations correspond to established thinking in the art.
The established design aim has been to avoid dilution jet
vortex flow by providing adequate annulus height if this is
possible or failing this to suppress vortex development by use
20   of splitter plates. However spurious irregularities in the
temperature traverse of turbine entry flow have persisted
despite this approach. lefebvre at page 7 of his book gives
one disadvantage of the annular combustor design as "Difficult
to maintain stable outlet temperature traverse" albeit he seems
25   to ascribe this to difficulty in maintaining a steady velocity
profile in the inlet gases (compressor outlet flow).

A recent investigation of the inventors (published in
their aforementioned paper) has shed new light on the flow and
mixing phenomena within a realistic multiple jet dilution zone
30   model. The model had simplified geometry representative of a
typical present day annular combustion zone but with only
single sided dilution. The model was manufacturered to an
extremely tight tolerance so as to remove physical
irregularities as a source of flow disturbance. Furthermore,
35   great care was taken to ensure that both the approach flow in

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the dilution zone and the feedflow to the dilution holes was

uniform and consistent to the limits of measurement. This

reported investigation demonstrated that there was vortex flow

with the dilution jets at issue and confirmed that this vortex

5   flow did significantly influence subsequent events within the

dilution zone. The presence of this vortex flow is consistent

with Lefebvre's hole pitch to annulus height criterion for the

relevent dimensions.of the model were 69.85 mm and 35.8 mm

respectively. It was however unexpected because the model was

10 representative of real engine designs and presumably not

predicted by the design rules on which these real engines had

been based. Moreover it was found that the dilution jet

internal vortex flow varied in configuration, strength, and

rotational sense from hole to hole around the dilution zone

15 annulus. It was noticed that there was aerodynamic twisting of

the jets from certain dilution holes at stations downstream of

the dilution hole annulus which gave rise to circumferential

asymmetry in the temperature distribution, and that the double

vortex structure within the jet core (caused by interaction

20 with the crossflow) usually consisted of vortices of unequal

strength. It was concluded that (amongst other things) there

was evidence to suggest that the direction and location of the

vortices formed in the holes influences the rate of mixing

between jet and crossflow fluid.

25   The nature of the in-hole vortex flow revealed by this

published investigation suggests that it is not solely

dicated by the overall geometry of the dilution zone and the

presence of consistent hole to hole differences in a precision

made model would seem to indicate that the basic dilution zone

30 arrangements are not sufficiently aerodynamically stable to

withstand miniscule irregularities still less those likely to

be encountered in a production engine once subjected to thermal

cycling in service.

        It has since been demonstrated that it is possible to

35 overcome the normally occurring randomness in the dilution zone

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by modifying the air inlet configuration in a particular way.
The flow through these modified holes is tripped by vortex
generators within or adjacent to the holes so as to create
strong vortices at the lateral edges of the jet which are
5   reinforced rather than decayed by interaction with adjacent
crossflow. These specially created vortices occupy the same
location in the downstream jetflow as would those vortices
which are normally induced by interaction between jet and
crossflow and give rise to the kidney shaped jet section.
10   However the normal self-induced vortices are not sufficiently
strong and consistant between opposite halves of the jet to
prevent jet deviation and twisting. The specially created
vortices overcome these limitations.

The invention is a gas turbine engine combustor having a
15   combustion liner pierced by through-holes constituting air
inlets, and having an air feed duct on the exterior side of the
combustion liner, there being in operation of the combustor a
flow of air under pressure along the air feed duct from which
air passes through the air inlets to issue forth as jets
20   within the combustion liner into an oncoming crossflow of
gases, in which combustor the combustion lining is configured
such that there is for each air inlet of an array thereof
disposed over a band or area of the combustion liner a
respective vortex generator means adjacent or within the air
25   inlet which is operative to establish in the flow through the
air inlet a pair of opposite handed vortices disposed one to
each half of the air inlet on an axis transverse to the
oncoming crossflow, the vortices having a sense of rotation
such that each vortex is reinforced by interaction with the
30   oncoming crossflow at the outer lateral edges of the vortex
pair.

Preferably each of the vortex generator means comprises a
pair of forward facing and inwardly projecting trip surfaces
one to each lateral edge of the air inlet with respect to the
35   crossflow, although it is possible that a single central trip

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positioned adjacent but upstream of the air inlet in the air
feed duct flow or the crossflow would have sufficient effect to
be useful also.

It is desirable to avoid configurations requiring

5   projections from the combustion liner into the crossflow at
least on the upstream side of the air inlet and in regions
where the crossflow gases are especially hot. It is preferable
that the vortex generator means are consituted by the
configuration of the air inlet through-holes rather than

10   additional ancilliary parts. In a preferred arrangement the
through holes incoporated abrupt changes in section at their
lateral edges between a broader forward section and a narrower
rearward section. This creates an inwardly directed step in
the wall contour which serves to trip the flow through the air

15   inlet in the required manner, as that flow has a cross hole
component of velocity consequent upon its feed duct momentum.

In conventional prior art practice, the holes in the
dilution zone of the combustion liner are either plain punched
form holes (in those combustors having a wide feed annulus with

20   consequent low feed flow rate) or are of plunged form in order
to increase the discharge coefficient particularly in those
combustors subject to higher feed flow rates. The plunged form
holes are those bevelled on the feed side to provide a smooth
transition.

25   In a preferred form of this invention the rearward section
of the inlet (that part behind the trip surfaces) has
rearwardly extending side walls leading to a part circular back
wall with both side walls and back walls having plain
unbevelled faces. This configuration of rearward section

30   assists the jet stabilizing effect of the vortex generators by
discouraging lateral deviation and spillage of the jet and by
reinforcing the flow at the rear of the jet in the direction of
the inlet axis. A similar effect in regard to the
reinforcement of rear jet flow can be achieved by a backstop

35   projection on the rearward periphery of the inlet on the

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interior (crossflow) side of the combustion liner.

The invention is described below against the background of existing (prior art) dilution zone arrangements and rig measurements of the flow and temperature patterns in this zone,

5   with reference to the drawings of which:-

Figure 1 is a half view in section of a representative present day combustor of the annular variety;

Figure 2 is a half view in section of a flow modelling rest rig;

10   Figure 3 is a drawing of the baseline (prior art) dilution hole configuration tested in the rig;

Figure 4 is a cross-dilution zone plot of temperature distribution for the baseline hole configuration;

Figure 5 is a cross hole velocity plot for the baseline

15   hole configuration;

Figure 6 is a cross-dilution zone plot of temperature and velocity for a particular hole in the baseline configuration;

Figure 7 illustrates a measure, twisted, cross jet temperature plot for a particular hole in the baseline

20   configuration and also a derived idealised distribution;

Figure 8 depicts one inlet design exemplifying the invention;

Figure 9 is a cross-hole velocity plot for the inlet design of Figure 8;

25   Figure 10 is a cross-dilution zone velocity plot for the inlet design of Figure 8;

Figure 11 is a plot of jet asymmetry factor for the baseline inlet and the inlet design of Figure 8;

Figure 12 is a comparison in terms of cross jet

30   temperature profile between the baseline inlet and the inlet design of Figure 8;

Figure 13 depicts another inlet design exemplifying the invention;

Figure 14 is a cross-hole velocity plot for the inlet

35   design of Figure 13;

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Figure 15 is a comparison in terms of cross jet temperature profile between the baseline inlet and the inlet design of Figure 13;

Figure 16 is a plot of jet asymmetry factor for the
5   baseline inlet and the inlet design of Figure 13; and

Figure 17 through 22 show alternative inlet designs exempliyfing the invention.

Figure 1 depicts a schematic sectional half view of an annular combustor incorporating features typical of present day
10   combustors. The main parts of the combustor are an air casing 1 (comprising separate inner and outer parts designated 1A and 1B respectively), a combustion liner 2 and a fuel injector 3. At the forward end of the air casing 1 is an inlet 4 having a diffuser section and air from the compressor stage flows into
15   the air casing through this. This airflow divides within the air casing 1. A significant portion is introduced to the primary zone through swirler vanes 5 and wall cooling passages 6 etc. The remainder is directed along the outside of the combustion liner 2 into two separate air feed ducts 7 and 8
20   both of annular section. Duct 7 is defined by the combustion liner 2 and the inner part 1A of the air casing. Duct 8 is defined by the combustion liner 2 and the outer part 1B of the air casing. Air is fed from ducts 7 and 8 to the interior of the air casing in the intermediate or secondary zone through
25   inlets 9 and 10 respectively and also in the dilution zone through inlets 11 and 12 respectively. All these inlets 9 through 12 are depicted as being of plunged form. At the rear of the combustion liner 2 it narrows to a nozzle 13 and the diluted airflow passes through this nozzle directly to the
30   inlet guide vanes 14 and first row turbine blades 15 of the turbine section.

Figure 2 depicts in a sectional half view the configuration of a test rig used to model and investigate the operation of the dilution zone of an annular combustor such as
35   that depicted in Figure 1. The rig is of full annular

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configuration comprising an outer passage 21 and an inner

passage 22. The rig is arranged to provide a carefully

controlled and uniform flow of air downwards along both these

passages. The wall between the two passages is pierced by a

5   circumferential row of sixteen holes 23 (spaced symmetrically

on a 22.5° pitch) which represent the air inlets of the

dilution zone. Air from inner passage 22 discharges from holes

23 as jets into the crossflow of air within outer passage 21.

