Title: SUPERSONIC AIRCRAFT WITH AERODYNAMIC CONTROL

Abstract: A supersonic aircraft (900) comprises a fuselage (901), a wing (904), and a canard (920) coupled onto the fuselage (901) forward of the wing (904) at an elevated position that enables stretching forward of the aircraft lifting length, forming an effective area distribution and a shaped sonic boom signature.
SUPersonic Aircraft with Aerodynamic Control

BACKGROUND OF THE INVENTION

The global economy makes long range business travel more essential than ever. However, other than Concorde, with presence declining as transatlantic flights have discontinued, the pace of business travel remains at 1960's-era speeds. Technology advances have produced longer range, safer, and more comfortable aircraft – but not faster flights.

Supersonic overland capability and range are drivers of market potential for aircraft in the commercial and business sector. Buyers of supersonic commercial aircraft are expected to be from entities such as corporations, governments and government agencies, and high net-worth individuals. Most operators are expected to be large organizations, for example corporations and governments, with sophisticated flight departments that can manage multiple aircraft types. Flights are expected to depart and arrive in a wide range of environments, from large international and national airports to small local airfields or suburban airports, with or without substantial service capabilities.

Although a supersonic aircraft for usage in commercial and business environments is to have many characteristics of a high-performance military aircraft, flight characteristics, operations, maintenance, and cost should be compatible to a business or commercial realm. The aircraft should be compatible with the infrastructure, servicing and operations experience base, and air traffic control system of the extant civil business jet.

The user community expects the aircraft to be usable not only in large, urban international hubs but also in suburban airports so that compatibility with shorter runway lengths, narrower taxiways, and lower maximum gross weight surfaces is desirable. Servicing and maintenance compatibility with personnel, equipment, and capabilities found at well-equipped fixed based operators (FBOs) and maintenance facilities is highly useful.

Many of the desirable features of supersonic civilian aircraft, particularly low-boom performance and long range, are very difficult to attain. Bill Sweetman in “Flights of fancy take shape – from Jane’s (www.janes.com)”, 21 July 2000, discusses the United States Defense Advanced Research Projects Agency (DARPA) Quiet Supersonic Platform (QSP) program that is
aimed at developing an efficient supersonic-cruise aircraft that does not produce a sonic boom. The difficulty of such a result is indicated by the agency’s admission that only a revolutionary design will meet the goal, and that incremental application of new technologies, or integration of existing technologies, is expected to be insufficient to attain the reduced boom goal.

Extension of aircraft range involves balancing of fuel capacity, payload volume, fuel consumption at desired speeds, aerodynamic, and other factors. Reduction of aerodynamic drag can assist in extending range, reducing sonic boom, and improving aircraft performance.

**SUMMARY OF THE INVENTION**

In accordance with an embodiment of the illustrative system, a supersonic aircraft comprises a fuselage, a wing, and a canard coupled onto the fuselage forward of the wing at an elevated position that enables stretching forward of the aircraft lifting length and forms an effective area distribution, forming a shaped sonic boom signature.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Embodiments of the invention relating to both structure and method of operation, may best be understood by referring to the following description and accompanying drawings:

**FIGURE 1** is a schematic pictorial and block diagram that illustrates an example of an aircraft thickness/camber control device capable of usage with an airfoil;

**FIGUREs 2A through 2F** show several examples of thickness/camber control devices that can be used to improve aerodynamics and reduce sonic boom amplitude in supersonic aircraft;

**FIGURE 3** is a pictorial schematic diagram showing an example of a supersonic aircraft that includes a thickness/camber control device capable of improving flight aerodynamics and reducing sonic boom effects;

**FIGURE 4** shows a graph and schematic pictorial view of an aircraft to illustrate a technique for minimizing or reducing sonic boom effects using the thickness/camber control device;

**FIGURE 5** is a flow chart depicting an embodiment of a method for reducing the sonic boom in a supersonic cruise aircraft;
FIGUREs 6A, 6B, and 6C are schematic pictorial diagrams respectively showing side, front, and top views of a supersonic aircraft with a thickness/camber control device;

FIGUREs 7A, 7B, 7C, and 7D show a series of graphs that illustrate theory upon which a low sonic boom signature is attained by controlling deployment of the thickness/camber control device;

FIGURE 8 is a graph that further illustrates theory of equivalent area minimization to reduce sonic boom signature, showing effective area against axial location along the longitudinal axis of the aircraft;

FIGUREs 9A, 9B, and 9C are schematic pictorial diagrams respectively showing side, front, and top views of an embodiment of a supersonic aircraft capable of reducing drag through channel relief;

FIGURE 10 is a highly schematic pictorial diagram showing an aircraft frontal with differential canard deflection;

FIGURE 11 is a schematic pictorial diagram depicting a top, cut-away view of the aircraft embodiment near the canard;

FIGURE 12 is a schematic pictorial diagram that shows a top, cut-away view of a left canard;

FIGURE 13 is a graph showing an example of a control configuration that can be controlled by the Vehicle Management Computers in an embodiment of the supersonic aircraft to attain longitudinal stability and control during takeoff and landing;

FIGURES 14A and 15B are schematic pictorial diagrams illustrating side and bottom perspective views of another embodiment of a supersonic aircraft in a configuration that enables channel relief;

FIGURE 15 is a schematic block diagram showing an example a flight control actuation architecture embodiment that can be used as the controller;

FIGURE 16 is a schematic block diagram that depicts an embodiment of a suitable hydraulic power and distribution system architecture for supplying actuating power to the control effectors and systems;
FIGURE 17 is a graph illustrating an example of a control configuration that can be controlled by the Vehicle Management Computers in an embodiment of the supersonic aircraft to attain longitudinal stability and control during supersonic cruise;

FIGURE 18 is a graph that shows an example of canard pitch control effectiveness as managed by the Vehicle Management Computers in an embodiment of the supersonic aircraft;

FIGURE 19 is a schematic pictorial diagram that illustrates an embodiment of a supersonic aircraft with a canard configured for sonic boom reduction, and pitch and directional control;

FIGURE 20 is a graph and schematic pictorial view of an aircraft showing an example of a technique for minimizing or reducing sonic boom effects using the canard;

FIGURE 21 is a pictorial diagram showing an aircraft employing the teachings of the disclosure;

FIGUREs 22A-22G are schematic pictorial diagrams respectively illustrating side, top, and three-dimensional perspective views of an embodiment of an aircraft leading-edge flap;

FIGUREs 23A-23C depict embodiments of the wing used with the disclosed airfoil;

FIGURE 24 provides a head on view of an aircraft employing the teachings of the disclosure;

FIGURE 25 is a schematic pictorial diagram that illustrates an example of a leading edge flap for usage in the aircraft lift device shown in FIGUREs 23A-23C;

FIGUREs 26A and 26B are schematic pictorial diagrams showing embodiments of different airfoil planforms;

FIGUREs 27A-27C depict different airfoil planforms;

FIGUREs 28A-28D depict pictorial and cross sectional views of one Krueger Flap arrangement;

FIGUREs 29A-29C are schematic pictorial diagrams respectively depicting side, front, and top views of a supersonic aircraft that can utilize the illustrative lift devices;
FIGUREs 30A, 30B, 30C, and 30D are a series of graphs that illustrate theory upon which a low sonic boom signature is attained by controlling the leading edge flaps of the wings;

FIGURE 31 is a graph that further illustrates theory of equivalent area minimization to reduce sonic boom signature, showing effective area against axial location along the longitudinal axis of the aircraft;

FIGURE 32 depicts how the winglet may be used to achieve roll control;

FIGURE 33A, 33B, and 33C are pictorial diagrams that depict how the winglet may be utilized to achieve directional control; and

FIGURE 34 is a graph of the equivalent area due to lift versus axial location for the illustrative aircraft.

DETAILED DESCRIPTION OF THE EMBODIMENTS

A sonic boom creates a major practical risk of commercial supersonic aviation so long as commercial supersonic aircraft are prohibited from flying over populated land masses.

A sonic boom occurs due to pressure waves that occur when an aircraft moves at supersonic speeds. During subsonic flight, air displaced by a passing plane flows around the plane in the manner water flows around an object in a stream. However, for a plane flying at supersonic speeds, the air cannot easily flow around the plane and is instead compressed, generating a pressure pulse through the atmosphere. The pressure pulse intensity decreases as a consequence of movement from the airplane, and changes shape into an N-shaped wave within which pressure raises sharply, gradually declines, then rapidly returns to ambient atmospheric pressure. A wall of compressed air that moves at airplane speed spreads from the wave and, in passing over ground, is heard and felt as a sonic boom. The rapid changes in pressure at the beginning and end of the N-wave produce the signature double bang of the sonic boom.

Research has recently shown that boom intensity can be reduced by altering aircraft shape, size, and weight. For example, small airplanes create a smaller amplitude boom due to a lower amount of air displacement. Similarly, a lighter aircraft produces a smaller boom since an airplane rests on a column of compressed air and a lighter plane generates a lower pressure column. An aircraft that is long in proportion to weight spreads the N-wave across a greater distance, resulting in a lower peak pressure. Furthermore, wings that are spread along the body
and not concentrated in the center as in a conventional aircraft produces a pressure pulse that is similarly spread, resulting in a smaller sonic boom.

One technique for boom reduction is shaping. Shaped sonic boom refers to a technique of altering source pressure disturbance such that a non-N-wave shape is imposed on the ground. Shaping sonic boom can reduce loudness by 15-20 dB or higher with no added energy beyond that to sustain flight. Shaping to minimize loudness is based on insight regarding changes in aircraft pressure disturbances during propagation to the ground.

Shaped sonic booms are only achieved deliberately. No existing aircraft creates a shaped sonic boom that persists for more than a fraction of the distance to the ground while flying at an efficient cruise altitude since non-shaped pressure distributions quickly coalesce into the fundamental N-wave shape. The N-wave form generates the largest possible shock magnitude from a particular disturbance. The N-wave shape results because the front of a supersonic aircraft generates an increase in ambient pressure while the rear generates a decrease in pressure. Variation in propagation speed stretches the disturbance during propagation to the ground.

Shaped boom techniques typically attempt to prevent coalescing of the pressure disturbance by adding a large compression at the aircraft nose and an expansion at the tail with pressure in between constrained between the compression and expansion. The shaped boom stretches the ends of the signature faster than the in-between pressures, creating a non-N-wave sonic boom at the ground.

Boom reduction makes a supersonic aircraft less objectionable by minimizing the loudness of a sonic boom. Audible frequencies in a sonic boom occur in the rapid pressure changes, or shocks, at the beginning and end of the typical N-waveform. More quiet shocks have decreased pressure amplitudes and increased pressure change time durations.

What is desired are external shapes and lift devices that facilitate sonic boom reduction.

According to various embodiments, an aircraft or aircraft control system utilizes a deployable and stowable structural element on the airfoil to counter the spillage at off-design conditions and obtain a lower amplitude sonic boom for a supersonic cruise aircraft.

In accordance with some embodiments of the disclosed aeronautical system, an aircraft fuselage thickness/camber control device create a local expansion that, when propagated to the far field, cancels the added compression generated by inlet spillage shock. The thickness/camber control device comprises a structural member capable of modifying the local camber and thickness of the fuselage at a position forward of the concentrated source of increase in
compression, for example the spillage shock, and a control element. The control element is coupled to the structural member and controls the structural member to adjust thickness/camber of the airfoil to cancel the far-field effect of the concentrated source of increased compression.

In accordance with other embodiments, an aircraft comprises a bulge, bump, protrusion, or the like, that extends along a longitudinal axis forward and aft and that has a concentrated source of expansion, a structural member capable of coupling to the bulge, bump, or protrusion at a position forward of the concentrated source of expansion that results from an off design condition, and a control element. The control element is coupled to the structural member and controls the structural member to adjust thickness/camber of the fuselage to cancel the far-field effect of the concentrated source of pressure.

According to further embodiments, a method of reducing the sonic boom in a supersonic cruise aircraft comprises deploying a structural member on an lower surface of a fuselage that extends along a longitudinal axis forward and aft and that has a concentrated source of expansions at a position forward of the concentrated source of pressure. The method further comprises controlling the structural member to adjust thickness/camber of the airfoil to cancel the far-field effect of the concentrated source of expansion.

Referring to FIGURE 1, a schematic pictorial and block diagram illustrates an example of an aircraft thickness/camber control device 100 extending along a longitudinal axis 104 forward and aft and that has a concentrated source of expansion 106 for example that results from inlet shock or spillage. The thickness/camber control device 100 comprises a structural member 108 that mounts on the bottom of the outer mold line at a position forward of the concentrated source of expansion 106 and a control element 110. The control element 110 is connected to the structural member 108 and controls the structural member 108 to adjust thickness/camber of the airfoil 102 and generates expansions that cancel the far-field effect created by the concentrated source of expansion 106.

Typically, the largest concentrated source of expansion 106 in an aircraft is a nacelle. An airfoil is generally designed for most aerodynamically-efficient performance at a particular Mach number or range of Mach numbers. In various circumstances and conditions, operation at off-design Mach numbers is desirable. For example, operating at off-design Mach numbers at selected times can increase aircraft range. During operations in off-design conditions, the nacelle 106 creates a spillage shock that is larger than a desired baseline cruise configuration for a low sonic boom signature. The control element 110 adjusts airfoil thickness/camber so that the far-field effects of the controlled structural member 108 and the nacelle 106 substantially cancel.
The thickness/camber control device 100 has particular utility in a supersonic cruise aircraft with an area distribution that matches a low sonic boom signature. In off-design conditions the concentrated source of expansion 106 generates a spillage shock larger than the baseline cruise configuration for the low sonic boom signature. To reduce the sonic boom, the control element 100 adjusts the structural member 108 so that the far-field effect of the adjusted structural member 108 cancels the far-field effect resulting from the spillage shock. The control element 110 adjusts the structural member 108 in off-design conditions so that the expansion generated around the structural member 108 effectively reduces the equivalent area distribution ahead of the spillage shock.

The thickness/camber control device 100 utilizes the control element 110 to adjust the structural member 108 to effectively modify the camber of the airfoil 102 to minimize or reduce spillage shock resulting from the concentrated source. Controlled adjustments of the fuselage thickness and camber can operate either to block the nacelle spillage effects, thereby softening the sonic boom signature, or as a moveable active feedback device to adjust aircraft aerodynamics.

The thickness/camber control device 100 adjusts body area of the airfoil 102 and fuselage thickness/camber ratio to reduce sonic boom effects. The thickness/camber control device 100 does introduce some drag when deployed, typically a drag increase of approximately 5% for a particular embodiment. Accordingly, the thickness/camber control device 100 is stowed when unused so that drag is reduced when operating in compliance with design conditions. For example, the thickness/camber control device 100 can be deployed when flying over land to reduce or minimize sonic boom effects. When flying over oceans, the thickness/camber control device 100 can be stowed.

