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(54) JET ENGINE NOZZLE EXIT CONFIGURATIONS, INCLUDING PROJECTIONS ORIENTED RELATIVE TO PYLONS, AND ASSOCIATED SYSTEMS AND METHODS

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See application file for complete search history.

(57) ABSTRACT
Nozzle exit configurations and associated systems and methods are disclosed. An aircraft system in accordance with one embodiment includes a jet engine exhaust nozzle having an internal flow surface and an exit aperture, with the exit aperture having a perimeter that includes multiple projections extending in an aft direction. Aft portions of individual neighboring projections are spaced apart from each other by a gap, and a geometric feature of the multiple can change in a monotonic manner along at least a portion of the perimeter. Projections near a support pylon and/or associated heat shield can have particular configurations, including greater flow immersion than other projections.

22 Claims, 10 Drawing Sheets
Fig. 3

Fig. 4
Fig. 12
Aircraft manufacturers are under continual pressure to reduce the noise produced by aircraft in order to satisfy increasingly stringent noise certification rules. Aircraft engines are a major contributor to overall aircraft noise. Accordingly, aircraft engines in particular have been the target of manufacturers' noise reduction efforts. Aircraft engines have been made significantly quieter as a result of advanced high bypass ratio engines. These engines derive a significant fraction of their total thrust not directly from jet exhaust, but from bypass air which is propelled around the core of the engine by an engine-driven forwardly mounted fan. While this approach has significantly reduced aircraft noise when compared with pure turbojet engines and low bypass ratio engines, engine and aircraft federal regulations nevertheless continue to require further engine noise reductions.

One approach to reducing engine noise is to increase the amount of mixing between the high velocity gases exiting the engine, and the surrounding freestream air. FIG. 1 illustrates a nozzle having "chevrons" that are designed to produce this effect. Chevrons generally include certain types of serrations on the nozzle lip, typically, triangular in shape having some curvature in the lengthwise cross-section, which slightly immerses them in the adjacent flow. The chevron can project either inwardly or outwardly, by an amount that is on the order of the upstream boundary layer thickness on the inner or outer surface, respectively. In general, the chevron planform shape can also be trapezoidal or rectangular. The nozzle includes a core flow duct through which the engine core flow is directed, and a fan flow duct arranged annularly around the core flow duct, through which the fan air passes. The exit aperture of the fan flow duct can include fan flow chevrons, and the exit aperture of the core flow duct can include core flow chevrons. The chevrons typically reduce the low-frequency noise by increasing the rate at which the engine flow streams mix with the surrounding freestream air at the length scale of the nozzle diameter.

While this approach has resulted in noise reduction compared with nozzles that do not include chevrons, further noise reduction is desired to meet community noise standards.
DETAILED DESCRIPTION

Aspects of the present disclosure are directed to nozzle exit configurations and associated systems and methods. Specific details of certain embodiments are described below with reference to FIGS. 2-14. Several details of structures or processes that are well-known and often associated with such methods and systems are not set forth in the following description for purposes of brevity. Moreover, although the following disclosure sets forth several embodiments of different aspects of the invention, several other embodiments of the invention can have different configurations or different components than those described in this section. Accordingly, the disclosure may have other embodiments with additional elements and/or without several of the elements described below with reference to FIGS. 2-14.

FIG. 2 is an illustration of a commercial jet transport aircraft [200] having wings [202], a fuselage [201], and a propulsion system [203]. The illustrated propulsion system [203] includes two turbofan engines [206] mounted to the wings [202]. Each engine [206] is housed in a nacelle [204], which includes an inlet [205] and a nozzle [220]. The nozzle [220] has particular features, discussed in greater detail below, that reduce and/or direct the noise generated by the engines [206] in a selected manner. As is also discussed below, the manner in which the noise is reduced and/or directed can depend upon a particular installation of the propulsion system [203]. Accordingly, in other embodiments, the aircraft [200] can include a different number of engines and/or engines carried by different portions of the aircraft, along with nozzles [220] that are tailored to the particular installation.

FIG. 3 is an enlarged side elevation view of an embodiment of the nozzle [220] of FIG. 2 as shown with reference to FIGS. 2-14. The nozzle [220] can include a fan flow duct [230] having a fan internal flow surface [232] that directs fan flow away from the upstream engine along a fan flow path [231]. The nozzle [220] also includes a core flow duct [240] having a core internal flow surface [242] that directs the core flow away from the engine along a core flow path [241]. The fan flow duct [230] terminates at a fan exit aperture [233] that is defined in part by a fan aperture perimeter [234] having multiple first or fan flow projections [235] that extend in an aft direction. Each of the fan flow projections [235] can have a generally triangular or chevron shape in a particular embodiment shown in FIG. 3, and can accordingly include aft or tip portions [219] that are spaced apart from each other by a gap [218]. The fan flow projections [235] can have other shapes (e.g., trapezoidal or irregular) in other embodiments. As is also shown in FIG. 3, at least one geometric feature of the fan flow projections [235] changes in a generally monotonic manner along at least a portion of the fan aperture perimeter [234]. For example, as shown in FIG. 3, the length of successive fan flow projections [235] changes in a circumferential direction around the fan aperture perimeter [234]. As will be discussed in greater detail below, other features of the fan flow projections [235] may be changed in addition to, or in lieu of, the length of the projections.