A wedge 24 is located on the inner wall of the feed annulus in

10   order to minimise back pressure effects on the flow entering

each dilution hole. In order to map the intermixing of the jet

flow with the crossflow the air provided to the jets is heated

to something like 30°C above ambient temperature which is the

temperature of the crossflow air. This is of course the

15   inverse of the temperature difference present in a real

combustor where the jets are much cooler than the crossflow but

it is believed that this reversal of temperatures has no

significant effect on the modelling accuracy in a vertical

facility such as this one. A representative jet to crossflow

20   velocity ratio of 2:1 is maintained. From the hole position

downstream and from the inside of passage 21 to its outside,

the flow can be measured in terms of velocity components by

five hole pitot probe traverses and thermocouple traverses. A

thermocouple is depicted at 25 in the Figure in order to

25   illustrate a typical instrumentation station.

In order to demonstrate the nature and source of the

particular problem addressed by this specificate - that of

randomness within the combustor outlet temperature traverse -

the operation of the test rig with prior art hole geometrics is

30   described below with reference to Figure 3 through 7. The

dilution hole geometry, a simple plunged hole form, is depicted

in Figure 3. This Figure defines also the measurement axes

used throughout the remainder of this specification.

Measurements given in the X direction are taken from the centre

35   of the hole downstream and the respective X direction

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coordinate is rendered non-dimensional by expressing it as a

fraction or multiple of the hole diameter D. Measurements in

the Y direction are taken from the inner surface of passage 21.

Figure 4 shows a temperature contour in the YZ plane over a

5   representative sector of the annular rig at a measurement

station X/D = 2.0. The scale is telescoped between alternate

pairs of holes to save space. The jet patterns as reflected in

their individual contours are in the main representative of the

expected kidney shaped jet section but, although the jet

10   sections are reasonably tied to their respective hole centre

line regarding overall jet disposition in the Z direction, some

of the jets exhibit a significant degree of twist. The jet

from hole 10 repeatedly exhibits a severe degree of twist and

the measurements reported below concentrate on hole 10 and its

15   surrounding holes, but other jets exhibit twist to varying

degrees and not all are twisted in the same direction. Figure

5 is a vector chart of the jet flow from holes 8 to 10 at exit

from the respective hole and resolved into components of

velocity in the ZX plane. It will be seen that there is severe

20   vortex flow within the jets from holes 9 and 10 and that these

vortices are offset from the hole centre line. The rotational

sense of the vortices in holes 9 and 10 is opposite. The flow

at exit from hole 8 is much less subject to vorticity. In the

case of holes 9 and 10, well defined vortices are present in

25   the rear of the hole which have an important influence on jet

development. The vortex flow pattern at the rear of hole 8 is

not so well defined or so intense but nevertheless still exerts

a great deal of influence on the development of the jet eg

Figure 4 indicates the amount of 'twist' or distortion of the

30   temperature distribution at X/D = 2.0 for hole 8 is almost as

great as that for hole 10. Figure 6 gives velocity and

temperature plots in the YZ plane at a measurement station X/D

= 0.30 immediately upstream of the rearward limit of the hole,

for hole 10 alone. The expected double vortex flow structure

35   is already apparent within the jet flow but it is significantly

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lacking in symmetry. At the left side as seen the vortex is
foreshortened in the Y direction compared to the right side.
The asymmetrical flow pattern is reflected in the temperature
contour plot and indeed is more easily seen here. Some

5 quantitative measure of the degree of twist manifest in
individual jet patterns is necessary for the purposes of
realistic comparison between jets. The term 'jet assymetry
factor' (JAF) is used for this purpose. By averaging the
temperature distribution in the YZ plane over a measured jet

10 flow (Figure 7A) an 'equivalent symmetric' distribution can be
deduced and plotted (Figure 7B) which has perfect symmetry in
the YZ plane about the dilution hole centre line. The effect
in real terms of the twisting distortion of the temperature
distribution in an actual jet is to vary the maximum

15 temperature at any given radius (Y direction) thereby
influencing turbine entry profile. This effect is quantified
in the calculation of JAF for a given radius. This calculation
is based on the difference between the highest temperature
recorded within a measured jet of a given radius and the

20 highest temperature found within the derived 'equivalent
symmetric' jet at the same radius. JAF is defined by the
following expression:

$$\text{JAF at radius} = (T_r - (T_e)_r)/(T_j - T_c)$$

where T_c is reference crossflow temperature,

25   T_j is reference jet temperature,

        T_r is maximum measured temperature at radius r, and

        $(T_e)_r$ is maximum temperature at radius r within the
        derived 'equivalent symmetric jet'

        Figure 8 depicts a novel form of air inlet exemplifying

30 one form suitable for utilization in the claimed combustor
within its dilution zone. The air inlet, designated 81,
comprises a forward part 82 and a rearward part 83 with an
abrupt change of section between these two parts on both
lateral edges of the inlet. All these orientational

35 designations relate to the configuration of the inlet 81 with

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respect to the predominant direction of crossflow which in the
dilution zone will coincide with the longitudinal axis of the
combustor. The exact form of the air inlet 81 is more easily
ascertained from the Figure than from a written description but

5   there are two significant features worthy of emphasis. The
first of these is that the aforementioned change of section is
such as to provide on each side of the inlet on the midway
point a bluff face 84 which extends some way inwards from the
lateral limit of the hole as defined by its forward part 82.

10   These bluff faces 84 are set against the incoming feed flow
from the air feed duct to the extent that this flow has a
component of velocity transverses to the section of the inlet -
ie the X direction - by virtue of momentum existing in the feed
duct. A portion of flow at each lateral extreme of the jet

15   interacts with the bluff face 84 being either scooped upwards
and projected in the Y direction or deflected inwards within
the jet. This action creates or leads to a strong vortex
recirculation at the lateral edges of the jet in the zone of
interaction with the crossflow. The second of these

20   significant features concerns the rearward part of the inlet
behind the bluff faces 84. Here the inlet is delimited by
straight-through unbevelled walls (so emphasising wall depth),
and the inlet section has parallel side walls 85 leading to a
part circular rear wall 86. This combination of face form and

25   encapturing section is such as to discourage lateral (Z axis)
deviations and spillage of jet flow and such as to reinforce
the stream from the jet at the rear of the inlet in respect to
jet velocity in the Y direction. The plan view of the flow
through and out of this inlet is given in Figure 9. This

30   should be compared with Figure 5 which gives a similar view for
adjacent inlets to the baseline design. The flow out of this
novel inlet is devoid of the off-centre vortex recirculation
found in the baseline at the rear of the inlet. The flow out
of this inlet shows good symmetry. The start of a stabilizing

35   vortex flow can be seen on top of the bluff faces 84. These

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vortices can be seen more readily in Figure 10 which gives a
cross-dilution zone (YZ plane) velocity traverse at a position
X/D = 0.3. Figure 10 should be compared with Figure 6. In
Figure 10 the double vortex flow pattern exhibits considerably

5   improved symmetry about the hole centre line. Figure 11
depicts a comparison between the same inlet designs, this time
at a station X/D = 2 where the mixing pattern is better
established, and given in terms of JAF. Figure 11 provides a
plot of JAF at various Y axis positions for baseline and

10   improved inlets. The improvement in this regard secured by the
improved design is immediately apparent. This improvement is
confirmed by analysis of Figure 12 which gives a side by side
comparison of temperature contours for both inlet designs in
the YZ plane across the jet at the same station X/D = 2.0.

15   That contour for the improved inlet is detached from the wall
of the dilution zone and is of the anticipated kidney shape
with improved internal symmetry.

Figure 13 shows a second air inlet form suitable for
utilization in the claimed combustor. This air inlet

20   designated 121 is of plunged form all round the inlet side so
as to provide a bevel 122. However the hole radius in the
inlets forward part 123 is greater than the hole radius in the
rearward part 124 and there is a step change in section between
the two parts on the transverse diameter of the inlet. This

25   provides a forward facing bluff body vortex generator 125 on
each side of the inlet 121. At the rear of the inlet 121, on
the side of the combustion liner exposed to the crossflow there
is a projecting, part-circular backstop projection 126 which
has a plain unbevelled forward face. The inlet form shown in

30   Figure 13 has been tested in rig tests in the form exactly as
shown and in an alternative form with the backstop removed.
Some of these test results are presented in Figures 14-16.
Figure 14 gives a velocity plot in the cross-dilution zone
plane (YZ plane) at a station X/D = 0.3 for the non-backstopped

35   version. A well developed and relatively symmetrical double

vortex structure is apparent. This should be compared with the
plot for the baseline configuration given in Figure 6. Figures
15 and 16 give results for a station further downstream at
$X/D = 2.0$, the former showing temperature contours across the

5   jet in the YZ plane and the latter providing a plot of JAF. In
both these Figures the improvement obtained with the Figure 13
configuration without the backstop is apparent, this being the
improvement attributable to the vortex generators alone.
However it is significant that the backstopped version yields

10   even further improvement.

      This backstop would seem to equate in function to the
plain wall rear wall portion 86 of the inlet 81 depicted in
Figure 8. The backstop 126 would seem to lie within the shadow
of protection offered by the cool jet flow against the full

15   heat of the combustion gases however this has not been
investigated. It is customary to avoid projections on the hot
side of the combustion liner to the extent that they can be
avoided but there could be situations where a suitable shielded
projecting backstop such as that depicted in Figure 13 could

20   provide improvement in jet flow sufficient to warrant use.

