US 20060037323A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2006/0037323 A1
Reynolds et al.
(43) Pub. Date: Feb. 23, 2006

(54) FILM EFFECTIVENESS ENHANCEMENT USING TANGENTIAL EFFUSION

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(21) Appl. No.: **10/923,120**

(22) Filed: **Aug. 20, 2004**

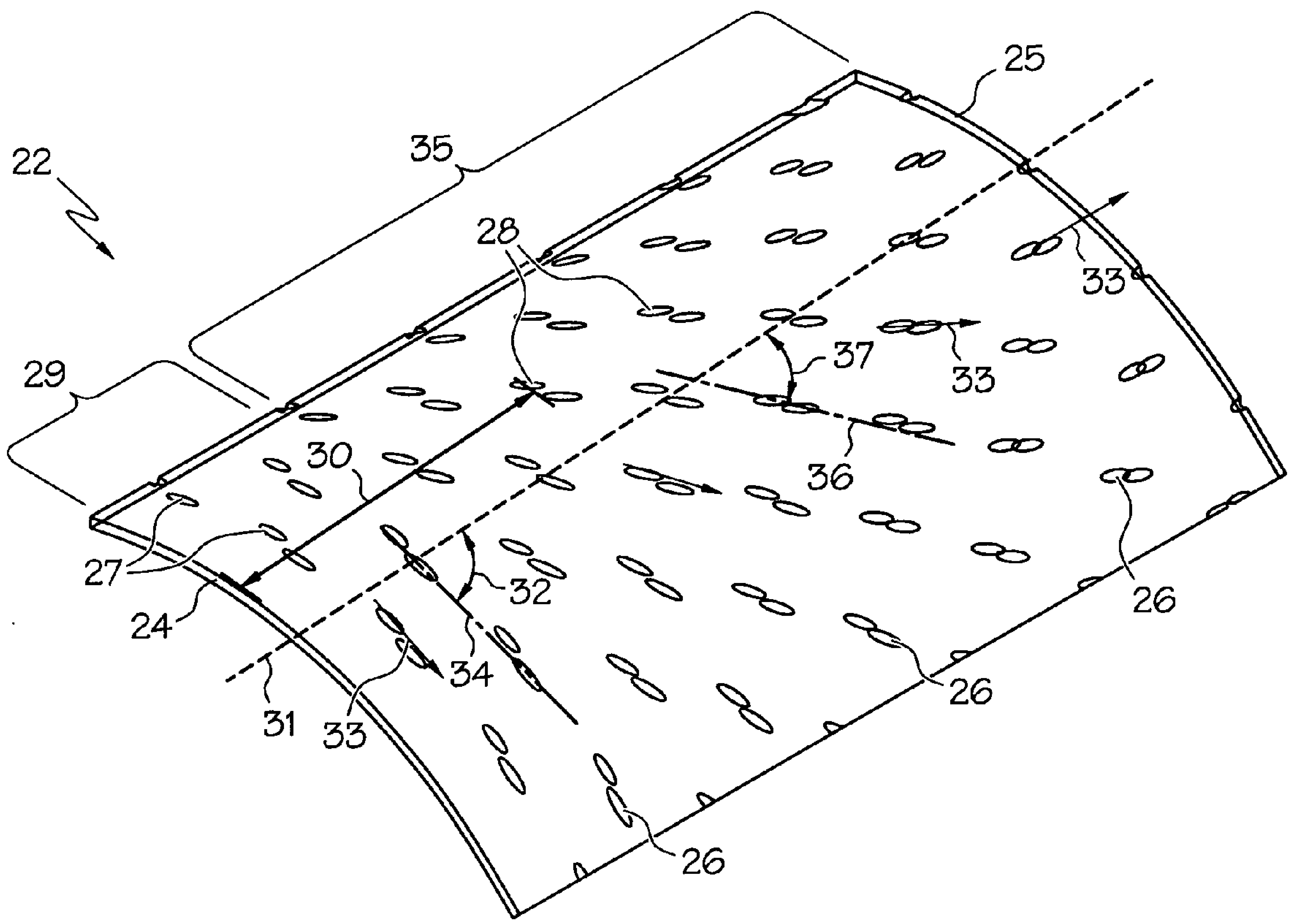
Publication Classification

(51) Int. Cl.
F23R 3/06 (2006.01)

(52) U.S. Cl. **60/754**

(57) **ABSTRACT**

Film effectiveness enhancement is provided by a plurality of tangentially angled effusion holes in a combustor liner. The effusion holes positioned in the initial flow region at the start of the panel have a tangential angle between about 75° and about 90° to the combustor axis. The tangential angle of the effusion holes positioned downstream from the initial flow region is gradually reduced to a value corresponding to the bulk swirl of the combustor internal flow or to zero so that the effusion hole orientation at the end of the panel corresponds to that of convention effusion.



