



US006360528B1

(12) **United States Patent**
Brausch et al.

(10) **Patent No.:** **US 6,360,528 B1**
(45) **Date of Patent:** **Mar. 26, 2002**

(54) **CHEVRON EXHAUST NOZZLE FOR A GAS TURBINE ENGINE**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 333 days.

(21) Appl. No.: **08/961,794**

(22) Filed: **Oct. 31, 1997**

(51) **Int. Cl.**⁷ **F02K 1/40**; F02K 1/48

(52) **U.S. Cl.** **60/262**; 60/264; 239/265.17;
239/265.19; 181/220

(58) **Field of Search** 60/262, 263, 264,
60/271, 39.5; 239/265.17, 265.13, 265.19;
181/213, 220

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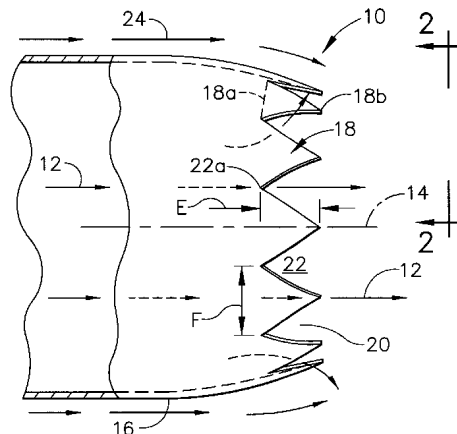
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(57) **ABSTRACT**

A gas turbine engine exhaust nozzle includes an exhaust
duct for channeling a gas jet. A plurality of adjoining
chevrons are disposed at an aft end of the duct to define an
exhaust outlet. Each of the chevrons is triangular in
configuration, with a base, apex, side trailing edges con-
verging therebetween, and radially opposite first and second
surfaces bounded thereby. The trailing edges of adjacent
chevrons are spaced laterally apart to define respective
diverging slots disposed in flow communication with the
duct. The chevrons have a concave contour axially between
the bases and apexes which promotes jet mixing through the
slots.