The control element 110 includes any operating controls that can be manipulated by a pilot, either with or without supporting electronics, processors, computers, controllers, and the like. The control element 110 further includes any linkages or actuators connected to the structural element 108 to physically move the structural element 108.

The airfoil 102 generally includes aircraft wings and also includes other aerodynamic shapes including a fuselage, tail, and other structures within the air stream.

FIGURES 2A through 2F show several examples of thickness/camber control devices that can be used to improve aerodynamics and reduce sonic boom amplitude in supersonic aircraft. Referring to FIGURE 2A, some embodiments of the thickness/camber control device utilize a structural member in the form of a body flap 200, such as control surface 202 hinged 204 to a lower section of the fuselage 206 forward of the wings 208 and nacelles.
FIGURE 2B shows an example of a thickness/camber control device embodiment that utilizes canards 210 as a structural member to effectively increase the thickness of the fuselage 206 forward of the nacelles. The canards 210 are stowable and deployable to cancel the far-field effect resulting from the spillage shock and tailor the sonic boom signature of the aircraft.

FIGURE 2C depicts an embodiment of a thickness/camber control device that deploys and stows a pair of fairings 220 as structural members for controlling aerodynamics of an aircraft. The fairings 220 are stowed in the aircraft fuselage 206 within a compartment 222 covered by doors 224. The fairings 220 are deployed by structural linkages that open the doors and extend the fairings 220 from the fuselage 206.

FIGURE 2D shows an embodiment of a thickness/camber control device that deploys and stows a speed brake 230 to control aircraft aerodynamics and manage sonic boom signature.

FIGUREs 2E and 2F respectively show a cross-sectional view of an aircraft fuselage 206 with a thickness/camber control device 200, and a side view of the aircraft. The thickness/camber control device 240 has the form of a protrusion 240 that can be rotated out of the fuselage 206 on deployment and into the fuselage 206 for stowage.

Other structures can be used such as protrusions, extensions, or wideners that are deployable and stowable to increase cross-sectional area of the fuselage forward of a concentrated source of expansion, such as the nacelle or nacelles. The structures can be an active drag device, fairing, protrusion, or bank of actuators that extends from the fuselage, thereby enlarging the cross-sectional area of the airfoil, when deployed, and that forms a flush surface with the fuselage when stowed.

Referring to FIGURE 3, a pictorial schematic diagram shows an example of a supersonic aircraft 300 that includes a thickness/camber control device 302 capable of improving flight aerodynamics and reducing sonic boom effects. The thickness/camber control device 302 comprises a structural member 310 coupled to the airfoil 304 at a position forward of the concentrated source of pressure 308, and a control element 312. The control element 312 is coupled to the structural member 310 and controls the structural member 310 to adjust thickness/camber of the airfoil 304 to cancel the far-field effect of the concentrated source of expansion 308.

The aircraft 300 further comprises a fuselage 314, an aircraft wing 316 coupled to the fuselage, and an engine nacelle 318. Commonly, the nacelle 318 is the largest concentrated source of expansion 308 in an aircraft. In the illustrative aircraft 300, the engine nacelle 318 is
coupled to the aircraft wing 316. The structural member 310 is coupled to the fuselage 314 forward of the engine nacelle 318 and is controllably deployed and stowed to adjust thickness/camber of the fuselage 314 to cancel the far-field effect of the engine nacelle 318.

Referring to FIGURE 4, a graph and schematic pictorial view of an aircraft show an example of a technique for minimizing or reducing sonic boom effects using the thickness/camber control device 302. Jones-George-Seebass-Darden sonic boom minimization theory states a ground signature will have minimum shock strength (ramp signature) by following a calculated equivalent area distribution 400, defined by a program SEEB, which becomes a design goal. To attain the goal signature defined by the SEEB curve 400 for predetermined flight conditions of aircraft weight, altitude, and Mach number, a control procedure either deducts or adds to the configuration equivalent areas. If Mach angle cross-sectional areas 402 are configured to approximate the SEEB curve 400, a control procedure is termed "area boom-ruling," as distinguished from "lift boom-ruling" if the lift distribution on the aircraft were modified to match the SEEB curve 400.

In off-design conditions, the concentrated source of pressure created by the nacelle 308 generates the spillage shock 406 that exceeds the baseline cruise level configuration for a low sonic boom signature 400. The thickness/camber control device 302 adjusts airfoil aerodynamics in the off-design conditions to generate an expansion 404 around the structural member 310 to effectively reduce the equivalent area distribution ahead of the shock 406 as shown in the controlled equivalent area plot 402 that is beneath the SEEB curve 400. The control element 312 adjusts the structural member 310 to improve aerodynamic flow fields for flight at Mach numbers different from the Mach number to which the aircraft design is optimized.

The equivalent area curve 402 of the aircraft 300 shows the increase in equivalent area resulting from the spillage shock 406. The thickness/camber control device 302 corrects for the increase in equivalent area by creating the expansion 404 that pulls the aircraft equivalent area curve 402 below the SEEB curve 400 at all positions relative to the aircraft 300. To attain the reduced sonic boom goal, the aircraft equivalent area curve 402 can fall below but not above the SEEB curve 400.

The thickness/camber control device 302 can remain stowed while the aircraft 300 is operating with optimal aerodynamics at a predetermined design condition. However, the aircraft 300 can be alternatively operated at other conditions, for example to increase range or other purposes, with aerodynamics controlled by deploying the thickness/camber control device 302 to reduce sonic boom effects.
Referring to **FIGURE 5**, a flow chart depicts an embodiment of a method 500 for reducing the sonic boom in a supersonic cruise aircraft. The method 500 comprises deploying a structural member 502 on an airfoil that extends along a longitudinal axis forward and aft and that has a concentrated source of expansion at a position forward of the concentrated source of expansion. The method 500 further comprises controlling the structural member 504 to adjust thickness/camber of the airfoil 506 thereby canceling the far-field effect 508 of the concentrated source of expansion.

One aspect of the method is that the aircraft is designed so that the structural member is positioned 510 at a location on the airfoil that facilitates cancellation of the far-field effect of the concentrated source of pressure.

The aircraft can be flown at off-design conditions 512 causing the concentrated compression to create a spillage shock larger than a baseline cruise configuration for a low sonic boom signature 514. In some embodiments, the method includes adjusting the structural member to vary airfoil thickness/camber so that the far-field effects of the controlled structural member and the concentrated source of expansion substantially cancel 516.

Referring to **FIGUREs 6A, 6B, and 6C**, schematic pictorial diagrams respectively showing side, front, and top views of a supersonic aircraft 600 with a thickness/camber control device 601 that, in various embodiments, is capable of improving aircraft performance by facilitating positive aerodynamic effects including adjustment of flow fields to improve aerodynamics at a range of air speeds and maintaining a low sonic boom signature. The aircraft 600 comprises a fuselage 604 and an aircraft wing 608 mounted on the fuselage 604. The wing 608 has a leading edge 606. The wing 608 extends from an inboard edge at the fuselage 604 to an outboard edge at the wing tip. The aircraft lift device 601 further comprises a strake 602 capable of coupling to the fuselage 604 and extending to the leading edge 606 of the wing 608. The aircraft 600 further comprises a Krueger flap 614 coupled to the leading edge 606 of an inboard portion of the wing 608 adjacent the strake 602, and a leading edge flap 612 coupled to the leading edge 606 of the wing 608 and extending from a junction at the Krueger flap 614 to an outboard portion of the wing 608.

The aircraft 600 further comprises a control element, such as the control element 310 shown in **FIGURE 3** and at least one structural member such as the structural members shown in **FIGURES 2A-2F**. The control element is used to adjust the position of deployment of the thickness/camber control device 601 to improve aerodynamic flow fields for flight at Mach numbers different from the Mach number to which the aircraft design is optimized.
In illustrative embodiments, the aircraft 600 has engines 616 positioned in aft locations beneath the wings 608 and have a highly integrated wing/inlet geometry 626 to produce low-boom compatibility and low inlet/nacelle installation drag. The aircraft 600 can have an inverted V-tail geometry 632 that enhances low-sonic-boom longitudinal trim in cruise and allows better structural support for the engines 616.

In the illustrative embodiment, the aircraft 600 has an blunted nose 628 with a conical tip 630 and an inverted V-tail surface 632 that overlaps the wing 608, features that facilitate low-sonic-boom aircraft performance. The configuration suppresses features of a sonic boom pressure waveform that otherwise would make the boom audible. The supersonic aircraft 600 creates an N-shaped pressure wave caused by overpressure at the nose 628 and under pressure at the tail 634. Pressure rises rapidly at the nose 628, declines to an under pressure condition at the tail 634, and then returns to ambient pressure. Rapid pressure rises at the front and rear of the pressure wave producing the characteristic double explosion of the sonic boom.

The conical tip 630 of the nose 628 can create a pressure spike ahead of the aircraft forward shock, raising local temperature and sound velocity, thereby extending the forward shock and slowing the pressure rise. The supersonic aircraft 600 has a sharply swept arrow wing configuration 608 that reduces peak overpressure in the wave by spreading wing lift along the aircraft length. The wing configuration 608 has reduced wing leading and trailing edge sweeps. The inverted V-tail 632 can generate additional lift near the tail to improve aerodynamics and reduce boom.

The illustrative aircraft arrangement 600 has twin non-afterburning turbofan engines 616 set below and behind the wing 608. The non-afterburning turbofan engines 616 operate behind simple fixed-geometry axisymmetric external compression inlets 618. Considerations of community noise and takeoff, transonic, and cruise thrust specifications determine engine cycle selection and engine sizing.

The shaping of the supersonic aircraft 600 including aspects of the wing 608, the tail assembly or empennage 620, and the engine 616 structural integration are adapted according to sonic boom signature and supersonic cruise drag considerations. The empennage or tail system 620 includes stabilizers, elevators, and rudders in the inverted V-tail geometry 632. The inverted V-tail geometry 632 supports nacelles 622 in highly suitable positions relative to the wing 608 to suppress boom, and trims the supersonic aircraft 600 in cruise to attain an improved low-boom lift distribution. Panels of the inverted V-tail 632 support the nacelles 622 and non-afterburning turbofan engines 616 in combination with support of the wing 608 to handle flutter. Inverted V-
tail control surfaces, termed ruddervators 624, adjust aircraft longitudinal lift distribution throughout the flight envelope to maintain a low boom, low drag trim condition.

The shape of the fuselage 604, the wing 608, and empennage 620 are integrated with the entire aircraft configuration so as to be conducive to attaining a low-boom signature and supersonic cruise drag levels. The wing 608 and/or fuselage 604 are integrated to achieve low-boom supersonic flight.

The wings 608 can have a substantial dihedral, or "gulling" incorporated into the wings 608 inboard of the engines 616. The dihedral geometry is most pronounced at the wing trailing edge. The gull or dihedral results from twisting and cambering the wing 608 for low-boom and low induced drag while preserving a tailored local wing contour in the position of main landing gear retraction.

In some embodiments, the inboard portion of the wing 608 can be configured to integrate with the nacelle 622 and a diverter formed between the nacelle 622 and the wing 608 to follow the contour of a low-sonic-boom fuselage 604 with as close a normal intersection as possible to attain low interference drag. In some embodiments, an inboard flap hinge line is fully contained within the wing contour with the wing upper and lower surfaces held as planar as possible to facilitate seal design.

With the resulting wing configuration, the wing gull raises the engines 616 to increase available tip back angle and reduce thrust-induced pitching moments. The gull enhances low-boom signature by vertically staggering the wing longitudinal lift distribution and lowers the aircraft body or fuselage 604 to reduce the height of the cabin door 638 above the ground, thereby reducing entry stair length. The low fuselage 604 assists in maintaining a low aircraft center of gravity, reducing tip over angle and promoting ground stability. The wing gull forms a wrapping of the wing 608 around the nacelle 622 that enhances favorable interference between the nacelles 618 and the wing 608, resulting in a wing/body/nacelle geometry conducive to successful ditching and gear-up landings.

The leading edge surfaces of the wing 608, including the leading-edge flap of the strake 602, the Krueger flap 614, and the leading edge flap 612 are controlled by one or more control elements to adjust aerodynamic flow fields, thereby improving aerodynamic performance in operation at various airspeeds. In addition, the leading edge surfaces can be controlled to adjust the leading-edge surface to maintain a low sonic boom signature. In some conditions, the control elements can deflect the strake 602 to reduce lift ahead of spillage at an off-design condition and maintain a low sonic boom signature.
Referring to FIGURES 7A, 7B, 7C, and 7D, a series of graphs illustrate theory upon which a low sonic boom signature is attained by controlling deployment of the thickness/camber control device 601, reducing sonic boom loudness while maintaining long supersonic range. The leading edge control elements reduce sonic boom loudness by shaping the sonic boom for low shock strengths. **FIGURE 7A** is a graph showing the pressure distribution from a conventional supersonic aircraft. The pressure distribution coalesces into an N-wave at the ground, a shape corresponding to the largest shock strength and thus the greatest loudness. One technique for reducing sonic boom amplitude at the ground involves a minimization theory in which a pressure distribution caused by a low boom aircraft follows an inversely calculated distribution to generate low shock strength at the ground. Contrary to intuition, a low boom distribution occurs when a strong leading edge compression quickly reduces in magnitude, followed by a gradually increasing weak compression that rapidly inverts into a weak expansion, followed by a stronger trailing edge expansion that gradually recompresses to ambient. Boom minimization occurs when an aircraft produces an inversely calculated pressure distribution. The pressure distribution produced by an aircraft results from a Mach angle, cross-sectional area distribution, for example as shown in **FIGURE 7B**, and a Mach angle lift distribution, as shown in **FIGURE 7C**. The thickness/camber control device operates to generate a local expansion on the airfoil to counteract spillage shock from the nacelles, thereby shaping the active area distribution to reduce sonic boom amplitude at the ground. A minimized pressure distribution, shown in **FIGURE 7D**, occurs when the sum of the area pressure distribution and the lift pressure disturbance equal the minimized pressure distribution. The leading edge devices described herein can be used to shape the pressure distribution.

Referring to **FIGURE 8**, a graph further illustrates theory of equivalent area minimization to reduce sonic boom signature, showing effective area against axial location along the longitudinal axis of the aircraft. When equivalent area due to geometric area and lift sum to the minimized distribution, a minimized ground sonic boom occurs. The thickness/camber control device is controlled to modify the airflow, counteracting the spillage shock generated by the nacelles, and possibly stretching the lifting length to move the active area distribution closer to the distribution that shapes the sonic boom signature.

