A jet engine exhaust nozzle flow effector is a chevron formed with a radius of curvature with surfaces of the flow effector being defined and opposing one another. At least one shape memory alloy (SMA) member is embedded in the chevron closer to one of the chevron’s opposing surfaces and substantially spanning from at least a portion of the chevron’s root to the chevron’s tip.

18 Claims, 7 Drawing Sheets
In accordance with the present invention, a jet engine exhaust nozzle flow effector includes an elastically deformable chevron having a root and a tip. The chevron is formed with a radius of curvature that matches the geometry of a portion of a jet engine exhaust nozzle exit such that an inner surface and an outer surface are defined and oppose one another with the inner surface facing the axial center of the nozzle exit. In one embodiment, at least one shape memory alloy (SMA) member is embedded in the chevron closer to the inner surface than the outer surface and substantially spanning from at least a portion of the chevron’s root to the chevron’s tip. In another embodiment, at least one shape memory alloy (SMA) member is embedded in the chevron closer to the outer surface than the inner surface and substantially spanning from at least a portion of the chevron’s root to the chevron’s tip.

Fig. 1 is a top view of chevron-shaped flow effector having a cylindrical radius of curvature for use in controlling jet engine noise in accordance with an embodiment of the present invention.

Fig. 2 is a cross-sectional view of the flow effector taken along line 2-2 in Fig. 1.

Fig. 3 is a cross-sectional view of the flow effector taken along the centerline thereof as indicated by line 3-3 in Fig. 1.

Fig. 4 is a top view of a chevron-shaped flow effector in accordance with another embodiment of the present invention.

Fig. 5 is a cross-sectional view of the flow effector taken along line 5-5 in Fig. 4.

Fig. 6 is a cross-sectional view of the flow effector taken along line 6-6 in Fig. 4.

Fig. 7 is a top view of a chevron-shaped flow effector in accordance with still another embodiment of the present invention.

Fig. 8 is a cross-sectional view of the flow effector taken along line 8-8 in Fig. 7.

Fig. 9 is a cross-sectional view of the flow effector taken along line 9-9 in Fig. 7.

Fig. 10 is a top view of a chevron-shaped flow effector in accordance with yet another embodiment of the present invention.

Fig. 11 is a cross-sectional view of the flow effector taken along line 11-11 in Fig. 10.

Fig. 12 is a side view of the flow effector taken along line 12-12 in Fig. 10.

Fig. 13 is a cross-sectional view of another embodiment of a flow effector for use with a jet engine exhaust nozzle exit that is rectangular, and

Fig. 14 is a cross-sectional view of another embodiment of a flow effector for use with a jet engine exhaust nozzle that is elliptical.

Detailed Description of the Invention

Referring now to the drawings, simultaneous reference will be made to Figs. 1-3 where a first embodiment of a flow effector for use in controlling jet engine noise is illustrated and is referenced generally by number 10. Flow effector 10 is generally a chevron-shaped flow effector that is symmetrical about its centerline referred by dashed line 12. In its chevron shape, flow effector 10 has a root 14 and a tip 16. When used in conjunction with a jet engine, flow effector 10 is mounted to the jet engine’s nozzle. More specifically and as would be understood in the art, root 14 is attached to a region of the jet...
engine nozzle such that tip 16 is positioned aft of the nozzle’s exit (illustrated in FIG. 2 by dashed line 100). In the illustrated example, the jet engine nozzle exit 100 is assumed to be circular so that flow effector 10 has a cylindrical radius of curvature that is geometrically matched to a portion of nozzle exit 100. However, as will be explained further below, the flow effector can be readily adapted to accommodate other nozzle exit geometries, e.g., rectangular, elliptical, etc., without departing from the scope of the present invention.

Since a plurality of flow effectors 10 would typically be attached to and distributed about the periphery of exit 100, flow effector 10 is generally shaped about centerline 12 to have a radius of curvature closely matching a corresponding portion of the jet engine nozzle exit 100. This is best seen in the cross-sectional view shown in FIG. 2. Thus, in the illustrated example, one surface 10A of flow effector 10 is convex while the opposing surface 10B is concave. More generally, surface 10A faces away from the axial center 102 of nozzle exit 100 while surface 10B faces towards axial center 102 as will always be the case regardless of the geometries of the nozzle exit and flow effectors.