20 Claims, 4 Drawing Sheets



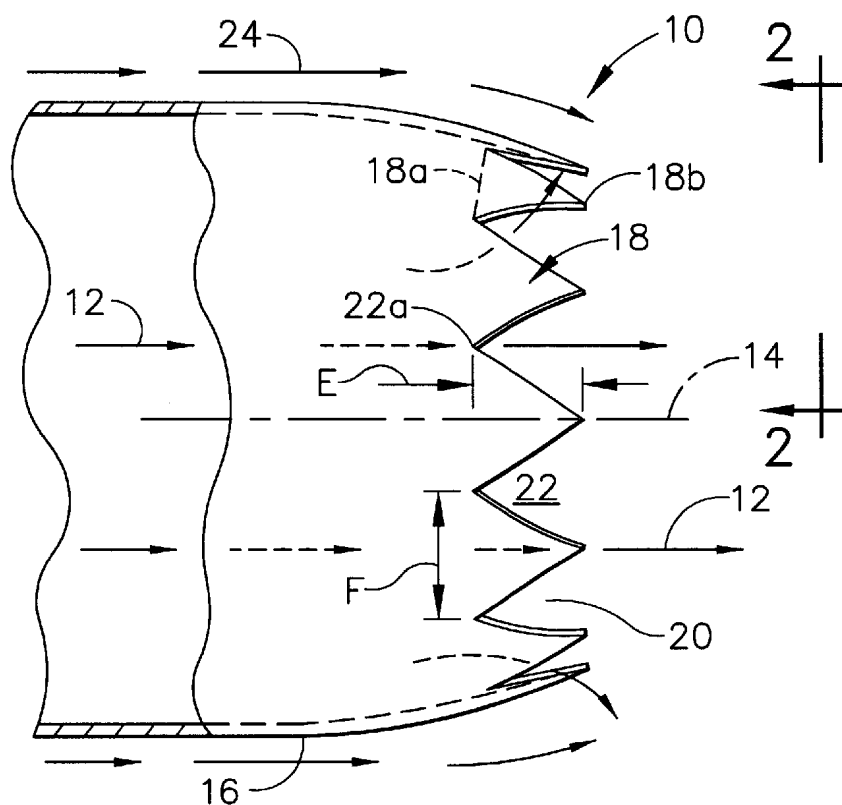


FIG. 1

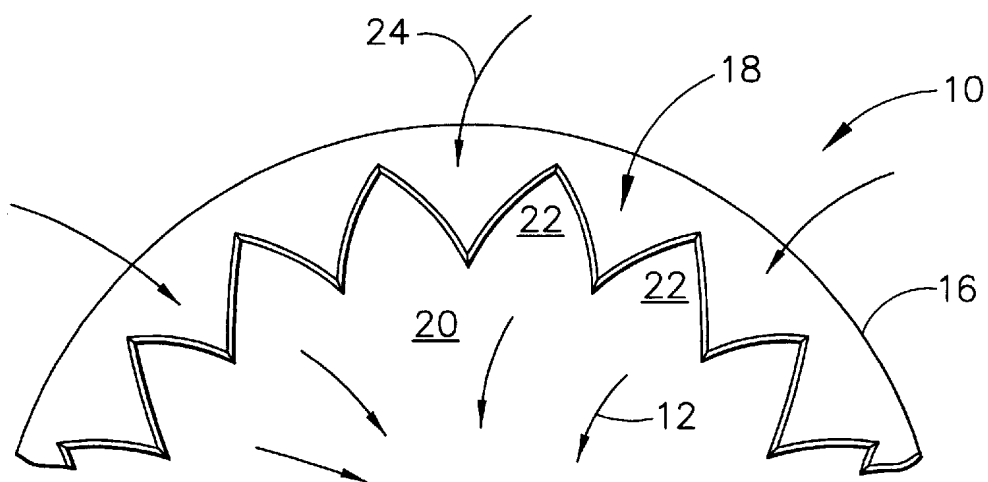
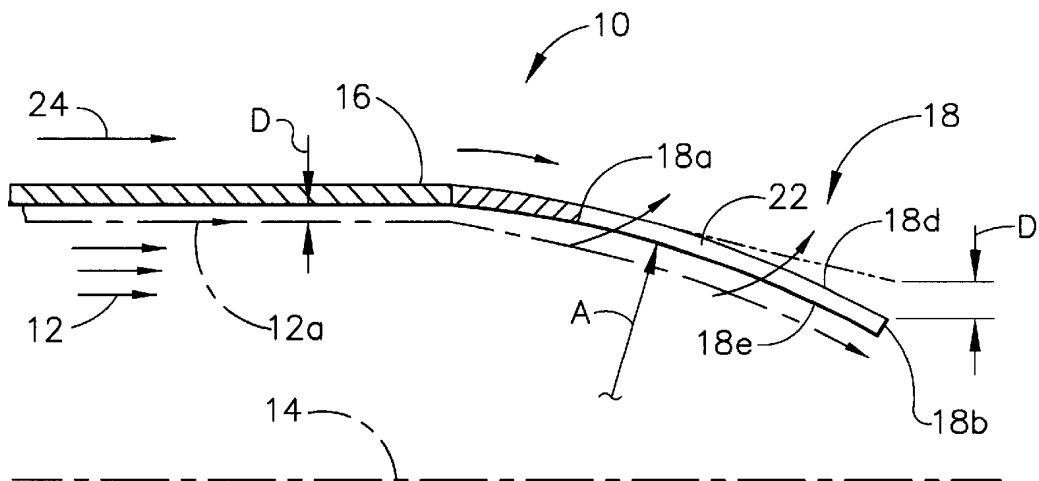
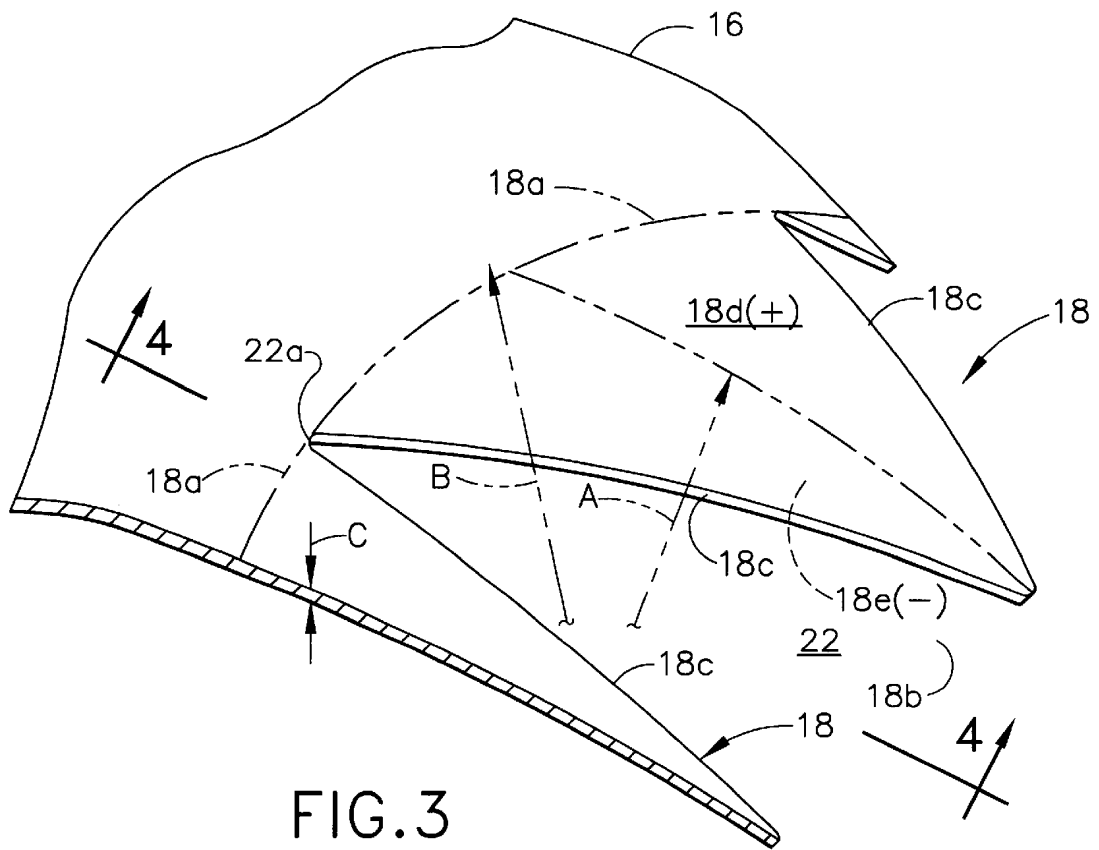


