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- (71) Applicant (for all designated States except US): THE BOEING COMPANY [US/US]; MC 110-SD54, P.O. Box 2515, Seal Beach, CA 90740-1515 (US).

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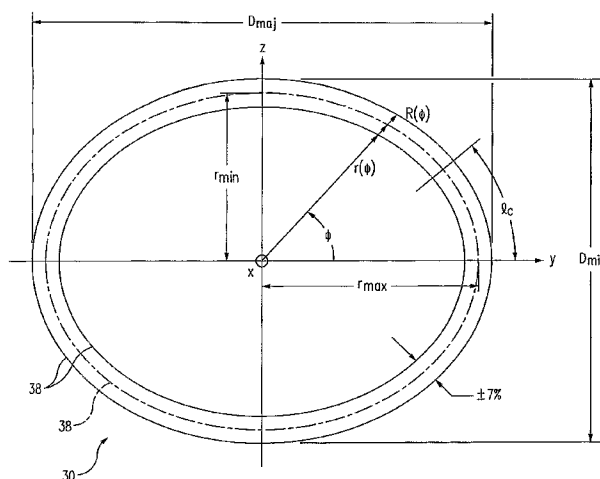
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- (72) Inventors; and
- (75) Inventors/Applicants (for US only): SANKRITHI, Mithra, M., K., V. [IN/US]; 17602 Bothell Way NE, Lake Forest Park, WA 98155 (US). RETZ, Kevin, M. [US/US]; 10318 NE 201st PL, Bothell, WA 98011 (US).
- (74) Agents: WOO, Euclid et al.; The Boeing Company, MC 110-SD54, P.O. Box 2515, Seal Beach, CA 90740-1515 (US).

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(54) Title: WEIGHT OPTIMIZED PRESSURIZABLE AIRCRAFT FUSELAGE STRUCTURES HAVING NEAR ELLIPTICAL CROSS SECTIONS



(57) Abstract: An aircraft fuselage includes a tubular shell having a centerline axis, opposite ends, and a cross-section having a radius $R(\varphi)$, where φ is the angular coordinate of a cylindrical coordinate system, a curvature $Curv(\varphi)$, where $Curv(\varphi)$ is the inverse of a local radius of curvature of a surface of the shell, and a circumferential shape that varies radially by no more than $\pm 7\%$ from that of an elliptical cross-section at substantially every station along the centerline axis between the nose and tail ends thereof. The weight of the shell is minimized by "tailoring," i.e., optimizing, at least one structural attribute, expressed as a function of φ , associated with every element of the shell, such that the weight of the shell required to react a design load incident thereon is less than that required to react the same design load, but wherein the same structural attribute has not been so tailored.

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WEIGHT OPTIMIZED PRESSURIZABLE AIRCRAFT FUSELAGE STRUCTURES HAVING NEAR ELLIPTICAL CROSS SECTIONS

TECHNICAL FIELD

This invention relates to aircraft design in general, and in particular, to the design of a
5 lightweight structure for a pressurizable aircraft fuselage having an elliptical or near-elliptical
cross-section.

BACKGROUND

Certain classes of internally pressurizable aircraft fuselages, such as passenger planes,
can beneficially employ near-elliptical cross-sections. For example, U.S. Pat. No. 6,834,833 to
10 M. K. V. Sankrithi discloses the use of an aircraft having a fuselage 10 with a quasi-elliptical, or
near-elliptical cross-section that is wider than it is tall. Representative front-end and a top plan
cross-sectional views of this class of fuselage shape are illustrated in Figs. 1A and 1B, respec-
tively, wherein the fuselage comprises a rigid, light weight shell 12 having respective opposite,
closed nose and tail ends 14 and 16. This cross-section efficiently encloses a main deck cabin 18,
15 typically provisioned as a spacious and comfortable twin-aisle, seven-abreast cabin, together
with a cargo container 14 (typically a LD-3-46W or similar, standardized type of container) in a
lower deck hold 20. This twin-aisle fuselage cross-sectional shape has also been shown to pro-
vide a perimeter-per-seat ratio comparable to that of a corresponding single-aisle, six-abreast,
conventional aircraft fuselage having a circular or blended circular arc cross-section, and conse-
20 quently, can also provide a cross-section-parasite-drag-per-seat ratio and an empty-weight-per-
seat ratio that, in a zeroth-order analysis, are comparable to those of the corresponding single-
aisle fuselage cross-section, while offering better passenger comfort and owner revenue options.