In general, flow effector 10 includes an elastically deformable chevron body 20 and one or more shape memory alloy (SMA) members 22 embedded within chevron body 20 and arranged to form a V-shape. As will be explained further below, SMA members 22 are used to deform chevron body 20 in order to alter the flow of exhaust exiting a jet engine nozzle where such alteration reduces jet engine noise. Accordingly, chevron body 20 must be of a deformable construction so that when SMA members 22 are actuated, they can re-shape chevron body 20. Since it may be desirable for chevron body 20 to re-attain its original shape when SMA members are deactivated, chevron body 20 will typically be constructed to be elastically deformable.

In the illustrated embodiment, chevron body 20 is a laminated structure with the delineation between the various layers thereof being indicated by the dashed lines in FIG. 2. Note that the number of layers comprising chevron body 20 is not a limitation of the present invention. Furthermore, the materials used to construct chevron body 20 can be any that will provide elastic deformation properties. When SMA members 22 are to be electrically actuated, it is advantageous if the material layers of chevron body 20 comprise an electrical insulating material to simplify the manufacturing of flow effector 10.

In at least one embodiment, to maximize control of flow effector 10, SMA members 22 span substantially the entire flow length of flow effector 10 from tip 16 to root 14. Each of SMA members 22 can be realized by a simple SMA wire, ribbon, etc., or multiple ones of such wires, ribbons, etc. However, to simplify the actuation of SMA members 22 (i.e., either by electrical or thermal actuation) while keeping convex surface 10A and concave surface 10B free of surface interruptions, SMA members 22 are to be electrically actuated, it is advantageous if the material layers of chevron body 20 comprise an electrical circuit accessible at root 14.

The advantages of the present invention are numerous. By embedding SMA members on one or both sides of a flow effector’s neutral axis, the active jet engine nozzle flow effectors described herein will provide jet engine designers with the building block needed to design/construct jet engines having lower noise signatures. Furthermore, the active nature of the flow effectors will allow optimization of noise reduction and continual adaptation of the chevron system configuration with operating conditions to maintain optimal performance. The novel flow effectors present flow surfaces that will not introduce unwanted disturbances into the exhaust flow at a jet engine nozzle exit.
The following text describes an example of two potential embodiments of the present invention and methods for their fabrication. This example is not intended to be limiting, but is only exemplary of the inventive features which are defined in the claims. The Example is as follows:

Two active chevron designs were devised to achieve the desired functionality, one that is powered to immerse (termed POR [power-off-retracted], see FIG. 1) into the flow and one that is powered to retract (termed POI [power-off-immersed], see FIG. 7). Prototypes of each chevron type were fabricated from glass-epoxy pre-preg and Nitinol ribbon actuator assemblies by a vacuum hot press approach. (As known in the art, Nitinol is an acronym for Nickel Titanium Naval Ordnance Laboratory, and is a family of intermetallic materials, which contain a nearly equal mixture of nickel and titanium.) Provisions for electrical continuity to the Nitinol actuators were accommodated to allow convenient and efficient actuator control and minimal overall structural thickness.

A SMA actuator material system consisting of glass-epoxy unidirectional pre-impregnated (pre-preg) tape and Nitinol ribbon was selected. The glass-epoxy matrix material offers electrical isolation for resistive heating of the SMA actuators and affords visual flaw detection. Pre-preg material is available in thin layers and affords precise control over directional and it was found that the thermal pulse traveling away from the weld site. Applied, and the stack was topped with a layer of bleeder cloth and polyimide release film. Finally, the matching ram was installed on top of the stack.