FIG. 2



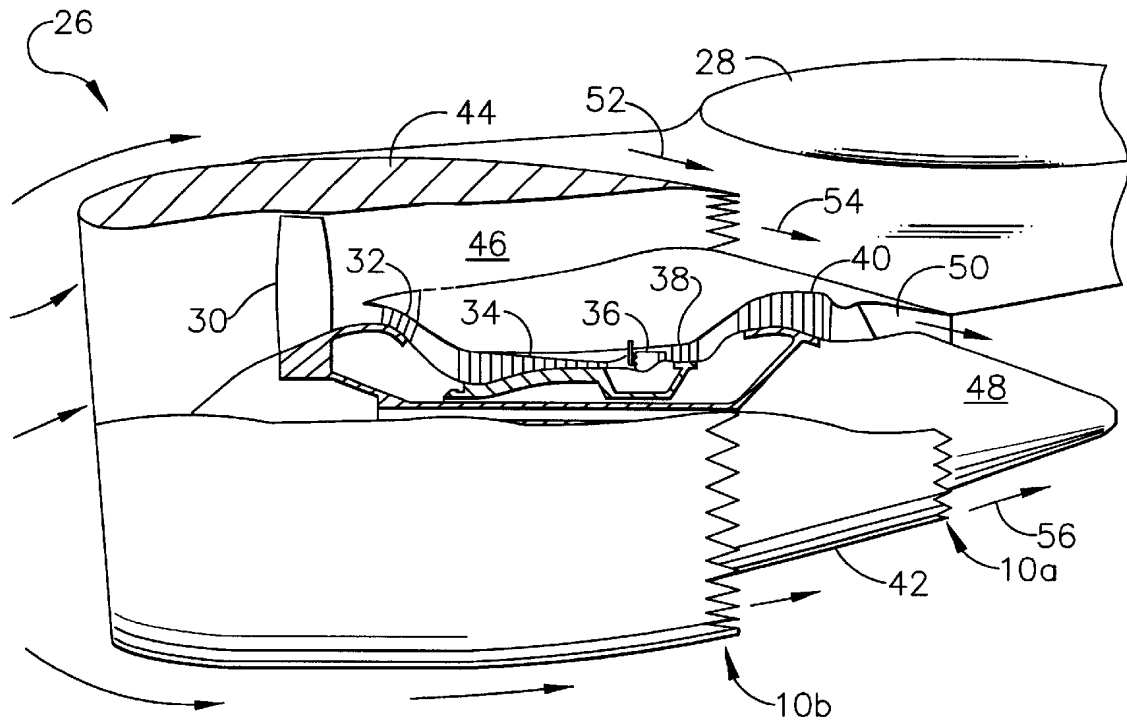


FIG. 5

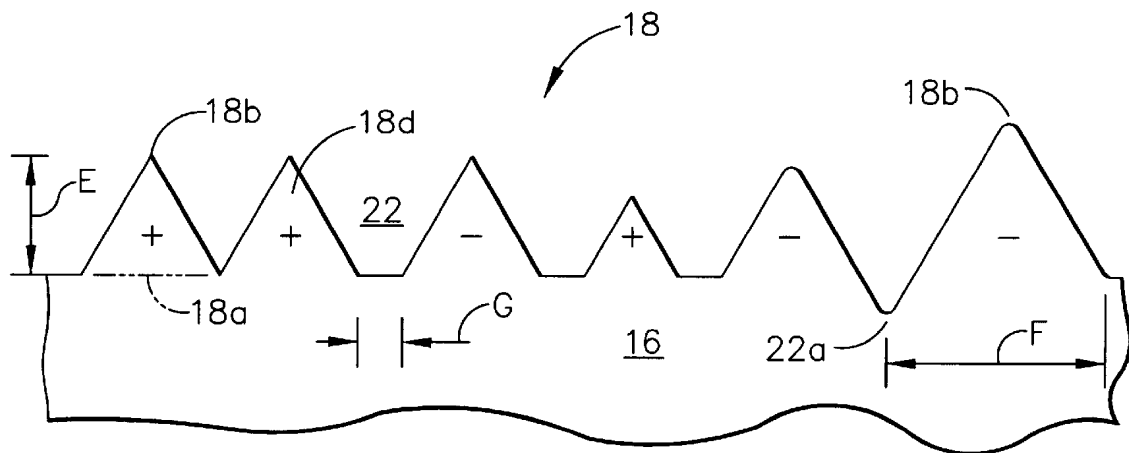


FIG. 6

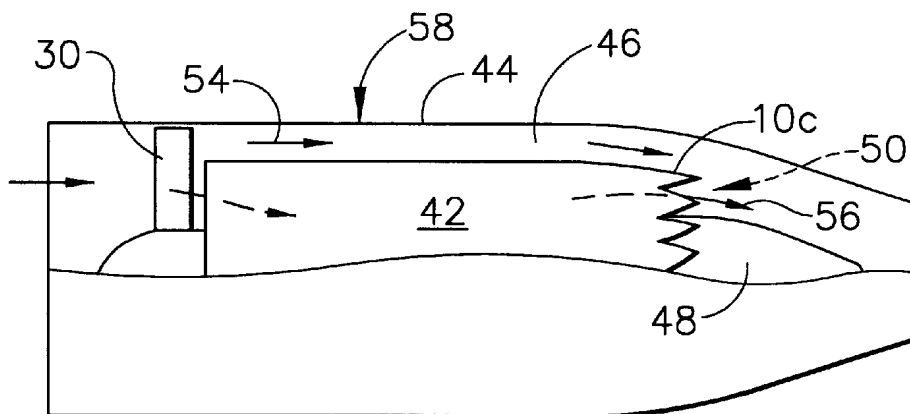


FIG. 7

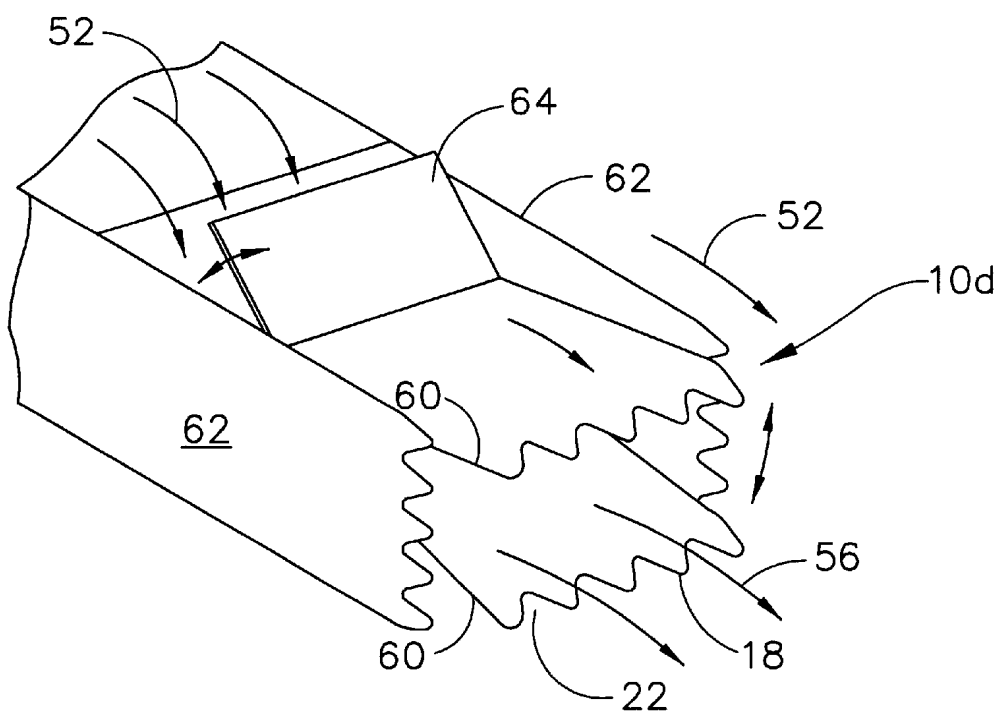


FIG. 8

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CHEVRON EXHAUST NOZZLE FOR A GAS TURBINE ENGINE

The invention herein described was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

The present invention relates generally to gas turbine engines, and, more specifically, to reduction of exhaust noise and infrared (IR) signature.

A typical gas turbine engine includes a compressor for compressing air which is mixed with fuel and ignited in a combustor for generating hot combustion gases which flow through one or more stages of turbines which power the compressor in a core engine configuration. Typically cooperating with the core engine is a low pressure compressor, such as a fan, disposed upstream of the high pressure compressor of the core engine, which is operatively joined to a low pressure turbine disposed downstream from the high pressure turbine of the core engine. The combustion exhaust gases discharged from the core engine flow through the low pressure turbine which extracts energy therefrom for powering the low pressure compressor or fan for use in powering an aircraft in flight for example. Alternatively, the low pressure turbine may be used for producing output shaft power in a marine or land-based industrial (M&I) application.