Referring again to **FIGURES 6A through 6C**, the illustrative aircraft 600 utilizes control of the thickness/camber control device 601, in accordance with an equivalent area technique to reduce sonic boom signature. Equivalent area is the Mach angle area distribution of an axisymmetric body that generates the same disturbance as a given geometric area or given lift distribution. The equivalent area due to geometric area can be approximated as equal to the Mach
angle area distribution. The equivalent area due to lift is equal to the integral of the Mach lift per unit of stream wise length times atmospheric constants.

In the illustrative embodiment, the leading edge control surfaces are controlled to reduce or minimize sonic boom by deflecting the air flow to reduce lift ahead of the spillage due to nacelles 622. For example, if the aircraft 600 is flying in an off-design condition in which the nacelles 622 are spilling air and are thus generating stronger shocks and stronger compressions, the leading edge control surfaces and be actuated to compensate by creating an expansion of air flow that blocks the spillage from coalescing into an N-wave.

The wings and engine are generally designed for selected for usage at various air speeds. Engine 616 and inlet 626 characteristics are configured to coordinate engine airflow schedules and flight Mach number. In a particular embodiment, a fixed geometry inlet 626 can be utilized, for example to reduce propulsion system weight and complexity, and thereby improve efficiency and performance. In particular fixed-geometry inlet configurations, airflow is matched at all pertinent Mach numbers so that no bypass or excessive subcritical spillage occurs under nominal conditions. Airflows at off-nominal conditions are matched using engine trim.

In one embodiment, an inlet/engine configuration is based on a supersonic aircraft engine that maintains a status range of 3600 nautical miles (nmi) at Mach 1.8. The fixed compression geometry engine inlet is optimized for Mach 1.8. A maximum Mach 1.8 capable design represents performance of the Mach 1.8-designed engine cruising at Mach 1.6. The Mach 1.8-capable engine flying at Mach 1.6 increases range and engine life, and potentially improves performance on hot-temperature days.

In an alternative embodiment, an engine 616 is configured with a fixed compression geometry inlet optimized for Mach 1.6, increasing range to approximately 4250 nmi by increasing lift/drag ratio by a full point, and a lower engine weight enabling more fuel to burn in cruise.

Various design techniques can be used to configure an aircraft for a range capability that is greater than a baseline Mach 1.8 point design approach, yet supply a greater speed capability than a Mach 1.6 point design method. One technique is to design a Mach 1.6 inlet and engine and cruise off-design at Mach 1.8 to improve range over a Mach 1.8 design inlet, for example attaining a 150-250 nmi improvement in range. A second technique involves designing the aircraft as a Mach 1.6 point design for maximum range and accepting any overspeed capability that happens to occur, resulting in a small speed increase for a fully optimized Mach 1.6 engine design that is further limited by engine life reduction as well as degradation of inlet stability and distortion. In a slight variation to the second approach, the engine can be configured as a Mach
1.6 point design with the engine and subsystem design Mach numbers tailored to any speed a Mach 1.6 inlet is capable of attaining in an overspeed condition. The range benefit is even smaller than the effect of a pure Mach 1.6 aircraft but the overspeed capability can be improved although not to the level of a Mach 1.8 design. A third approach incorporates a variable geometry inlet into an otherwise Mach 1.8 configuration so that efficient on-design inlet performance can be obtained from a range from Mach 1.6 to Mach 1.8, resulting in a small range penalty due to higher weight and higher losses inherent to the variable geometry inlet. Mach 1.6 performance of the third approach is further hindered due to increased inlet weight. Translating cowlts can also be used to enhance subsonic performance.

In a fourth approach, the inlet design Mach number is set such that a Mach 1.8 cruise can be attained in an overspeed condition with engine, subsystem, and aerodynamic design configured to maximize range at Mach 1.6. The illustrative concept does not operate on-design in a purest sense, although enabling the largest range of a fixed compression geometry inlet capable of cruising at Mach 1.8. Potentially, flight at a lower than design Mach number using the fixed geometry external compression engine can increase spillage drag and integrate the inlet and propulsion system in a manner that results in a higher drag.

An illustrative aircraft 600 can have inlet 626, engine 616, and airframe generally designed for Mach 1.8 performance, and further includes optimizations to improve various performance aspects. The configuration enables cruising at a slightly lower Mach number than 1.8 to attain a higher range performance. In an illustrative embodiment, the wings are sized slightly larger than normal for a Mach 1.8 design to improve takeoff and landing performance.

The control elements operating the thickness/camber control device 601 can be controlled to further facilitate operation of the aircraft 600 at off-design Mach numbers.

Other mission-related characteristics facilitated by control of the leading edge surfaces include a capability to cruise at lower Mach numbers, and a tendency to cruise at lower altitudes and lower Mach numbers, resulting from an optimum lift coefficient occurring at lower altitude as a consequence of lower speed. Furthermore, suitable engines for the desired Mach performance typically produce lower specific fuel consumption at the lower altitudes. Also, lower cruise altitudes yield excess thrust at cruise, enabling a reduction in engine cruise thrust requirement and reduced engine weight. Additionally, lower cruise altitudes allow cruise to begin earlier and end later in a mission so that the aircraft spends proportionately more of a mission in a cruise condition. Also, lower cruise Mach numbers yield lower total air temperatures, benefit engine and subsystem life. Lower cruise Mach numbers can also reduce emissions.
The structural member or body flap can be used as a sonic boom reduction device in conjunction with or separately from other boom devices such as a leading edge flap. Sonic boom reduction can be affected undertrack and off-track.

What are further desired are an aircraft and constituent components that enable supersonic flight by applying new technologies and an innovative aircraft design approach. What is further desired is an aircraft that can significantly reduce travel times, for example by a factor of two through supersonic cruise speed capability, while retaining extending cruise ranges and spacious passenger comfort. In various embodiments, the speed advantage can be achieved with an environmentally-friendly design, compliant with takeoff and landing noise standards, engine emission requirements, and producing a very soft sonic signature during supersonic flight.

In accordance with some embodiments, a supersonic aircraft comprises the fuselage extending forward and aft along a longitudinal axis and having a lower surface and an upper surface, a wing coupled to the fuselage, and a canard. The canard is coupled onto the fuselage forward of the wing at an elevated position that enables stretching of the aircraft lifting length and forms an effective area distribution to attain a shaped sonic boom signature.

In accordance with other embodiments, a supersonic aircraft comprises the fuselage extending forward and aft along a longitudinal axis and having a lower surface and an upper surface, a wing coupled to the fuselage, and at least two canards coupled at opposing sides of the fuselage at the elevated position. The canards have differential deflection for directional control. The aircraft further comprises a controller coupled to the canards that comprising a process for differentially controlling the canards to induce lift on the fuselage and the wing on respective opposing sides of the body, causing lift from the canard and body lift to blend into lift produced by the wing.

In further embodiments, a supersonic aircraft comprises a fuselage extending forward and aft along a longitudinal axis and having a lower surface and an upper surface, a wing coupled to the fuselage, and at least two canards coupled at opposing sides of the fuselage at the elevated position. The canards have differential deflection for directional control. The aircraft further comprises a controller coupled to the canards and comprising a process for differentially controlling the canards to modify the aircraft lift distribution to reduce or minimize the aircraft sonic boom.

Referring again to FIGUREs 9A, 9B, and 9C, schematic pictorial diagrams respectively showing side, front, and top views of an embodiment of a supersonic aircraft 900. The aircraft 900 comprises the fuselage 901 extending forward and aft along a longitudinal axis and having a
lower surface and an upper surface. A wing 904 is coupled to the fuselage 901. The aircraft 900 has a canard 920 coupled onto the fuselage 901 at a position forward of the wing 904 at an elevated location. The elevated positioning of the canard 920 on the fuselage 901 enables stretching of the aircraft lifting length, resulting in an effective area distribution that attains a shaped sonic boom signature.

The canards 920 have a dihedral that is sufficiently high to increase the aircraft lifting length and attain a target equivalent area distribution for low sonic boom performance. The canard 920 operates as a longitudinal power control device that is particularly effective during takeoff and in high-speed flight. The canard 920 also functions to fine tune the aircraft longitudinal trim condition. The canard 920 augments rudder operation by supplying yaw control power when left and right canard surfaces are deflected differentially.

In the illustrative embodiment, the canards 920 can be controlled with differential deflections to enable directional control. Referring to FIGURE 10, a frontal view of the aircraft 900 shows an aircraft 900 with two canards 920 coupled to opposing sides of the fuselage 901 at the elevated position on the body 901. The high dihedral of the canards 920 and differential deflection to exploit asymmetric lift on the canards for directional control. The canards 920 can be differentially controlled to deploy at different angles, or the same angle, illustrative shown as angles $\alpha$ and $\Delta$.

Symmetric deflection of the canards 920 enables setting of the angles on different sides of the fuselage 901 and, in combination with the relatively high position of the canards 920 on the body 901, induces lift on the fuselage 901 and the wing 904 on respective opposing sides of the body 901, causing lift from the canard 926 and body lift to blend into lift produced by the wing 904.

Referring to FIGURE 9C, control effectors are shown for the supersonic aircraft 900. Two sets of surfaces are available for pitch control including the canards 920 and ruddervators 916. Roll control uses ailerons 928 and high speed spoilers 930. Yaw control is supplied by a rudder 940, ruddervators 916, and differential canard 920.

In combination with the canards 920, the supersonic aircraft 900 has multiple stability and control effectors. The canard 920 and symmetric deflections of the ruddervators 916 control pitch power. A vertical rudder 940 controls yaw. Inboard, midboard and outboard ailerons 928, and the high speed roll spoilers 930 control roll. The segmented ailerons 928 provide both roll control power and automatic wing camber control to optimize lift and drag throughout the flight envelope. The roll spoilers 930 are configured to control roll at supersonic Mach numbers. High-
speed spoilers 930 supplement aileron roll power at transonic and supersonic speeds where Mach number and aeroelastic effects reduce aileron effectiveness.

In an illustrative embodiment, trailing edge (TE) flaps 932 are deployed 30° down to generate additional lift during landing. TE flap deployment reduces angle-of-attack specifications by approximately 2° during landing. During second-segment climb, the TE flaps 932 are extended 10° to improve the lift-to-drag ratio for better climb performance.

Leading edge (LE) Krueger flaps 934 are extended 130° for low speed operations including takeoff, approach and landing. The LE Krueger flaps 934 improve lift-to-drag ratio by 1.5, resulting in better climb performance that facilitates second-segment climb in case of engine malfunction.

In some embodiments, the aircraft 900 can be configured with a high lift system that includes simple inboard trailing edge flaps 932 and a full-span leading edge Krueger flaps 934. Some aircraft embodiments can have non-Krueger leading edge flaps.

The multiple control surfaces of the supersonic aircraft 900, for example the ruddervators 916 inboard and outboard design, enable continued operation and landing following single actuator failure or a single control surface jamming. Differential canard deflection can generate a yawing moment to counter a jammed rudder. Ailerons 928 and ruddervators 916 include multiple surfaces, increasing fault tolerant capability and supplying redundant elements for improved reliability.

Referring again to FIGURES 9A, 9B, and 9C, in the illustrative aircraft 900, shaping of the wing 904, body 901, empennage 908, and the integration of the propulsion system 918 are configured to produce a shaped sonic signature and control supersonic cruise drag. An inverted V-tail geometry 908 facilitates the overall low-boom design and supports nacelles 922 in an appropriate position relative to the wing 904, as well as enabling for trim to attain a low sonic-boom lift distribution. Inverted V-tail control surfaces, called ruddervators 916, adjust the aircraft longitudinal lift distribution throughout the flight envelope to maintain a low-boom, low-drag trim condition. The canard 920 supplies additional trim control and augments longitudinal control power.

In various embodiments, the illustrative aircraft 900 may include one or more of several advancements including addition of an all-flying canard 920, an optimized wing 904, incorporation of leading edge flaps 934 and spoilers 930, and a reconfigured body or fuselage 901. The canard 920 improves takeoff rotation and high-speed control. Wing planform and airfoil
shapes are configured to assist high-speed performance, low-speed performance, low sonic boom, stability and control, and structural mass fraction characteristics. Sizes of the inverted V-tail 908 and fins can be configured to improve both structural and aerodynamic integration, benefiting both weight and drag characteristics. Flaps 934 improve takeoff performance. Spoilers 930 assist high-speed roll control.

The illustrative aircraft 900 has a twin-engine, slender-body configuration with a highly swept low aspect ratio wing 904, a configuration highly appropriate for low-boom performance. The aft engine location beneath the wing 904, in combination with a highly integrated wing/inlet geometry, produce both low-boom compatibility and low inlet/nacelle installation drag. The inverted V-tail geometry 908 supplies both a low sonic-boom performance while generating longitudinal trim in cruise, and structural support for the engine/nacelle installation.

Some embodiments of the aircraft 900 implement one or more of several features including a multi-spar wing 904, a fuselage structure 901 with stringer-stiffened skins supported by frames, canards 920 that are integrated with the pressurized fuselage cabin structure, and aft-located engines 918 supported by a torque-box structure that extends aft of the wing 904 and is attached to the inverted V-tails 908.

Referring to FIGURE 11, a schematic pictorial diagram depicts a top, cut-away view of the aircraft 900 embodiment in the vicinity of the canard 920. The canard 920 can be particularly effective during takeoff and in high-speed flight. The canard 920 augments the rudder 940 by supplying substantial yaw control power when the left and right canard surfaces are deflected differentially. The diagram shows left and right canard control surfaces 1102L and 1102R, canard leading edges 1104L and 1104R, and canard rotation joints 1106L and 1106R. Also shown is the body or fuselage 901 enclosing a flight crew compartment 1108 and a passenger compartment 1110. The left and right canard control surfaces 1102L and 1102R can pivot about the rotation joints 1106L and 1106R.

Referring to FIGURE 12, a schematic pictorial diagram shows a top, cut-away view of a left canard 920. The canards 920 are each driven by a linear electromechanical actuator (EMA) 1202. In an illustrative embodiment, the canard surface 1204 can rotate ±30° about the pivot 1206. The canard 920 is used to control pitch and can also be dithered for yaw. The dihedral of the canard enables directional control in addition to pitch control capabilities. In alternative embodiments, a hydraulic actuator can be used to drive motion of the canard. The illustrative electromechanical actuator 1202 includes three electric motors for triplex redundancy. To facilitate servicing, the actuator 1202 can be accessible for maintenance from inside the aircraft cabin at a position above avionics bays. An advantage of the electromechanical actuator over a
hydraulic actuator is lower noise operation, resulting in reduced sound damping between the actuator and the cabin.

The actuators 1202 to multiple canards 920 enable differential control of the canards 920 to induce lift on the fuselage 901 and the wing 904 on opposing sides of the body 901 to cause canard lift and body lift to blend into lift produced by the wing 904.