As is also shown in FIG. 3, the core flow path [241] terminates at a core exit aperture [243] having a perimeter [244] with a core exit aperture perimeter [245]. The core flow projections [245] are arranged in accordance with a monotonic change of this geometric feature extends over a portion of the core exit aperture perimeter [244] of the core exit aperture [243]. In other embodiments discussed later with reference to additional Figures, the core flow projections [245] can have geometric features that vary around the perimeter [244]. The manners in which the core flow projections [245] and/or the fan flow projections [235] vary can depend upon factors which can include the manner in which the nozzle [220] is mounted to an aircraft, the frequency range over which noise reduction is desired, and/or the region of the local environment in which the noise is to be reduced (e.g., the ground beneath the aircraft and/or the aircraft interior). The nozzle [220] can have either fan flow projections [235], core flow projections [245], or both. In at least some embodiments, the projections may extend around only a portion of the corresponding perimeter (e.g., with no projections on the remainder of the perimeter), and/or they have irregular spacings.

FIG. 4 is a forward-looking schematic view of the nozzle [220], schematically illustrating the fan flow projections [235] and the core flow projections [245]. As shown in FIG. 4, the length of the fan flow projections [235] changes in a monotonic fashion from the 12:00 position to the 6:00 position in both clockwise and counterclockwise directions. Accordingly, the monotonic change of this geometric feature extends over 180° of the fan aperture perimeter [234] (e.g., opposite lateral halves of the nozzle [220] are generally symmetric). In other embodiments, the change can take place over a greater or lesser circumferential range. For example, the monotonic change may in some embodiments extend over a portion of the fan exit aperture [234] occupied by three fan flow projections [235]. In still further embodiments, the monotonic variations can apply to groups or sets of fan flow projections [235].
For example, pairs of fan flow projections 235 (or core flow projections 245) may have characteristics that vary in a monotonic manner. Further details of one such arrangement are described below with reference to FIG. 11D. In any of these embodiments, the change in the geometric feature can result in an asymmetric nozzle 220. FIG. 5 is a partially schematic, side elevation view of the nozzle 220 and the nacelle 204 installed on the wing 202. In this arrangement, the nacelle 204 is carried below the wing 202 and is supported by a pylon 207 relative to the wing 202.

Accordingly, the fan flow projections 235 are longer toward the wing 202 than they are away from the wing 202, which can advantageously reduce nozzle noise without compromising thrust levels. In particular, the wing 202 can include movable trailing edge devices 208, such as flaps. The exhaust jet flow exiting the nozzle 220 can interact with the wing 202, and particularly with any trailing edge devices 208. This jet-flap interaction can increase the noise above that which is generated by the nozzle 220 alone. Such interactions can also occur between the downstream wake of the pylon 207 and the exhaust flow. Accordingly, it may be advantageous to encourage additional mixing between the nozzle flow and the adjacent freestream flow near the pylon 207 and near the lower surface of the wing 202, including near the trailing edge device 208 to reduce this jet-flap interaction.

The projections can enhance mixing between the jet flow and the ambient flow by introducing axial or streamwise vorticity generated by the pressure difference between the outwardly and inwardly facing surfaces of the fan flow projections 235. It is expected that by encouraging additional mixing in these regions, the flow velocity gradients, and/or the flow velocity magnitudes in these regions will be reduced, compared to levels that would be present without the enhanced mixing provided by the fan flow projections 235.

The enhanced mixing that can lead to decreased turbulence intensity far away from the nozzle can also increase it near the nozzle. Accordingly, the elongated fan flow projections 235 can be concentrated in the region expected to provide an enhanced acoustic performance (e.g., toward the top of the nozzle 220). At the same time, the fan flow projections 235 positioned toward the bottom of the nozzle 220 can be smaller than those positioned toward the top. An expected benefit of this arrangement is that the smaller projections 235 near the bottom of the nozzle 220 impinge less into the flow exiting the nozzle 220 and accordingly have a reduced impact on the mass flow exiting the nozzle 220 and the turbulence intensity downstream near the bottom sector. As a result, the potential reduction in thrust created by the presence of the fan flow projections 235 and the potential increase in the turbulence intensity overall can be mitigated by having smaller fan flow projections 235 in those regions that may not be as important for sound reduction as other regions.

FIG. 6A schematically illustrates the effect described above. In this figure, a thrust vector T and an acoustic intensity vector A are superimposed on a schematic illustration of the nozzle 220. The thrust vector T represents the direction and magnitude of the thrust produced by the nozzle 220, and the acoustic intensity vector A represents the direction and magnitude of the vector sum of far field acoustic intensities in the upper and lower hemispheres projected in the plane of the nozzle axis and the observer at a particular frequency or range of frequencies. For a nozzle having no projections, or uniform projections (such as are shown in FIG. 1), the thrust vector T and the acoustic intensity vector A are generally parallel but in opposite directions and generally axial. By tailoring the fan flow projections 235 in a manner shown in FIGS. 3-5, the acoustic intensity vector component directed toward the observer (assumed to be below the nozzle in FIG. 6A) can be reduced. This can be achieved by directing the acoustic intensity vector A effectively upward, thus reducing the downwardly directed component, or simply by reducing the magnitude of the acoustic intensity vector A without changing its direction. At the same time, the thrust vector T can remain axial. In fact, in a particular embodiment using this arrangement, the direction of the thrust vector T with the azimuthally varying fan flow projections 235 is identical or nearly identical to that associated with a nozzle having no projections.