In a typical turbofan aircraft gas turbine engine application for powering an aircraft in flight, a core exhaust nozzle is used for independently discharging the core exhaust gases inwardly from a concentric fan exhaust nozzle which discharges the fan air therefrom for producing thrust. The separate exhausts from the core nozzle and the fan nozzle are high velocity jets typically having maximum velocity during take-off operation of the aircraft with the engine operated under relatively high power. The high velocity jets interact with each other as well as with the ambient air and produce substantial noise along the take-off path of the aircraft. Furthermore, the core jet is hot and produces an infrared signature which may be detected from afar.

The prior art includes various solutions for reducing jet noise and infrared signature. The solutions typically rely on vigorously mixing the hot core jet with the fan jet, or ambient air, or both, for reducing the velocities thereof and reducing the temperature thereof. In this way both noise and infrared signature may be reduced, but typically at the expense of engine efficiency and performance.

For example, convoluted or lobed mixers, also known as daisy mixers, may be used at the end of the core engine inside a long duct outer nacelle for internally mixing the core exhaust with the fan exhaust. Although noise and IR signature may be reduced, this is done at the expense of increases in nozzle weight, installed friction, and boat-tail drag. And, although jet noise may be reduced at lower frequencies, this is typically accompanied by an increased noise level at mid and high frequency ranges.