Referring to FIGURE 13, a graph shows an example of a control configuration that can be controlled by the Vehicle Management Computers in an embodiment of the supersonic aircraft to attain longitudinal stability and control during takeoff and landing. Pitch axis static stability and controllability are assessed by determining the lift coefficient (CL) at a range of aircraft baseline pitch moment coefficients (CM) with all control surfaces at a null position as shown in the graph. The graph shows an example of a nominal center of gravity (CG) range of an aircraft embodiment.

Primary pitch control surfaces include the canard and the ruddervators. Total pitch control power is supplied by full deflections of the canard and the ruddervators, shown in the CL vs. CM plot for the low speed takeoff 1300 and landing 1302 condition.

In the example, full canard trailing edge down deflection is scheduled as a function of angle-of-attack alpha (\(\alpha\)) to prevent canard stall. Full trailing edge down is 30\(^\circ\) at \(\alpha < 5\^\circ\), 20\(^\circ\) at \(\alpha < 14\^\circ\), and 10\(^\circ\) at \(\alpha > 14\^\circ\). Full TE up canard is 30 deg. Intersections of center of gravity (CG) lines with the CL-CM curves are trim controls. Trim control is appropriate for the nominal CG range of the aircraft in takeoff 1300 and landing 1302 configurations.

In the example, control configurations are defined as canard plus ruddervator deflections from sums of -30 1304 to +30 1316 at increments of 10.

Referring again to FIGURES 14A and 14B, schematic pictorial diagrams show side and bottom perspective views of an embodiment of a supersonic aircraft 1400. The supersonic aircraft 1400 comprises a fuselage 1402 that extends forward and aft along a longitudinal axis and has a lower surface and an upper surface. A wing 1404 is coupled to the fuselage 1402. At least two canards 1418 are mounted at elevated positions on opposing sides of the fuselage 1402. The canards 1418 are capable of independent and differential deflection for directional control. The aircraft 1400 further comprises a controller 1414 that is communicatively coupled to the canards 1418. The controller 1414 includes a process for differentially controlling the canards 1418 to modify the aircraft lift distribution to reduce or minimize the aircraft sonic boom. The canards
have dihedral sufficiently high to increase aircraft lifting length and attain a target
equivalent area distribution for low sonic boom performance.

The controller 1414 performs analysis and generates signals to direct multiple aircraft
systems and control effectors. The illustrative aircraft 1400 has an inverted V-tail 1408 attached
to the fuselage 1402 and wing 1404. Other embodiments may utilize a different tail
configuration, for example a T-tail or other forms. The illustrative inverted V-tail 1408 has a
central vertical stabilizer 1420, inverted stabilizers 1422 coupled to sides of the central vertical
stabilizer 1420 and also coupled to the fuselage 1402. The inverted stabilizers 1422 assist the
fuselage 1402 in supporting engine nacelles 1424. The inverted V-tail 1408 also includes
ruddervators 1412 that are pivotally coupled to the inverted stabilizers 1422 and can have
operations managed by the controller 1414. Generally, the controller 1414 controls the
ruddervators 1412 to move up and down together for longitudinal control.

The ruddervators 1412 can be configured with sufficient torsional stiffness to reduce or
minimize flutter resulting from rudder rotation coupling with V-tail bending and torsion.
Ruddervators 1412 have appropriate actuator stiffness and ruddervator torsional stiffness, along
with a V-tail mass distribution controlled using ballast weight to manage ruddervator rotation
coupling with V-tail bending and torsion. The ruddervators 1412 can be symmetrically deflected
in combination with the canards to supply pitch control power. The vertical rudder 1426 supplies
yaw control with roll control supplied by inboard, outboard, and midboard ailerons, and high
speed roll spoilers.

The controller 1414 also manages other control effectors in combination with the canards
1404 and the ruddervators 1412, including leading edge Krueger flaps 1432, trailing edge flaps
1406, ailerons 1428, and spoilers 1430.

Referring again to FIGURE 15, a schematic block diagram shows an example a flight
control actuation architecture embodiment 1500 that can be used as a controller. In the illustrative
example, primary flight control actuation uses "Fly-by-Wire" dual tandem linear hydraulics with
triple electronic redundancy. Dual tandem actuation 1502 is powered by two independent
hydraulic systems 1504 and 1506 and sized for full rated performance based on a single system
operation. The flight control system is closed-loop and commanded by the Vehicle Management
Computers 1508. The flight control system 1500 performs control law implementations to
produce aircraft handling qualities throughout flight. The system 1500 can implement outer loop
control modes such as Autopilot, Autolanding, and Auto collision avoidance control. The flight
control actuation system 1500 can also execute system integrity and health management
functions. Various types of actuators can be implemented including, for example, Dual Tandem
hydraulic actuators, Simplex hydraulic actuators, Rotary vane hydraulic actuators, multiple cylinders hydraulic actuators, integrated rotary electromechanical actuators (IREMA), and the like.

The flight management computers 1508 can implement a process that differentially controls the canards to induce lift on the fuselage and the wing on respective opposing sides of the fuselage to cause lift from the canard and body lift to blend into lift produced by the wing. The computers 1508 further controls the canards to stretch the aircraft lifting length and tailor the effective area distribution to produce a shaped sonic boom signature. Differential control of the canards can be used to offset effects of the canard dihedral.

The control effector configuration, controlled by the Vehicle Management Computers 1508, uses redundant control surfaces, enabling continued safe flight and landing in event of a single actuator failure or mechanically-jammed control surface. Redundancy is extended to the ailerons and ruddervators, which are also designed into multiple surfaces for increased fault tolerance and improved overall safety.

The Vehicle Management Computers 1508 implement processes for controlling the effectors, including the canards to distribute lift to reduce or minimize sonic signature and to drive the aircraft to relaxed stability. In an illustrative embodiment, two electronic flight control systems are used to give superior handling qualities and optimal performance throughout the flight envelope. The first system is a full-authority Fly-By-Wire system designed for stability and handling qualities and determining the basic dynamic response of the aircraft.

The second flight control system is an active center-of-gravity (CG) management system. As fuel is burned throughout the mission, the CG management system redistributes the remaining fuel to maximize range and trim to achieve sonic boom signature reduction. The CG management system also enables the canard, wing and inverted V-tail to interact in harmony to lift the vehicle efficiently for maximum range while producing a low sonic boom signature.

Referring to FIGURE 16, a schematic block diagram shows an embodiment of a suitable hydraulic power and distribution system architecture 1600 for supplying actuating power to the effectors and systems. For high reliability, the system 1600 is highly redundant with a hydraulic system supplying three independent sources 1602, 1604, 1606 of hydraulic power to operate primary flight controls, landing gear 1614, nose wheel steering 1616, wheel brakes 1618, and thrust reversers 1620. The three independent systems 1602, 1604, and 1606 give triple redundancy for continued safe flight and landing.
Hydraulic power for the systems is supplied by two engine driven pumps 1622 and an AC motor pump 1624 on system 1 1602 and system 2 1604. The engine driven pumps 1622 can operate continuously while the AC motor pumps 1624 operate on demand basis. Additionally, the AC motor pumps 1624 are an extra source of hydraulic power that gives redundancy within each system. The AC motor pumps 1624 can be operated on the ground for system checkout without running the engines or using a hydraulic ground cart.

System 3 1606 has two air driven pumps 1626 and an AC motor pump 1624. One air driven pump 1626 operates continuously while the other air driven pump 1626 and the AC motor pump 1624 operate on a demand basis. The AC motor pump 1624 in system 3 1606 can also be operated on the ground for system checkout without running the engines or using a hydraulic ground cart. System 3 1606 also includes a ram air turbine 1628 for emergency hydraulic and electrical power in the event of dual engine flameout. The ram air turbine 1628 is sized to supply hydraulic and electrical power to essential equipment from the certified altitude to safe landing for level 3 handling quality.

Referring to FIGURE 17, a graph shows an example of a control configuration that can be controlled by the Vehicle Management Computers in an embodiment of the supersonic aircraft to attain longitudinal stability and control during supersonic cruise. The lift coefficient (CL) vs. pitch moment coefficient (CM) plot is depicted for a supersonic cruise condition of Mach 1.8 and includes flexible effects due to aircraft bending. The illustrative aircraft embodiment is stable in the pitch axis in the supersonic cruise condition. Moving the center-of-gravity (CG) aft reduces canard trim. In the center-of-gravity (CG) range from about 40% to approximately 50%, the aircraft has adequate control power for trim for the cruise angle-of-attack α of 2 to 3 degrees.

Referring to FIGURE 18, a graph shows an example of canard pitch control effectiveness as managed by the Vehicle Management Computers in an embodiment of the supersonic aircraft. The graph shows pitch control effectiveness of the canard as measured by the pitching moment coefficient ΔCm for various angles-of-attack (α) and Mach numbers and further depicts flexible effects due to structural bending. Maximum canard deflections of ±30° are used for low speeds and ±10° for high speeds. With 10° deflection, the canard is effective throughout the Mach range with constant ΔCm of approximately 0.02. For higher angles-of-attack (α) at low Mach numbers, the canard is more effective pitch down than pitch up, for example -0.07 ΔCm as compared to +0.045 ΔCm. The canard can be supplemented by other control effector surfaces to attain pitch control in the subsonic Mach numbers, particularly during takeoff rotation when large pitch up control moment is used. For low speed operations, combined ruddervator and canard for pitch control can be employed.
Referring to FIGURE 19, a schematic pictorial diagram illustrates an embodiment of a supersonic aircraft 1900 with a canard 1902 configured for sonic boom reduction, and pitch and directional control. The aircraft 1900 comprises a fuselage 1904 extending forward and aft along a longitudinal axis 1906. A wing 1908 is mounted to the fuselage 1904. Two or more canards 1902 are mounted on opposing sides of the fuselage 1904 at the elevated position 1910 on the fuselage side. The canards 1902 have differential deflection for directional control. The aircraft 1900 further comprises a controller 1912 that is communicatively coupled to the canards 1902. The controller 1912 implements and executes a process for symmetrically controlling deflection of the canards 1902 to induce lift on the fuselage 1904 and the wing 1908 on respective opposing sides of the fuselage body 1904, causing lift from the canard and body lift to blend into lift produced by the wing.

Lift 1914 from the high, dihedralized canard 1902 includes lift on the fuselage body 1904 and the wing 1908 on the opposite side of the aircraft 1900 from each canard 1902, causing the canard lift to blend into the wing 1908.

The dihedral of the canards 1902 is configured to create a canard wing tip vortex that passes through the inverted V-tail channel and not impinge on any lifting surfaces at either subsonic or supersonic cruise conditions.

Referring to FIGURE 20, a graph and schematic pictorial view of an aircraft 1900 show an example of a technique for minimizing or reducing sonic boom effects using the canard 1902. A first graph shows the aircraft lift distribution 2000 along the longitudinal dimension of the aircraft 1900. In the illustrative embodiment, the lift distribution 2000 is composed of lift resulting from the canard 2002 and lift from the fuselage body and wing 2004.

A second graph shows the aircraft equivalent area distribution 2008 that results from the aerodynamic configuration of the aircraft 1900. Jones-George-Seebs-Darden sonic boom minimization theory states a ground signature will have minimum shock strength (ramp signature) by following a calculated equivalent area distribution 2006, defined by a program SEEB, which becomes a design goal. To attain the goal signature defined by the SEEB curve 2006 for predetermined flight conditions of aircraft weight, altitude, and Mach number, a control procedure either deducts or adds to the configuration equivalent areas. Mach angle cross-sectional areas 2008 of the aircraft configuration can be configured so that the sum of the volume and the lift contributions to the equivalent area distribution is less than or equal to the SEEB curve 400 in a control procedure termed “area boom-ruling.” Alternatively, the aircraft lift distribution can be modified so that the sum of volume and lift equivalent area distributions is less than or equal to the SEEB curve 2006 in a “lift boom-ruling” procedure.

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The canards 1902 can be adjusted under control of the controller 1912 to generate lift that includes lift on the fuselage body 1904 and wing 1908 to effectively reduce the equivalent area distribution 2008 as shown in the controlled equivalent area plot that results in an area beneath the SEEB curve 2006.

The equivalent area curve 2008 of the aircraft 1900 shows the increase in effective equivalent area resulting from the canard 1902. The canards 1902 generate lift that corrects for the increase in equivalent area by including lift on the body 1904 and wing 2008 that pulls the aircraft equivalent area curve 2008 below the SEEB curve 2006 at all positions relative to the aircraft 1900. To attain the reduced sonic boom goal, the aircraft equivalent area curve 2008 can fall below but not above the SEEB curve 2006.

Referring to again to FIGUREs 7A, 7B, 7C, and 7D, a series of graphs illustrate theory upon which a low sonic boom signature is attained by controlling deployment of the canard, reducing sonic boom loudness while maintaining long supersonic range. The leading edge control elements reduce sonic boom loudness by shaping the sonic boom for low shock strengths. The canard in an elevated position on the fuselage and capability of differential deflection operates to extend the lifting length of the aircraft to achieve a target equivalent area distribution for low sonic boom, thereby shaping the active area distribution to reduce sonic boom amplitude at the ground. A minimized pressure distribution, shown in FIGURE 7D, occurs when the sum of the area pressure distribution and the lift pressure disturbance equal the minimized pressure distribution. The canards described herein can be used to shape the pressure distribution at off-design conditions, for example when operating at a different Mach number or angle of attack than the optimized design conditions.

Referring again to FIGURE 8, a graph further illustrates theory of equivalent area minimization to reduce sonic boom signature, showing effective area against axial location along the longitudinal axis of the aircraft. When equivalent area due to geometric area and lift sum to the minimized distribution, a minimized ground sonic boom occurs. The canards are controlled to modify the airflow, including lift on the body on the wing on the opposing side of the aircraft, causing the canard lift and body lift to blend into the wing. In fact the canard deflection can induce lift on the body. The lift from the canard thus stretches the lifting length to move the active area distribution closer to the distribution that shapes the sonic boom signature.

Although a particular aircraft geometry and configuration is described, the canards and techniques for controlling the canards can be utilized in aircraft with different geometries. In particular, although the described aircraft has an inverted V-tail configuration, other tail configurations such as T-tail configurations and others may be used. Although the described
aerial aircraft have two canards, in other embodiments, other suitable aircraft can have additional canards. The described propulsion configuration includes two engines mounted at aft positions in a highly swept wing. Other suitable embodiments may have different engine configurations with fewer or more engines, with engines mounted on the fuselage or tail rather than on the wing, or mounted above rather than beneath the wing.

What are desired are wings and lift devices that facilitate sonic boom reduction and enable good off-design performance and control characteristics.