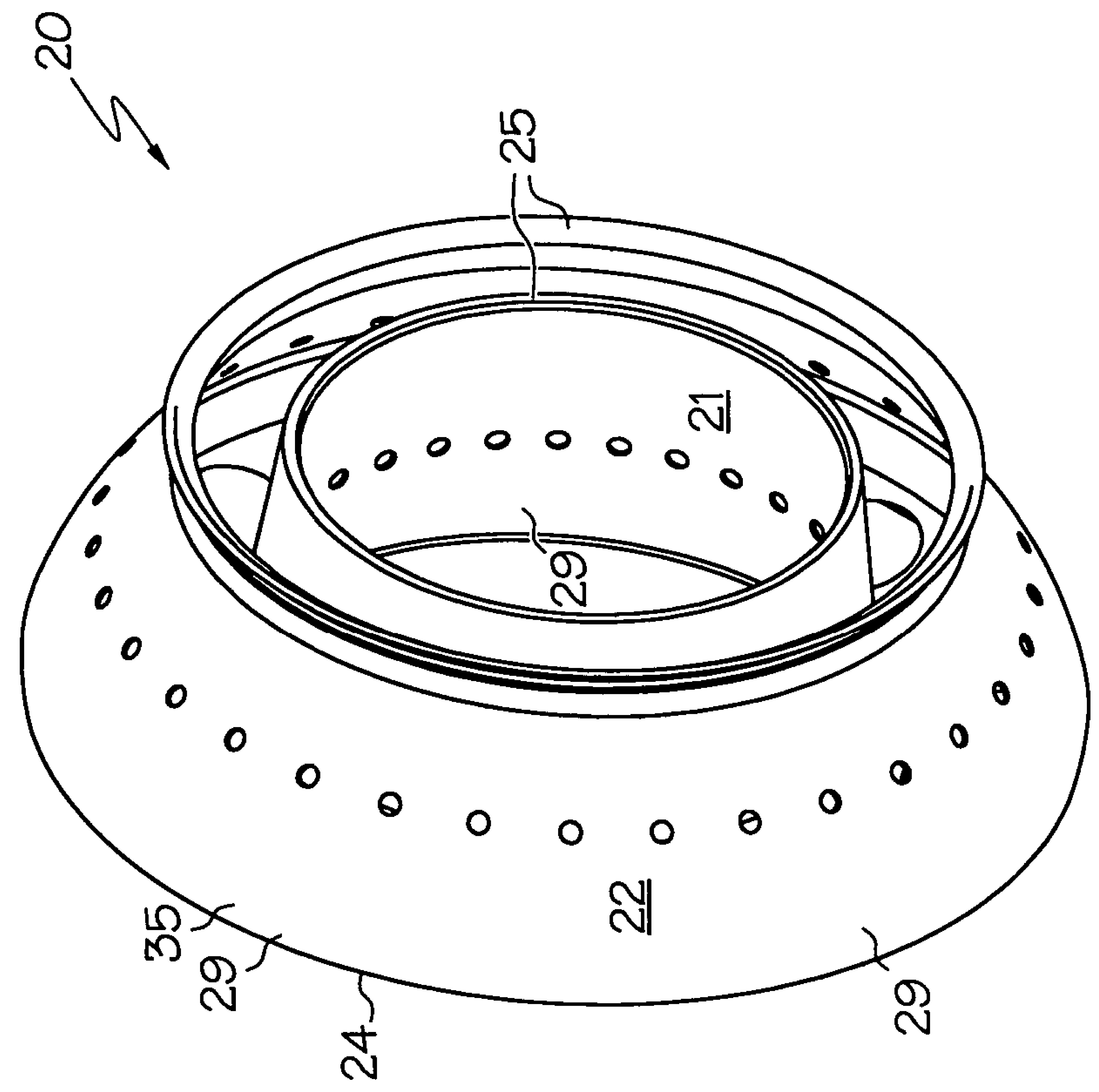


FIG. 1b

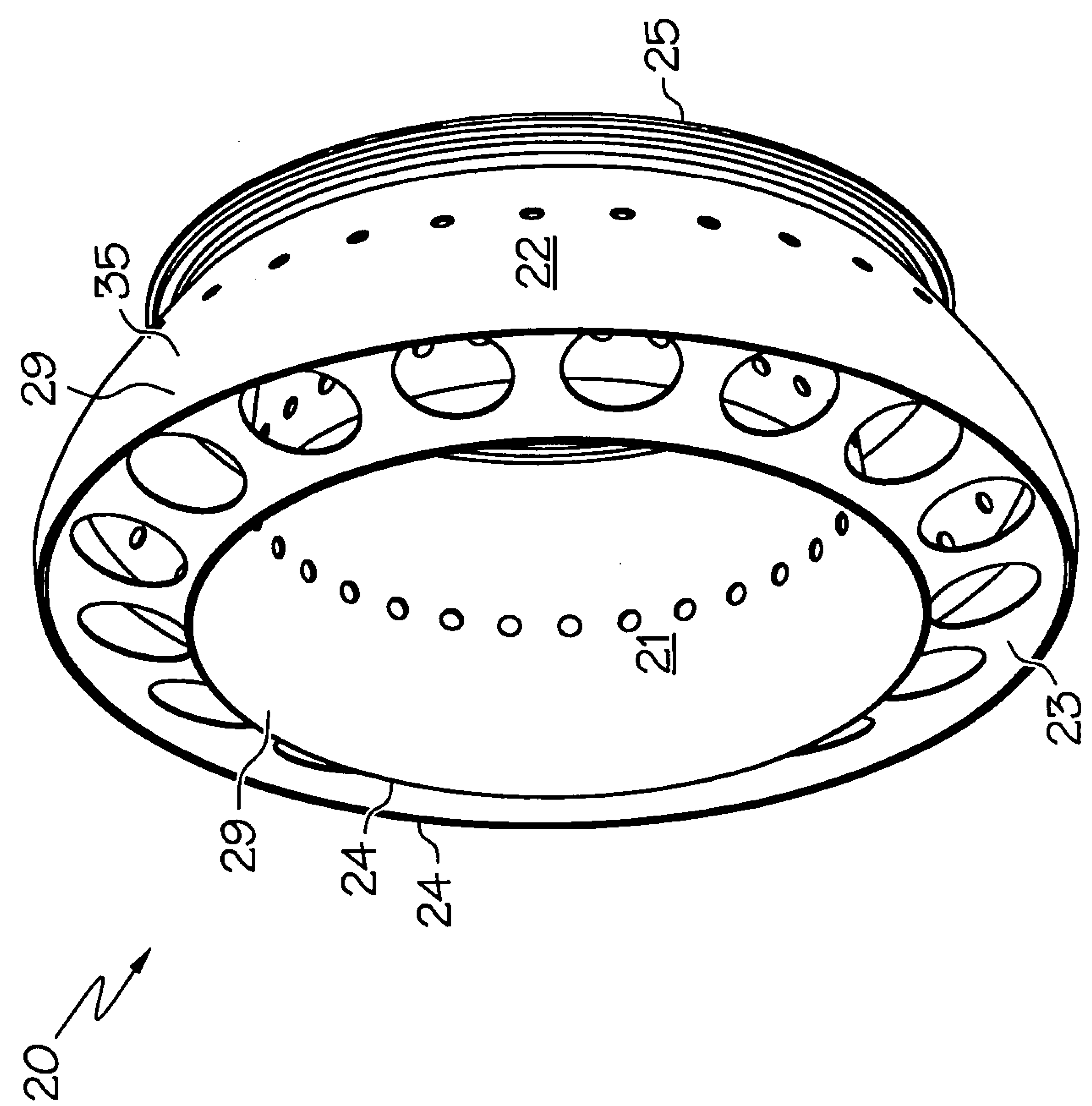


FIG. 1a

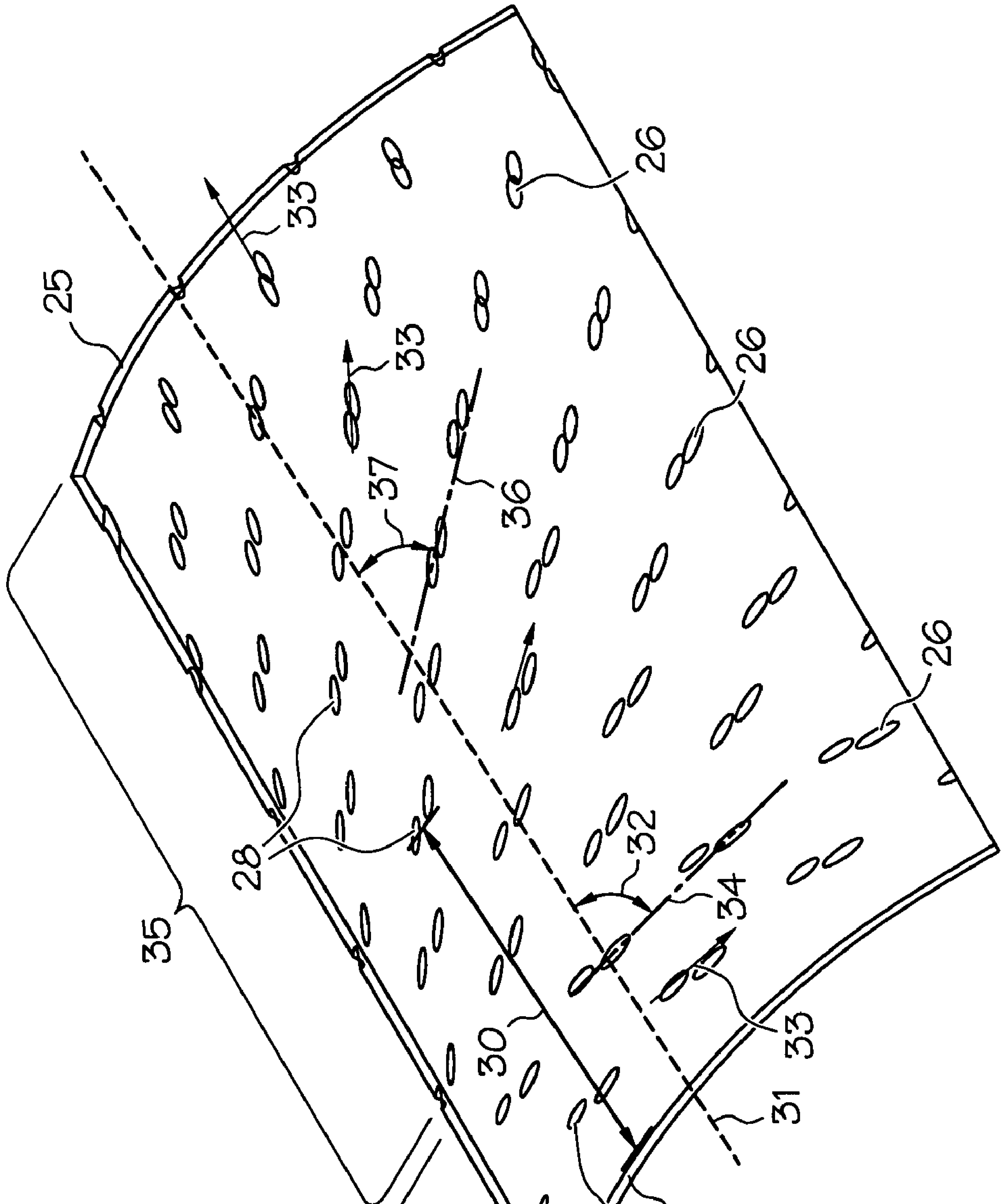


FIG. 2

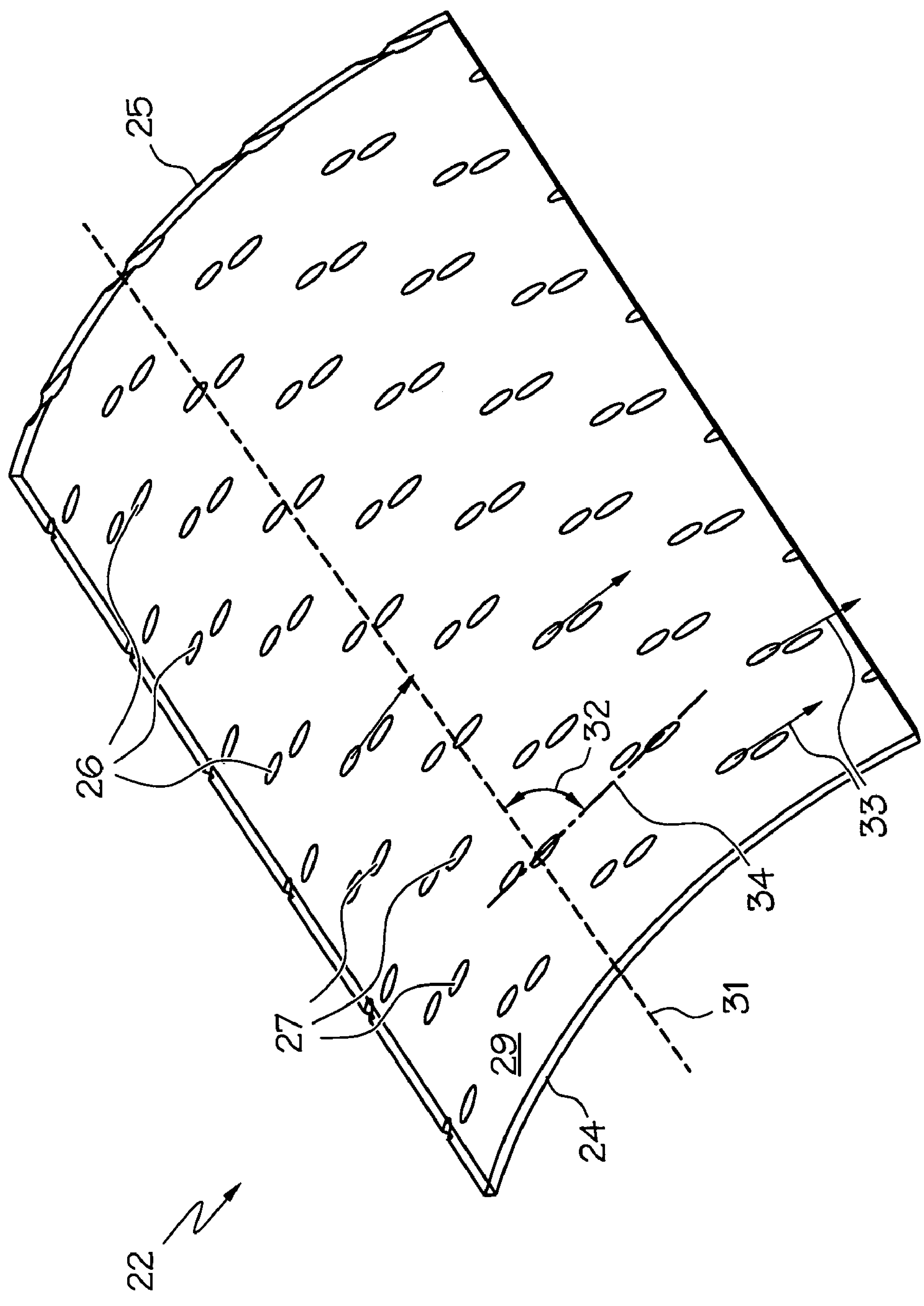


FIG. 3

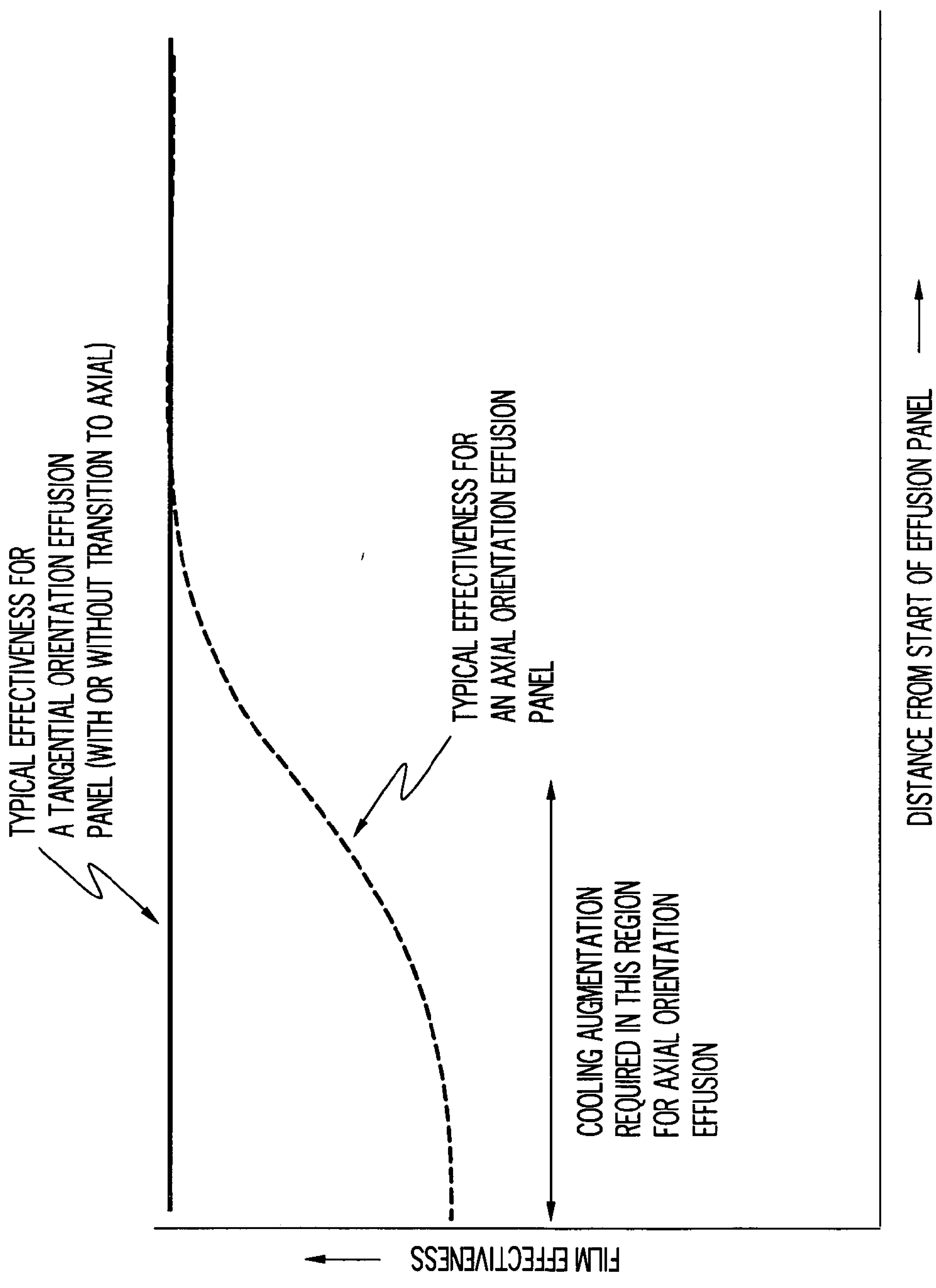