However, achieving an optimized, lightweight structure for such near-elliptical cross-
section fuselages presents a substantial engineering design challenge because of the structural
25 and weight penalties involved in moving from a fuselage design having a conventional circular
cross-section to a fuselage design having a non-circular cross-section, especially those penalties
that are associated with pressurization effects inherent in the design of high-altitude jet airliners.

Accordingly, there is a need in the aviation industry for design methods and techniques
for achieving lightweight structures for pressurizable aircraft fuselages having an elliptical or a
30 near-elliptical cross-section.

BRIEF SUMMARY

In accordance with the various exemplary embodiments thereof described herein, the present invention provides an internally pressurizable fuselage structure for an aircraft having a near-elliptical shape and a weight that is minimized by “tailoring,” *i.e.*, optimizing, the structural attributes of substantially every element of the fuselage, expressed as a function of the angular coordinate ϕ of a cylindrical coordinate system of the fuselage, to react, *i.e.*, to sustain without failure, all design loads incident thereon.

In a preferred exemplary embodiment thereof, the fuselage structure comprises an elongated tubular shell having a central axis x , opposite closed nose and tail ends, and a non-circular cross-section having a radius $R(\phi)$ at substantially every point along the x axis between the two ends, where ϕ is the cylindrical angular coordinate, *i.e.*, a roll elevation angle of the shell, that varies from 0 degrees to +360 degrees about the x axis. The radius $R(\phi)$ of each cross-section of the shell is constrained to vary radially by no more than $\pm 7\%$ from a radius $r(\phi)$ of a true elliptical cross-section having a major axis of dimension $2 \cdot r_{\max}$ and a minor axis of dimension $2 \cdot r_{\min}$, and where $r(\phi)$ is given by the relation:

$$r(\phi) = \frac{r_{\min}}{\sqrt{\left[\left(\frac{r_{\min}}{r_{\max}}\right)^2 \cdot (\cos \phi)^2\right] + (\sin \phi)^2}}$$

In the preferred embodiment, the maximum width of the shell exceeds the maximum height thereof, and the maximum width and height of the shell are respectively substantially aligned with the major and minor axes of the true elliptical cross-section. A curvature, $\text{Curv}(\phi)$, defined as the inverse of the local radius of curvature of a surface of the shell, is associated with $R(\phi)$, and a corresponding curvature $\kappa(\phi)$ associated with $r(\phi)$ of the true elliptical cross-section is given by:

$$\kappa(\phi) = \frac{\left[r^2 + 2 \cdot \left(\frac{\partial r}{\partial \phi} \right)^2 - r \cdot \frac{\partial^2 r}{\partial \phi^2} \right]}{\left[r^2 + \left(\frac{\partial r}{\partial \phi} \right)^2 \right]^{1.5}}$$

The exemplary shell has at least one structural attribute associated with every cross-sectional element thereof that has been tailored as a function of the elevation angle ϕ such that the weight of the shell required to react the design loads incident on that element is less than that required to react the same design load, but wherein the at least one structural attribute has not

been so tailored. In a preferred embodiment, the function of ϕ consists of either $R(\phi)$ or $\text{Curv}(\phi)$. Thus, an exemplary embodiment of a method for weight-optimizing, *i.e.*, minimizing the weight of, the fuselage comprises defining at least one structural attribute of every circumferential element of the shell as a function of either $R(\phi)$ or $\text{Curv}(\phi)$, *i.e.*, as a “functional,” and then tailoring the at least one structural attribute of the element such that the weight of the shell required to react all design loads incident on each circumferential element thereof is less than that required to react the same design loads acting thereon, but wherein the at least one structural attribute has not been so tailored.

Advantageously, the shell of the fuselage can function as a pressure vessel in which the design loads of major interest include internal pressurization loads. The shell can comprise a circumferential outer skin and circumferentially spaced longitudinal stringers, disposed adjacent to an inner surface of the skin, and the at least one tailored structural attribute can comprise at least one of a cross-sectional shape and size, number, and material of the stringers. Each of at least one of the circumferential skin and the stringers can comprise a “composite” of a plurality of plies, each having a selected angular orientation relative to the others, the at least one tailored structural attribute can comprise at least one of the number, relative angular orientation, and material of the plies.