The disclosed aeronautical system teaches a wing for use on a supersonic aircraft. The wing includes an inboard section, a central section and an outboard section. The inboard and central section have sweep greater than their cruise Mach cone angle. The outboard section of the wing has a sweep lower than the Mach cone angle and a sharp leading edge. The outboard section of the wing could also be embodied as a winglet defined by a dihedral break in orientation angle relative to that of the wing dihedral angle.

In a first embodiment, the outboard lower sweep section has the same dihedral angle as the inboard portions of the wing. This embodiment shifts the aircraft’s aerodynamic center and center of pressure aft. This shift aft helps achieve a minimized sonic boom according to the methodology of George-Seebass-Darden and prior patent U.S. Patent Application Serial No. 10/006,505, entitled Tail-Braced Wing Aircraft and Configurations for Achieving Long Supersonic Range and Low Sonic Boom, which is hereby incorporated by reference. It also results in lower induced drag at the cruise Mach number because the outboard section can trap all the upwash generated by the inboard wing, behind the Mach cone angle but ahead of the inboard wing leading edge. This makes the outboard wing a more efficient place to generate lift than otherwise possible. Integrating this outboard with sonic boom minimization, by keeping the equivalent area less than or equal to the George-Seebass-Darden ideal equivalent area definition, allows the aft load needed for minimization to be met with less induced drag. The tip of the outboard wing may have a leading edge flap or all-moving tip for roll control with less aeroelastic effectiveness loss due to twist, especially supersonically.

The outboard lower sweep section might also have a discontinuous increase in chord and dog-toothed leading edge break. This sharp leading edge extended forward can have a leading edge flap with its hingeline aligned with the center wing round leading edge, allowing deflections of the flap to be made without steps being created with the center wing.
Another embodiment employs a winglet having anhedral of about 30 degrees, typically outboard of the fuel extent. The resulting winglet's closer proximity to the ground intensifies the ground effect increasing lift, reducing drag and resulting in improved take-off performance. Further, George-Seeback-Darden minimization requires the aircraft lift to be carried aft, and because the Mach cone angle moves farther aft the higher the lift is carried vertically, dihedral raises the height of the wing as one goes outboard. Unfortunately, too much dihedral makes the aircraft roll during sideslip. To maximize the height of the wing for sonic boom minimization without saturating roll control during sideslip, the wing should have higher inboard dihedral and an anhedral wing tip. The tip takes advantage of its greater moment arm to counter the roll from greater inboard dihedral. By making greater inboard dihedral controllable, this anhedral winglet improves sonic boom minimization. In addition, the winglet can capture a little more of the shock wave coming off the nacelle for drag reduction. Additional embodiments may incorporate an all-moving winglet with a rotational axis in the dihedral plane of the wing, to control roll with reduced aerelastic effectiveness loss. This is especially true when operating supersonically. Such an all-moving winglet also results in less adverse yaw during roll conditions. High reliability actuators, like dual-tandem, can be housed in a streamwise upper surface wing bulge to avoid interference with the winglet and nacelle. Upper surface actuators with hinges located at the lower surface allow large hinge radii on the upper surface, where it is more useful for keeping control surface flow attached. The winglet incidence can be changed when the Mach number is changed from the design point to maximize drag reduction.

A third embodiment employs a winglet having a dihedral of -60 to -90 or about +90 degrees. This winglet or a portion thereof may rotate about an axis perpendicular to the plane of the inboard portions of the wing. The actuator can be placed in the axis of the wing spars. This embodiment allows increased yaw control from aft placed sideforces, and contributing drag differentials at the winglets due to the winglets or a combination of the winglets and ailerons. It could be possible to reduce or eliminate a larger center fin and rudder.

The inboard section of the wing may have a higher leading edge sweep that is adjusted to fill-in the typical dip that occurs in the equivalent area just ahead of the wing. The spanwise extent of this higher swept region can be limited to the first 20 to 30 percent of span where a leading edge flap is not typically needed, to allow for a straighter leading edge flap. This higher inboard sweep can be separate or combined with the previous outboard wing sections. A canard can also be used with or without the higher inboard sweep to fill-in the typical dip that occurs in the equivalent area just ahead of the wing.
In one embodiment, the leading-edge flap of the central section of the wing is a Krueger flap and the leading-edge flap of the outboard winglet is a simple leading-edge flap. The leading edge flaps can increase aft lift, reduce trim and vortex drag, and reduce the sonic boom signature of the supersonic aircraft. The outboard winglet can increase ground effect during take off and can provide positive wave drag interference with the nacelle. The leading edge flap of the outboard winglet can also provide roll control at supersonic conditions and directional control with proverse roll effects. Some embodiments may further include trailing-edge flaps on one or more sections, wherein the leading edge flaps are controlled in conjunction with the trailing edge flaps to reduce drag while cruising subsonically. Additionally, the control system coupled to the leading-edge flaps can adjust the leading-edge flaps to improve aerodynamic flow fields for flight at Mach numbers different from the Mach number to which the aircraft design is optimized.

Another embodiment more specifically has an aircraft wing capable of coupling to an aircraft fuselage and having a leading edge, the wing extends inboard to outboard. A strake couples to the aircraft fuselage and extends to the leading edge of the wing. In some embodiments the strake further includes a leading-edge flap. A Krueger flap couples to the leading edge of an inboard portion of the wing adjacent the strake. If present, the strake leading-edge flap operates as a leading-edge device to create an airflow field impinging on the Krueger flap to reduce or eliminate inboard vortices in an upper surface airflow field. The outboard winglet may have a simple leading edge flap coupled to its leading edge, wherein the outboard winglet is anhedrally oriented relative to a lateral axis of the aircraft, and wherein its leading edge flap provides roll control and directional control for the aircraft.

The wing and strake form a swept wing that extends with at least one sweep angle from the fuselage. In fact, the wing and strake may form a swept wing that extends in a plurality of sweep angle segments from the fuselage. The sweep angle of the inboard portion of the wing differs from the sweep angle of the strake and outboard winglet. As in the previous embodiment, the outboard winglet increases ground effect during take off provides positive wave drag interference with the nacelle. The wing may further employ trailing-edge flaps on one or more sections, wherein the leading edge flaps are positioned in conjunction with the trailing edge flaps by a control system to reduce drag at subsonic cruise conditions. By themselves, the leading edge flaps increase aft lift, reduce trim and vortex drag, and reduce the sonic boom signature of the supersonic aircraft. Furthermore, the control system coupled to the leading-edge flaps allows the flaps to be adjusted to improve aerodynamic flow fields for flight at Mach numbers different from the Mach number to which the aircraft design is optimized.
Wing control surfaces, flaps, tails and canards can be used to meet sonic boom minimization requirements. By using movable surfaces to alter the lift distribution to meet sonic boom minimization requirements, resulting drag penalties do not have to be incurred wherever low sonic boom is not required, like over water. Since maximum range is generally most important over water, using movable surfaces for sonic boom minimization can reduce the drag penalty associated with reducing sonic boom.

**FIGURE 21** illustrates an example of an aircraft 2100 having a longitudinal axis 2104 forward and aft to which an airfoil is coupled. Airfoils are generally designed to maximize aerodynamic performance at a particular Mach number or range of Mach numbers. In various circumstances and conditions, operation at off-design Mach numbers is desirable. The airfoil includes aircraft wings 2102. However, the airfoil may also include other aerodynamic shapes including the fuselage, tail, and other structures within the air stream. Wings 2102 further include winglets 2103.

**FIGUREs 22A, 22B, and 22C** illustrate side, top, and three-dimensional perspective views of an embodiment of portions of wings for usage on aircraft 2100. Wings 2102 couple to a strake 2108 that couples to aircraft fuselage 2110 and extends along a portion of the aircraft fuselage 2110 to leading edge 2112 of wings 2102. Strake 2108, generally a small aspect ratio lifting surface with large sweep angles, typically functions as a vortex lift generator. A leading-edge flap 2116 may be coupled to the strake leading edge 2118. However, this leading edge flap is not necessary in all embodiments. If present, strake leading-edge flap 2116 can extend over a portion of the length of strake 2108 or can extend the full span of strake 2108. As shown in **FIGURE 22C**, strake leading-edge flap 2116 is a simple or plain flap. In the simple flap, a portion of the leading edge 2118 can have a hinged pivot 2120 or can be driven by a wheel on rail type of mechanism as in commercial jets. The pivot or other moveable structure enables a surface of strake leading-edge flap 2116 to move or extend downward. Leading-edge flap 2116 can be controlled to improve aerodynamic flow fields for flight at Mach numbers different from the Mach number to which the aircraft design is optimized. Operation of the strake leading edge flap improves aerodynamic performance at off-design conditions. Strake leading-edge flap 2116 can also reduce lift ahead of spillage at an off-design condition and maintain a low sonic boom signature.

In the embodiment depicted, strake 2108 typically functions as a leading edge flap device configured to function as a subsonic leading edge even at supersonic conditions and a vortex lift generator positioned in front of the leading edge of wing 2102. Wing 2102 typically has a smaller sweep angle and a larger aspect ratio than strake 2108. Strake 2108 creates spiral vortices by
separating flow at its leading edge 2118. Flow reattaches on the wings’ upper side, producing a nonlinear lift due to depression on strake 2108 and on portions of wing 2102.

Strake 2108 or a portion thereof functions as a leading edge device that in some embodiments can be controlled to improve aircraft performance and utility. For example, strake leading-edge flap 2116 can be controlled to adjust the airflow fields around wing 2102 and airfoil at different air speeds. For a wing 2102 designed to optimize aerodynamic performance at a particular Mach number or range of Mach numbers, for example 1.6 to 1.8, the leading-edge flap 2116 can adjust aerodynamic flow fields to the actual Mach number during flight. In a specific example, if a wing is designed for optimal aerodynamic performance at Mach 1.6 and airspeed of Mach 1.8 is desired, strake leading-edge flap 2116 can be adjusted to produce flow fields to optimize the airfoil for Mach 1.8 conditions. Flow fields are most affected by airfoil shape and form at the leading edge, which sets the form of the downwash on wing 2102. Accordingly, strake leading-edge flap 2116 optimizes airfoil effective shape to adjust the optimum Mach number of the aircraft. Additionally, the strake can be deflected up or down to control the aircraft’s sonic boom signature, to manage or reduce air spillage and also to improve drag when flying at off-design Mach conditions.

Referring to FIGUREs 22D and 22E, pictorial diagrams respectively show bottom and side views of embodiment of a leading edge strake flap 2116, particularly showing a swept hinge line 2117 of the strake flap 2116. The swept hinge line 2113 enables strake flap rotation without unsealing the flap 2108 from the fuselage 2110. FIGURE 21E depicts the range of motion 2119 of the leading edge strake flap 2116.

Referring to FIGUREs 22F and 22G, schematic pictorial diagrams show top views of an embodiment of the leading edge strake flap 2116 to illustrate aerodynamic influence of the flap 2116 in operation. As Mach number is reduced, as shown in FIGURE 22G in comparison to FIGURE 22F, the leading edge flap’s influence moves ahead of the wing, shown by movement 2121. Therefore, the optimal deflection of the leading edge strake flap 2116 tends to change when Mach changes. In addition, sonic boom lift distribution constraints tend to benefit from deflection. From another perspective, flight not constrained for sonic boom has a reduced drag penalty when the strake leading edge flap 2116 is deflectable. The outboard section can trap all the upwash generated by the inboard wing, behind the Mach cone angle but ahead of the inboard wing leading edge. This makes the outboard wing a more efficient place to generate lift than otherwise possible. Integrating this outboard with sonic boom minimization, by keeping the equivalent area less than or equal to the George-Seeback-Darden ideal equivalent area definition,
allows the aft load needed for minimization to be met with less induced drag. **FIGUREs 23A and 23B** further illustrate such wingtips.

**FIGURE 23A** depicts wing 2102 in further detail. Aircraft wing 2102 mounts onto aircraft fuselage 2110. Leading edge 2122 extends along the wing inboard 2124 to outboard 2126. Strake 2108 couples to aircraft fuselage 2110 and extends from the fuselage to leading edge 2122. As shown, leading edge 2122 comprises a Krueger flap 2128 outboard of strake 2108 and inboard of a simple flap 2130. Krueger flap 2128 and simple flap 2130 generally have different leading edge structures. The Krueger flap may extend over a range of leading edge 2122 and functions to reduce vortex drag at supersonic cruise speeds, increase lift, and reduce trim drag while providing a reduced sonic boom signature. Generally, leading edge flaps bend or extend a surface downward along a forward portion of the wing. The entire leading edge may be a single structure or may have multiple leading edge segments with leading edge flaps of various types as known to those skilled in the art. For example, in some embodiments, Krueger flap 2128 can extend from strake 2108 to the wing tip. Krueger flap 2128 couples to leading edge 2122 at a relatively inboard portion of the wing adjacent strake 2108. Simple leading edge flap 2130 couples to leading edge 2122 of wing 2102 and extends from junction 2134 with Krueger flap 2128 to outboard winglet 2132. Strake leading-edge flap 2116 operates as a leading-edge device that, for subsonic performance, deflects to create an airflow field impinging on Krueger flap 2128 so that the upper surface airflow field reduces or eliminates inboard vortices.

Wing 2102 and strake 2108 are both arranged at a sweep angle from the fuselage and form a swept wing that extends at a sweep angle from the fuselage. As depicted, wing 2102 and strake 2108 are configured with different sweep angles to form a swept wing that extends in a plurality of sweep angle segments 2136, 2138, and 2140 from the fuselage. For example, the sweep angle of wing 2102 differs from the sweep angle of strake 2108. Furthermore, the sweep angle of wing segment 2138 inboard of junction 2134 can differ from the sweep angle of wing segment 2140 outboard of junction 2134. In other embodiments, the sweep angles may be the same for wing 2102 and strake 2108. Outboard section 2140 may partially trap the upwash generated by inboard segments 2136 and 2138.

Referring to **FIGUREs 23B and 23C**, schematic pictorial diagrams show top pictorial views of an embodiment of an aircraft lift device with a Krueger flap 2128 in respective non-deployed and deployed positions. As shown in **FIGURE 23B**, with the Krueger flap 2128 in the retracted position, the leading edge 2122 transitions inboard to outboard along the retracted Krueger flap 2128 to the junction with the leading edge plain flap 2130. The intersection between the retracted Krueger flap 2128 and the leading edge plain flap 2130 forms a sharp leading edge.
angle (or discontinuous increase in chord), termed a dog-toothed arrangement 2131. As shown in FIGURE 23C, the deployed Krueger flap 2128 meets and seals with the deflected outboard leading edge plain flap.