FIGS. 6B and 6C compare measured acoustic test data proximate to an uninstalled baseline nozzle 20 generally similar to that shown in FIG. 1, with an uninstalled nozzle 220 generally similar to that shown in FIG. 3. At the particular frequency shown in these Figures (1225 Hz), the peak acoustic emission level at the source is reduced by approximately 1.4 dB, as is indicated graphically by the contour plots of constant sound level shown in these Figures. At the same time, the overall thrust vector direction is expected to be unchanged (e.g., axial), for the configuration shown in FIG. 6C, as compared with the baseline configuration shown in FIG. 6B. The thrust level for the configuration shown in FIG. 6C is expected to be at least very close to, if not equal to, the thrust level for the configuration shown in FIG. 6B. It is expected that the low impact of the circumferentially varying fan flow projections 235 on the thrust level may be due to the smaller projections 235 at the bottom perimeter of the nozzle 220 leading to a higher effective area of the nozzle. These projections tend not to extend into the nozzle exit flow by a great amount (e.g., they are not significantly immersed in the nozzle flow), and so have a reduced impact on nozzle mass flow rate, discharge coefficient and thrust. The foregoing results for noise reduction at the source are expected to also be significant for community noise reduction.

A comparison of acoustic data far away from the nozzle 220 (in the “far field”) at low frequencies showed that the isolated nozzle 220 reduced noise compared to an isolated conventional round nozzle (with no projections) over a large sector of all angles by about 3 to 4 dB at take-off and, and by about 1.5 dB when compared to an isolated baseline nozzle 20 generally similar to that shown in FIG. 1. Under installed conditions, the range of observer angles and the frequencies over which the noise benefit attributed to the nozzle 220 is observed is reduced somewhat, impacting the overall noise benefit; however, embodiments of the installed nozzle 220 is still quieter than the baseline nozzle 20 (FIG. 1).

One feature of the foregoing embodiments described above with reference to FIGS. 3-6C is that azimuthally or circumferentially varying one or more geometric features of the fan flow projections 235 can reduce overall acoustic emissions from the engine, without an adverse or significantly adverse effect on engine thrust. In particular, relatively low frequency noise may be reduced and/or deflected away from observers on the ground. This noise is generally associated with jet-mixing interactions, for example, the type of mixing that occurs between the exhaust jet and the freestream flow, particularly adjacent to the pylon and the wing. The effect of reducing jet-wing and/or jet-pylon interaction noise can be particularly important on takeoff and approach, where community noise issues are a significant design factor. In particular, during takeoff, jet velocities are very high (although the trailing edge devices are typically not deployed by a great amount), while on landing, the trailing edge devices are deployed by a greater amount, while the jet exit velocities are not as high. In either embodiment, jet interaction noise can be a significant contributor to the overall acoustic signature of the aircraft, and can be reduced by a beneficial amount with-
out a significant thrust penalty, as a result of projections having geometric features that vary circumferentially around the nozzle exit.

Another contributor to the overall acoustic signature of the aircraft is shockcell noise, which is typically associated with supersonic fan flow. Accordingly, shockcell noise may also be reduced by projections which diminish circumferential coherence and thereby weaken the shockcells addressed by the arrangement of the fan flow projections. In some cases, the core flow may also contribute to shockcell noise, in which case the second or core flow projections may be tailored, in addition to (or in lieu of) tailoring the fan flow projections.

Comparison of shockcell noise data between an embodiment of the nozzle 220 and a conventional round coxial nozzle without projections (during a flight test at cruise conditions) showed a noise reduction of up to 5 dB on the exterior of the fuselage on the side where the engine was located. At the same time, the overall thrust vector direction between these two nozzles was unchanged, and the thrust level of the nozzle 220 actually increased slightly (0.65% at cruise) when compared to the conventional nozzle with no projections.

FIG. 7 illustrates a nozzle 720 having first or fan flow projections 735 and second or core flow projections 745. The fan flow projections 735 and the core flow projections 745 vary in monotonic, opposite manners. That is, the fan flow projections 735 tend to be longer toward the bottom of the nozzle 720 than toward the top of the nozzle 720, while the core flow projections 745 vary in the opposite manner. The variation of the fan flow projections 735 is the opposite of the arrangement of fan flow projections 235 shown in FIG. 3. Accordingly, this arrangement may be suitable when the nozzle 720 is carried by a pylon extending downwardly (rather than upwardly) from the engine. Such an arrangement is shown in FIG. 8. In particular, FIG. 8 illustrates the wing 202 with an upper surface mounted pylon 807 carrying a nacelle 804 housing the nozzle 720. In this arrangement, the trailing edge devices 208 deploy downwardly (in a typical fashion) and, therefore, may not contribute significantly to the jet-flap interaction noise described above. However, the downstream wake of the pylon 807 may interact with the exhaust products and accordingly, it may be advantageous to have the fan flow projections 735 be longer in a region adjacent to the pylon 807, than in a region distant from the pylon 807.