Alternatively, the shell can comprise a “sandwich” structure, *i.e.*, circumferential outer and inner skins attached to a rigid core, which can comprise either of a continuous rigid foam or of interconnected cells, and the at least one tailored structural attribute can comprise at least one of a thickness of the core, a core density or core cell density and a core material. The skins can be made from either thermosetting or thermoplastic material, and by hand lay up, machine lay up or resin infused.

In another embodiment, the shell can comprise an “isogrid” structure having at least one external face sheet attached to a grid comprising internal stiffening members, and the at least one tailored structural attribute can comprise at least one of grid spacing, grid geometry, grid material and face sheet material.

In still yet another embodiment, the shell can comprise a filament-wound structure in which the at least one tailored structural attribute may include the filament cross-sectional shape and size, winding pitch, and/or the number of fibers in the filament.

A better understanding of the above and many other features and advantages of the present invention may be obtained from a consideration of the detailed description of the exemplary embodiments thereof below, particularly if such consideration is made in conjunction with the

appended drawings, wherein like reference numerals are used to identify like elements illustrated in one or more of the figures therein.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Figs. 1A and 1B are cross-sectional front end and top plan views, respectively, of an internally pressurizable aircraft fuselage in accordance with the prior art;

Figs. 2A and 2B are cross-sectional front end and top plan views, respectively, of an exemplary embodiment of an internally pressurizable aircraft fuselage in accordance with the present invention;

10 Fig. 3 is a representative cross-sectional diagram of the fuselage of Fig. 2, as expressed in a cylindrical coordinate system;

Fig. 4 is a representative diagram of an exemplary embodiment of structural components of the fuselage of Fig. 2, as expressed in a cylindrical coordinate system and mapped onto a two-dimensional plane, showing a stringer-frame type of fuselage architecture;

15 Figs. 5A – 5D are plan views of alternative embodiments of structural components of the fuselage of Fig. 2, showing exemplary embodiments of core cells of a composite-sandwich fuselage architecture;

Figs. 6A - 6G are plan views of alternative embodiments of structural components of the fuselage of Fig. 2, showing exemplary embodiments of grids of a composite Isogrid fuselage architecture;

20 Fig. 7 illustrates an exemplary tailoring function of a structural attribute; and,

Fig. 8 is a schematic plan view of a fuselage structure showing exemplary ply orientations.

DETAILED DESCRIPTION

25 Figs. 1A and 1B respectively illustrate cross-sectional front end and plan views of a prior art pressurizable aircraft fuselage 10 having a passenger cabin 18 and a cargo compartment 20. This invention provides a lightweight fuselage shell structure for such an aircraft in which the shell has a near-elliptical cross-section by applying “tailoring,” *i.e.*, optimally selected adjustments, of the structure to more closely match critical design loads as a function of the roll elevation angle ϕ measured around the centerline axis of the cross-section. An exemplary embodiment
30 of a fuselage shell 20 having a near-elliptical cross-section in accordance with the present invention is illustrated in the front-end cross-sectional view of Fig. 2A. In Fig. 2A, the periphery or

outer periphery of the shell is designated 28, and a window belt 31 is disposed adjacent to a passenger cabin 22 having a main cabin floor 32. A cargo compartment 26 is shown with a Unit Load Device or cargo container 24. A crown region 27 and a keel region 29 of the shell define the upper and lower extremities of the shell.

5 For the purposes of this invention, the term “near-elliptical cross-section” should be understood as a cross-section that is approximately elliptical in shape, with a width-to-height (or height-to-width) ratio that is between 1.01 and 1.30, and with a cross-sectional periphery, or circumference, that is either a “pure” ellipse, *i.e.*, strictly elliptical in shape, or that is between $\pm 7\%$ from such a strictly elliptical shape, as measured in a direction extending radially outward from
10 the centerline axis of the fuselage shell cross-section, at substantially every point, or longitudinal station, along the central axis thereof.

Figure 2B illustrates a plan view of the embodiment of Fig. 2A, showing an elongated, internally pressurizable tubular shell 21 and opposite closed nose and tail ends 23 and 25, as well as means for lifting 13 (*e.g.*, wings) the shell off the ground and for propelling 15 (*e.g.*, engines)
15 it relative to the ground.