The mixer lobes are effective since they project into both the core exhaust and the fan exhaust, but therefore have performance losses associated therewith. Other types of sound suppressors are known which also project into the jet streams with differing degrees of performance loss and noise reduction. Exemplary devices include paddles, corrugations, mini-mixers, tabs, and vortex generators.

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Accordingly, it is desired to reduce jet noise and IR signature with minimum reduction in engine performance, reduced mechanical complexity, and minimum increase, or even reduced, nozzle weight.

SUMMARY OF THE INVENTION

A gas turbine engine exhaust nozzle includes an exhaust duct for channeling a gas jet. A plurality of adjoining chevrons are disposed at an aft end of the duct to define an exhaust outlet. Each of the chevrons is triangular in configuration, with a base, apex, side trailing edges converging therebetween, and radially opposite first and second surfaces bounded thereby. The trailing edges of adjacent chevrons are spaced laterally apart to define respective diverging slots disposed in flow communication with the duct. The chevrons have a concave contour axially between the bases and apexes which promotes jet mixing through the slots.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, in accordance with preferred and exemplary embodiments, together with further objects and advantages thereof, is more particularly described in the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is an axial side view, partly in section, of a portion of an exemplary gas turbine engine exhaust nozzle having an exhaust outlet defined by a plurality of adjoining chevrons in accordance with an exemplary embodiment of the present invention.

FIG. 2 is an aft facing forward view of a portion of the exhaust nozzle illustrated in FIG. 1 and taken generally along line 2—2.

FIG. 3 is an isometric view of an exemplary one of the chevrons illustrated in FIGS. 1 and 2 enlarged to show more detail.

FIG. 4 is a side elevational view through one of the chevrons illustrated in FIG. 3 and taken generally along line 4—4.

FIG. 5 is a side elevational view of an exemplary aircraft turbofan gas turbine engine including chevron exhaust nozzles in accordance with the present invention for both the fan and core exhausts.

FIG. 6 is a top plan view of a chevron exhaust nozzle in accordance with additional embodiments of the present invention including variously configured alternate chevrons.

FIG. 7 is a side elevational view of a long duct mixed flow gas turbine engine including a chevron mixer in accordance with an alternate embodiment of the present invention.

FIG. 8 is a schematic representation of a two-dimensional mixer ejector nozzle including chevrons in accordance with an alternate embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Illustrated in FIG. 1 is an exemplary exhaust nozzle **10** for exhausting a gas jet **12** from a conventional gas turbine engine (not shown). The nozzle **10** is axisymmetric about an axial centerline axis **14**, and includes an annular exhaust duct **16** for channeling the jet **12** therethrough along the centerline axis **14**. The nozzle **10** also includes a plurality of circumferentially or laterally adjoining chevrons **18** integrally disposed at an aft end of the exhaust duct **16** to define an exhaust outlet **20**, shown in more particularity in FIG. 2.

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The chevrons **18** are illustrated in more particularity in FIG. **3**, with each chevron **18** being triangular in configuration, with a base **18a** fixedly or integrally joined to the duct aft end circumferentially or laterally coextensively with adjacent chevron bases **18a**. Each chevron **18** also includes an axially opposite apex **18b**, and a pair of circumferentially or laterally opposite trailing edges or sides **18c** converging from the base **18a** to the respective apex **18b** in the downstream, aft direction. Each chevron **18** also includes a radially outer or first triangular surface **18d**, and a radially opposite inner or second triangular surface **18e** bounded by the trailing edges **18c** and base **18a**.

The trailing edges **18c** of adjacent chevrons **18** are spaced circumferentially or laterally apart from the bases **18a** to apexes **18b** to define respective slots or cut-outs **22** diverging laterally and axially, and disposed in flow communication with the inside of the exhaust duct **16** for channeling flow radially therethrough. In the exemplary embodiment illustrated in FIG. **3**, the slots **22** are also triangular and complementary with the triangular chevrons **18** and diverge axially aft from a slot base **22a**, which is circumferentially coextensive with the chevrons bases **18a**, to the chevron apexes **18b**.

In accordance with a significant feature of the present invention, each chevron **18** has a concave contour axially between the respective bases **18a** and apexes **18b** as illustrated in FIG. **3**, and in more particularity in FIG. **4**. The axial contour illustrated in FIG. **4** is defined by a first radius of curvature **A** disposed in the exemplary vertical plane including the centerline axis **14**. The radius **A** of the axial contour may vary in magnitude from the chevron base **18a** to the chevron apex **18b**, and in the exemplary embodiment the axial contour is parabolic.

The individual chevrons **18** preferably also have a concave contour circumferentially or laterally between the trailing edges **18c** as defined by a radius of curvature **B** as shown in FIG. **3**. The radius **B** of the lateral contour may also vary along the circumferential arc between the opposite trailing edges **18c** of each chevron **18**, and preferably provides a smooth surface with the firstly defined axial contours. In this way, the chevron has a compound, three-dimensional flow surface contour defining a shallow concave depression or bowl for promoting mixing effectiveness. The compound curvatures may be defined by simple circular arcs, or by parabolic curves, or by higher order quadratic curves.