      Some other alternative forms of air inlet suitable for use
in the claimed combustor are depicted in Figures 17-22.

      The invention has been described above largely in the
context of a combustor having a field or band of these new

25   inlets in its dilution zone, because it is in this zone where
the problem which gave rise to these inlets first became
apparent. It is clear however that the flow phenomenon
exemplified in the dilution zone is not confined to that zone.
The same factors of jet interaction with crossflow and jet feed

30   through inlets transverse to air feed flow apply within any
secondary/intermediate zone and could apply within the primary
zone also. It follows that this inlet configuration can be
applied elsewhere in the combustor and accordingly the
invention as claimed is not restricted only to those combustors

35   having the air inlets in the dilution zone. These inlet
configurations can be utilized in place of inlets of prior art
form for those inlets for example designated 9-13 of Figure 1.

18

CLAIMS

1.   A gas turbine engine combustor having a combustion liner
pierced by through-holes consituting air inlets, and having an air
feed duct on the exterior side of the combustion liner, there being
in operation of the combustor a flow of air under pressure along the
air feed duct from which air passes through the air inlets to issue
forth as jets within the combustion liner into an oncoming crossflow
of gases, in which combustor the combustion lining is configured such
that there is for each air inlet of an array thereof disposed over a
band or area of the combustion liner a respective vortex generator
means adjacent or within the air inlet which is operative to
establish in the flow through the air inlet a pair of opposite handed
vortices disposed one to each half of the air inlet on an axis
transverse to the oncoming crossflow, the vortices having a sense of
rotation such that each vortex is reinforced by interaction with the
oncoming crossflow at the outer lateral edges of the vortex pair.

2.   A gas turbine engine combustor as claimed in claim 1 in which
each of the vortex generator means comprises a pair of forward facing
and inwardly projecting trip surfaces one to each lateral edge of the
air inlet with respect to the crossflow.

3.   A gas turbine engine combustor as claimed in claim 1 in which
each air inlet of said array comprises a forward section and a
rearward section with an abrupt change of section between the two
sections and with the rearward section having a lesser transverse
dimension than the forward section.

4.   A gas turbine engine combustor as claimed in claim 3 in which
each air inlet of said array has a rearward section comprising
parallel side walls leading to a part circular rear wall, all these
walls having plain unbevelled faces.

5.   A gas turbine engine combustor as claimed in claim 3 in which
each air inlet of said array incorporates on its crossflow side a
backstop projection.

19

6.   A gas turbine engine combustor as claimed in claim 1 in which said array of air inlets comprises the dilution zone of the combustor.

7.   A gas turbine engine combustor as claimed in claim 3 in which said array of air inlets comprises the dilution zone of the combustor.

Fig.1.

Fig.2.

Fig.3(a)

Fig.3(b)

CROSS-FLOW

VIEW A-A

$R_p = 9.5mm$
$D = 25.4mm$

Fig.4(c)

Fig.4(b)

Fig.4(a)

20°C

34°C

TEMPERATURE CONTOURS 20°C TO 34°C
IN INCREMENTS OF 2°C

7

8

9

10

11

12

Fig.5(c)

8
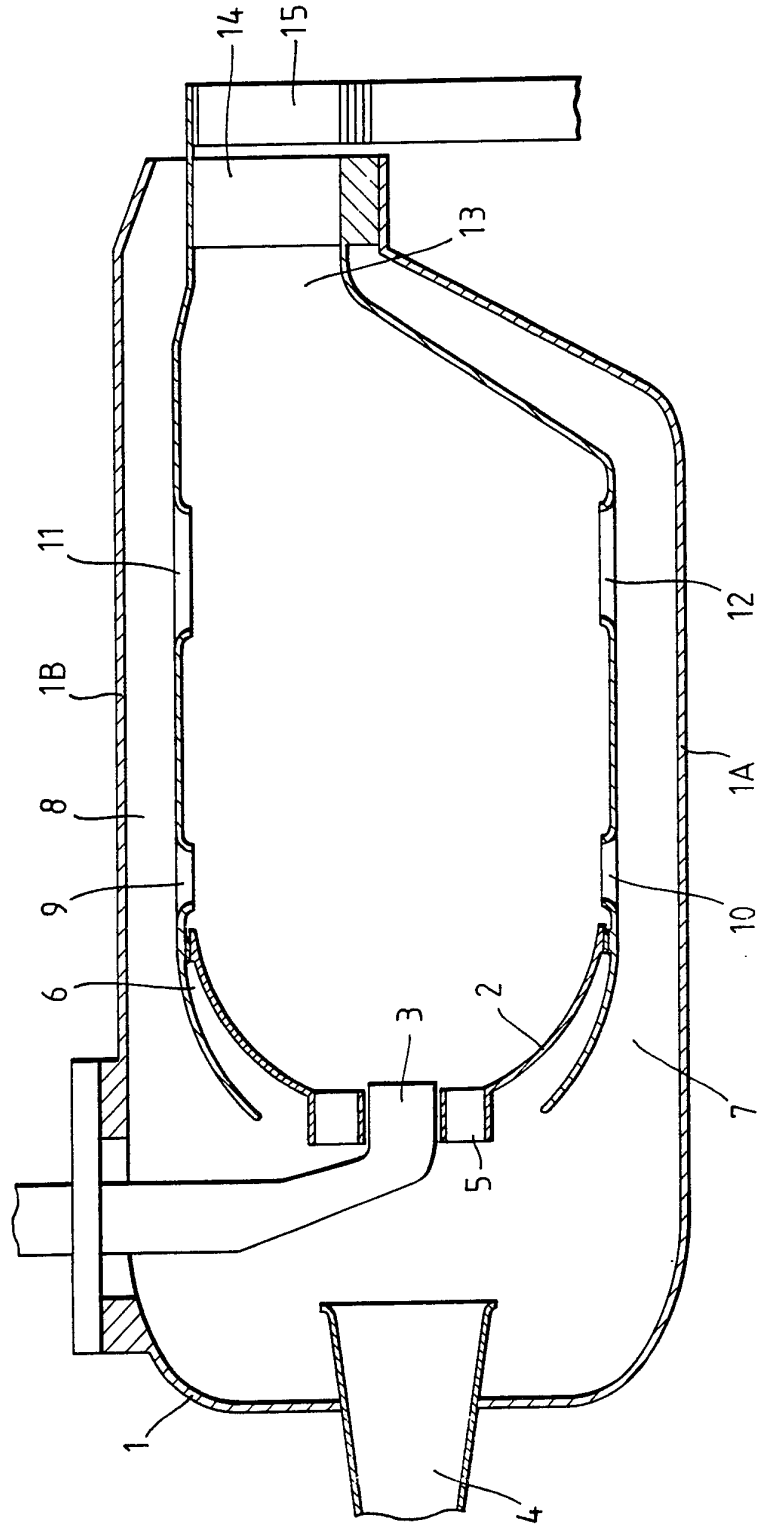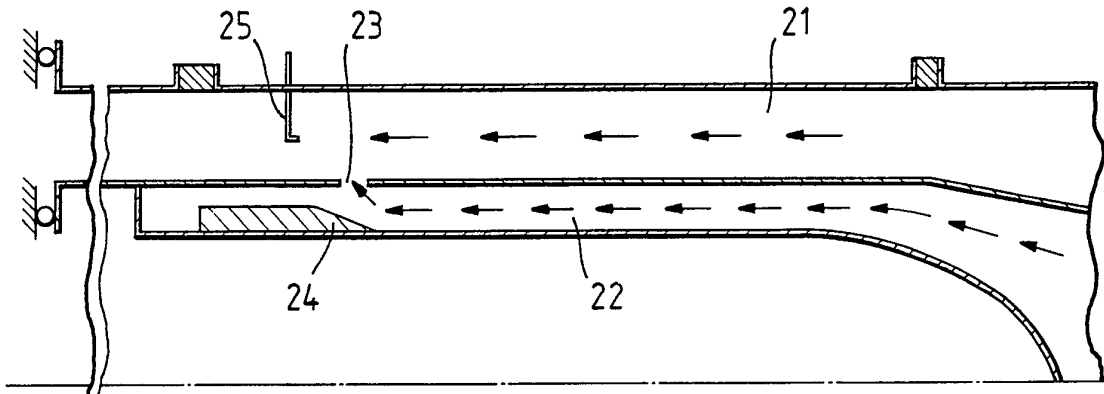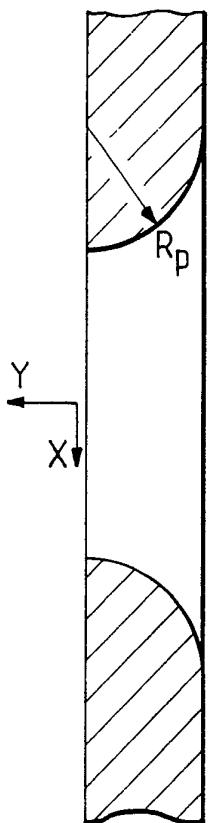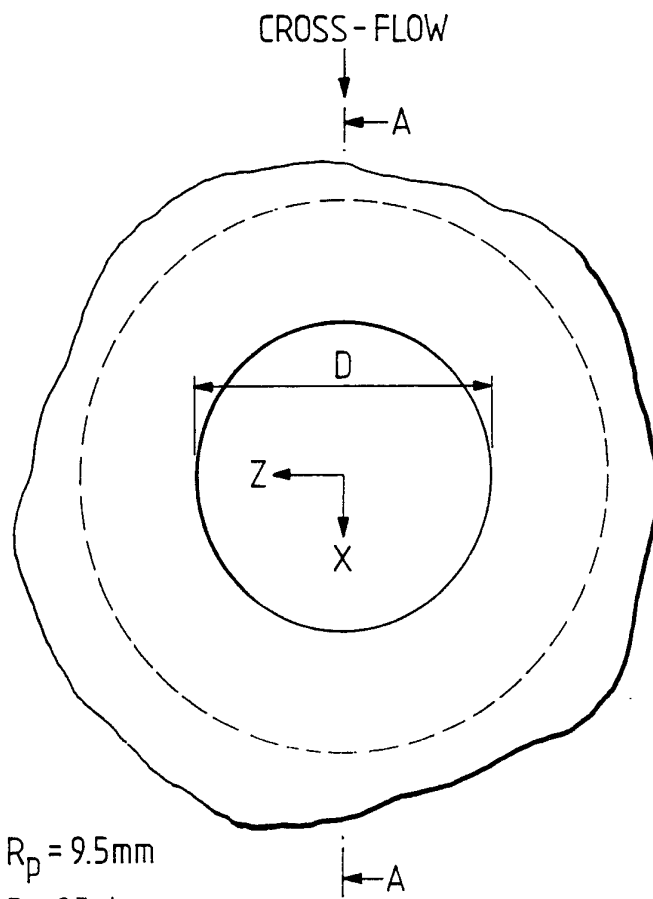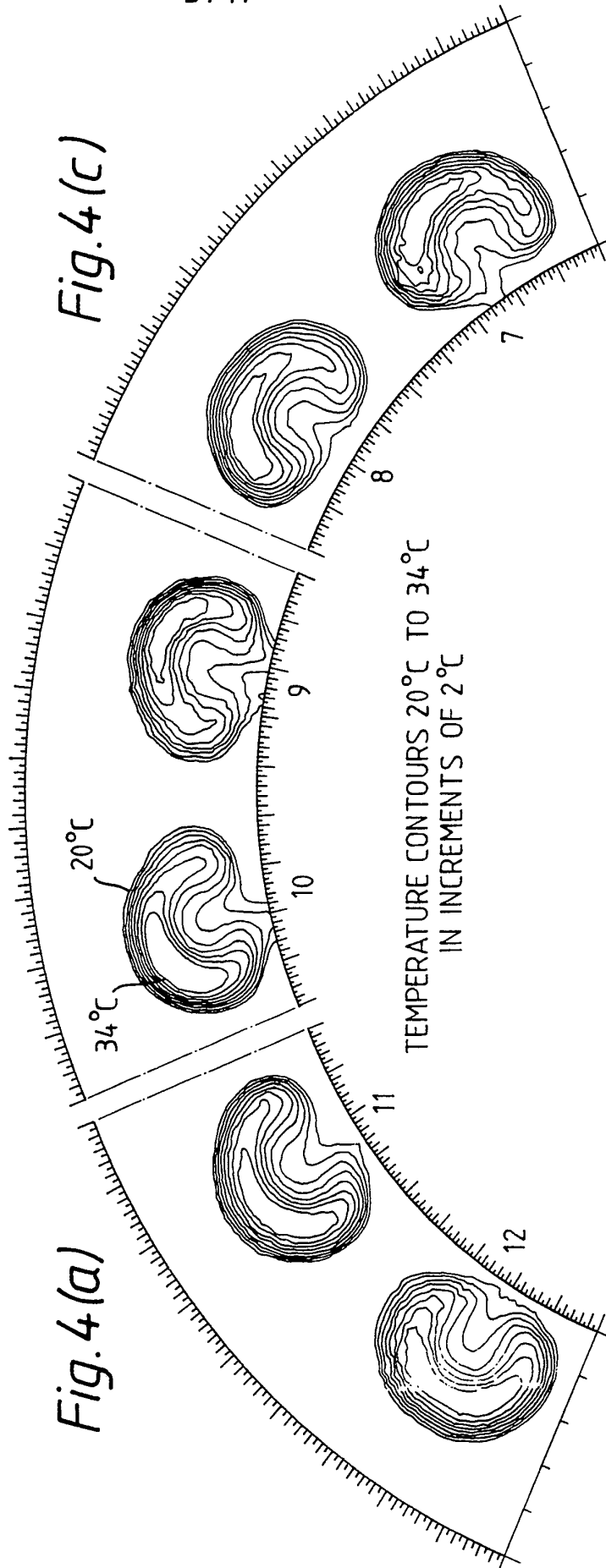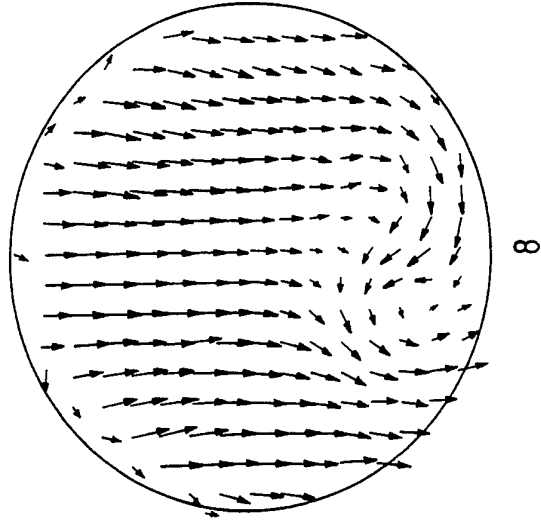
Fig.5(b)