As illustrated schematically in Fig. 3, for purposes of description, a cylindrical coordinate system is assumed, with x positive forward substantially along the longitudinal, or centerline axis of the fuselage shell 30; where the radius r is positive radially outward from the x axis, and the angular coordinate ϕ is positive rotating upward from $\phi = 0$ from a substantially horizontal vector pointing to the right of the aircraft, looking forward, at right angles to the x axis. Thus, it may
20 be seen that the cylindrical angular coordinate ϕ corresponds to a “roll elevation angle” of the shell that varies from 0 degrees to +360 degrees about the x axis. The corresponding Cartesian coordinate system has an x-axis that is positive forward along the centerline axis of the fuselage shell cross-section, a y axis that is positive to the left side of the centerline axis of the aircraft,
25 and a z axis that is positive upwards from the centerline axis, as illustrated in Fig. 3.

If the nominal shape of the periphery or circumferential perimeter 38 of the cross-section of the aircraft’s fuselage shell 30 is that of a “true” ellipse, as shown by the phantom outline of Fig. 3, *i.e.*, one having a substantially horizontal major axis of diameter D_{maj} (width) equal to $2 \cdot r_{\text{max}}$ and a substantially vertical minor axis with a diameter D_{min} (height) equal to $2 \cdot r_{\text{min}}$, and
30 with an eccentricity e given by

$$e = \sqrt{1 - (r_{\text{min}}/r_{\text{max}})^2},$$

then the radius r , expressed as a function of ϕ , is given by

$$r(\phi) = \frac{D_{\min}}{2 \cdot \sqrt{\left[\left(\frac{r_{\max}}{r_{\min}}\right)^2 \cdot (\cos \phi)^2\right] + (\sin \phi)^2}},$$

or, by defining $A = (r_{\min}/r_{\max}) = (D_{\min} / D_{\max})$, by

$$r(\phi) = \frac{D_{\min}}{2 \cdot \sqrt{\left[A^2 \cdot \cos^2 \phi\right] + \sin^2 \phi}}.$$

5 A “curvature,” $\kappa(\phi)$, defined as the inverse of the local radius of curvature for the surface, is given for the true elliptical shape 38 by the following equation:

$$\kappa(\phi) = \frac{\left[r^2 + 2 \cdot \left(\frac{\partial r}{\partial \phi} \right)^2 - r \cdot \frac{\partial^2 r}{\partial \phi^2} \right]}{\left[r^2 + \left(\frac{\partial r}{\partial \phi} \right)^2 \right]^{1.5}}.$$

10 However, if the nominal cross-sectional outer surface or perimeter 38 of the shell 30 is not a true ellipse, but rather, a near-ellipse, as described above, the equations for the local radius and curvature are not exactly as stated above, but instead, result in slightly different equations, or more practically, can comprise digitally specified curves that are amenable to digital computer modeling techniques. Thus, for purposes of this invention, a fuselage shell 30 is considered to have a near-elliptical cross-sectional shape when its radius function $R(\phi)$ varies radially by no more than $\pm 7\%$ from a radius $r(\phi)$ of a true elliptical cross-section $r(\phi)$, as illustrated in Fig. 3.

15 Likewise, the local curvature of the near-ellipse, defined herein as “Curv(ϕ),” may differ correspondingly from the curvature $\kappa(\phi)$ of the pure elliptical shape, and still be deemed to have a near-elliptical cross-sectional shape in accordance with the invention.

20 As those of skill in the art will appreciate, the distribution of critical design loads around the circumferential perimeter 38 of a fuselage shell 30 having a near-elliptical cross-section may vary at different longitudinal fuselage locations, or stations, depending not only on pressurization-induced loads, but also on combinations of such pressurization loads with other fuselage bending and torsional loads, for example, those resulting from horizontal and vertical tail-

25 maneuver related loads, or wind gust loads, and critical design loads may further be driven by compression, tension, shear and buckling considerations in selected parts of the fuselage structure, as well as minimum material gauge or thickness considerations, barely visible impact dam-

age (BVID) criteria for potential damage by hail or other impacts, and fatigue and/or aeroelastic design considerations and criteria.

It may be further appreciated that achieving an optimized, lightweight structure, or shell, for such near-elliptical cross-section fuselages presents a design challenge because of the structural and weight penalties involved in implementing a design having a non-circular cross-section, especially those associated with pressurization effects. However, it has been discovered that it is possible to achieve a weight-optimized near-elliptical fuselage shell in accordance with the method described below.