FIG. 9A illustrates an aircraft 900 having two engine nacelles 904a, 904b that depend from or are at least proximate to the fuselage 901. In this particular embodiment, each of the engine nacelles 904a, 904b is carried by the fuselage 901 via a corresponding pylon 907. The nacelles 904a, 904b can include fan flow projections 935a, 935b that are configured to reduce the noise transmitted to the interior of the fuselage 901 (e.g., the passenger compartment). In particular, the fan flow projections 935a, 935b can be longer at a position close to the fuselage 901 than they are in a position distant from the fuselage 901. As a result, the fan flow projections 935a on the left nacelle 904a tend to be longest near the 3:00 position, and shortest near the 9:00 position, while the fan flow projections 935b on the second nacelle 904b have the opposite arrangement. It is expected that the enhanced mixing provided by the longer fan flow projections 935a, 935b near the fuselage 901 can reduce the acoustic signature close to the fuselage 901, and can accordingly reduce the sound level experienced by passengers within the passenger compartment. The fan flow projections 935a, 935b that are more distant from the fuselage 901 can be shorter so as to reduce the overall effect of the fan flow projections 935a, 935b on engine thrust. FIG. 9B illustrates an acoustic intensity vector A corresponding to the sound level expected to be produced by the left nacelle 904a at a given frequency. In particular, the net acoustic intensity vector A points outwardly away from the fuselage 901, indicating that sound levels are expected to be lower near the fuselage 901 than distant from the fuselage 901.

The manner in which the geometric features of the projections vary around the perimeter of the nozzle can be selected to have a wide variety of effects, and different feature changes can be superimposed so as to address different acoustic requirements simultaneously. While superimposing different feature changes may not necessarily result in an optimum level of noise reduction for each requirement, the combination may be one that results in an overall noise reduction that meets multiple design requirements. For example, the longer fan flow projections 235 positioned toward the top of the nozzle (described above with reference to FIG. 3) may be combined with the longer projections 935a, 935b positioned toward the inboard side of the nozzle (described above with reference to FIG. 9A). The result may be fan flow projections having an increased length toward the top of the nozzle to reduce jet-flap interaction noise, and also longer toward the fuselage to reduce cabin noise. The projections may be shorter toward the bottom of the nozzle and toward the side of the nozzle away from the fuselage, so as not to significantly impact the overall exhaust product mass flow and thrust level, in a region of the nozzle where reduced acoustic signature may not be as important as it is near the fuselage and near the wing.

FIG. 9C schematically illustrates a nacelle 904c and nozzle 920 having projections configured to meet multiple acoustic objectives in the manner described above. In particular, longer projections 935c toward the top of the nozzle 920 are positioned to reduce jet-mixing noise (e.g., due to an overhead wing and/or pylon), as represented by a first acoustic radiation vector A1. Longer projections 935d toward the inboard side of the nozzle 920 are positioned to reduce shockcell noise, as represented by a second acoustic vector A2.

FIG. 9D schematically illustrates a nozzle 920 configured in accordance with another embodiment of the invention to include two types of azimuthally varying projections: fan flow projections 935d that are longer and/or more immersed toward the top of the nozzle (near the pylon), and core flow projection 945d having monotonically decreasing lengths in a direction away from the fuselage 901. It is expected that this arrangement can reduce both community noise at low frequencies and shockcell/cabin noise at higher frequencies.

In still further embodiments, the manner in which the projections vary around the nozzle perimeter (and therefore the degree of mixing between the adjacent flows) can be changed depending on flight regime of the aircraft, by changing the degree to which the projections are immersed as a function of time. This arrangement can be used to reduce different spectra of noise in different flight regimes. For example, to obtain more mixing between the fan flow and the freestream air near the pylon (e.g., to reduce low-frequency noise during takeoff), the projections near the pylon can be actively bent inwardly during takeoff. If mid-frequency shockcell noise at cruise is reduced by another type of azimuthal variation, (e.g., by immersing projections near the fuselage by a greater amount than projections away from the fuselage), then this change can be made during the appropriate flight regime (e.g., during cruise). Such desired azimuthal variations in projection immersions can be obtained, for example, by using shape memory alloys inside the projections and suitable heat control elements. This arrangement can be applied to fan flow projections, and core flow projections. Further aspects of
active systems for accomplishing this variation are included in U.S. Pat. No. 6,718,752, incorporated herein by reference.

As discussed above, certain aspects of the manners by which projection geometric features are varied can be combined in a variety of ways. FIG. 10 illustrates schematically representative features that may be applied to the fan flow projections (along the horizontal axis), and/or the core flow projections (along the vertical axis). In these illustrations, R refers to regular or baseline projections that do not vary circumferentially, T refers to projections that are longer toward the top than the bottom, B refers to projections that are longer toward the bottom than the top, K refers to an arrangement in which projections are longer toward the top and the bottom, and V refers to an arrangement in which the immersion or degree to which the projections are bent inwardly toward the flow varies around the circumference of the nozzle, but the length does not. Depending upon the desired acoustic signature and the particular installation in which the nozzle is placed, these features may be combined in any of a variety of manners.