Not only may the sweep angle of the segments differ, the dihedral angle of these segments may differ as well. For example, the dihedral angle of the segment outboard of junction 2134 may be negative or anhedral. As previously discussed an anhedral of about 30° provides improved roll control. An anhedral of about 90° provides improved directional control. In either case, the ground effect may be enhanced to provide improved take-off performance. In this instance, wing 2102 takes on a gull like profile with outboard winglet 2140 inclined downward from the lateral axis of the aircraft. The profile is depicted in FIGURE 24. Segment 2136 has a positive dihedral angle relative to the aircraft’s lateral axis. Segment 2138 is approximately parallel to the aircraft’s lateral axis. Segment 2140, which in this embodiment comprises winglet is anhedral orientation relative to the aircraft. Anhedral segment 2140 increases directional stability and control, increases the ground effect during takeoff, and has positive wave interference with the nacelles 2106.

Modifying wing tip flow with outboard winglets alters the trailing tip vortex produced by an aircraft wing and enhances the aircraft’s overall performance. Winglets take advantage of the strong sidewash that occurs at the wing tip. The sidewash meets the winglet at an angle of attack and produces a side force. From this the winglet forms its own horseshoe vortex system. The winglet vortex system partly cancels the wing tip vortex at the wing-tip/winglet junction and therefore the main tip vortex now forms at the tip of the winglet. By moving at the tip vortex out of the plane of the main wing with the anhedral orientation of the winglet relative to the aircraft’s lateral axis, the downwash over the wing’s surface can be substantially reduced thereby reducing the induced drag. In addition, the side force produced on a winglet when resolved, provides a forward thrust component or negative drag. These two effects more than offset the parasitic drag produced at the winglet junctions and thus provide a beneficial effect on the overall drag of the aircraft. In addition to providing aerodynamic efficiency and both roll and directional stability and control, the control surfaces on the winglet in the form of leading or trailing edge devices allow the position of the aerodynamic center of the aircraft to be actively controlled during supersonic flight with minimal control surface deflections. This further aids in minimizing trim drag.

In operation, leading edge flaps, including Krueger flaps and simple edge flaps, extend for low speed operations during takeoff, approach, and landing. In a particular example, leading edge flaps can be extended up to and beyond 130 degrees to improve lift-to-drag ratio in a range
around 1.5 to 2.5, resulting in better climb performance, and reduced takeoff and landing field length. Additionally, leading edge flap devices on the outboard winglet can provide a measure of roll control at supersonic speeds and directional control with proverse roll effects.

**FIGURE 24** depicts a front profile of aircraft 2100 with anhedral outboard winglet 2132. The inboard portion of the wing may comprise about 85% of the wing span and does not require a negative dihedral. Leading edge 2122 has incorporated therein leading edge flap devices which are controlled to reduce the vortex and trim drag of the wing at supersonic cruise and increase at lift for the boom while providing a low boom signature. The anhedral orientation of the winglet increases directional stability and increases the ground effect during take-off as well as providing positive wave drag interference with nacelles 2133.

Leading edge devices may be used in conjunction with trailing edge devices to reduce drag at subsonic cruise conditions. The use of the leading edge flap in conjunction with a trailing edge may reduce drag. In addition, the leading edge flaps on winglet 2132 may be used for roll or directional control. The anhedral angle of winglet 2140 depends on the specific configuration as there is an optimal combination of wave drag reduction at supersonic cruise and increased lift at take-off, as well as directional stability. These three factors influence how much anhedral or downward inclination of the winglet there is in relation to the aircraft’s lateral axes. This relation may be predicted or empirically determined by the desired combination of properties to be exhibited by the supersonic winglet.

**FIGURE 25** illustrates one embodiment of leading edge flap 2130. As shown, leading edge flap 2130 is a simple leading edge flap having a cross-sectional form transitioning from a sharp or pointed form 2502 at the outboard end 2504 to a rounded form 2506 at Krueger flap junction 2508. The variable form of leading edge flap 2130 from the outboard sharp point transitioning to a more rounded form in the inboard direction to a junction with the Krueger flap reduces or minimizes sharp edges or gaps in the wing leading edge. Some aircraft embodiments may omit the simple flap in favor of a Krueger flap(s), or other similar device, that extends to the wing tip.

Leading edge flap 2130 at the outboard end 2504 can have varying degrees of sharpness or pointed character. In general, leading edge flap 2130 transitions from an edge with a relatively small radius of curvature at the outboard end 2504 to an edge with a relatively larger radius of curvature at the inboard edge a the Krueger flap function 208.
Although, leading edge flap 2130 is depicted as a simple leading edge flap, combinations of other types of flaps can be used. For example, some arrangements can use a split flap in the span wise direction, in which a hinged portion of the bottom surface of the wing can be extended to increase the angle of attack by changing the chord line. In other configurations, a Fowler flap can be used that, when extended, both tilts downward and also slides rearward. In other systems, a slotted flap may be used that, in addition to changing the wing camber and chord line, also allows some high-pressure air beneath the wing travel through the slot. Other embodiments can use any other suitable type of flap. Furthermore, some embodiments, for example configurations in which the leading edge is subsonic, may omit usage of the leading edge flap.

FIGURES 26A and 26B provide cross-sectional partial airfoil views showing the transition from the inboard to outboard leading edge. FIGURE 26A illustrates the transition from a round inboard leading edge 2602 to the outboard dog-toothed, sharp leading edge flap 2604. As shown, sharp leading edge 2604 can have a leading edge flap wing with a hinge line aligned with center section round leading edge 2602. The sharp plain leading edge flap 2604 pivots about a pivot point 2606 along a hinge line 2608. Also shown is a portion of the wing under the flap surface. This arrangement allows deflections of the flaps to occur without creating steps or discontinuities in the wings leading edge.

As the Mach cone angle moves farther aft the higher the lift is carried vertically, dihedral raises the height of the wing as one goes outboard. However, too much dihedral makes the aircraft roll during sideslip. To maximize the height of the wing for sonic boom minimization without saturating roll control during sideslip, the wing should have higher inboard dihedral and a wing tip with an anhedral configuration. As shown in FIGURE 29B, winglet 2916 takes advantage of its greater moment arm to counter the roll from greater inboard dihedral. By making greater inboard dihedral controllable, the anhedral winglet improves sonic boom minimization.

Additionally, winglet 2916 typically outboard of the fuel extent allowing the fuel bearing portion of the wing 2908 to be flat or dihedralized easing pumping fuel, and allows movement as a control surface. This much smaller, lower sweep outboard winglets 2916 works without negatively impacting fuel volume and bending loads as much.

FIGURE 26B shows the transition from the round Krueger flap 2610 to the dog-toothed, sharp plain leading edge flap 2604. Krueger flap 2610 has a round leading edge radius 2612 that gradually blends to a sharp edge moving inboard to outboard along the leading edge 2602. The gradual tapering from rounded to sharp of the Krueger flap leading edge encourages attached flow and thereby lowers drag.
Referring to FIGUREs 27A, 27B, and 27C, schematic pictorial diagrams show various planform embodiments of aircraft lift devices 2700, 2710, and 2720, respectively. In various embodiments, an aircraft lift device comprises a simple leading-edge flap 2702 mounted to a strake 2704 of a highly swept leading edge supersonic planform. The supersonic planform includes a wing and a body, also called a fuselage. Leading-edge flap 2702 may include the entire strake 2704 and sweeps about a body junction. The hinge line or pivot 2706 may vary from a direction that is orthogonal to the fuselage to a configuration that is parallel to the strake leading-edge.

The leading-edge device 2700, 2710, 2720 are used to soften the sonic-boom signature for a given supersonic configuration and/or improve aerodynamic performance, in other words lower drag, at off design conditions such as lower or higher cruise Mach numbers. If a Krueger flap is used as a leading-edge device for subsonic performance the leading-edge strake device, when deflected, facilitates formation of a favorable flow field for the Krueger flap so that the upper surface flow field is substantially free from inboard vortices. A smooth transition of simple leading-edge flap device to a Krueger flap similarly assists in avoidance of inboard vortices.

FIGUREs 28A and 28B provide schematic diagrams showing one embodiment of a Krueger flap 2850. Krueger flaps 2850 are aerodynamically-effective movable components on the leading edge of the airfoil. These high-lift devices supply additional lift in certain configurations and under certain flight attitudes. Krueger flaps 2850 are connected to the leading edge 2852 of the wing 2854 and extend from lower surface 2856 to increase lift capability during low-speed operation. High-lift devices, such as Krueger flaps 2850, facilitate lift-off and landing at low speeds, and maintain undisturbed wing root airflow over the wing upper surface 2858 without separation at the transition from fuselage to wing.

In one embodiment, leading edge Krueger flaps 2850 include two surfaces, inboard and outboard, which rotate out 145°. The surfaces are driven by rotary actuators 2860, with multiple slices connected to each panel. The slices are interconnected with torque tubes, and the entire assembly is driven by a central power drive unit (PDU). The PDU may be located in the wing root area. A position sensor and an asymmetry brake are located on the outboard end of the rotary actuator assembly.

From the stowed position, rotary actuators 2860 may rotate Krueger flap 2850 downward and forward from the lower surface 2856 of the wing 2854. As shown, Krueger flap 2850 depicts one type of a suitable rotary actuator 2860 suitable for usage on a wing or other airfoil. In general, any Krueger flap with appropriate configuration, aerodynamic configuration, and actuating mechanism can be used. Generally, a suitable Krueger flap has an actuating mechanism
capable of forming the wing leading edge configuration into a rigid airfoil structure at multiple different operating positions maintaining short and efficient load paths. Furthermore, a suitable Krueger flap has a control linkage mechanism that is stable at the different operating positions and deflects downward when actuated through a range of selected rotational angles while maintaining a substantially smooth wing surface with an aerodynamic, relatively constant radius of curvature. The actuating linkage operates to controllably stow and deploy the flap 2850 during takeoff and landing, and for usage as a speed brake, if desired, during either high or low-speed in-flight operating conditions.

FIGURE 28B shows a close-up view of a portion of the Krueger flap 2850 in greater detail. Details shown include a left wing front spar 2862, left Krueger flap hinge point 2864, a flight spoiler hinge beam 2866, left leading edge rib 2868, and left outboard flight spoiler 2870.

Referring to FIGUREs 28C and 28D, pictorial cross-sectional partial airfoil views show two embodiments of Krueger flap arrangements. FIGURE 28C shows an embodiment of the Krueger flap 2850 in which the location of the Krueger flap 2850 on the wing lower surface is chosen so that the curvature of the upper wing surface 2858 matches the Krueger flap curvature for a desired deflection. The matched curvature increases or maximizes the radius at the transition from flap 2850 to wing 2854, maintaining flow attachment to wing 2854 to result in lower drag. Krueger flap 2850 attaches wing 2854 below the stagnation point and thereby does not disturb laminar flow on upper surface 2858.

FIGURE 28B shows an alternative embodiment of a Krueger flap 2850 that is simplified, having a single pivot point 2862, in comparison to the flap shown in FIGURE 28C.

FIGUREs 28A through 28D in combination with FIGUREs 26A and 26B, the rounded form of the inboard portion of the leading edge flap 2602 smoothly transitions to the form of the Krueger flap at the Krueger flap junction to reduce or minimize any gap in the wing leading edge.

Referring again to FIGUREs 23A-23C, leading edge 2122 of wing 2102 is configured so that the shape of the leading edge flap 2130 merges into the form of Krueger flap 2128. In particular, the structure and configuration of the leading edge flap 2130 and Krueger flap 2128 are arranged so that when Krueger flap 2128 is deployed, airflow separation over wing 2102 is reduced or minimized. The cross-sectional morphology of the leading edge flap 2130 matches Krueger flap 2128 to avoid structural discontinuities, protrusions, or gaps that can create a vortex at a position along leading edge 2122, such as at the junction 2134. Vortices formed at the top of wing 2102 corrupt the flow field. Leading edge flap 2130 avoids flow field corruption via usage
of rounded edges and structures in Krueger flap 2128 and the leading edge flap 2130, particularly in the vicinity of the junction.

In various embodiments, junction 2134 between the leading edge flaps can have some structural discontinuity. A structural element that smooths the transition between segments can be used to improve aerodynamic performance. This structural material can be a flexible material such as rubber, plastic, a synthetic, or other like materials known to those skilled in the art.

The particular structure of Krueger flap 2128 and the leading edge flap 2130 can vary depending on the wing configuration. For example, leading edge 2122 may be either a subsonic or supersonic leading edge. When leading edge is contained within the Mach cone of the aircraft, structural discontinuities, protrusions, and gaps are to be avoided. However, when the leading edge is outside the Mach cone, the leading edge flap 2130 can include more irregular structures such as a sharp edge transitioning to a Krueger flap structure.

Any suitable element or structure can be used to mate the leading edge flap segments when either stowed or deployed. Generally, the portions of the leading edge flaps at the junction can be formed so that the edges of each have similar shape, thereby reducing or eliminating structural discontinuity at the junction.

FIGUREs 29A, 29B, and 29C depict side, front, and top views of a supersonic aircraft 2900 that employs an airfoil capable of improving aircraft performance by facilitating positive aerodynamic effects including adjustment of flow fields to improve aerodynamics at a range of air speeds and maintaining a low sonic boom signature. Aircraft 2900 comprises a fuselage 2902 and wing 2904 coupled to fuselage 2902. Wing 2904 has a leading edge 2906 that extends from an inboard edge at fuselage 2902 to an outboard edge at the wing tip. The airfoil further comprises a strake 2908 that couples wing 2904 to fuselage 2902 and extends to leading edge 2906 of wing 2904. Krueger flap 2910 couples to leading edge 2906 adjacent strake 2908. Similarly, leading edge flap 2912 couples to leading edge 2906 and extends from junction 2914 along the leading edge of winglet 2916. As the Mach cone angle moves farther aft the higher the lift is carried vertically, dihedral raises the height of the wing as one goes outboard. However, too much dihedral makes the aircraft roll during sideslip. To maximize the height of the wing for sonic boom minimization without saturating roll control during sideslip, the wing should have higher inboard dihedral and an anhedral wing tip. As shown in FIGURE 29B, winglet 2916 takes advantage of its greater moment arm to counter the roll from greater inboard dihedral. By making greater inboard dihedral controllable, this anhedral winglet improves sonic boom minimization. Additionally, winglet 2916 typically outboard of the fuel extent allowing the fuel bearing portion of the wing 2908 to be flat or dihedral easing pumping fuel, and allows movement as a control.
surface. This much smaller, lower sweep outboard winglets 2916 works without negatively impacting fuel volume and bending loads as much.