APPROACH FLOW DIRECTION
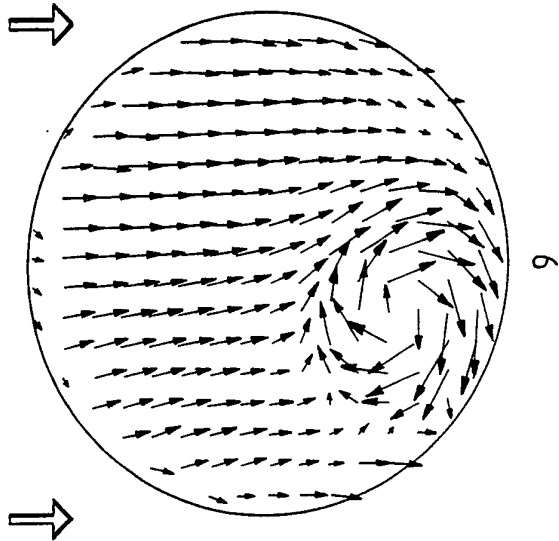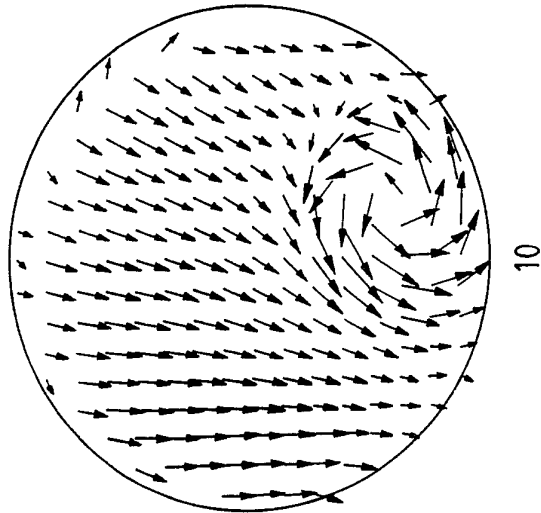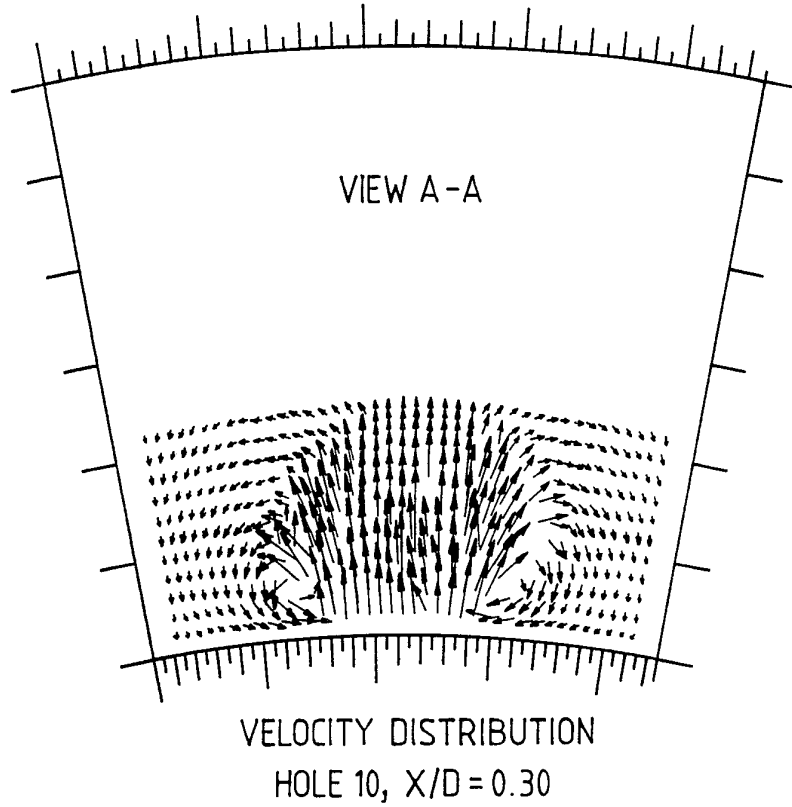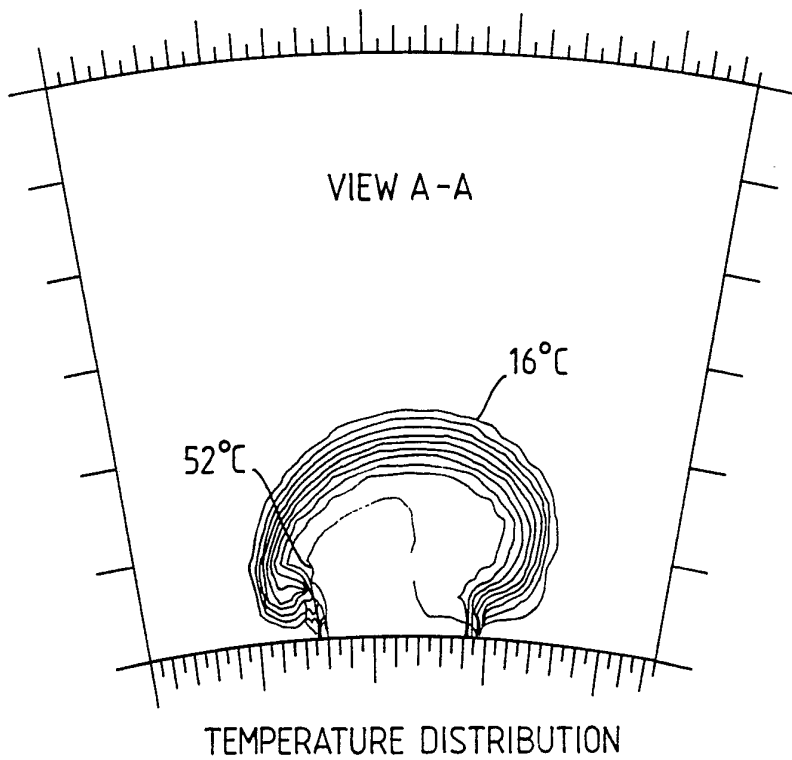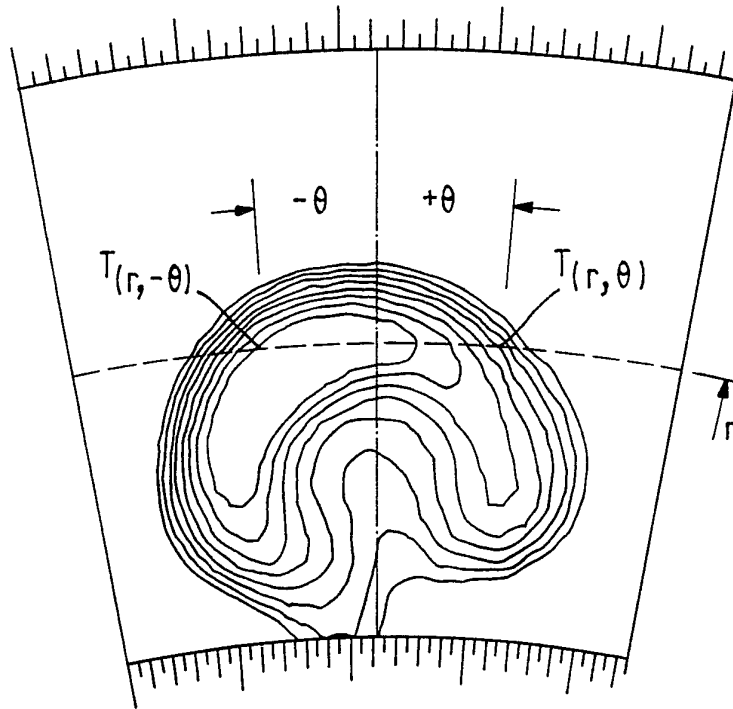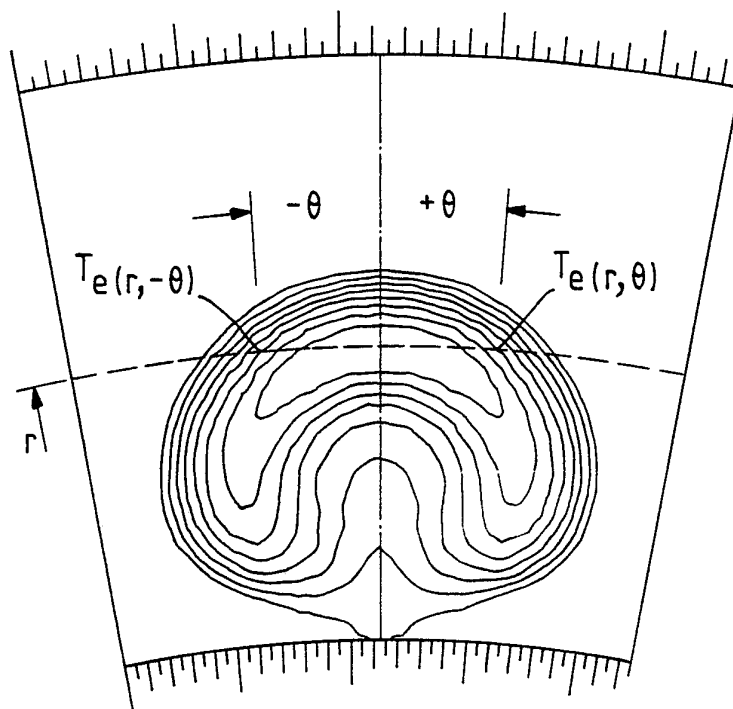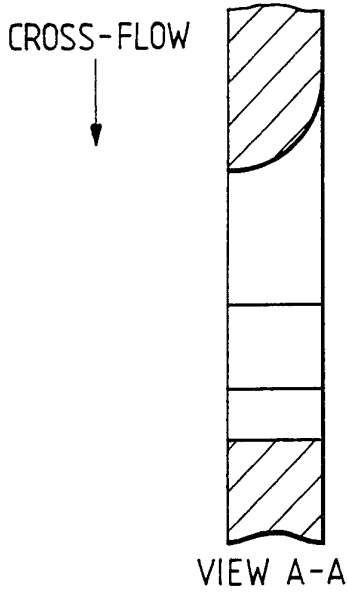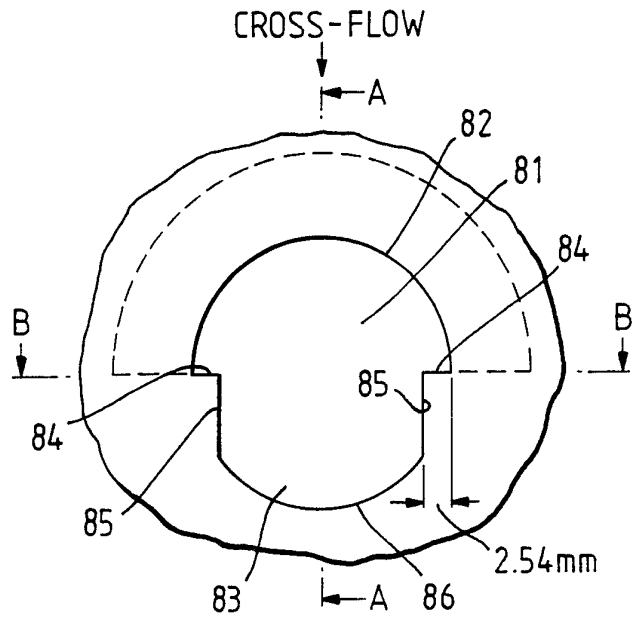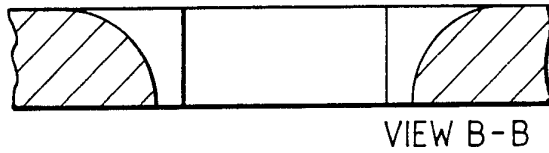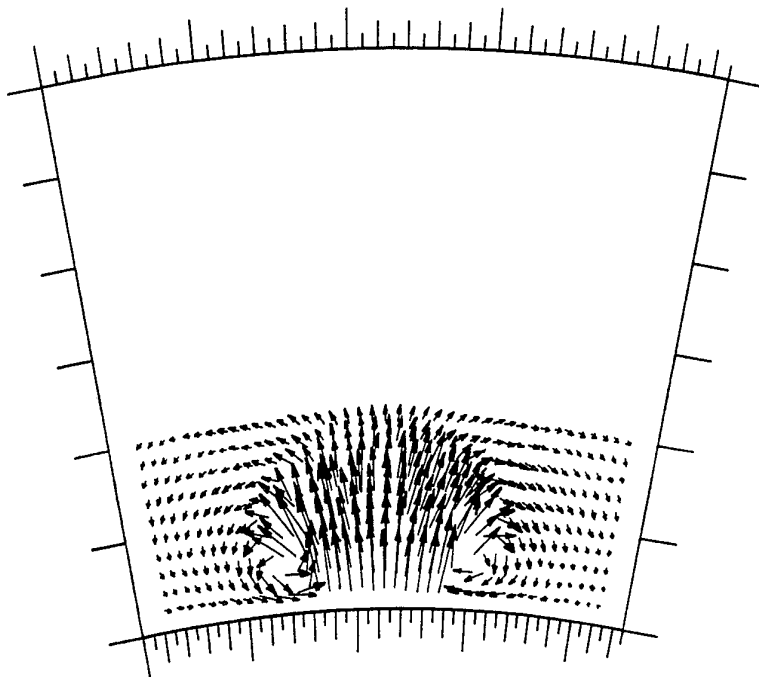
9