Initially, it should be understood that the exemplary shell 30 has at least one structural attribute associated with every circumferential element of every cross-section thereof that can be tailored as a function of the elevation angle ϕ such that the weight of the shell required to react a design load acting thereon, including any safety factor desired, is less than the weight of an identical shell necessary to react the same design load, but in which same elemental structural attribute has not been so tailored. In one preferred embodiment, the function of ϕ comprises either $R(\phi)$, $Curv(\phi)$ or a combination thereof. Thus, an exemplary embodiment of a method for minimizing the weight of the fuselage shell 30 comprises defining at least one structural attribute of every circumferential element of every cross-section of the shell as a function of either $R(\phi)$, $Curv(\phi)$, or a combination thereof, *i.e.*, as a functional, and then tailoring the at least one structural attribute of the element such that the weight of the shell required to react all design loads incident on each element thereof is less than that required to react the same design loads incident thereon, but wherein the at least one structural attribute has not been so tailored.

Figure 4 schematically illustrates a representative "skin-stringer" geometry used in typical aircraft fuselage shell architecture, shown as if cut open longitudinally and laid out flat, or "mapped," onto a two-dimensional plane having an abscissa parallel to the centerline axis x of the shell, and an ordinate corresponding to a circumferential distance l_c from the abscissa (see Fig. 3), in which the structural components of the shell comprise at least an outer circumferential skin 40, or "aeroskin," attached to a generally orthogonal grid structure that includes a plurality of circumferentially spaced longitudinal "stringers" 42 disposed generally parallel to each other and the longitudinal x -axis of the shell, and a plurality of longitudinally spaced formers, or "frames" 44, disposed generally parallel to each other and orthogonal to the stringers. The frames may include circumferential flanges 46 and radial webs 48.

In accordance with the present invention, the weight-optimization, or tailoring, of the structure for a skin-stringer fuselage architecture such as that illustrated in Fig. 4 can include one

or more of tailoring the associated structural attributes, in terms of ϕ , of: The gauge, or thickness of, the skin 40; the radial depth of the frames 42; the thickness of the respective frame flanges 46; the thickness of the respective frame webs 48; and, tailoring of the attribute as a function of ϕ and stringer 42 cross-sectional shape and/or size (*e.g.*, “hat-shaped”, “F”, “T”, “L” shaped, *etc.*), plus the type of material, *e.g.*, a metal, such as aluminum, or a non-metal, *e.g.*, carbon fibers embedded in specified orientations, patterns and layers, in a resin matrix, from which each of these structural components are formed.

For so-called “composite-body” skins 40, the structural attributes can be tailored as a function of ϕ and, *e.g.*, the number of plies, or layers, in the skin, and/or the relative angular orientation angle of the plies to each other, and/or a percentage distribution, by orientation angle, of the plies provided at that particular ϕ . The skins can also be tailored in terms of variations in the types and quantities of materials (*i.e.*, composite, metallic, or a combination thereof) used therein as a function of ϕ .

As is known, composite-body aircraft fuselage shells can advantageously incorporate skins comprising composite “sandwiches,” *i.e.*, stiff, lightweight “core” structures 50 comprising either a continuous foam or honeycomb cells 52 laminated between two circumferential skins, or face sheets. Representative core cell geometries are illustrated in Figs. 5A-5D, where it should be understood that the cores are sandwiched between inner and outer face sheets (not illustrated).

Such tailoring of fuselage shell structural attributes as a function ϕ and one or more other variables can also be advantageously applied to other structural components of sandwich composite structures, including the skins thereof, *i.e.*, tailoring as a function of ϕ and inner and outer face sheet properties, including the number of plies therein, respective ply relative and/absolute orientation angles, and/or percentage distribution by orientation angle of the plies provided at that particular value of ϕ , as well tailoring in terms of ϕ of sandwich core thickness, and/or cell density, core material and/or sandwich-specific localized design and construction. Thus, for example, the core material can be tailored throughout the design process by varying, *e.g.*, core material, type and density.