In the exemplary embodiment illustrated in FIGS. **3** and **4**, the chevrons **18** have a substantially uniform thickness **C** which may also be equal to the thickness of the exhaust duct **16** from which they extend, and may be formed of one or more thin walled members or plates. Alternatively, the chevrons may vary in thickness to allow for structural rigidity and flow surface blending. And, in the exemplary embodiment illustrated, the chevron outer surface **18d** is convex as represented by the plus sign (+), with the chevron inner surface **18e** being concave as represented by the minus sign (-).

Although the individual chevrons **18** illustrated in FIG. **3**, for example, could be flat components suitably inclined to define either a converging or diverging nozzle, the chevrons **18** have a slight, compound curvature for cooperating with the gas flow for promoting mixing effectiveness while at the same time providing an aerodynamically smooth and non-disruptive profile for minimizing losses in aerodynamic efficiency and performance.

For example, in the embodiment illustrated in FIG. **3**, the chevron first surface **18d** is disposed radially outwardly of

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the chevron second surface **18e** with the outer surface **18d** being convex, and the inner surface **18e** being concave. The chevrons **18** and cooperating slots **22** are generally laterally or circumferentially coextensive with each other at generally common radii from the bases **18a** to the apexes **18b** for minimizing or reducing radial projection of the chevrons **18** into the exhaust jet **12**. In the exemplary embodiment illustrated in FIGS. **1-4**, the nozzle **10** is configured as a converging nozzle of decreasing flow area with an effective throat of minimum flow area being defined at a suitable location between the chevron bases **18a** and apexes **18b**. The individual chevrons **18** are therefore inclined radially inwardly from their forward bases **18a** to their aft apexes **18b** and thusly confine the exhaust jet **12** radially therebelow. However, the slots **22** allow the exhaust jet **12** to expand radially outwardly therethrough for promoting forced mixing.

As shown in FIG. **1**, the exhaust jet **12** flows inside the exhaust duct **16** and is discharged both axially from its aft outlet **20** and radially outwardly through the chevron slots **22**. The so discharged exhaust jet **12** may therefore mix with a radially outwardly surrounding outer gas stream **24** which, for example, may be ambient air flowing over the exhaust nozzle **10** either during aircraft ground static or flight, or may alternatively be fan air discharged from the gas turbine engine fan nozzle. Since the exhaust nozzle **10** may be used in various applications, the exhaust jet **12** and outer stream **24** may be any fluid streams typically found in a gas turbine engine, or in industrial applications involving gas handling and/or discharging apparatus.

For example, FIG. **5** illustrates an aircraft turbofan gas turbine engine **26** suitably joined to a wing of an aircraft **28** illustrated in part. The engine **26** includes in serial flow communication a fan **30**, low pressure compressor **32**, high pressure compressor **34**, combustor **36**, high pressure turbine (HPT) **38**, and low pressure turbine (LPT) **40** operatively joined together in a conventional configuration. The engine **26** also includes a core nacelle or cowl **42** surrounding the core engine and LPT **40**, and a fan nacelle or cowl **44** surrounding the fan **30** and the forward part of the core cowl **42** and spaced radially outwardly therefrom to define a bypass duct **46**. A conventional centerbody or plug **48** extends aft from the LPT **40** and is spaced radially inwardly from the aft end of the core cowl **42** to define a core exhaust duct **50**.

During operation, ambient air **52** flows into the fan **30** as well as around the fan cowl **44**. The air is pressurized by the fan **30** and discharged through the fan duct **46** as a fan jet **54** for producing thrust. A portion of the air channeled past the fan **30** is compressed in the core engine and suitably mixed with fuel and ignited for generating hot combustion gases which are discharged through the core duct **50** as a core jet **56**.

The improved exhaust nozzle **10** may be used at various locations in various types of gas turbine engines such as the turbofan aircraft engine illustrated in FIG. **5**. For example, the exhaust nozzle is designated **10a** for providing the chevrons **18** and slots **22** at the discharge end of the core cowl **42** for mixing the core jet **56** and the fan jet **54** for reducing jet noise and infrared signature. Another embodiment of the exhaust nozzle is designated **10b** and is disposed at the discharge end of the fan cowl **44** for mixing the fan jet **54** with the ambient air **44** for reducing noise of the fan jet **54**.

Both the core nozzle **10a** and the fan nozzle **10b** may be configured as disclosed in FIGS. **1-4** for providing prefer-

entially configured chevrons **18** and slots **22** for mixing the various combinations of the gas jet **12**, e.g. core jet **56** or fan jet **54**, with the outer gas stream **24**, e.g. fan jet **54** or ambient air **52**, respectively. The various dimensions and contour shapes of the chevrons **18** and slot **22** may be suitably varied for each design application for maximizing noise reduction, or reducing infrared signature, or both, without a substantial increase in weight or aerodynamic efficiency losses.

For example, illustrated schematically in FIG. **4** is a boundary layer **12a** of the exhaust jet **12** which flows along the radially inner surface of the exhaust duct **16** and chevrons **18**. In a preferred embodiment, the chevron apexes **18b** are displaced radially inwardly in depth **D** from an axial tangent to the chevron bases **18a** with a magnitude on the order of the thickness of the boundary layer **12a**. In this way, the axial contour of the chevrons **18** is relatively shallow as compared with a flat chevron for displacing the chevron apex **18b** relative to the chevron base **18a** sufficiently for disrupting the exhaust jet **12** at its boundary layer **12a** and enhancing mixing. Alternatively, the depth **D** may be less than or substantially greater than the boundary layer thickness.