25m/s

Fig.5(a)

10

Fig.6(a)

VIEW A-A

VELOCITY DISTRIBUTION
HOLE 10, X/D = 0.30

Fig.6(b)

VIEW A-A

16°C

52°C

TEMPERATURE DISTRIBUTION

SUBSTITUTE SHEET

Fig. 7(a)

Fig. 7(b)

Fig.8(a)

Fig.8(b)

CROSS-FLOW

CROSS-FLOW

VIEW A-A

82
81
84
85
84
85
83
86
2.54mm

Fig.8(c)

VIEW B-B

Fig.10.

Fig.9.

HOLE 10 Y/D = 0.20

9/17

Fig. 11.

OUTER WALL

Y/D

INJECTION WALL

3.0   2.0   1.0   0.0

• UNMODIFIED HOLE
+ Fig. 8. DESIGN

JET ASYMMETRY FACTOR (JAF) %

(HOLE 10, X/D = 2.00)

0.0   1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0   9.0   10.0

Fig.12(a)

UNMODIFIED HOLE
(HOLE 10, X/D=2.00)

Fig.12(b)

Fig.8. DESIGN

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Fig.13(a)

122

BACKSTOP HEIGHT = 7.62mm

VIEW A-A

Fig.13(b)

CROSS-FLOW

A

123   121

B   B

125   125

124

126   70°

A

Fig.13(c)