Tailoring of fuselage structural attributes as a function of ϕ can also be effected in the context of so-called “isogrid” structures. An isogrid panel comprises at least an external skin, or face sheet, as above, with integral stiffening or stringer members 60 that are arranged in patterns of cells 62, as illustrated in Figs. 6A-6G, and is amenable to analysis using known isogrid plate modeling techniques. (See, *e.g.*, Meyer, R., et al., *Isogrid Design Handbook*, NASA Center for Aerospace Information (CASI), NASA-CR-120475; MDC-G4295A, Feb. 1, 1973.) In the case of

an aircraft fuselage shell, such isogrid structures can comprise a face sheet and integral stringer members that, in the case of composite-body structures as described above, can be laid up together by, for example, known fiber placement or filament winding techniques. Tailoring of the structural attributes of isogrid structures as a function of ϕ can be effected for isogrid structures in a manner similar to isogrid design and construction attributes that vary as a function of ϕ . This can include grid type, shape, spacing and material utilization, including mixing material types for both the grid face sheets and the isogrid integral stringer members.

Figure 7 illustrates an exemplary tailoring function of a structural attribute plotted as a function of ϕ . This type of exemplary function is representative of when the structural attribute is linearly or monotonically increasing with increasing $[|R(\phi) - \bar{R}|]$ or $[|\text{Curv}(\phi) - \overline{\text{Curv}}|]$. The structural attribute could be skin gage, frame depth, or other structural attribute. If the structural attribute is frame depth, local frame depth in a crown region (*i.e.*, ϕ near 90°) is increased relative to average frame depth, and local frame depth in a keel region (ϕ near 270°) is also increased relative to average frame depth. It should be understood that the tailoring function shown in Fig. 7 is only exemplary, and that airplane-specific tailoring functions can differ in shape, character and magnitude as needed to minimize weight and drag for applicable loads.

Figure 8 illustrates a plan view illustrating representative composite fiber ply orientations, including zero degree plies 81, ninety degree plies 82, and plus and minus forty-five degree plies 83.

By now, those of skill in this art will appreciate that many modifications, substitutions and variations can be made in and to the materials, apparatus, configurations and methods of implementing and weight optimization of the near-elliptical aircraft fuselage structures of the present invention without departing from its spirit and scope. Accordingly, the scope of the present invention should not be limited to the particular embodiments illustrated and described herein, as they are merely exemplary in nature, but rather, should be fully commensurate with that of the claims appended hereafter and their functional equivalents.

CLAIMS

WHAT IS CLAIMED IS:

1. An internally pressurizable aircraft fuselage structure, comprising:

an elongated tubular shell having a centerline axis x, opposite closed nose and tail ends,
 5 and a non-circular cross-section having a radius R(ϕ) at substantially every point along the x axis
 between the two ends, where ϕ is a roll elevation angle varying from 0 degrees to +360 degrees
 about the x axis; and,

wherein the radius R(ϕ) of each cross-section of the shell varies radially by no more than
 $\pm 7\%$ from a radius r(ϕ) of an elliptical cross-section having a major axis with a dimension of
 10 $2 \cdot r_{\max}$ and a minor axis with a dimension of $2 \cdot r_{\min}$.

2. The fuselage structure of claim 1, wherein:

a maximum width of the shell is greater than a maximum height thereof; and,
 the maximum width and height of the shell are respectively substantially aligned with the
 major and minor axes of the elliptical cross-section.

15 3. The fuselage structure of claim 1, wherein r(ϕ) is given by the relation:

$$r(\phi) = \frac{r_{\min}}{\sqrt{\left[\left(\frac{r_{\min}}{r_{\max}}\right)^2 \cdot (\cos \phi)^2\right] + (\sin \phi)^2}}$$

4. The fuselage structure of claim 1, wherein a curvature Curv(ϕ), defined as the inverse
 of the local radius of curvature of a surface of the shell, is associated with R(ϕ), and a corre-
 sponding curvature $\kappa(\phi)$ associated with r(ϕ) is given by:

20
$$\kappa(\phi) = \frac{\left[r^2 + 2 \cdot \left(\frac{\partial r}{\partial \phi} \right)^2 - r \cdot \frac{\partial^2 r}{\partial \phi^2} \right]}{\left[r^2 + \left(\frac{\partial r}{\partial \phi} \right)^2 \right]^{1.5}}$$

5. The fuselage structure of claim 1, wherein:

the shell has at least one structural attribute that has been tailored as a function of the ele-
 vation angle ϕ such that the weight of the shell required to react a design load incident thereon is
 less than that required to react the same design load, but wherein the at least one structural attrib-
 25 ute has not been so tailored.