Aircraft 2900 contains a control systems that adjust the leading edge control surfaces of the wings 2904 to improve aerodynamic flow fields for flight at Mach numbers different from the Mach number to which the aircraft design is optimized, reduce vortex and trim drag, reduce the sonic boom signature of the aircraft while at supersonic cruise conditions, and provide a measure of roll or directional control. Additionally, the leading edge control surfaces may be used in conjunction with trailing edge device 2918 to reduce drag at subsonic cruise conditions.

In the illustration shown, aircraft 2900 has engines 2920 positioned in aft locations beneath wings 2904 and have a highly-integrated wing/inlet geometry 2922 to produce low-boom compatibility and low inlet/nacelle installation drag. As shown, aircraft 2900 has an inverted V-tail geometry 2924 that generates low-sonic-boom longitudinal trim in cruise and structural support for the engines 2920.

Aircraft 2900 has an elongated nose 2928 with nose tip 2930 and inverted V-tail surface 2924 that overlaps wing 2904. These features facilitate low-sonic-boom aircraft performance. The configuration suppresses a sonic boom pressure waveform that otherwise amplify the sound of the sonic boom. Rapid pressure rises at the front and rear of the pressure wave produce the characteristic double explosion of the sonic boom. These pressure rises are ameliorated in the illustrative design by various structural and operational improvements including the wing leading edge structures and control techniques described herein.

Tip 2930 can create a pressure spike ahead of the aircraft forward shock, raising local temperature and sound velocity, thereby extending the forward shock and slowing the pressure rise. Supersonic aircraft 2900 has a sharply swept arrow wing configuration that reduces peak overpressure in the wave by spreading wing lift along the aircraft length. The wing configuration has reduced wing leading and trailing edge sweeps.

Aircraft 2900 has twin non-afterburning turbofan engines 2920 set below and behind wing 2904. The illustrative non-afterburning turbofan engines operate behind simple fixed-geometry axis-symmetric external compression inlets 2932. Other engines may be used in other embodiments. Considerations of community noise and takeoff, transonic, and cruise thrust specifications determine engine cycle selection and engine sizing.
The shape of supersonic aircraft 2900 integrates wing 2904, tail assembly 2934, and engines 2920 to provide a reduced sonic boom signature and improved supersonic cruise drag considerations. Empennage or tail system 2934 includes stabilizers, elevators, and rudders in inverted V-tail geometry 2924. Inverted V-tail geometry 2924 supports nacelles 2936 in highly suitable positions relative to wing 2904 to suppress supersonic-booms, and trim supersonic aircraft 2900 to attain an improved low-boom lift distribution. Panels of the inverted V-tail 2924 support nacelles 2936 and non-afterburning turbofan engines 2920 and combine with support from wing 2904 to handle flutter. Inverted V-tail control surfaces, termed ruddervators 2938, adjust aircraft longitudinal lift distribution throughout the flight envelope to maintain a low boom, low drag trim condition.

Fuselage 2902, wing 2904, and empennage 2934 integrate with the entire aircraft configuration in order to achieve a low-boom signature and supersonic cruise drag levels. Wing 2904 and/or fuselage 2902 form an airfoil having aerodynamic characteristics appropriate for low-boom supersonic and transonic flight.

As depicted in FIGURE 24, the wings can have a substantial dihedral, or “gulling” inboard of the engines. Negative dihedral geometry or anhedral is pronounced at the wing’s trailing edge. The gull or dihedral results from twisting and cambering wing 2904 for low-boom and low induced drag while preserving a tailored local wing contour in the position of main landing gear retraction.

In some embodiments, the inboard portion of wing 2904 can be configured to integrate with nacelle 2936 and a diverter formed between nacelle 2936 and wing 2904 to follow the contour of a low-sonic-boom fuselage 2902 with as close a normal intersection as possible to attain low interference drag. In some embodiments, an inboard flap hinge line is fully contained within the wing contour with the wing upper and lower surfaces held as planar as possible to facilitate seal design.

With the resulting wing configuration, the “gull” wing raises engines 2920 to increase available tipback angle and reduce thrust-induced pitching moments. Gulling enhances low-boom signature by vertically staggering the wing longitudinal lift distribution and lowers the aircraft body or fuselage 2902 to reduce the height of the cabin above the ground, thereby reducing entry stair length. The low fuselage 2902 assists in maintaining a low aircraft center of gravity, reducing tipover angle and promoting ground stability. The gull wraps wing 2904 around nacelle 2936 and enhances a favorable interference between inlets 2932 and wing 2904, resulting in a wing/body/nacelle geometry conducive to successful ditching and gear-up landings. The anhedral
of the outboard winglets increase the ground effect during take off as well as providing positive wave drag interference with the nacelles.

The leading edge surfaces of wing 2904, including the leading-edge flap of strake 2908, Krueger flap 2910, and flap 2912 are controlled or directed by one or more control systems to adjust aerodynamic flow fields, thereby improving aerodynamic performance in operation at various airspeeds. The leading edge surfaces can also be controlled to adjust the leading-edge flow field to maintain a low sonic boom signature or to provide roll or directional control.

FIGUREs 30A, 30B, 30C, and 30D provide a series of graphs that illustrate the theory upon which a low sonic boom signature is attained by controlling the leading edge flaps of the wings 2904, reducing sonic boom loudness while maintaining long supersonic range. The leading edge control elements reduce sonic boom loudness by shaping the sonic boom for low shock strengths. FIGURE 30A is a graph showing the pressure distribution from a conventional supersonic aircraft. The pressure distribution coalesces into an N-wave at the ground, a shape corresponding to the largest shock strength and thus the greatest loudness. One technique for reducing sonic boom amplitude at the ground involves a minimization theory in which a pressure distribution caused by a low boom aircraft follows an inversely calculated distribution to generate low shock strength at the ground. Contrary to intuition, a low boom distribution occurs when a strong leading edge compression quickly reduces in magnitude, followed by a gradually increasing weak compression that rapidly inverts into a weak expansion, followed by a stronger trailing edge compression that gradually recompresses to ambient. Boom minimization occurs when an aircraft produces an inversely calculated pressure distribution without sacrificing performance. The pressure distribution produced by an aircraft results from a Mach angle, cross-sectional area distribution, for example as shown in FIGURE 30B, and a Mach angle lift distribution, as shown in FIGURE 30C. The leading edge devices can include the strake leading edge flaps, the Krueger flaps, and the outboard leading edge flaps, individually or in various combinations, operate to shift the lift distribution of the aircraft and shape the active area distribution to reduce sonic boom amplitude at the ground. A minimized pressure distribution, shown in FIGURE 30D, occurs when the sum of the area pressure distribution and the lift pressure disturbance equal the minimized pressure distribution. The leading edge devices described herein can be used to shape the pressure distribution.

The graph presented in FIGUREs 31 and 35 further illustrates the theory of equivalent area minimization to reduce sonic boom signature, showing effective area against axial location along the longitudinal axis of the aircraft. When equivalent area due to geometric area and lift sum to the minimized distribution, a minimized ground sonic boom occurs. The leading edge
surfaces are controlled to modify the airflow over wing, stretching the lifting length to move the active area distribution closer to the distribution that shapes the sonic boom signature and maintains a clean flow of air over wing, clearing any vortices from wing. Accordingly, the leading edge flaps including the flaps of strake, Krueger flaps, and leading edge flaps, can be controlled to create an area distribution for sonic boom shaping to a desired target.

Returning to FIGURES 29A, 29B and 29C, aircraft 2900 controls the leading edge control surfaces, including one or more of leading edge flap segments in accordance with an equivalent area technique to reduce sonic boom signature. Equivalent area is the Mach angle area distribution of an axis-symmetric body that generates the same disturbance as a given geometric area or given lift distribution. The equivalent area due to geometric area can be approximated as equal to the Mach angle area distribution. The equivalent area due to lift is equal to the integral of the Mach lift per unit of streamwise length times atmospheric constants.

In the illustrative embodiment, the leading edge control surfaces are controlled to reduce or minimize sonic boom by deflecting the airflow to reduce lift ahead of the spillage due to nacelles 2936. For example, if aircraft 2900 is flying in an off-design condition in which the nacelles 2936 are spilling air and are thus generating stronger shocks and stronger compressions, the leading edge control surfaces and be actuated to compensate by creating an expansion of airflow that blocks the spillage.

The wings and engine are generally designed to operate at various air speeds. Engine 2920 and inlet 2926 characteristics are configured to coordinate engine airflow schedules and flight Mach number. In a particular embodiment, a fixed geometry inlet 2926 can be utilized, for example to reduce propulsion system weight and complexity, and thereby improve efficiency and performance. In particular fixed-geometry inlet configurations, airflow is matched at all pertinent Mach numbers so that no bypass or excessive subcritical spillage occurs under nominal conditions. Airflows at off-nominal conditions can be matched using engine trim and a translating engine cowl.

In one embodiment, an inlet/engine configuration is based on a supersonic aircraft engine that maintains a status range of 3600 nautical miles (nmi) at Mach 1.8. The fixed compression geometry engine inlet is optimized for Mach 1.8. A maximum Mach 1.8 capable design represents performance of the Mach 1.8-designed engine cruising at Mach 1.6. The Mach 1.8-capable engine flying at Mach 1.6 increases range and engine life, and potentially improves performance on hot-temperature days.
In an alternative embodiment, an engine 2920 is configured with a fixed compression geometry inlet optimized for Mach 1.6, increasing range to approximately 4250 nmi by increasing lift/drag ratio by a full point, and a lower engine weight enabling more fuel to burn in cruise.

Various design techniques can be used to configure an aircraft for a range capability that is greater than a baseline Mach 1.8 point design approach, yet supply a greater speed capability than a Mach 1.6 point design method. One technique is to design a Mach 1.6 inlet and engine and cruise off-design at Mach 1.8 to improve range over a Mach 1.8 design inlet, for example attaining a 150-250 nmi improvement in range. A second technique involves designing the aircraft as a Mach 1.6 point design for maximum range and accepting any over-speed capability that happens to occur, resulting in a small speed increase for a fully optimized Mach 1.6 engine design that is further limited by engine life reduction as well as degradation of inlet stability and distortion. In a slight variation to the second approach, the engine can be configured as a Mach 1.6 point design with the engine and subsystem design Mach numbers tailored to any speed a Mach 1.6 inlet is capable of attaining in an over-speed condition. The range benefit is even smaller than the effect of a pure Mach 1.6 aircraft but the over-speed capability can be improved although not to the level of a Mach 1.8 design. A third approach incorporates a variable geometry inlet into an otherwise Mach 1.8 configuration so that efficient on-design inlet performance can be obtained from a range from Mach 1.6 to Mach 1.8, resulting in a small range penalty due to higher weight and higher losses inherent to the variable geometry inlet. Mach 1.6 performance of the third approach is further hindered due to increased inlet weight.

In a fourth approach, the inlet design Mach number is set such that a Mach 1.8 cruise can be attained in an over-speed condition with engine, subsystem, and aerodynamic design configured to maximize range at Mach 1.6. The illustrative concept does not operate on-design in a purest sense, although enabling the largest range of a fixed compression geometry inlet capable of cruising at Mach 1.8. Potentially, flight at a lower than design Mach number using the fixed geometry external compression engine and translating engine cowl can increase spillage drag and integrate the inlet and propulsion system in a manner that results in a higher drag.

An illustrative aircraft 2900 can have inlets, engines, and an airframe generally designed for Mach 1.8 performance, and further includes optimizations to improve various performance aspects. The configuration enables cruising at a slightly lower Mach number than 1.8 to attain a higher range performance. In an illustrative embodiment, the wings are sized slightly larger than normal for a Mach 1.8 design to improve takeoff and landing performance.
The control elements operating the leading edge flap of strake 2908, Krueger flap 2910, and leading edge flap 812 can be controlled to further facilitate operation of aircraft 2900 at off-design Mach numbers.

**FIGURE 32** illustrates an aircraft wing that employs winglet 2916 having an anhedral of about 30 degrees, typically outboard of the fuel extent. The resulting winglet's closer proximity to the ground intensifies the ground effect increasing lift, reducing drag and resulting in improved take-off performance. Further, George-Seebass-Darden minimization requires the aircraft lift to be carried aft, and because the Mach cone angle moves farther aft the higher the lift is carried vertically, dihedral raises the height of the wing as one goes outboard. Too much dihedral can make the aircraft roll during sideslip. To maximize the height of the wing for sonic boom minimization without saturating roll control during sideslip, the wing may have a higher inboard dihedral and an anhedral wing tip. The tip takes advantage of its greater moment arm to counter the roll from greater inboard dihedral. By making greater inboard dihedral controllable, this anhedral winglet improves sonic boom minimization. In addition, the winglet can capture a little more of the shock wave coming off the nacelle for drag reduction. Additional embodiments may incorporate an all-moving winglet with a rotational axis in the dihedral plane of the wing, to control roll with reduced aerelastic effectiveness loss. This is especially true when operating supersonically. Such an all-moving winglet also results in less adverse yaw during roll conditions. High reliability actuators, like dual-tandem actuators 2919 can be housed in streamwise upper surface wing bulge 2921 to avoid interference with winglet 2916 and nacelle. Upper surface actuators 2919 with hinges located at the lower surface allow large hinge radii on the upper surface, where it is more useful for keeping control surface flow attached. The winglet incidence can be changed with rotation shaft 2923 when the Mach number is changed from the design point to maximize drag reduction.

**FIGUREs 33A and 33B** depict an aircraft that employs a winglet 2916 having a dihedral of -60 to -90 or about +90 degrees. This winglet or a portion thereof, through rotation shaft 2923 rotates about an axis perpendicular to the plane of the inboard portions of the wing 2904. Actuator 2919 can be placed in the axis of the wing spars. This embodiment allows increased yaw control from aft placed sideforces, and contributing drag differentials at winglets 2916 due to the winglets or a combination of the winglets and ailerons. It could be possible to reduce or eliminate a larger center fin and rudder.

The inboard section of wing 2904 may be have a higher leading edge sweep that is adjusted to fill-in the typical dip that occurs in the equivalent area just ahead of the wing. The spanwise extent of this higher swept region may be limited to the first 20 to 30 percent of span
where a leading edge flap is not typically needed, to allow for a straighter leading edge flap. This higher inboard sweep can be separate or combined with the previous outboard wing sections. Canard 2923 of FIGURE 33C can also be used with or without the higher inboard sweep to fill in the typical dip that occurs in the equivalent area just ahead of the wing.

Wing control surfaces 2925, flaps 2927, tails and canards 2923 can be used to meet sonic boom minimization requirements. By using movable surfaces to alter the lift distribution to meet sonic boom minimization requirements, resulting drag penalties do not have to be incurred wherever low sonic boom is not required, like over water. Since maximum range is generally most important over water, using movable surfaces for sonic boom minimization can reduce the drag penalty associated with reducing sonic boom.