The chevrons **18** cooperate with the slot **22** to disrupt the gas jet **12** forcing a portion thereof to be ejected radially outwardly through the slot **22** into the outer gas stream **24** in the event of a positive differential pressure in the radial outward direction. With an opposite positive differential pressure in the radially inward direction, the outer gas stream **24** is forced radially inwardly through the slot **22** for promoting enhanced mixing. The chevrons also introduce paired sets of vortices which grow in scale as they travel axially and enhance the mixing process between the jet **12** and outer gas stream **24**.

The various dimensions of the chevrons **18** and their compound curvature may be optimized for each design application depending on the location of the exhaust nozzle and types of gas jet **12** and outer gas stream **24**, as well as on the differential pressure between those two gas streams. In embodiments wherein the exhaust nozzle **10** illustrated in FIGS. **1-4** is configured as a converging nozzle, the chevrons **18** are preferably concave inwardly as shown which cooperates with the gas jet **12** expanding radially outwardly in the chevron slots **22**.

FIG. **6** illustrates schematically exemplary design parameters for various configurations of the chevrons **18** and cooperating slots **22** at the end of the exhaust duct **16**. These various chevrons and slots are merely illustrated together on a common exhaust duct **16** for clarity of presentation and would not be used together as shown, but in various combinations thereof. An exhaust duct may either be axisymmetrical, elliptical, rectangular, or combinations thereof in cross section in accordance with conventional or advanced-design configurations. A number of individual chevrons **18** and sizes thereof may be selected for each design application for maximizing effectiveness.

Each chevron **18** has an axial length **E** measured perpendicularly from its base **18a** to its apex **18b**, and a lateral width **F** varying from a maximum value at the base **18a** to a minimum value at the apex **18b**. The chevron width **F** may be represented by the chord length for an axisymmetrical or elliptical nozzle, or may be measured by the circumferential length of the chevron. For a rectangular nozzle, the chevron width **F** may be simply measured by the lateral width of the chevron. The individual chevrons **18** may be spaced laterally or circumferentially apart at their bases **18a** by a suitable spacing **G** as desired. In the embodiment illustrated in FIGS.

1-4, the adjacent chevrons **18** adjoin each other at the slot bases **22a** with substantially no or little circumferential spacing **G** therebetween.

As illustrated in FIG. **1**, the chevrons **18** preferably have equal axial lengths **E** from the bases **18a** to the apexes **18b**. However, as shown in FIG. **6**, the chevron lengths **E** may be unequal and vary as desired.

Also in the exemplary embodiment illustrated in FIG. **1**, the chevron apexes **18b** are coplanar in a single axial plane, and at a common radius from the centerline axis **14**. Similarly, the chevron bases **18a**, and slot bases **22a**, are also coplanar at another common axial plane spaced forwardly from the chevron apexes **18b**, also at another common radius. However, as illustrated in FIG. **6**, the chevron apexes **18b** may be in different axial planes from chevron to chevron, and similarly, the slot bases **22a** may also be in different axial planes from slot to slot if desired.

As also shown schematically in FIG. **6**, the respective contours of the chevron outer and inner surfaces **18d, e** may also vary from convex (+) to concave (-), respectively, or vice versa, or in any combination. And, as shown in FIG. **4**, the deflection of the chevron apexes **18b** may be radially inwardly toward the axial centerline axis **14**, or may be opposite in the radially outward direction away from the centerline axis **14**, or the deflection may be zero if desired.

However, the three dimensional geometric contour of the individual chevrons **18** may be used to advantage depending upon the specific design application for enhancing mixing while minimizing or eliminating aerodynamic performance losses during operation. Significant jet noise reduction may be obtained, as well as significant infrared signature reduction when a relatively cold airstream is mixed with the relatively hot core jet **56**. The individual chevrons **18** blend well with the aft end of the exhaust duct **16** preferably initially tangent thereto, with a nonlinear contour both in the axial downstream direction and in the circumferential or lateral direction. This three dimensional contoured profile eliminates chevron surface discontinuities in both the outer and inner flowpaths for providing improved aerodynamic efficiency.

The relatively small projection of the chevron apexes **18b** into the jet produces aerodynamically smooth flow guidance to force an accelerated mixing process of jet-to-jet or jet-to-ambient air, and generates significant streamwise vorticity which further accelerates the mixing process. The resultant shorter mixed-jet plume length and reduced plume perimeter results in lower levels of audible jet noise and significantly reduced infrared signature over the prior art.

As indicated above, the improved chevron exhaust nozzle may be used in various configurations in gas turbine engines such as the turbofan engine illustrated in FIG. **5**. FIG. **7** illustrates an alternate embodiment of the chevron exhaust nozzle designated **10c** disposed in an otherwise conventional long duct turbofan engine **58**. In this engine **58**, the fan cowl **44** extends the entire length of the engine to encase also the centerbody plug **48**. The chevron nozzle defines a mixer **10c** disposed concentrically between the fan bypass duct **46** and the core exhaust duct **50** for mixing the fan air **54** with the core gases **56** in a manner analogous to a conventional convoluted daisy mixer. In view of the improved efficiency of the chevron mixer **10c**, the aft portion of the fan cowl **44** may be eliminated, if desired, for reducing weight and further increasing performance through reduced friction and boattail drag.