TYPICAL EFFECTIVENESS FOR A TANGENTIAL ORIENTATION EFFUSION PANEL (WITH OR WITHOUT TRANSITION TO AXIAL)
TYPICAL EFFECTIVENESS FOR AN AXIAL ORIENTATION EFFUSION PANEL
COOLING AUGMENTATION REQUIRED IN THIS REGION FOR AXIAL ORIENTATION EFFUSION
DISTANCE FROM START OF EFFUSION PANEL
FILM EFFECTIVENESS

FIG. 4

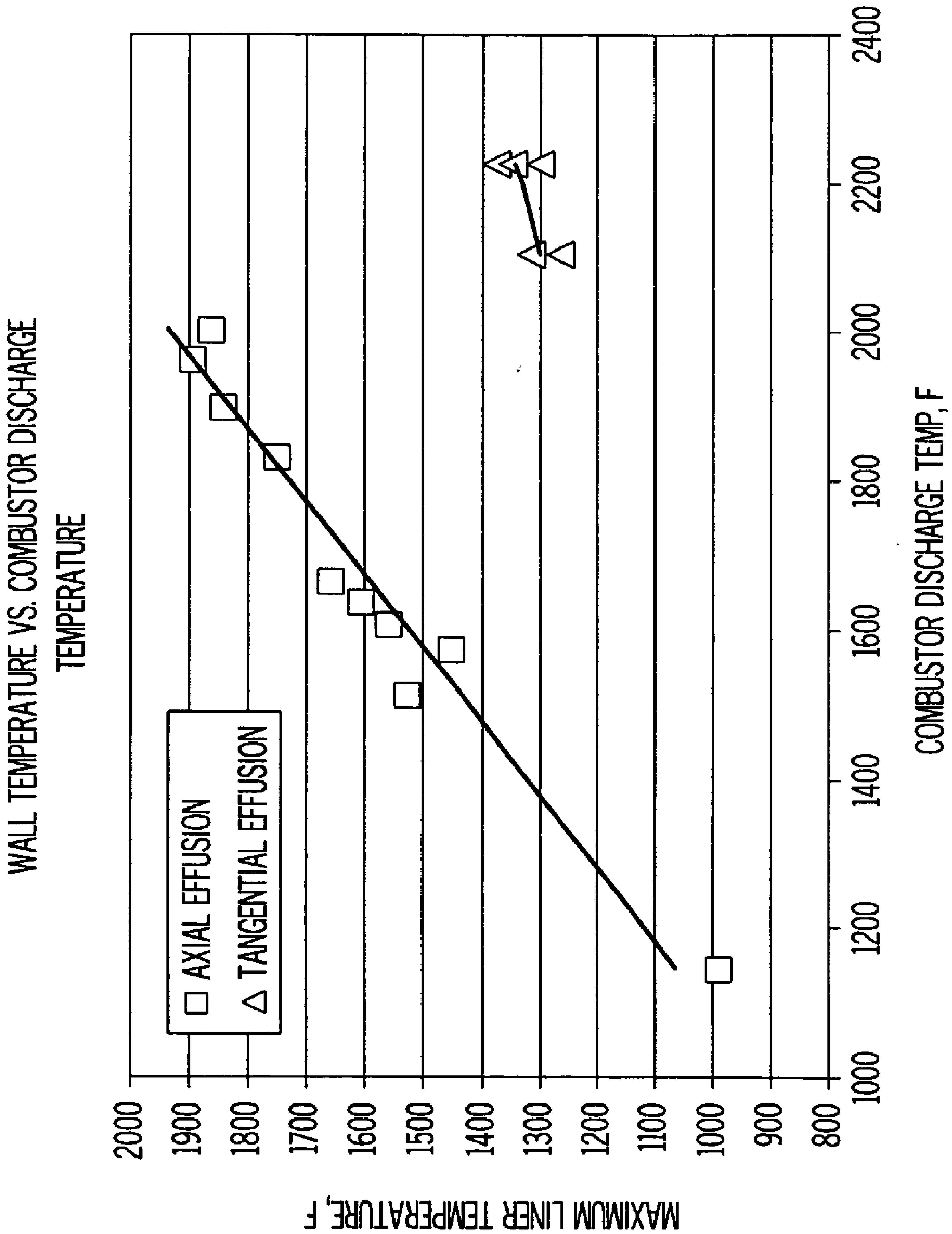

WALL TEMPERATURE VS. COMBUSTOR DISCHARGE TEMPERATURE
AXIAL EFFUSION
TANGENTIAL EFFUSION
MAXIMUM LINER TEMPERATURE, F
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
1000
1200
1400
1600
1800
2000
2200
2400
COMBUSTOR DISCHARGE TEMP, F