FIGURE 34 is a graph illustrating the relationship between the equivalent area of the aircraft and the axial location.

Other mission-related characteristics facilitated by control of the leading edge surfaces include a capability to cruise at lower Mach numbers, and a tendency to cruise at lower altitudes at lower Mach numbers, resulting from an optimum lift coefficient occurring at lower altitude as a consequence of lower speed. Furthermore, suitable engines for the desired Mach performance typically produce lower specific fuel consumption at the lower altitudes. Also, lower cruise altitudes yield excess thrust at cruise, enabling a reduction is engine cruise thrust requirement and reduced engine weight. Additionally, lower cruise altitudes allow cruise to begin earlier and end later in a mission so that the aircraft spends proportionately more of a mission in a cruise condition. Also, lower cruise Mach numbers yield lower total air temperatures, benefit engine and subsystem life. Lower cruise Mach numbers can also reduce emissions.

While the present disclosure describes various embodiments, these embodiments are to be understood as illustrative and do not limit the claim scope. Many variations, modifications, additions and improvements of the described embodiments are possible. For example, those having ordinary skill in the art will readily implement the steps necessary to provide the structures and methods disclosed herein, and will understand that the process parameters, materials, and dimensions are given by way of example only. The parameters, materials, and dimensions can be varied to achieve the desired structure as well as modifications, which are within the scope of the claims. Variations and modifications of the embodiments disclosed herein may also be made while remaining within the scope of the following claims. For example, although a particular aircraft geometry and configuration is described, the channel configuration and techniques for controlling the channel can be utilized in aircraft with different geometries. In particular, although the described aircraft has an inverted V-tail configuration, other tail configurations such as T-tail
configurations and others may be used. The described propulsion configuration includes two engines mounted at aft positions in a highly swept wing. Other suitable embodiments may have different engine configurations with fewer or more engines, with engines mounted on the fuselage or tail rather than on the wing, or mounted above rather than beneath the wing.
WHAT IS CLAIMED IS:

1. An aircraft thickness/camber control device (100) for usage with an airfoil (304) that extends along a longitudinal axis (104) forward and aft and constitutes a concentrated source of expansion (106), the thickness/camber control device (100) comprising:

   a structural member (108) capable of coupling to the airfoil (304) at a position forward of the concentrated source of expansion (106); and

   a control element (110) coupled to the structural member (108) that controls the structural member (108) to adjust thickness/camber of the airfoil (304) to cancel the far-field effect of the concentrated source of expansion (106).

2. The control device (100) according to Claim 1 wherein:

   the concentrated source of expansion (106) is a nacelle (318) that creates a spillage shock in off-design conditions that is larger than a baseline cruise configuration for a low sonic boom signature; and

   the control element (110) adjusts airfoil thickness/camber so that the far-field effects of the controlled structural member (108) and the nacelle shock substantially cancel.

3. An aircraft (300) comprising:

   an airfoil (304) that extends along a longitudinal axis (104) forward and aft and that has a concentrated source of expansion (106) on the airfoil lower surface;

   a structural member (108) capable of coupling to the airfoil (304) at a position forward of the concentrated source of expansion (106); and

   a control element (110) coupled to the structural member (108) that controls the structural member (108) to adjust thickness/camber of the airfoil (304) to cancel the far-field effect of the concentrated source of expansion (106).

4. The aircraft (300) according to Claim 3 further comprising:

   a fuselage (314);

   an aircraft wing (316) coupled to the fuselage (314);

   an engine nacelle (318) coupled to the aircraft wing (316) and generating the concentrated source of expansion (106), wherein the structural member (108) is coupled to the fuselage (314) forward of the engine nacelle (318) and is capable of deployment to adjust thickness/camber of the fuselage (314) to cancel the far-field effect of the engine nacelle (318).
5. The aircraft (300) according to Claim 4 wherein:
the engine nacelle (318) creates a spillage shock in off-design conditions that is larger
than a baseline cruise configuration for a low sonic boom signature; and
the control element (110) adjusts airfoil thickness/camber so that the far-field effects of
the controlled structural member (108) and the nacelle (318) substantially cancel.

6. The aircraft (300) or control device (100) according to any of Claims 1-5
wherein:
the aircraft (300) is a supersonic cruise aircraft with an area distribution that closely
corresponds to a low sonic boom signature; and
the control element (110) adjusts the structural member (108) in off-design conditions
that cause the concentrated source of expansion (106) to generate a spillage shock
larger than a baseline cruise configuration so that the far-field effect of the
adjusted structural member (108) cancels the far-field effect resulting from the
spillage shock.

7. The aircraft (300) or control device (100) according to any of Claims 1-5
wherein:
the aircraft (300) is a supersonic cruise aircraft with an area distribution that matches a
low sonic boom signature; and
the control element (110) adjusts the structural member (108) in off-design conditions
that cause the concentrated source of expansion (106) to generate a spillage shock
larger than a baseline cruise configuration so that the expansion generated around
the structural member (108) effectively reduces the equivalent area distribution
ahead of the shock.

8. The aircraft (300) or control device (100) according to any of Claims 1-5
wherein:
the control element (110) is capable of adjusting the structural member (108) to improve
aerodynamic flow fields for flight at Mach numbers different from the Mach
number to which the aircraft design is optimized.
9. The aircraft (300) or control device (100) according to any of Claims 1-5
wherein:
the control element (110) is capable of adjusting the structural member (108) to
effectively modify the camber of the airfoil (304) to minimize or reduce spillage
shock resulting from the concentrated source of expansion (106).

10. The aircraft (300) or control device (100) according to any of Claims 1-5
wherein:
the structural member (108) is selected from among a group comprising a body flap
(200), a canard (210), a fairing (220), a speed brake (230), and/or a protrusion
(240).

11. A supersonic aircraft (900) comprising:
the fuselage (901) extending forward and aft along a longitudinal axis and having a lower
surface and an upper surface;
a wing (904) coupled to the fuselage (901); and
a canard (920) coupled onto the fuselage (901) forward of the wing (904) at an elevated
position that enables stretching forward of the aircraft lifting length and forms an
effective area distribution, forming a shaped sonic boom signature.

12. A supersonic aircraft (900) comprising:
the fuselage (901) extending forward and aft along a longitudinal axis and having a lower
surface and an upper surface;
a wing (904) coupled to the fuselage (901);
at least two canards (920) coupled at opposing sides of the fuselage (901) at the elevated
position, the at least two canards (920) having differential deflection for
directional control; and
a controller (911) coupled to the canards (920) and comprising a process for differentially
controlling the canards (920) to induce lift on the fuselage (901) and the wing
(904) on respective opposing sides of the fuselage (901) to cause lift from the
canard (920) and fuselage body (901) lift to blend into lift produced by the wing
(904).

13. A supersonic aircraft (900) comprising:
a fuselage (901) extending forward and aft along a longitudinal axis and having a lower
surface and an upper surface;
a wing (904) coupled to the fuselage (901);
at least two canards (920) coupled at opposing sides of the fuselage (901) at the elevated position, the at least two canards (920) having differential deflection for directional control; and

a controller (911) coupled to the canards (920) and comprising a process for differentially controlling the canards (920) to modify the aircraft lift distribution to reduce or minimize the aircraft sonic boom.

14. The aircraft (900) according to any of Claims 11-13 further comprising:
a controller (911) that controls at least two canards (920) with differential deflection for directional control.

15. The aircraft (900) according to any of Claims 11-13 further comprising:
a canard (920) with a high dihedral sufficient to increase the aircraft lifting length and attain a target equivalent area distribution for low sonic boom performance.

16. The aircraft (900) according to any of Claims 11-13 further comprising:
at least two canards (920) coupled at opposing sides of the fuselage (901) at the elevated position, the at least two canards (920) having a high dihedral and differential deflection to exploit asymmetric lift on the canards (920) for directional control.

17. The aircraft (900) according to any of Claims 11-13 further comprising:
at least two canards (920) coupled at opposing sides of the fuselage (901) at the elevated position, the at least two canards (920) inducing lift on the fuselage (901) and the wing (904) on respective opposing sides of the fuselage (901) to cause lift from the canard (920) and fuselage body (901) lift to blend into lift produced by the wing (904).

18. The aircraft (900) according to any of Claims 11-13 further comprising:
an inverted V-tail (908) coupled to the fuselage (901) aft of the canards (920); wherein:
the canards (920) have a dihedral configured to create a canard wing tip vortex that passes through the inverted V-tail channel and not impinge on any lifting surfaces at either subsonic or supersonic cruise conditions.

19. The aircraft (900) according to any of Claims 11-13 further comprising:
at least two canards (920) coupled at opposing sides of the fuselage (901) at the elevated position, the at least two canards (920) having a high dihedral and differential deflection;
a plurality of actuators coupled to the at least two canards (920); and
a controller (911) coupled to the actuators and comprising a process for symmetrically deflecting the actuators to induce lift on the fuselage (901) and the wing (904) on respective opposing sides of the fuselage (901) to cause lift from the canard (920) and fuselage body (901) lift to blend into lift produced by the wing (904).

20. The aircraft (900) according to any of Claims 11-13 further comprising:
a controller (911) that differentially controls the canards (920) to enable stretching of the aircraft lifting length and form an effective area distribution that enables a shaped sonic boom signature.

21. A wing (904) for use on a supersonic aircraft (900) comprising:
a wing (904) further comprising:
an inboard section of the wing (904) adjacent to the fuselage (901);
a central section of the wing outboard of the inboard portion;
an outboard winglet oriented anhedrally relative to a lateral axis of the supersonic aircraft (900) and outboard of the central section of the wing (904); and

20 22. An aircraft wing (904) capable of coupling to an aircraft fuselage (901) and having a leading edge, the wing (904) extending inboard to outboard, comprising:
a strake capable of coupling to the aircraft fuselage (901) and extending to the leading edge of the wing (904), the strake further comprising a leading-edge flap;
a Krueger flap (934) coupled to the leading edge of an inboard portion of the wing (904) adjacent the strake and having upper and lower surfaces, wherein the strake leading-edge flap operates as a leading-edge device that can be deflected to create an airflow field impinging on the Krueger flap (934) to reduce or eliminate inboard vortices in an upper surface air flow field; and
an outboard winglet having a simple leading edge flap coupled to the leading edge of the outboard winglet, wherein the outboard winglet is anhedrally oriented relative to a lateral axis of the aircraft (900), and wherein the simple leading edge flap provides roll control and directional control for the aircraft (900).
23. An aircraft (900) comprising:
   a fuselage (901);
   an aircraft wing (904) coupled to the fuselage (901) and having a leading edge, the wing
   (904) extending inboard to outboard, and wherein an inboard section of the wing
   (904) proximate to the fuselage (901) is oriented at a positive dihedral angle
   relative to a lateral axis of the aircraft (900);
   a strake capable of coupling to the fuselage (901) and extending to the leading edge of the
   wing (904);
   a Krueger flap (934) coupled to the leading edge of an inboard section of the wing (904)
   adjacent the strake;
   a leading edge flap (934) coupled to the leading edge of the wing (904) and extending
   outboard from a junction at the Krueger flap; and
   an outboard winglet having a simple leading edge flap coupled to the leading edge of the
   outboard winglet, wherein the outboard winglet is anhedrally oriented relative to
   the lateral axis of the aircraft (900), and wherein the simple leading edge flap
   provides roll control and directional control for the aircraft (900).

24. A wing (904) for use on a supersonic aircraft (900) comprising:
   a wing (904) further comprising:
   an inboard section of the wing adjacent to the fuselage (901);
   a central section of the wing outboard of the inboard portion;
   an outboard winglet outboard of the central section of the wing (904), wherein the
   outboard winglet's moment from the supersonic aircraft's fuselage (901)
   allows control surfaces of the winglet to be reduced in size relative to
   control surfaces inboard of the outboard winglet; and
   a leading edge formed from leading edge segments on the inboard section, central
   section and outboard winglet, wherein the leading edge segments have
   mounted thereon leading-edge flaps (934); and
   a control system operable to reposition the leading edge flaps (934) to improve
   aerodynamic performance of the supersonic aircraft (900).

25. The wing (904) according to any of Claims 21-24, wherein the inboard section of
   the wing (904) is oriented dihedrally relative to the lateral axis of the supersonic aircraft (900).

26. The wing (904) according to any of Claims 21-24, wherein the leading-edge flap
   of the central section of the wing (904) comprises a Krueger flap (934) and the leading-edge flap
   of the outboard winglet comprises a simple leading-edge flap.
27. The wing (904) according to any of Claims 21-24, wherein the outboard winglet has a configuration that increases ground effect during take off.

28. The wing (904) according to Claim 7 further comprising a nacelle, and wherein the outboard winglet supplies positive wave drag interference with the nacelle.

29. The wing (904) according to any of Claims 21-24, wherein the leading edge flap (934) of the outboard winglet generates roll control at supersonic conditions and directional control with proverse roll effects.

30. The wing (904) according to any of Claims 21-24 further comprising: trailing-edge flaps (932) on one or more sections, whereby the leading edge flaps (934) are controlled in conjunction with the trailing edge flaps (932) by the control system to reduce drag at subsonic cruise conditions.

31. The wing (904) according to any of Claims 21-24, whereby the leading edge flaps (934) are configured to increase aft lift, reduce trim and vortex drag, and reduce the sonic boom signature of the supersonic aircraft (900).

32. The wing (904) according to any of Claims 21-24, wherein the control system couples to the leading edge flaps (934) and adjusts the leading-edge flaps (934) to improve aerodynamic flow fields for flight at Mach numbers different from the Mach number to which the aircraft design is optimized.

33. The wing (904) according to any of Claims 21-24 further comprising: a strake leading-edge flap that repositions to deflect or reduce lift ahead of spillage at an off-design condition and maintain a low sonic boom signature.

34. The wing (904) according to any of Claims 21-24 whereby the wing (904) and strake form a swept wing (904) that extends at least one sweep angle from the fuselage (901).

35. The wing (904) according to any of Claims 21-24 whereby the wing (904) and strake form a swept wing (904) that extends in a plurality of sweep angle segments from the fuselage (901), the sweep angle of the inboard portion of the wing (904) differs from the sweep angle of the strake and outboard winglet.
36. The wing (904) according to any of Claims 21-24 in a configuration whereby a dihedral angle of the inboard section and central section of the wing (904) enables fuel stored within the inboard section and central section to be readily pumped.

37. The wing (904) according to Claim 36 whereby the outboard winglet rotates on about an axis in the plane of the outboard winglet and normal to a longitudinal axis of the supersonic aircraft (900).

38. The wing (904) according to Claim 36 whereby the anhedral angle of the outboard winglet enables the dihedral angle of the inboard section and center section of the wing (904) to be increased to minimize a sonic boom signature of the aircraft (900).