FIGS. 11A-11E illustrate representative features of individual projections 1135 that may be varied in accordance with particular embodiments of the invention. For example, FIG. 11A illustrates multiple projections 1135 located at a perimeter 1121 of a corresponding nozzle 1120. Geometric features of each projection 1135 that can be varied include the length 1122 of the projection 1135, the width 1123 of the projection 1135, and/or the apex angle 1124 of the projection 1135. The overall shape of the projection 1135 may also be varied. For example, the projections 1135 can have a triangular or chevron shape as shown in FIG. 11A, with generally sharp vertices, or the projections 1135 may have other shapes and/or shapes with rounded or other less abrupt transitions between edges. The number of projections 1135 per unit length of the perimeter 1121 is another variable that may be selected to have the desired effect on the acoustic signature, again depending upon the particular installation. As shown in FIG. 11B, the angle 1125 between the projection 1135 and the flow surface located just upstream of the projection 1135, or the curvature of the projection 1135, can also be varied so as to vary the immersion or degree to which the projection 1135 is deflected or bent inwardly into the nozzle flow. As shown in FIG. 11C, the density of projections 1135 (e.g., the number of projections 1135 per unit length along the nozzle exit perimeter) can also be varied. As noted above, in particular embodiments, there may be portions of the nozzle perimeter or circumference without projections, and/or the gap spacing between projections may vary in an irregular manner.

Many of the foregoing factors may be varied in combination with each other to produce a desired geometry. For example, if each projection 1135 has a fixed width 1123, then reducing the length 1122 of the projection 1135 will change the apex angle 1124. In at least some embodiments, the projections 1135 form part of an inwardly-sloping body of revolution around the axial centerline of the nozzle. Accordingly, longer projections 1135 will tend to be more immersed in the nozzle flow than shorter projections. In other embodiments the projections can be deflected outwardly away from the nozzle centerline, as opposed to inwardly toward the nozzle centerline. Similar considerations can be applied to determine the geometric features of such projections.

In a particular embodiment shown in FIG. 11D, at least some adjacent projections can be alternately immersed inwardly and outwardly (e.g., by the same amount or by different amounts). Accordingly, the nozzle 1120 can include pairs of inwardly deflected projections 1135a and outwardly deflected projections 1135b. The vortices from the adjacent edges of an inwardly deflected projection 1135a and a neighboring outwardly deflected projection 1135b tend to merge to form only one axial vortex from those adjacent edges. Thus, for all practical purposes, each pair of alternately immersed projections can act like one projection having a larger combined width and a stronger axial vorticity. The parameters described above for obtaining azimuthal variation of mixing with respect to individual neighboring projections can also apply to each pair taken as a unit. For example, in order to obtain a monotonic variation in mixing from the top of the nozzle 1120 to the bottom of the nozzle 1120 the projections 1135a, 1135b can have a monotonically decreasing level of immersion (inwardly for the inwardly deflected projections 1135a and outwardly for the outwardly deflected projections 1136b) from top to bottom. In other embodiments, other geometric characteristics of the projection pairs can be varied.

FIG. 11E illustrates a nozzle 1120 configured in accordance with another embodiment of the invention. The nozzle 1120 is positioned proximate to a pylon 1107 (a portion of which is visible in FIG. 11E), which in turn includes a heat shield 1109 to protect the pylon 1107 from hot exhaust gases in an exhaust core flow 1147. The nozzle 1120 includes a fan exit aperture 1133 (through which a fan flow 1148 passes) and a core exit aperture 1143 (through which the core flow 1147 passes) which may be positioned annularly around a nozzle plug 1110. The core exit aperture 1143 can include first core flow projections 1145e and second core flow projections 1145f. The second core flow projections 1145f are positioned proximate to the heat shield 1109 and can be longer and/or more immersed in the core flow than the first core flow projections 1145e. It is expected that this arrangement will increase mixing between the (relatively hot) core flow 1147 and the (cooler) fan flow 1148, thereby reducing the temperature at the sides of the pylon 1107, as discussed in greater detail below. The fan exit aperture 1133 can include no projections, as shown in FIG. 11E, or in other embodiments, it can include fan flow projections having any of the characteristics described above.

In a particular aspect of the arrangement shown in FIG. 11E, the pylon 1107 can include a first side 1112a facing in a first direction, and a second side 1112b facing in the opposite direction. The heat shield 1109 can be generally positioned adjacent to the downwardly facing portion of the pylon, and can terminate at the sides 1112a, 1112b of the pylon 1107. Accordingly, the outer edges of the heat shield 1109 can be generally aligned with the first and second sides 1112a, 1112b of the pylon 1107. The lower portion of the pylon 1107 and/or the heat shield 1109 can be slightly flared in an outward direction, as shown in FIG. 11E, or it can include no flare or a greater amount of flare in other embodiments.

The second core flow projections 1145f can include a first pylon projection 1146a and a second pylon projection 1146b (e.g., "corner projections" or "pylon projections") that have particular orientations, configurations, and/or locations relative to features of the pylon 1107, including (but not limited to) the sides 1112a, 1112b and/or the heat shield 1109. Each of the pylon projections 1146a, 1146b can include a tip 1125, e.g., a point or a rounded tip or region of the projection that extends further aft than the rest of the projection, and/or is more immersed in the core flow than the rest of the projection. The pylon projections 1146a, 1146b can also include inner roots or valleys 1126a, 1126b that are offset circumferentially and axially forward of the tip 1125. In a particular aspect of an arrangement shown in FIG. 11E, the inner roots or valleys 1126a, 1126b of the pylon projections 1146a, 1146b are...
the heat shield 1109 and/or the core exhaust, or they can have other orientations (e.g., unflared, as shown in FIG. 11F), this arrangement can further reduce the degree of jet-flap interaction noise reduction associated with the core flow produced by the nozzle 1120. The particular solution selected as a result of the foregoing design methodology can also be chosen to produce the lowest weight configuration or can be selected to emphasize other desirable characteristics. An advantage of this design methodology is that it recognizes and can exploit the interdependency of these geometric features.