FIG. 5

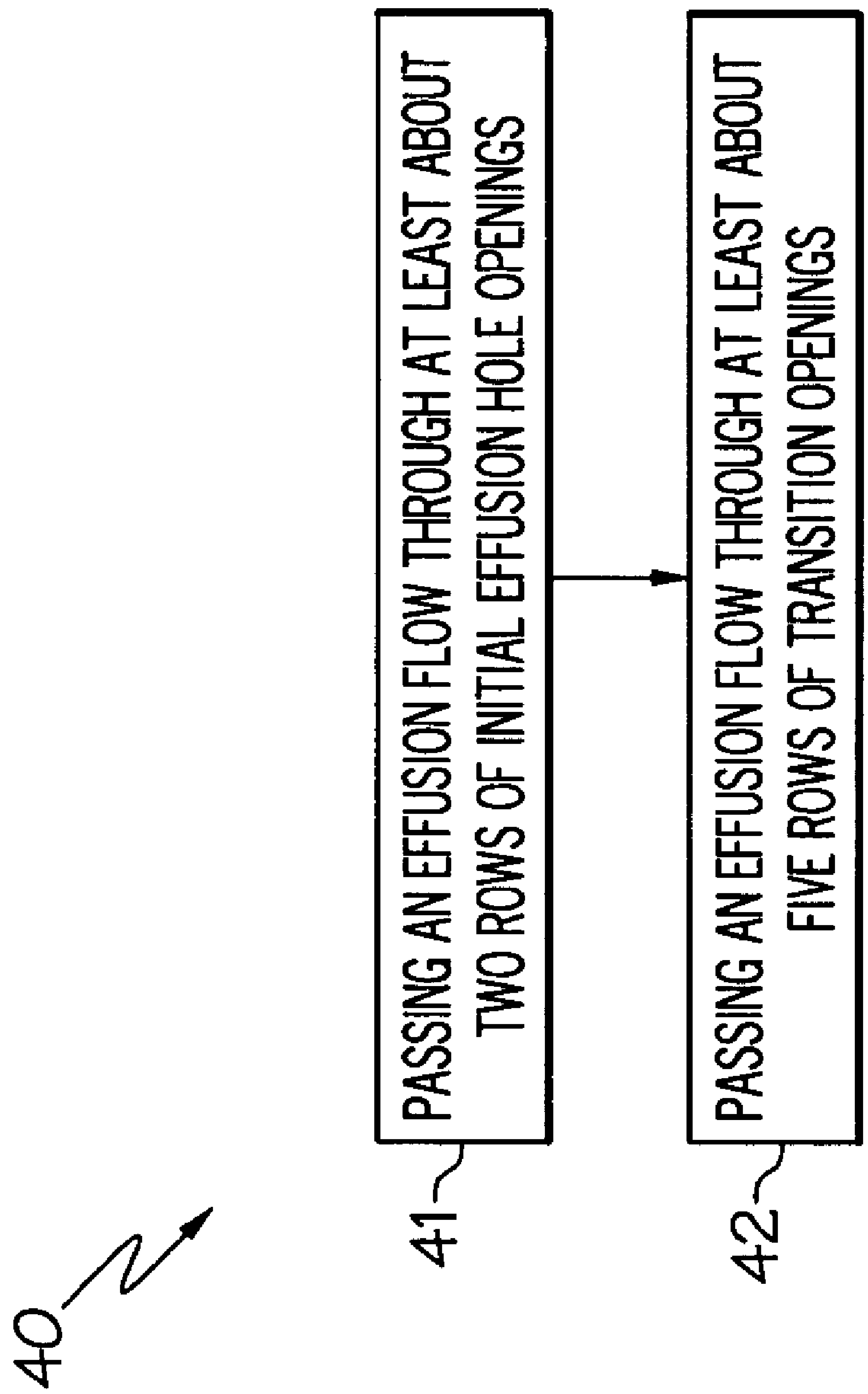

40
PASSING AN EFFUSION FLOW THROUGH AT LEAST ABOUT TWO ROWS OF INITIAL EFFUSION HOLE OPENINGS
41
PASSING AN EFFUSION FLOW THROUGH AT LEAST ABOUT FIVE ROWS OF TRANSITION OPENINGS
42

FIG. 6

FILM EFFECTIVENESS ENHANCEMENT USING TANGENTIAL EFFUSION

BACKGROUND OF THE INVENTION

[0001] The present invention generally relates to gas turbine engines and, more particularly, to effusion cooled components, such as combustor liners.

[0002] An important component of any gas turbine engine is the combustor. Because of the high temperatures (>3500° F.) generated inside the combustor and because metals used in combustor construction are limited to 1700-1800° F., cooling must be provided for the combustor liner walls.

[0003] Effusion cooling is a widely used technique for protecting gas turbine combustor liner walls from hot combustion gases. This cooling technique involves covering the combustor wall with a matrix of small holes. A supply of cooling air is passed through the holes from the cooler surface of the combustor wall to the surface exposed to higher temperatures. The cooling air actively cools the liner by convection as it passes through the hole and after the cooling air is discharged.

[0004] The holes are usually 0.015 to 0.030 inches in diameter and angled so that the centerline of the hole forms a 15 to 30 degree angle with respect to the liner surface. This small angle increases the length of the hole through the liner wall thus increasing the surface area from which the effusion flow can extract heat from the liner material. The small angle also allows the effusion flow to enter the combustor nearly parallel to the panel surface so that a cooling film is generated on the inside of the combustor liner. Conventional effusion holes are oriented in an axial plane such that they discharge into the combustor in a purely axial direction, however sometimes a tangential component is added to the holes corresponding to the tangential component of the bulk flow inside the combustor. Although conventional effusion cooling may be sufficient for cooling some areas of the combustor liners, other areas of the liner are not cooled sufficiently and require additional cooling.

[0005] In U.S. Pat. No. 6,408,629, wall cooling in hot spot areas, such as dilution hole wake regions, is increased by altering the orientation of the effusion holes in the vicinity of those regions. The effusion holes between adjacent dilution holes are angled in a circumferential direction opposite to the circumferential direction of the upstream effusion holes. Although these groups of oppositely directed effusion holes may be useful in cooling hot spot areas caused by cooling film disruption, they are not useful in cooling all hot spot areas of the liner.

[0006] In U.S. Pat. No. 5,261,23 rectangular film starting holes are positioned downstream of the dilution holes. The rectangular film starting holes are slanted at an angle corresponding to the swirl angle of the flow, usually between 30 and 65 degrees with respect to the downstream direction of the flow. Although these rectangular holes may increase cooling in the cooling film shadow area caused by the dilution holes, they may not provide sufficient cooling in the initial flow region at the forward end of the liner.

[0007] One characteristic of effusion cooling is that the film effectiveness is low at the start of a panel (initial flow region) and increases as one travels along the panel. The initial low film effectiveness is because conventional effusion requires 5-10 rows of effusion holes for the cooling film to develop such that the combustor wall is protected from the hot combustion gases. Each individual effusion row by itself provides little protection, but it is only when the effect of a number of rows are superimposed on each other that sufficient thermal protection is provided.

[0008] Because of this characteristic, some form of cooling augmentation is usually required in the initial flow region of an effusion panel in order to protect the wall while the effusion film is developing. This augmentation typically takes the form of a starter film cooling skirt located at the beginning of the effusion panel. The necessity of using starter skirts complicates the construction of combustors and increases their cost. Also, in situations where the geometry does not permit the use of a starter skirt or where the effusion panel is very short, the usefulness of effusion cooling is greatly reduced.

[0009] As can be seen, there is a need for increased cooling in the initial region of an effusion panel. Further, cooling augmentation is needed for applications where a starter film cooling skirt cannot be used.