6. The fuselage structure of claim 5, wherein the shell functions as a pressure vessel, and wherein the design load comprises internal pressurization loads.

7. The fuselage structure of claim 1, wherein the shell includes structural components comprising one of:

- 5 at least one external circumferential skin attached to internal longitudinal stringers and axially spaced circumferential frames;
 an external circumferential skin and an inner skin laminated to internal core structures;
and,
 an isogrid structure having at least one external circumferential skin attached to stiffening
10 members arranged in a grid pattern.

8. The fuselage structure of claim 7, wherein at least one dimension of at least one of the structural components is tailored as a function of at least one of $R(\varphi)$ and $Curv(\varphi)$.

9. The fuselage structure of claim 8, wherein the at least one dimension comprises a radial dimension, an axial dimension or a circumferential dimension.

- 15 10. The fuselage structure of claim 8, wherein the at least one dimension comprises a thickness of the circumferential skin.

11. A method for minimizing the weight of a pressurizable aircraft fuselage of a type comprising an elongated tubular shell having a central axis x , opposite nose and tail ends, and a non-circular cross-section having a radius $R(\varphi)$ at substantially every point along the x axis between the two ends, wherein:

φ is a roll elevation angle of the shell varying from 0 degrees to +360 degrees about the x axis;

$R(\varphi)$ varies radially by no more than $\pm 7\%$ from a radius $r(\varphi)$ of an elliptical cross-section having a major axis of dimension $2 \cdot r_{\max}$ and a minor axis of $2 \cdot r_{\min}$,

- 25 a curvature $Curv(\varphi)$ is defined as the inverse of the local radius of curvature of a surface of the shell and is associated with $R(\varphi)$, and

a curvature $\kappa(\varphi)$ associated with $r(\varphi)$ is given by:

$$\kappa(\varphi) = \frac{\left[r^2 + 2 \cdot \left(\frac{\partial r}{\partial \varphi} \right)^2 - r \cdot \frac{\partial^2 r}{\partial \varphi^2} \right]}{\left[r^2 + \left(\frac{\partial r}{\partial \varphi} \right)^2 \right]^{1.5}};$$

the method comprising:

defining at least one structural attribute of the shell as a function of the elevation angle φ ;

5 and,

tailoring the at least one structural attribute of the shell such that the weight of the shell required to react a design load incident thereon is less than that required to react the same design load, but wherein the at least one structural attribute has not been so tailored.

12. The method of claim 11, wherein:

10 the shell comprises a circumferential skin having a thickness; and,

tailoring the at least one structural attribute comprises tailoring the thickness of the skin substantially as a function of at least one of $R(\varphi)$ and $\text{Curv}(\varphi)$.

13. The method of claim 12, wherein:

15 the circumferential skin comprises a multi-ply composite structure made of at least one of non-metallic and metallic materials;

each ply is oriented at a selected angle relative to the other plies; and,

tailoring the at least one structural attribute comprises tailoring the plies with respect to at least one of the number of plies, the angular orientation of at least one of the plies, and the material of the plies.

20 14. The method of claim 11, wherein:

the shell comprises a plurality of generally parallel, longitudinally spaced circumferential frames; and,

tailoring the at least one structural attribute comprises tailoring a radial depth of the frames substantially as a function of at least one of $R(\varphi)$ and $\text{Curv}(\varphi)$.

25 15. The method of claim 14, wherein:

each circumferential flange comprises at least one of an inner and an outer circumferential flange; and,

tailoring the at least one structural attribute comprises tailoring a radial depth of the flange substantially as a function of at least one of $R(\varphi)$ and $\text{Curv}(\varphi)$.

16. The method of claim 14, wherein:

each circumferential flange comprises a radial web; and,

5 tailoring the at least one structural attribute comprises tailoring a longitudinal thickness of the web substantially as a function of at least one of $R(\varphi)$ and $\text{Curv}(\varphi)$.

17. The method of claim 16, wherein:

the longitudinal thicknesses of the webs are variable in a radial direction; and,

10 tailoring the at least one structural attribute comprises tailoring the radial distribution of the web thicknesses substantially as a function of at least one of $R(\varphi)$ and $\text{Curv}(\varphi)$.

18. The method of claim 14, wherein:

each circumferential flange comprises a multi-ply composite structure made of at least one of non-metallic and metallic materials;

each ply is oriented at a selected angular orientation relative to the other plies; and,

15 tailoring the at least one structural attribute comprises tailoring the plies with respect to at least one of the number of plies, the relative angular orientation of the plies, and the material of the plies.