Each laminate was subjected to the cure cycle recommended by the pre-preg manufacturer; heated from room temperature to 121.1° C. (250° F.) at 1.7-2.8° C./min (3-5° F./min), held for 15 minutes at 121.1° C. (250° F.), 586 kPa (85 psi) of pressure was applied, held at 121.1° C. (250° F.) and 586 kPa (85 psi) for an additional 45 minutes, heated again to 176.7° C. (350° F.) at 1.7-2.8° C./min (3-5° F./min) while holding 586 kPa (85 psi), held at 176.7° C. (350° F.) and 586 kPa (85 psi) for 2 hours, cooled to room temperature at 1.7-2.8° C./min (3-5° F./min) while holding 586 kPa (85 psi), and the pressure was released at room temperature. The resulting consolidated laminates were machined to final
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chevron dimensions. The Nitinol leads remaining at the root edge of the chevron were copper plated to enable soldering to the leads and to improve contact-type electrical connections.

Although both laminates are symmetric due to the embedded Nitinol ribbon, no warping of the laminates result after cure because the restraint on the actuators prevents recovery of the prestrain and participation in generation of a thermal moment during cooling. The POR chevron exhibited a thickness of ~0.061 cm (0.024 inches) and ~0.069 cm (0.027 inches) in regions without and with the embedded Nitinol, respectively, but was largely uniform within a region. The thickness difference between the two regions was shared on both sides of the laminate. The POR chevron exhibited a greater thickness variation between the two regions, with corresponding thicknesses of ~0.048 cm (0.019 inches) and ~0.071 cm (0.028 inches), and a slightly greater variation in thickness in the region between the Nitinol actuators. The thickness difference between the two regions was carried entirely on the convex side of the laminate in the POR case. The greater thickness variation and one-sided nature of the discontinuity was attributable to the flexible rubber layer on the top of the laminate. Fabrication of the POR chevron by the alternate approach involving the strategic recess in the mold surface produced parts with similar thickness distribution and variation as the POI chevrons.

The chevron prototypes were subjected to a total of 55 thermal cycles between room temperature and 132.2° C. (270° F.), while measuring the full-field temperature and out-of-plane displacement distributions. Both chevron types exhibited very repeatable performance, achieving the desired functionality without and with representative flow loading.

Although the invention has been described relative to specific embodiments thereof, and an example describing the construction of two specific chevrons has been given, nevertheless, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. As mentioned above, the chevron’s radius of curvature need not be cylindrical. For example, FIG. 13 illustrates a rectangular nozzle exit 200 and a chevron body 50 that is flat, i.e., an infinite radius of curvature. Only one chevron body is illustrated so that the shape of nozzle exit 200 is visible. Furthermore, not all chevrons at a nozzle exit need to have the same size, shape or radius of curvature. For example, FIG. 14 illustrates an elliptical nozzle exit 300 where chevron bodies 60 and 62 have different radius of curvatures. Once again, only two chevron bodies are illustrated so that the shape of nozzle exit 300 is visible. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A jet engine exhaust nozzle flow effector, comprising:
   an elastically deformable chevron having a root and a tip, said chevron formed to have a radius of curvature adapted to match a portion of the geometry of a jet engine exhaust nozzle exit such that an inner surface and an outer surface are defined and oppose one another with said inner surface facing a center of the nozzle exit; and at least one shape memory alloy (SMA) member embedded in said chevron to be closer to said inner surface than said outer surface and substantially spanning from at least a portion of said root to said tip, wherein said at least one SMA member comprises first and second SMA members arranged substantially in a V-shape with an apex of said V-shape located in proximity to said tip, and wherein said apex is located closer to said tip than said root.

2. A jet engine exhaust nozzle flow effector as in claim 1 wherein said first and second SMA members are coupled to one another at said apex to provide at least one of electrical conductivity and thermal conductivity therebetween.

3. A jet engine exhaust nozzle flow effector as in claim 1 wherein said chevron comprises a laminated structure with said at least one SMA member disposed between layers thereof.

4. A jet engine exhaust nozzle flow effector, comprising:
   an elastically deformable chevron having a root and a tip with a centerline of said chevron extending from said root to said tip, said chevron formed to have a radius of curvature symmetric about said centerline with an inner surface and an outer surface of said chevron being defined and opposing another, said chevron having a neutral axis extending from said root to said tip; and at least one shape memory alloy (SMA) member embedded in said chevron to be (i) non-coincident with said neutral axis, and (ii) substantially spanning from at least a portion of said root to said tip wherein, when said at least one SMA member contracts, said tip moves into a region defined by said radius of curvature; and wherein said at least one SMA member comprises first and second SMA members arranged substantially in a V-shape with an apex of said V-shape located in proximity to said tip, and wherein said apex is located closer to said tip than said root.