SUMMARY OF THE INVENTION

[0010] In one aspect of the present invention, an apparatus for an effusion cooled component comprises a plurality of initial effusion hole openings positioned in an initial flow region of the effusion cooled component, at least one initial effusion hole opening positioned such that a longitudinal line of the effusion cooled component and a centerline of the initial effusion hole forms an initial hole tangential angle of between about 75° and about 90°.

[0011] In another aspect of the present invention, an effusion array for a component comprises a plurality of effusion hole openings through the component, the plurality of effusion hole openings positioned such that a plurality of initial effusion hole openings are formed in an initial flow region of the component, the plurality of initial effusion hole openings capable of providing an effusion flow at a tangential angle of between about 75° and about 90° to an axis of the component.

[0012] In still another aspect of the present invention, a component requiring cooling comprises at least two circumferential rows of initial effusion hole openings through the component, each initial effusion hole opening positioned such that a longitudinal line of the component and a centerline of the initial effusion hole opening forms an initial hole tangential angle of between about 80° and about 90°; and at least five circumferential rows of transition openings positioned downstream from the initial effusion hole openings, each transition opening positioned such that a longitudinal line of the component and a centerline of the transition opening forms a transition hole tangential angle, the transition hole tangential angle having a value less than a value of the initial hole tangential angle.

[0013] In yet another aspect of the present invention, a combustor for a gas turbine engine comprises an inner liner; an outer liner positioned radially outward from the inner liner, the outer liner having at least about two circumferential rows of initial effusion hole openings there through, the initial effusion hole openings having a tangential angle between about 75° and about 90° to an axis of the gas turbine engine; and a dome positioned between and connected to the inner liner and the outer liner.

[0014] In another aspect of the present invention, an effusion array for an annular combustor liner comprises at least three circumferential rows of initial effusion hole openings positioned in an initial flow region of the annular combustor liner, each initial effusion hole opening positioned such that a longitudinal line of the annular combustor liner and a centerline of the initial effusion hole opening forms an initial hole tangential angle of between about 75° and about 90°, each initial effusion hole opening having a diameter between about 0.015 and about 0.030 inches, each initial effusion hole opening forming an axial angle of between about 15° and about 30° with a surface of said annular combustor liner; and at least five circumferential rows of transition openings positioned downstream from the initial effusion hole openings, each transition opening positioned such that a longitudinal line of the annular combustor liner and a centerline of the transition opening forms a transition hole tangential angle, the transition hole tangential angle having a value of less than the value of the initial hole tangential angle.

[0015] In a further aspect of the present invention, a method of enhancing the film effectiveness for an effusion cooled component comprises the step of passing a first portion of effusion flow through a plurality of initial effusion hole openings in an initial flow region of said effusion cooled component, at least one initial effusion hole opening positioned such that a longitudinal line of the effusion cooled component and a centerline of the initial effusion hole opening forms an initial hole tangential angle of between about 75° and about 90°.

[0016] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] **FIG. 1***a* is a front side perspective view of a combustor according to one embodiment of the present invention;

[0018] **FIG. 1***b* is a back side perspective view of the combustor of **FIG. 1***a;*

[0019] **FIG. 2** is a perspective view of a portion of a combustor liner according to one embodiment of the present invention;

[0020] **FIG. 3** is a perspective view of a portion of a combustor liner according to another embodiment of the present invention;

[0021] **FIG. 4** is a plot of film effectiveness as a function of distance from start of effusion panel according to one embodiment of the present invention;

[0022] **FIG. 5** is a plot of maximum liner wall temperature as a function of combustor discharge temperature according to one embodiment of the present invention; and

[0023] **FIG. 6** is a flow chart of a method of enhancing the film effectiveness for an effusion cooled component according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0024] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

[0025] The present invention generally provides film effectiveness enhancement for effusion cooled components, such as combustor liners, and methods for producing the same. The film effectiveness enhancement according to the present invention may find beneficial use in many industries including aerospace, automotive, and electricity generation. The present invention may be beneficial in applications including manufacturing and repair of aerospace components. This invention may be useful in any effusion cooled component application.

[0026] In one embodiment, the present invention provides film effectiveness enhancement through a unique orientation of the effusion hole openings for an annular combustor liner. The effusion hole openings may comprise initial effusion hole openings positioned in an initial flow region and transition openings positioned in a transition region. Unlike the prior art, the initial effusion hole openings may have a tangential angle between about 75° and about 90°. The initial effusion hole openings may direct a cooling flow tangentially such that there may be no "beginning" to the effusion due to the cyclic nature of the circumferential direction. This is unlike the prior art that directs the cooling flow in an axial direction. With no beginning, the initial region of low film effectiveness may be eliminated.

[0027] The transition openings may be positioned in a transition region downstream from the initial effusion hole openings. The transition openings may direct a cooling flow such that the angle of the flow transitions from the tangential flow of the upstream initial effusion hole openings to the axial flow of downstream effusion holes. The tangential angle of the transition openings may be gradually reduced to zero so that at the end of the panel the effusion hole orientation corresponds to that of conventional effusion. Alternatively, the tangential angle of the transition openings may be gradually reduced to a value corresponding to the bulk swirl of the combustor internal flow. Unlike the prior art, the cooling protection provided by the present invention may be essentially constant for the entire length of the effusion cooled component.

[0028] An effusion cooled component, such as a combustor **20**, according to an embodiment of the present invention is shown in **FIGS. 1***a* and **1***b*. One of the more common combustor configuration types, an annular combustor, is depicted. The combustor **20** may comprise an inner liner **21** and an outer liner **22**. The inner liner **21** and the outer liner **22** may be connected at an upstream end **24** by a dome **23**. A downstream end **25** may be open and may connect to a turbine section of the engine (not shown). The upstream end **24** and the downstream end **25** may be defined with respect to the direction of a combustion gas flow (not shown) through the combustor **20**.

[0029] A combustor liner, such as the outer liner **22**, may comprise an initial flow region **29**. The initial flow region **29** may be the area of a combustor liner that is toward the upstream end **24**. The combustor liner may comprise a transition region **35**. The transition region **35** may be the area of a combustor liner that is downstream from and adjacent to the initial flow region **29**. As depicted in **FIG. 2**, the outer liner **22** may have a plurality of effusion hole openings **26** there through. Effusion hole openings **26** is a generic term for initial effusion hole openings **27** and transition openings **28**. A plurality of initial effusion hole openings **27** may be positioned in the initial flow region **29**. A plurality of transition openings **28** may be positioned in the transition region **35**.

[**0030**] Each initial effusion hole opening **27** may be tangentially angled and may be positioned in the initial flow region **29**. A longitudinal line **31** and a centerline of the initial effusion hole opening **27** (initial hole centerline **34**) may form an initial hole tangential angle **32** of between about 75° and about 90°. In other words, the initial hole tangential angle **32** may be between about 75° and about 90° from axial. A longitudinal line **31** may be a line from the upstream end **24** to the downstream end **25** of the combustor liner. An initial hole centerline **34** may be a line having the same orientation as the initial effusion hole opening **27**. For some applications, the initial hole tangential angle **32** may be between about 75° and about 85°. For some applications, the initial hole tangential angle **32** may be between about 80° and about 90°. The tangential angle of the initial effusion hole opening **27** (initial hole tangential angle **32**) may allow an effusion flow **33** (cooling flow) to capitalize on the cyclic nature of an annular combustor panel and to more effectively cool the panel. The initial effusion hole opening **27** may be angled with respect to the liner surface in the same manner as known effusion holes. The initial effusion hole opening **27** and the surface of the combustor liner may form an angle (not shown) of between about 15° and about 30°.