As discussed above, an advantage of pylon projections 1146a, 1146b having any one or combination of the features described above is that they can reduce the exposure of the core flow projections 1112a, 1112b and/or the heat shield 1109 to heat from the exhaust core flow, while the remaining projections produce enhanced noise reduction. In particular embodiments, this effect can be achieved by entraining additional by-pass air from the adjacent by-pass air flow path, and/or by increasing vorticity in the region adjacent to the pylon 1107. This effect can be of increased importance during cross-wind conditions, when the hot core flow exhaust may have an increased effect in a lateral direction, and hence an increased effect on the pylon 1107.

In a particular embodiment, the foregoing characteristics can be used to configure the pylon projections 1146a, 1146b and the heat shield 1109 in an interdependent manner. For example, the pylon projections 1146a, 1146b can have a particular configuration (e.g., location, position, and/or geometry), and the heat shield 1109 can be configured to provide sufficient heat protection to the pylon 1107 in light of the expected flow characteristics produced by the pylon projections 1146a, 1146b. The configurations of both elements can then be adjusted in an interdependent manner to produce a design that results in both adequate heat protection for the pylon 1107, and adequate sound attenuation for the overall flow produced by the nozzle 1120. The particular solution selected as a result of the foregoing design methodology can also be chosen to produce the lowest weight configuration or can be selected to emphasize other desirable characteristics. An advantage of this design methodology is that it recognizes and can exploit the interdependency of these geometric features.