5. A jet engine exhaust nozzle flow effector as in claim 4 wherein said first and second SMA members are coupled to one another at said apex to provide at least one of electrical conductivity and thermal conductivity therebetween.

6. A jet engine exhaust nozzle flow effector as in claim 4 further comprising at least one additional SMA member embedded in said chevron to be (i) non-coincident with said neutral axis, and (ii) substantially spanning from at least a portion of said root to said tip wherein, when said at least one SMA member contracts, said tip moves into a region defined by said radius of curvature; and wherein said at least one additional SMA member is contracted, said tip moves out of said region defined by said radius of curvature.

7. A jet engine exhaust nozzle flow effector as in claim 6 wherein said at least one additional SMA member is symmetrically disposed about the centerline of said chevron.

8. A jet engine exhaust nozzle flow effector as in claim 6 wherein each said at least one additional SMA member is configured to be activated at a portion thereof that is in proximity to said root.

9. A jet engine exhaust nozzle flow effector as in claim 6 wherein said chevron comprises a laminated structure with said at least one SMA member disposed between layers thereof.

10. A jet engine exhaust nozzle flow effector, comprising:
    an elastically deformable chevron having a root and a tip with said root adapted to be fixedly coupled to a portion of a nozzle of a jet engine to thereby position said tip aft of the jet engine’s nozzle exit wherein the nozzle exit has an axial center, said chevron formed to have a radius of curvature adapted to match the geometry of a portion of the nozzle exit such that an inner surface and an outer surface are defined and oppose one another with said inner surface facing a center of the nozzle exit; and at least one shape memory alloy (SMA) member embedded in said chevron to be closer to said inner surface than said outer surface and substantially spanning from at least a portion of said root to said tip wherein said at least one SMA member comprises first and second SMA members arranged substantially in a V-shape with an apex of said V-shape located in proximity to said tip, and wherein said apex is located closer to said tip than said root.
said V-shape located in proximity to said tip, and wherein said apex is located closer to said tip than said root.

11. A jet engine exhaust nozzle flow effector as in claim 10 wherein said first and second SMA members are coupled to one another at said apex to provide at least one of electrical conductivity and thermal conductivity therebetween.

12. A jet engine exhaust nozzle flow effector as in claim 10 wherein said chevron comprises a laminated structure with said at least one SMA member disposed between layers thereof.

13. A jet engine exhaust nozzle flow effector, comprising: an elastically deformable chevron having a root and a tip with a centerline of said chevron extending from said root to said tip, said chevron formed to have a radius of curvature symmetric about said centerline with an inner surface and an outer surface of said chevron being defined and opposing one another, said chevron having a neutral axis extending from said root to said tip; and at least one shape memory alloy (SMA) member embedded in said chevron to be (i) non-coincident with said neutral axis, and (ii) substantially spanning from at least a portion of said root to said tip wherein, when said at least one SMA member is in a relaxed state while said at least one additional SMA member is contracted, said tip moves into said region defined by said radius of curvature.

14. A jet engine exhaust nozzle flow effector as in claim 13 wherein said at least one SMA member is symmetrically disposed about said centerline of said chevron.

15. A jet engine exhaust nozzle flow effector as in claim 13 wherein each said at least one SMA member is configured to be activated at a portion thereof that is in proximity to said root.

16. A jet engine exhaust nozzle flow effector as in claim 13 further comprising at least one additional SMA member embedded in said chevron to be (i) non-coincident with said neutral axis, and (ii) substantially spanning from at least a portion of said root to said tip wherein, when said at least one additional SMA member is contracted, said tip moves into said region defined by said radius of curvature.

17. A jet engine exhaust nozzle flow effector as in claim 13 wherein said chevron comprises a laminated structure with said at least one SMA member disposed between layers thereof.

18. A jet engine exhaust nozzle flow effector as in claim 13 wherein said chevron comprises a laminated structure with said at least one SMA member disposed between layers thereof.