[**0031**] The diameter of an initial effusion hole opening **27** may vary with application. The initial effusion hole opening **27** may have a diameter between about 0.01 and about 0.05 inches. For some applications, the initial effusion hole opening **27** may have a diameter between about 0.015 and about 0.030 inches. The initial effusion hole openings may comprise any known effusion hole shape, such as cylindrical and tapered.

[**0032**] The effusion hole openings **26** may comprise a plurality of initial effusion hole openings **27**. The effusion hole openings **26** may comprise at least about two circumferential rows of initial effusion hole openings **27**. A circumferential row may comprise a plurality of about equally spaced openings along a circumference of an effusion-cooled component. The effusion hole openings **26** may comprise between about five and about ten circumferential rows of initial effusion hole openings **27**. The number of circumferential rows of initial effusion hole openings **27** may depend on factors including the dimensions and composition of the effusion-cooled component, dimensions of the initial effusion hole openings **27**, and the temperature of the combustion gases.

[**0033**] A plurality of transition openings **28** may be positioned downstream from the initial effusion hole openings **27**. At least one, and desirably each, transition opening **28** may be a tangentially angled effusion hole and may be positioned in the transition region **35**. A longitudinal line **31** and a centerline of the transition opening **28** (transition hole centerline **36**) may form a transition hole tangential angle **37**, as depicted in **FIG. 2**. A transition hole centerline **36** may be a line having the same orientation as the transition opening **28**. The transition hole tangential angle **37** may be less than the initial hole tangential angle **32**. The tangential angle of the transition openings **28** (transition hole tangential angle **37**) may be gradually reduced as the distance from the initial flow region **29** is increased. For example, the tangential angle of a transition opening **28** adjacent to the initial flow region **29** may be about 70° and the tangential angle of a transition opening **28** further downstream may be about 60°. The transition hole tangential angle **37** may be inversely proportional to a distance **30** between the transition opening **28** and the upstream end **24**. For some applications, the tangential angle of the transition openings **28** may be gradually reduced to zero so that the orientation of the transition openings **28** furthest downstream correspond to the orientation of axial effusion. Alternatively, the tangential angle of the transition openings **28** may be gradually reduced to a value corresponding to the bulk swirl of the combustor internal flow. The bulk swirl of the combustor internal flow may be the orientation of a flow of combustion gases through the combustor **20** and may depend on the configuration of the combustor **20**. For example, for some annular combustors, the bulk swirl of the combustor internal flow may be about 30° and the tangential angle of the transition openings **28** may be gradually reduced to about 30°.

[**0034**] The transition opening **28** may be angled with respect to the liner surface in the same manner as known effusion holes. The transition opening **28** and the surface of the combustor liner may form an axial angle (not shown) of between about 15° and about 30°. Any known effusion hole shape, such as cylindrical and tapered, may be useful with the present invention. The diameter of a transition opening **28** may vary with application and may depend on factors including, the diameter of the combustor **20**, the temperature of the combustion gases, and the velocity of the cooling air. The transition opening **28** may have a diameter between about 0.01 and about 0.05 inches. For some applications, the transition opening **28** may have a diameter between about 0.015 and about 0.030 inches. The effusion hole openings **26** may comprise at least about five circumferential rows of transition openings **28**. The number of circumferential rows of transition openings **28** may depend on factors including the dimensions of the combustor **20**, the diameter of the transition openings **28**, and the temperature of the combustion gases. The effusion hole openings **26** may comprise between about five and about ten circumferential rows of transition openings **28**. The number of circumferential rows of transition openings **28** may depend on the tangential angle of the transition opening **28** furthest downstream. For example, there may be a greater number of circumferential rows of transition openings **28** for an application where the tangential angle of the transition openings **28** is gradually reduced to zero than for an application where the tangential angle of the transition openings **28** is gradually reduced to about 30°.

[**0035**] The number of rows of initial effusion hole openings **27** and transition openings **28** may vary with application and may depend on factors including the dimensions of the combustor **20** and the temperature of the combustion gases. For example, there may be about 7 rows of initial effusion hole openings **27** and about 11 rows of transition openings **28** for an annular combustor liner application. Computational fluid dynamic (CFD) analysis may be useful in determining the desired number of rows and array configuration for a particular application. The effusion hole openings **26** may comprise a plurality of initial effusion hole openings **27** and a plurality of transition openings **28**. The effusion hole openings **26** may comprise a plurality of initial effusion hole openings **27**.

[**0036**] For some applications, the entire length of an effusion cooled component may have initial effusion hole openings **27** there through, as depicted in an alternate embodiment of the present invention shown in **FIG. 3**. For some applications, film effectiveness may be low only in the initial flow region **29** of an effusion wall. For such an application, it may not be necessary, nor particularly desirable, to maintain the large tangential angle of the initial effusion hole opening **27** for the entire panel as depicted in **FIG. 3** and the embodiment depicted in **FIG. 2** may be used.

[**0037**] The effusion hole openings **26** may be formed by conventional drilling techniques such as electrical-discharge machining (EDM), stationary percussion laser machining and percussion on-the-fly laser drilling or with complex casting techniques. The density of the effusion hole openings **26** may vary with application and may depend on factors including the dimensions of the combustor **20**, the composition of the combustor liners, the velocity of the cooling air, and the temperature of the combustion gases. For some combustor applications, the density of the effusion hole openings **26** may be between about 10 and about 100 holes/in^2.

[**0038**] The effusion cooled component, such as but not limited to the combustor **20** discussed above, may comprise any component exposed to high temperatures. Useful components may include gas turbine engine components, for example combustors, vanes and shrouds. The effusion cooled component may comprise a metal or a metal alloy. The effusion cooled component may comprise nickel based and cobalt based superalloys such as HA230™ (Haynes International), Rene' alloy N5™ (General Electric), MarM247™ (Martin Marietta), PWA 1422™ (Pratt Whitney), PWA 1480™ (Pratt Whitney), PWA 1484™ (Pratt Whitney), Rene' 80™ (General Electric), Rene' 142™ (General Electric), SC 180™ (Honeywell), HA188™ (Haynes International), MarM509™ (Martin Marietta) and others.

[**0039**] A method **40** of enhancing the film effectiveness for an effusion cooled component is depicted in **FIG. 6**. The method **40** may comprise a step **41** of passing an effusion flow **33** through at least about two rows of initial effusion hole openings **27** in an initial flow region of the component. The step **41** may comprise passing a first portion of effusion flow **33** through a plurality of initial effusion hole openings **27** in an initial flow region **29** of the effusion cooled component. The method may comprise a further step **42** of passing an effusion flow **33** through at least about five rows of transition openings **28** in a transition region. The step **42** may comprise passing a second portion of effusion flow **33** through a plurality of transition openings **28** in a transition region **35** of said effusion cooled component.