122

VIEW B-B
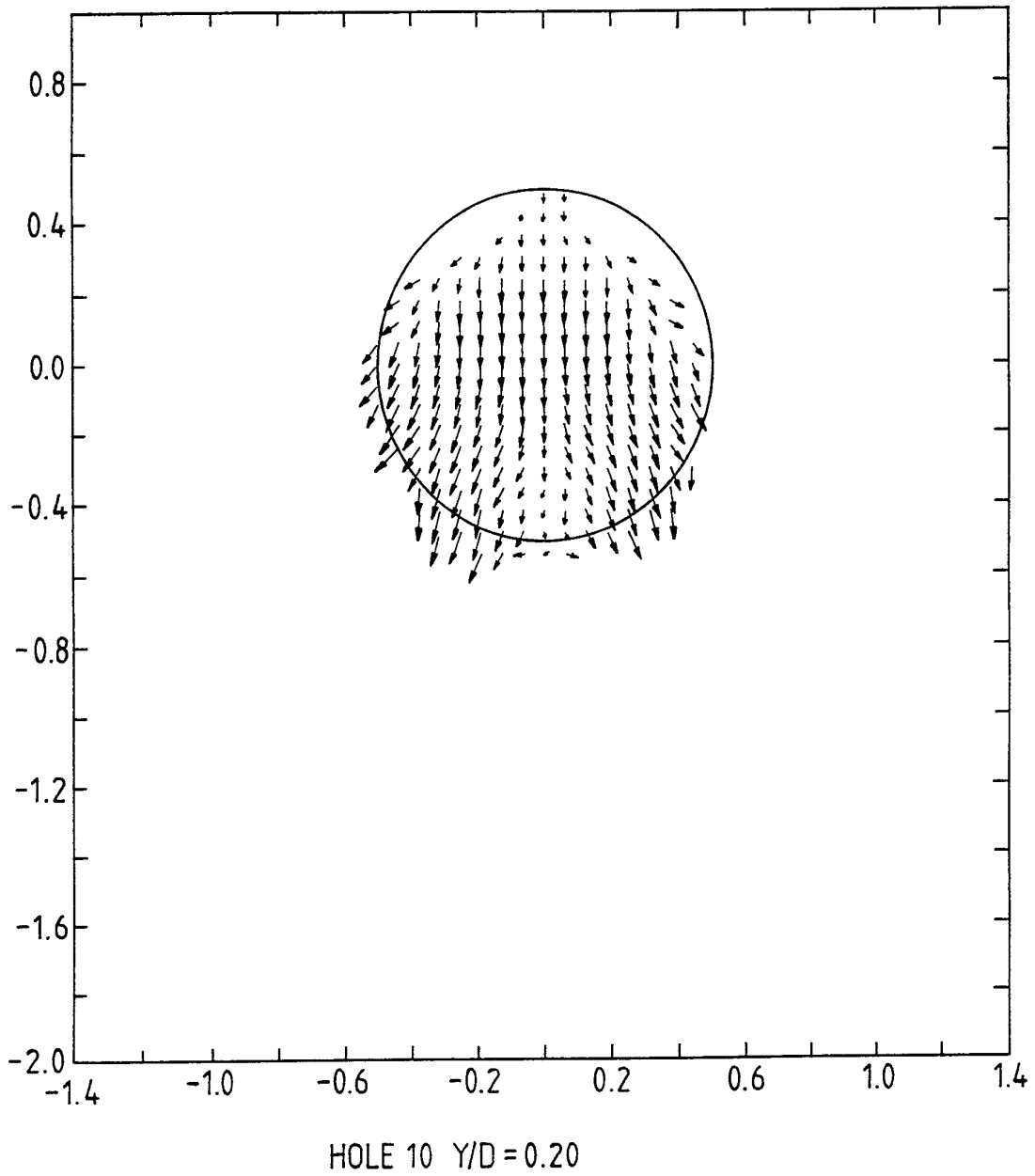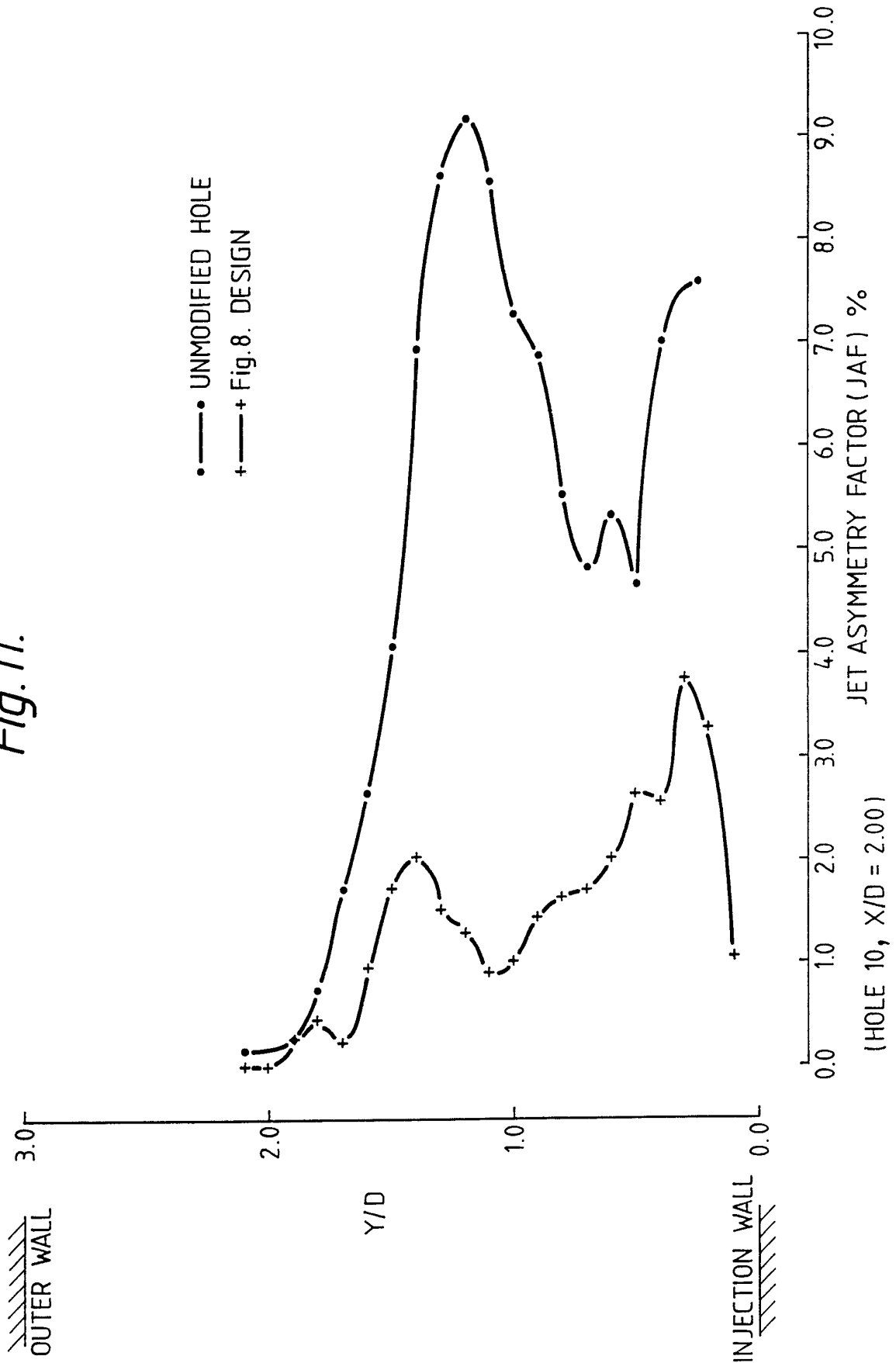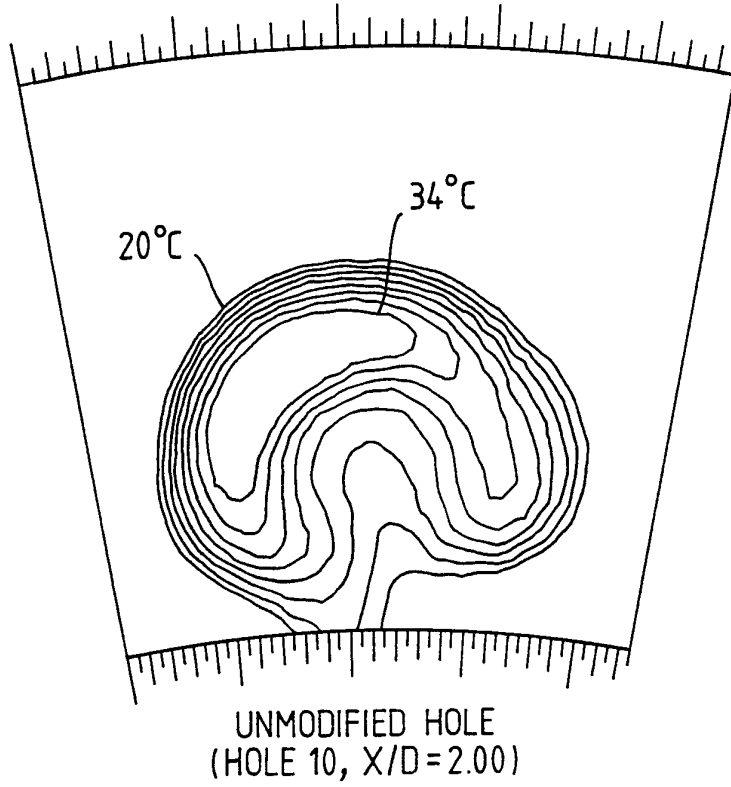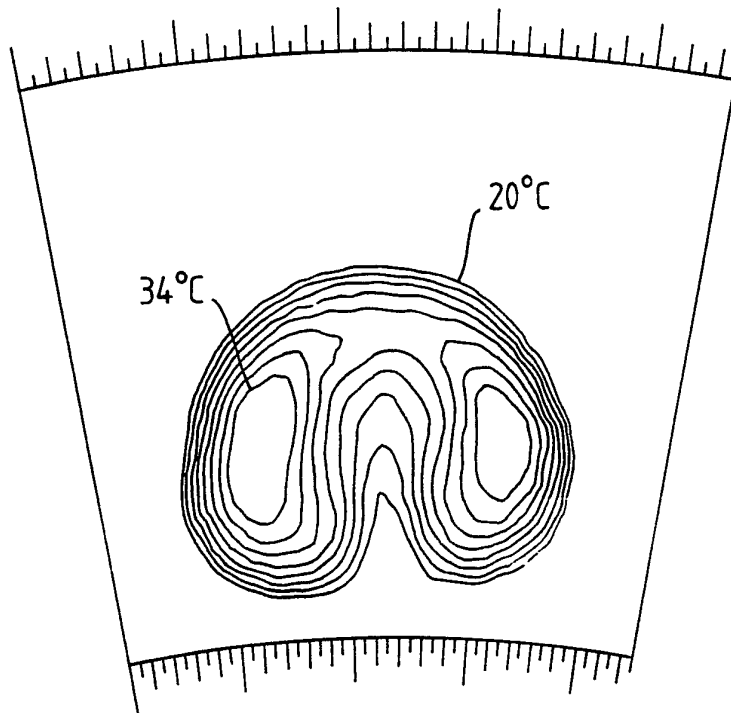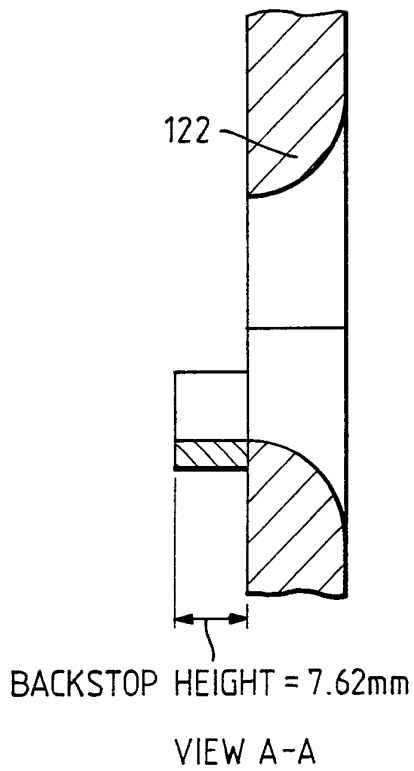