FIG. **8** illustrates yet another embodiment of the chevron exhaust nozzle designated **10d** in an otherwise conventional

two-dimensional rectangular mixer-ejector exhaust nozzle. The chevron nozzle **10d** is defined by a plurality of opposing movable exhaust flaps **60** having the chevrons **18** and slots **22** disposed at an aft end thereof. The chevron nozzle **10d** is rectangular in this embodiment and is further defined by a pair of opposite sidewalls **62** laterally bounding the exhaust flaps **60**. Disposed at the aft ends of the sidewall **62** are additional ones of the chevrons **18** and slots **22** which cooperate with the flap chevrons for jet noise and infrared signature reduction. In this embodiment, the chevron nozzle **10d** includes conventional movable ejector doors **64** which open as illustrated in FIG. **8** for receiving a portion of ambient air **52** for internally mixing with the core jet **56**. The ambient air **52** also flows outside the nozzle and over the several chevrons **18** for mixing with the core jet **56** as described in the alternate embodiment.

Since the chevrons **18** and cooperating chevron slots **22** are relatively simple components, they may be incorporated at the junction of any two gas streams where desired for promoting mixing thereof to advantage. This specific configurations of the chevrons and slots may be optimized for each design application for maximizing noise reduction and infrared signature reduction as desired.

While there have been described herein what are considered to be preferred and exemplary embodiments of the present invention, other modifications of the invention shall be apparent to those skilled in the art from the teachings herein, and it is, therefore, desired to be secured in the appended claims all such modifications as fall within the true spirit and scope of the invention.

Accordingly, what is desired to be secured by Letters Patent of the United States is the invention as defined and differentiated in the following claims:

What is claimed is:

1. A nozzle for exhausting a gas jet from a gas turbine engine comprising:
 - an exhaust duct for channeling said jet along an inner surface thereof;
 - a plurality of adjoining chevrons disposed at an aft end of said duct to define an exhaust outlet;
 - each of said chevrons being triangular in configuration, with a base fixedly joined to said duct aft end laterally coextensively with adjacent chevron bases, an opposite apex, a pair of laterally opposite trailing edges converging from said base to said apex, and radially opposite outer and inner surfaces bounded by said trailing edges and base, with said chevron inner surfaces at said bases being laterally and radially coextensive with said duct inner surface;
 - said trailing edges of adjacent chevrons being spaced laterally apart to define respective laterally diverging slots disposed in flow communication with said duct for channeling flow radially therethrough; and
 - said chevrons having a compound concave contour both axially between said bases and apexes and laterally between said trailing edges thereof to define a bowl in one of said outer and inner surfaces thereof.

2. A nozzle according to claim **1** wherein said chevrons and slots are generally laterally coextensive for minimizing radial projection into said jet.

3. A nozzle according to claim **2** wherein said chevron outer surface is convex, and said chevron inner surface defines said concave bowl.

4. A nozzle according to claim **2** wherein said jet flows through said duct with a boundary layer along said inner surface thereof, and said chevron apexes are displaced radially in depth from a tangent to said chevron bases with a magnitude on the order of the thickness of said boundary layer thereat.

5. A nozzle according to claim **2** wherein said chevrons are spaced laterally apart at said bases.

6. A nozzle according to claim **2** wherein said chevrons have equal length **E** from said bases to apexes.

7. A nozzle according to claim **6** wherein said chevron apexes are coplanar.

8. A nozzle according to claim **2** wherein said duct comprises a core engine nozzle for discharging combustion gases in said jet.

9. A nozzle according to claim **2** wherein said duct comprises a fan nozzle for discharging fan air in said jet.

10. A nozzle according to claim **2** wherein said duct comprises a mixer disposed radially between a fan bypass duct and a core exhaust duct for mixing fan air and core gases.

11. A nozzle according to claim **2** defined by a plurality of opposing movable flaps having said chevrons and slots disposed at an aft end thereof.

12. A nozzle according to claim **11** being rectangular, and further defined by a pair of opposite sidewalls bounding said flaps, and also having said chevrons and slots disposed at an aft end thereof.

13. A nozzle according to claim **2** wherein said chevron outer and inner surfaces are parallel to each other.

14. A nozzle according to claim **2** wherein said chevrons have a constant thickness.

15. A nozzle according to claim **2** wherein said chevron inner and outer surfaces are coextensive with said duct inner surface and an outer surface thereof, respectively.

16. A nozzle according to claim **2** wherein said chevrons are laterally contiguous at said bases.

17. A nozzle according to claim **2** wherein said chevron outer surface defines said concave bowl, and said chevron inner surface is convex.

18. A nozzle according to claim **2** wherein said chevrons tangentially blend with said duct aft end, with said bowl being nonlinear in contour both axially and laterally.

19. A gas turbine engine nozzle for exhausting a gas jet comprising an annular exhaust duct and a plurality of circumferentially adjoining triangular chevrons extending integrally therefrom at a common radius to define an exhaust outlet, and each of said chevrons has a shallow compound contour bowl therein.

20. A nozzle according to claim **19** wherein said chevrons are circumferentially contiguous around said duct and tangentially blend therewith, with said bowls terminating thereat.