FIG. 12 is a schematic illustration of four nozzles, labeled 1220a-d, each of which has core flow projections with a different configuration, in accordance with several embodiments. For example, nozzle 1220a has core flow projections that do not vary in a circumferential direction, nozzle 1220b has core flow projections that are longer at the top than at the bottom, nozzle 1220c has the opposite arrangement, and nozzle 1220d has core flow projections that are longer at the top and bottom and shorter in an intermediate region. In this particular embodiment, the fan flow projections for each of these nozzles are uniform. The graph of FIG. 12 illustrates the level of jet-flap interaction noise reduction associated with each of the nozzle configurations 1220a-d, as a function of frequency (on a logarithmic scale) compared to a simple round coaxial nozzle with no projections. Nozzles 1220a, b, d each reduce noise by a lesser amount at lower frequencies than at lower frequencies. By contrast, nozzle 1220c has a greater noise reduction capability at higher frequencies than at lower frequencies. FIG. 12 accordingly indicates that the manner in which the geometric feature varies around the perimeter of the nozzle may be selected based (at least in part) on the frequency of the noise that is to be reduced. If lower frequency noise is to be reduced, nozzles 1220a, b, or d may be appropriate, and if higher frequency noise is to be reduced, nozzle 1220c may be more appropriate. Typically, community noise is a greater problem at lower frequencies than at higher frequencies, while cabin noise is typically a greater problem at higher frequencies than at lower frequencies. Accordingly, the appropriate arrangement of nozzle projections (or combination of nozzle projection arrangements) can be selected in a manner that depends on the particular noise reduction target. Similar noise reduction trends as a function of frequency were found for nozzles having varying fan flow projections and uniform core flow projections; however, at
least some of these cases, the reduction in the noise that is due
to jet-flap interaction was higher than for the (baseline) nozzle
1220a.
FIGS. 13A-C and 14 illustrate further geometric fea-
tures that may be varied to achieve desired thrust and acoustic
performance in accordance with the embodiments of the inven-
tion. In particular, FIGS. 13A-C illustrate nozzles
having different root locus lines 1326 (shown as root locus
lines 1326a-1326c) and tip locus lines 1327 (shown as tip
locus lines 1327a-1327c). The root locus lines 1326a-1326c
connect the root locations of successive fan flow projections
1335, and the tip locus lines 1327a-1327c connect the tip
locations of the same projections 1335. FIG. 13A illustrates a
generally vertical root locus line 1326a and an aft-canted tip
locus line 1327a. FIG. 13B illustrates a forwardly-canted root
locus line 1326b and a generally vertical tip locus line 1327b.
FIG. 13C illustrates a forwardly-canted root locus line
1326c, an aft-canted tip locus line 1327c, and a generally
vertical centroid locus line 1328c. The appropriate orienta-
tion of the root and tip locus lines may be selected to produce
the desired acoustic vector, thrust vector, and/or other appro-
appropriate parameter. For example, canting the root locus line
1326 and/or the tip locus line 1327 may cant the thrust vector.
If a particular azimuthal arrangement of projections 1335
shifts the thrust vector in an undesirable manner, canting the
root locus line 1326 and/or the tip locus line 1327 can be used
to correct the thrust vector back to the desired orientation.
This methodology is illustrated in the context of fan flow
projections, but may be applied to core flow projections in
addition to or in lieu of the fan flow projections.
FIG. 14 illustrates the "rolling ball" flow area through the
fan flow duct of a nozzle configured in accordance with
another embodiment of the invention. FIG. 14 illustrates that
the nozzle has a locally convergent-divergent arrangement,
with a geometric throat T upstream of a corresponding root
locus line 1426. This arrangement is expected to have several
beneficial effects. For example, a local convergent-divergent
region of the nozzle is expected to have enhanced aerody-
amic effects at particular flight regimes. By positioning the
geometric throat T upstream of the root locus line 1426, the
effective exit area of the nozzle can be controlled such that it
does not become susceptible to fan instability problems at low
nozzle pressure ratios of the fan stream. The latter can occur
when using inwardly immersed fan flow projections which
can aerodynamically effectively behave like convergent
nozzles. The shape of the projections that controls the local
convergent-divergent behavior of the rolling ball area can be
used to control the effective exit area and avoid fan instabil-
ties. It is expected that this arrangement can reduce thrust
degradation. It will be understood that in at least some cases,
the nozzle can include an aerodynamic convergent section
downstream of the local convergent-divergent region dis-
cussed above.
For the foregoing, it will be appreciated that specific
embodiments of the invention have been described herein for
purposes of illustration, but that various modifications may be
made without deviating from the invention. For example,
several of the embodiments described above were described in
the context of nozzles having core flow paths that extend
axially further aft than the corresponding fan flow paths (e.g.,
externally mixed nozzles). In other embodiments, the nozzles
may be internally mixed and may have fan flow paths that
extend further aft than the corresponding core flow paths. The
nozzles may have a variety of exit perimeter shapes, including
round, rectangular, and elliptical.
Still further embodiments are described in the following
documents, all of which are incorporated herein by reference:
AIAA Paper 2001-2185, entitled "Computational Analysis of a
Pylon-Chevron Core Nozzle Interaction, dated May 28-30,
of High Bypass Ratio Separate Flow Nozzle Configurations";
AIAA Paper 2006-2467, entitled "Reducing Propulsion Air-
frame Aeroacoustic Interactions with Uniquely Tailored
Chevrons: 1. Isolated Nozzles," dated May 8-10, 2006; AIAA
Paper 2006-2434, entitled "Reducing Propulsion Airframe
Aeroacoustic Interactions with Uniquely Tailored Chevrons:
2. Installed Nozzles," dated May 8-10, 2006; AIAA Paper
2006-2435, entitled "Reducing Propulsion Airframe Aero-
acoustic Interactions with Uniquely Tailored Chevrons: 3. Jet-
Flap Interaction," dated May 8-10, 2006; AIAA Paper 2006-
2439, entitled "Flight Test Results for Uniquely Tailored
Propulsion-Airframe Aeroacoustic Chevrons: Shockwave
Noise," dated May 8-10, 2006; AIAA Paper 2006-2438,
 entitled "Flight Test Results for Uniquely Tailored Propul-
sion-Airframe Aeroacoustic Chevrons: Community Noise,"
dated May 8-10, 2006; AIAA Paper 2006-2436, entitled
"Computational Analysis of a Chevron Nozzle Uniquely Tai-
lored for Propulsion Airframe Aerodynamics," dated May
8-10, 2006; AIAA Paper 2005-0996, entitled "Relative
Clocking of Enhanced Mixing Devices for Jet Noise Benefit,
" dated Jan. 10-13, 2005; AIAA Paper 2005-2934, entitled "Jet
Noise Characteristics of Chevrons in Internally Mixed
Nozzles," dated May 23-25, 2005; and AIAA Paper 2006-
0623, entitled "Internal Flow and Noise of Chevrons and
Aspects of the disclosure described in the context of par-
ticular embodiments may be combined or eliminated in other
embodiments. For example, many of the geometric features
described individually above may be combined in any of a
variety of manners to meet corresponding acoustic and thrust
design goals, while integrating appropriately with other struc-
tures of the aircraft into which the nozzles are integrated.
Further, while advantages associated with certain embodi-
ments of the disclosure have been described in the context of
those embodiments, other embodiments may also exhibit
such advantages, and not all embodiments need necessarily
exhibit such advantages to fall within the scope of the disclu-
We claim:
1. An aircraft system, comprising:
a pylon having a first side, a second side facing opposite
the first side, and a heat shield having a first edge proximate
to the first side of the pylon and a second edge proximate
to the second side of the pylon; and
a jet engine exhaust nozzle carried by the pylon and having
an internal flow surface adjacent a hot exhaust flow path,
the internal flow surface having an exit aperture with a
perimeter that includes multiple projections extending in an
axial direction and circumferentially spaced about the
perimeter, with a geometric feature of the multiple
projections changing in a monotonic manner along at
least a portion of the perimeter, wherein a first projection
nearest the first side of the pylon and a second projection
nearest the second side of the pylon are both oriented
inwardly into the flow path by a greater amount than the
remaining projections, and wherein at least a portion of
the first projection is positioned circumferentially out-
wardly from the first edge of the heat shield and at least
a portion of the second projection is positioned circum-
ferentially outwardly from the second edge of the heat
shield.
2. The system of claim 1 wherein at least a portion of the
first projection is positioned circumferentially outwardly
from the first side of the pylon and at least a portion of the
second projection is positioned circumferentially outwardly from the second side of the pylon.