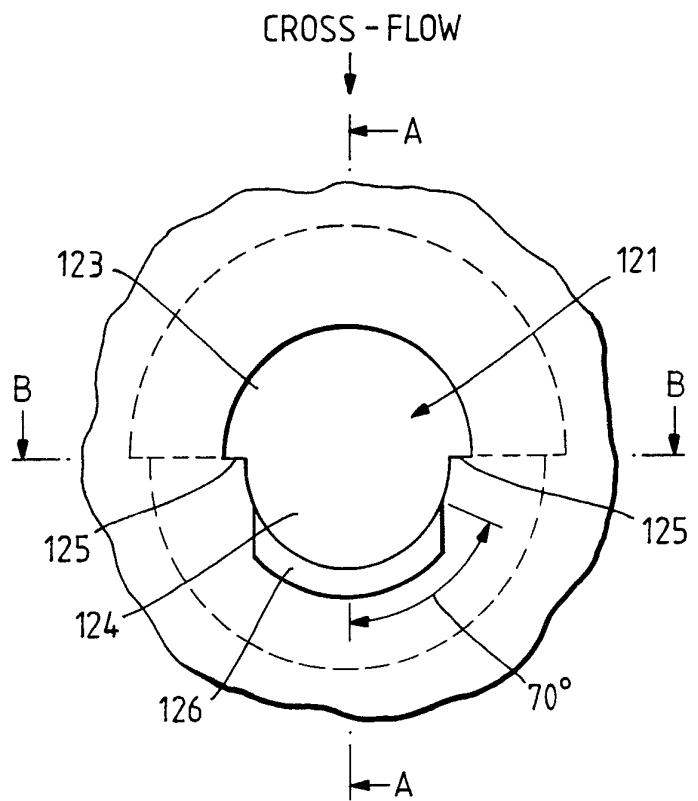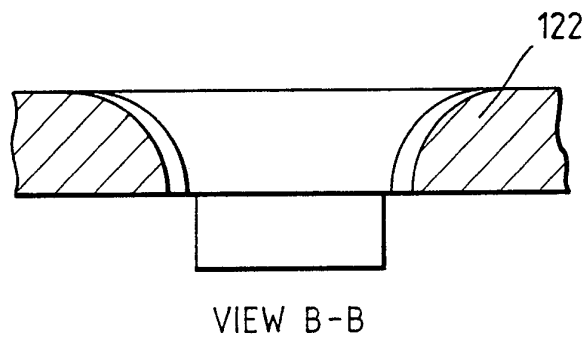
Fig. 14.
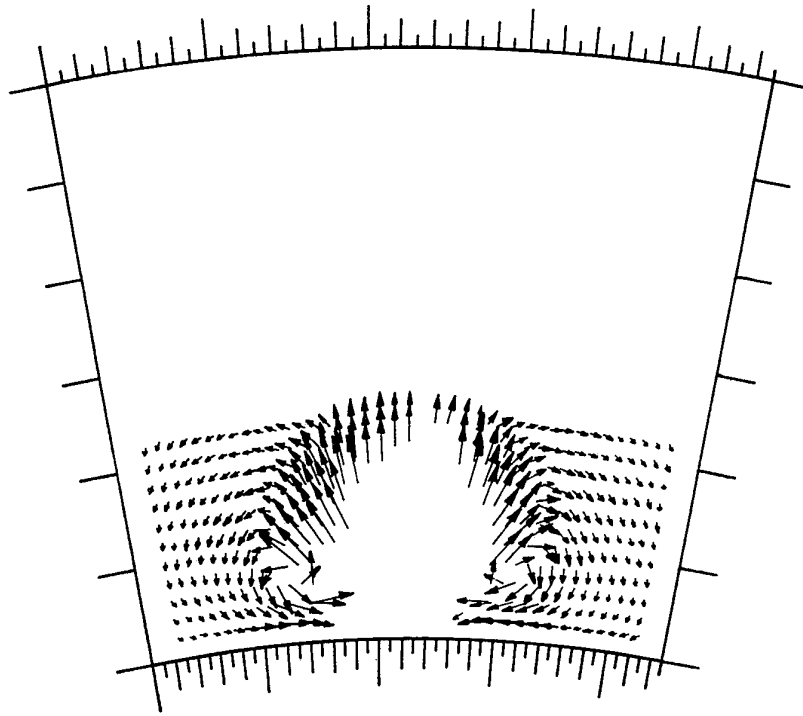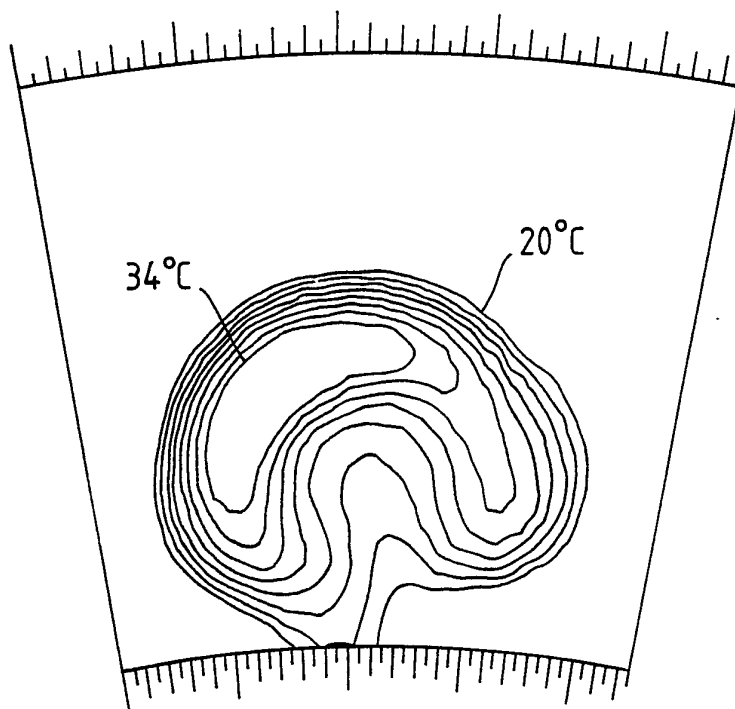
Fig.15(a)