EXAMPLE 1

[**0040**] The film effectiveness of a conventional effusion panel and an effusion panel of the present invention were compared. A plot of film effectiveness as a function of distance from start of panel is depicted in **FIG. 4**. The dashed curve represents the film effectiveness of a conventional axial orientation effusion panel. The solid line represents the film effectiveness of an effusion panel of the present invention. The present invention provides greater film effectiveness at the start of the effusion panel, the initial flow region. As can be appreciated by those skilled in the art, the present invention may decrease liner temperatures in the initial flow region of the panel, making starter skirts unnecessary.

EXAMPLE 2

[**0041**] The impact of tangential effusion can be seen in **FIG. 5**, which shows thermocouple measured liner metal temperatures for an annular combustor. The figure plots the maximum inner wall temperature as a function of the combustor discharge temperature. The axial orientation effusion panel used conventional axial effusion and generated the upper line of data. By changing to tangential effusion according to one embodiment of the present invention which transitioned to axial as discussed above, and without changing the amount of cooling flow, the lower line of data was generated which represents a reduction over 500° F. in liner temperature.

[**0042**] As can be appreciated by those skilled in the art, the present invention provides improved film effectiveness at the start of an effusion panel. This means that the complication and expense of starter skirts can be eliminated and/or effusion cooling can be effectively used in situations where a starter skirt is geometrically impossible.

[**0043**] It should be understood, of course, that the foregoing relates to exemplary embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims.

1. An apparatus for an effusion cooled component comprising:

a plurality of initial effusion hole openings positioned in an initial flow region of said effusion cooled component, at least one of said initial effusion hole openings positioned such that a longitudinal line of said effusion cooled component and a centerline of said at least one initial effusion hole opening forms an initial hole tangential angle of between about 75' and about 90°; and

a plurality of transition openings positioned downstream from said initial effusion hole openings, at least one of said transition openings positioned such that a longitudinal line of said effusion cooled component and a centerline of said at least one transition opening forms a transition hole tangential angle, said transition hole tangential angle having a value less than a value of said initial hole tangential angle.

2. (canceled)

3. The apparatus of claim 1, wherein said transition hole tangential angle is inversely proportional to a distance between said transition opening and an upstream end of said effusion cooled component.

4. The apparatus of claim 1, wherein said plurality of transition openings comprises between about five and about ten circumferential rows of transition openings.

5. The apparatus of claim 1, wherein said effusion cooled component comprises a combustor.

6. The apparatus of claim 5, wherein said combustor comprises an annular combustor liner.

7. The apparatus of claim 1, wherein said plurality of initial effusion hole openings comprises between about five and about ten circumferential rows of initial effusion hole openings.

8. The apparatus of claim 1, wherein each said initial effusion hole opening has a diameter between about 0.015 and about 0.030 inches.

9. The apparatus of claim 1, wherein said initial hole tangential angle is between about 75° and about 85°.

10. The apparatus of claim 1, wherein said initial hole tangential angle is between about 80° and about 90°.

11. An effusion array for a component comprising:

a plurality of effusion hole openings through said component, said plurality of effusion hole openings positioned such that (i) a plurality of initial effusion hole openings are formed in an initial flow region of said component and (ii) at least five circumferential rows of transition openings are formed in a transition region of said component, said plurality of initial effusion hole openings capable of providing an effusion flow at a tangential angle of between about 75° and about 90° to an axis of said component, said at least five circumferential rows of transition openings capable of providing an effusion flow at a tangential angle of less than that of said plurality of initial effusion hole openings.

12. (canceled)

13. The effusion array of claim 13, wherein each said transition opening has a diameter between about 0.01 and about 0.05 inches.

14. The effusion array of claim 13, wherein said at least five circumferential rows of transition openings comprise between about 5 and about 10 circumferential rows of transition openings.

15. The effusion array of claim 11, wherein said plurality of initial effusion hole openings comprises between about 5 and about 10 circumferential rows of initial effusion hole openings.

16. The effusion array of claim 11, wherein said plurality of initial effusion hole openings are capable of providing an effusion flow at a tangential angle of between about 75° and about 85° to an axis of said component.

17. The effusion array of claim 11, wherein said component comprises a combustor.

18. The effusion array of claim 11, wherein said component comprises an annular combustor liner.

19. The effusion array of clam **11**, wherein a density of said initial effusion hole openings is between about 10 and about 100 holes/in^2.

20. A component requiring cooling comprising:

at least two circumferential rows of initial effusion hole openings through said component, each said initial effusion hole opening positioned such that a longitudinal line of said component and a centerline of said initial effusion hole opening forms an initial hole tangential angle of between about 80° and about 90°; and

at least five circumferential rows of transition openings positioned downstream from said initial effusion hole openings, each said transition opening positioned such that a longitudinal line of said component and a centerline of said transition opening forms a transition hole tangential angle, said transition hole tangential angle having a value less than a value of said initial hole tangential angle.

21. The apparatus of claim 20, wherein said at least two circumferential rows of initial effusion hole openings comprise between about 5 and about 10 circumferential rows of initial effusion hole openings.

22. The apparatus of claim 20, wherein said at least five circumferential rows of transition openings comprise between about 5 and about 10 circumferential rows of transition openings.

23. A combustor for a gas turbine engine comprising:

an inner liner;

an outer liner positioned radially outward from said inner liner, said outer liner having at least about two circumferential rows of initial effusion hole openings there through and at least about five circumferential rows of transition openings downstream from said at least about two circumferential rows of initial effusion hole openings, said initial effusion hole openings having a tangential angle between about 75° and about 90° to an axis of said gas turbine engine; and

a dome positioned between and connected to said inner liner and said outer liner.

24. The combustor of claim 23, wherein said inner liner comprises an annular combustor liner.

25. (canceled)

26. The combustor of claim 23, wherein said outer liner has at least about five circumferential rows of transition openings there through, each transition opening having a tangential angle inversely proportional to a distance between said transition opening and an upstream end of said outer liner.

27. An effusion array for an annular combustor liner comprising:

at least three circumferential rows of initial effusion hole openings positioned in an initial flow region of said annular combustor liner, each initial effusion hole opening positioned such that a longitudinal line of said annular combustor liner and a centerline of said initial effusion hole opening forms an initial hole tangential angle of between about 75° and about 90°, each initial effusion hole opening having a diameter between about 0.015 and about 0.030 inches, each initial effusion hole opening forming an axial angle of between about 15° and about 30° with a surface of said annular combustor liner; and

at least five circumferential rows of transition openings positioned downstream from said initial effusion hole openings, each said transition opening positioned such that longitudinal line of said annular combustor liner and a centerline of said transition opening forms a transition hole tangential angle, said transition hole tangential angle having a value of less than a value of said initial hole tangential angle.

28. A method of enhancing the film effectiveness for an effusion cooled component comprising the step of:

passing a first portion of effusion flow through a plurality of initial effusion hole openings in an initial flow region of said effusion cooled component, at least one said initial effusion hole opening positioned such that a longitudinal line of said effusion cooled component and a a centerline of said at least one initial effusion hole opening forms an initial hole tangential angle of between about 75° and about 90°; and

passing a second portion of effusion flow through a plurality of transition openings in a transition region of said effusion cooled component, at least one transition opening positioned such that longitudinal line of said effusion cooled component and a centerline of said at least one transition opening forms a transition hole tangential angle, said transition hole tangential angle less than said initial hole tangential angle.

29. (canceled)

30. The method of claim 28, wherein said step of passing a first portion of effusion flow provides a cooling film capable of protecting said initial flow region from a hot combustion flow through said effusion cooled component.

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