3. The system of claim 1 wherein:
   a. each of the first and second projections has a generally triangular shape with a root and a tip;
   b. the root of the first projection has a first orientation relative to the first side of the pylon; and
   c. the root of the second projection has a second orientation relative to the second side of the pylon that generally mirrors the first orientation.

4. The system of claim 3 wherein the root of the first projection is offset from the first side of the pylon by a first value in a first direction, and wherein the root of the second projection is offset from the second side of the pylon by a second value generally the same as the first value in a second direction generally opposite the first direction.

5. The system of claim 4 wherein the root of the first projection is offset from the first side of the pylon by a first angle in a first direction, and wherein the root of the second projection is offset from the second side of the pylon by a second angle generally the same as the first angle in a second direction generally opposite the first direction.

6. The system of claim 4 wherein the root of the first projection is offset from the first side of the pylon by a first distance in a first direction, and wherein the root of the second projection is offset from the second side of the pylon by a second distance generally the same as the first distance in a second direction generally opposite the first direction.

7. The system of claim 3 wherein the tip of the first projection is offset from the first side of the pylon by a first value in a first direction, and wherein the tip of the second projection is offset from the second side of the pylon by a second value generally the same as the first value in a second direction generally opposite the first direction.

8. The system of claim 3 wherein the tip of the first projection is circumferentially aligned with the first side of the pylon and wherein the tip of the second projection is circumferentially aligned with the second side of the pylon.

9. The system of claim 1 wherein the first projection is inclined radially inwardly into the flow by a greater amount than is a neighboring projection located circumferentially outwardly from the first projection.

10. The system of claim 1 wherein the first projection has a greater axial extent than does a neighboring projection located circumferentially outwardly from the first projection.

11. The system of claim 1 wherein the exhaust nozzle includes a fan flow path positioned radially outwardly from the internal flow surface.

12. A method for operating an aircraft engine, comprising:
   a. directing a flow of hot exhaust gas from an aircraft engine through an exhaust nozzle exit aperture, the aperture having a perimeter with axially extending projections arranged around the perimeter, and with a geometric feature of the projections changing in a monotonic manner along at least a portion of the perimeter; and
   b. controlling the flow of hot exhaust gas near a pylon supporting the engine by directing the flow adjacent to first and second projections located at least partially outwardly from and nearest to first and second oppositely facing sides of the pylon, the first and second projections being oriented inwardly into the flow by a greater amount than are the remaining projections, wherein the pylon includes a heat shield having a first edge proximate to the first side of the pylon and a second edge proximate to the second side of the pylon, and wherein at least a portion of the first projection is positioned circumferentially outwardly from the first edge of the heat shield and at least a portion of the second projection is positioned circumferentially outwardly from the second edge of the heat shield.

13. The method of claim 12 wherein controlling the flow includes at least restricting the hot flow from passing adjacent to at least one of the sides of the pylon.

14. The method of claim 12 wherein controlling the flow includes directing the hot flow from entering into the side of the pylon or the heat shield compared with an axial vorticity component of the flow at other circumferential locations around the nozzle exit aperture.

15. The method of claim 12 wherein each of the first and second projections has a generally triangular shape with a tip and an inner and outer root, and wherein directing the hot flow includes directing the flow adjacent to the outer root of the first projection that is located circumferentially outwardly from the first side of the pylon, and directing the flow adjacent to the outer root of the second projection that is located circumferentially outwardly from the second side of the pylon.

16. The method of claim 12 wherein controlling the flow includes increasing an axial vorticity component of the flow near the pylon or the heat shield compared with an axial vorticity component of the flow at other circumferential locations around the exit aperture.

17. The method of claim 12 wherein controlling the flow includes controlling an amount of heating at the sides of the pylon.

18. A method for designing an aircraft system, comprising:
   a. sizing an engine pylon for carrying an aircraft engine and exhaust nozzle having a hot exhaust flow path,
   b. configuring a set of multiple projections extending aft around an exit aperture of the nozzle to have a geometric feature that changes in a monotonic manner along at least a portion of a perimeter of the exit aperture, the projections including a first projection positioned nearest a first side of the pylon and a second projection positioned nearest a second side of the pylon facing generally opposite the first side; and
   c. configuring a heat shield positioned to protect the pylon from exhaust gases, wherein configuring at least one of the heat shield and the set of projections is based at least in part on expected results of configuring the other of the heat shield and the set of projections, and wherein configuring at least one of the heat shield and the set of projections includes configuring at least a portion of the first projection to be circumferentially outwardly from a first edge of the heat shield positioned proximate to the first side of the pylon, and at least a portion of the second projection to be circumferentially outwardly from a second edge of the heat shield positioned proximate to the first side of the pylon.

19. The method of claim 18 wherein configuring multiple projections includes configuring the first and second projections to be immersed in the exhaust flow path to a greater degree than the remaining projections.

20. The method of claim 19 wherein configuring the first and second projections includes configuring the first and second projections to be angled inwardly into the flow path by a greater degree than the remaining projections.

21. The method of claim 18 wherein each of the first and second projections includes a tip and a root, and wherein configuring the heat shield includes aligning edges of the heat shield to be offset inwardly from the tips of the first and second projections.

22. The method of claim 18 wherein each of the first and second projections includes a tip and a root, and wherein configuring the heat shield includes aligning edges of the heat shield to be circumferentially aligned with the tips of the first and second projections.