UNMODIFIED HOLE
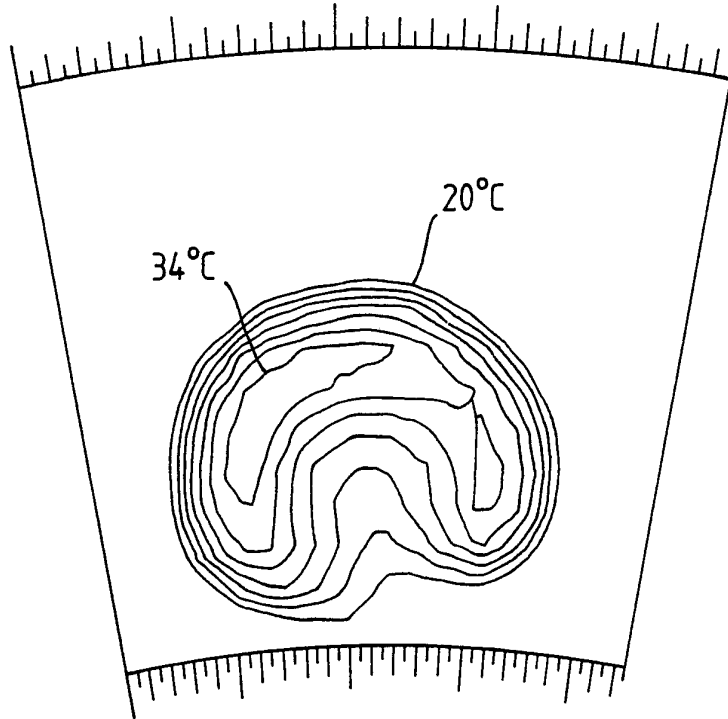
Fig.15(b)

Fig.13. DESIGN HOLE-WITHOUT BACKSTOP

Fig.15(c)
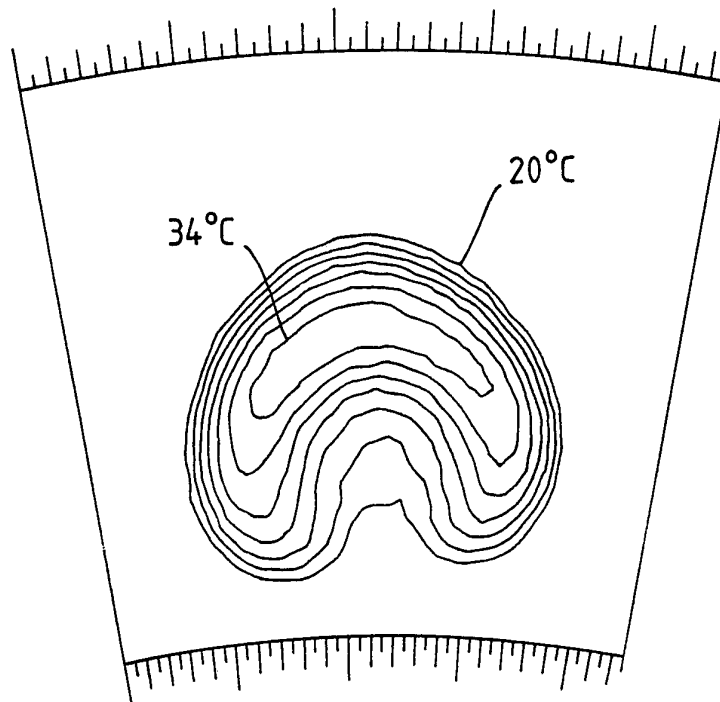
Fig.13. DESIGN HOLE-WITH BACKSTOP

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Fig. 16.

Fig.17(a)

CROSS-FLOW

Fig.17(b)

CROSS-FLOW

RAPID CHANGE IN
HOLE GEOMETRY
INITIATES
VORTEX
DEVELOPMENT

Fig.18(a)

CROSS-FLOW

Fig.18(b)

CROSS-FLOW

HOLE GEOMETRY
INITIATES VORTEX
DEVELOPMENT

COMPLEX FLOW-FIELD
CENTRALISED AT
REAR OF HOLE

Fig.19(a)

Fig.19(b)

CROSS-FLOW

VORTEX TRIP
UPSTREAM OF HOLE

Fig.20(a)

Fig.20(b)

CROSS-FLOW

CROSS-FLOW

TRIPS LOCATED AT
LATERAL EDGES OF
HOLE

VORTEX
TRIP

Fig.21(a)

CROSS-FLOW

VORTEX TRIP
UPSTREAM OF HOLE

Fig.21(b)

CROSS-FLOW

VORTEX TRIP
LOCATED
IN FEED ANNULUS

Fig.22(a)

CROSS-FLOW

VORTEX
TRIP

Fig.22(b)

CROSS-FLOW

VORTEX TRIP
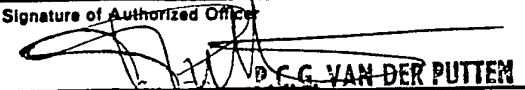
INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4:   F 23 R 3/04

II. FIELDS SEARCHED

Minimum Documentation Searched ^{7}

Classification System	Classification Symbols
IPC^4	F 23 R

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched *

III. DOCUMENTS CONSIDERED TO BE RELEVANT *

Category *	Citation of Document, ^{11} with Indication, where appropriate, of the relevant passages ^{12}	Relevant to Claim No. ^{13}
Y	GB, A, 819065 (MURRAY) 22 January 1960 see page 1, line 40 - page 2, line 20; page 2, line 97 - page 3, line 24; figures 1-4	1,2,6
A	--	4,5
Y	GB, A, 676473 (RICARDO) 30 July 1952 see page 1, line 73 - page 2, line 57; page 3, line 19 - page 4, line 25; page 4, line 56 - page 5, line 62; figures 1-3,5-8	1,2,6
A	--	4,5
A	GB, A, 943250 (JOHNSON) 4 December 1963 see the whole document --	1,2,4-6
A	GB, A, 2017827 (KENWORTHY) 10 October 1979 ./.	1-7

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
21st February 1989	2 0. 03. 89

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	C.G. VAN DER PUTTEN

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III. DOCUMENTS CONSIDERED TO BE RELEVANT	**(CONTINUED FROM THE SECOND SHEET)**	
Category*	Citation of Document. with indication. where appropriate. of the relevant passages	Relevant to Claim No
	see page 2, line 128 - page 3, line 5; figure 9	1-7
	--	
A	US, A, 2916878 (WIRT) 15 December 1959 see column 4, line 74 - column 6, line 63; figures 1-7	1,2,4-6
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A	FR, A, 1331084 (KLEMENTA GOTTWALDA) 20 May 1963 see the whole document	1
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A	GB, A, 2113377 (ALEXANDER) 3 August 1983	
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A	DE, A, 2636520 (MEYER) 16 February 1978 see page 2, last paragraph - page 3, paragraph 2	

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ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.

GB 8800476
SA 22795

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The members are as contained in the European Patent Office EDP file on 13/03/89
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
GB-A- 819065		None		
GB-A- 676473		CH-A- BE-A- FR-A-	289492 501690 1033539	
GB-A- 943250		DE-B- FR-A-	1211863 1346205	
GB-A- 2017827	10-10-79	FR-A- DE-A- JP-A-	2422035 2913223 54158729	02-11-79 11-10-79 14-12-79
US-A- 2916878		None		
FR-A- 1331084		None		
GB-A- 2113377	03-08-83	None		
DE-A- 2636520	16-02-78	None		

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82