19. An aircraft, comprising:

20 a fuselage, including an elongated internally pressurizable tubular shell having a centerline axis, opposite closed nose and tail ends, and a near-elliptical cross-section having a radius $R(\varphi)$, where φ is the angular coordinate of a cylindrical coordinate system concentric with the centerline axis, a curvature $\text{Curv}(\varphi)$, where $\text{Curv}(\varphi)$ is the inverse of a local radius of curvature of a surface of the shell, and a circumference that varies radially by no more than $\pm 7\%$ from the circumference of an elliptical cross-section at substantially every position along the centerline axis between the nose and tail ends thereof; and,

25 means for lifting the fuselage off the ground and propelling it in at least a forward direction relative to the ground.

20. The aircraft of claim 19, wherein substantially every element of the circumference of substantially each of the cross-sections of the shell, expressed as a function of φ consisting of at least one of $R(\varphi)$ and $\text{Curv}(\varphi)$, has at least one associated structural attribute that has been tai-

30

lored as a function of ϕ such that the weight of the shell required to react a design load incident thereon is less than that required to react the same design load, but wherein the at least one structural attribute has not been so tailored.

5 21. The aircraft of claim 20, wherein:
 the shell comprises a circumferential outer skin and circumferentially spaced longitudinal stringers disposed adjacent to an inner surface of the skin; and,
 the at least one tailored structural attribute comprises at least one of a cross-sectional shape and size, number, and material of the stringers.

10 22. The aircraft of claim 20, wherein:
 each of at least one of the circumferential skin and the stringers comprises a composite of a plurality of plies, each having a selected angular orientation relative to the others; and,
 the at least one tailored structural attribute comprises at least one of the number, relative angular orientation, and material of the plies.

15 23. The aircraft of claim 20, wherein:
 the shell comprises a circumferential outer skin attached to a rigid core of at least one of a foam material and a plurality of rigid, interconnected cells; and,
 the at least one tailored structural attribute comprises at least one of a thickness of the
20 core, a core cell density and a core material.

 24. The aircraft of claim 20, wherein:
 the shell comprises an isogrid structure having at least one external face sheet attached to a grid comprising internal stiffening members; and,
25 the at least one tailored structural attribute comprises at least one of grid spacing, grid geometry, grid material and face sheet material.

 25. The aircraft of claim 19, wherein the shell comprises a filament-wound structure.

 26. The aircraft of claim 19, wherein the shell comprises a tape-laid composite structure.

27. The aircraft of claim 19, wherein the shell comprises at least one of an autoclave-cured composite structure, a microwave-cured composite structure and an E-beam cured composite structure.

5 28. The aircraft of claim 19, wherein the shell includes at least one of a carbon-fiber-in-resin composite structure and a combination of composite and metallic materials.

29. The aircraft of claim 19, wherein the shell includes at least one of stitched multiply composite structure, a stitched resin-film-infused (RFI) composite structure and a stapled multiply composite structure.

10 30. The aircraft of claim 19, wherein the shell comprises a composite structure including electrically conductive elements for mitigating at least one of electromagnetic effects (EME) and lightning effects acting upon the aircraft.

15 31. The aircraft of claim 19, wherein the shell comprises a composite structure having an outer surface with a colored, electrically conductive riblet film disposed thereon for providing a decorative color, reduced aerodynamic drag, and mitigation of lightning and electromagnetic effects (EME) acting the aircraft.

20 32. The aircraft of claim 19, wherein the shell comprises a composite skin having some longitudinally oriented fiber plies having an orientation of zero degrees, plus or minus 20 degrees, relative to a local fuselage surface axis system, and other plies wound circumferentially around the shell and having orientations varying within a range of 90 degrees, plus or minus 20 degrees, relative to the local fuselage surface axis system.

33. The aircraft of claim 32, wherein the shell further comprises first angled plies having orientations varying within a range of +45 degrees, plus or minus 20 degrees, relative to the local fuselage surface axis system, and second angled plies with orientations varying within in a range of -45 degrees, plus or minus 20 degrees, relative the local fuselage surface axis system.

25 34. The aircraft of claim 33, wherein the first angled plies and the second angled plies are laid down around the shell during its construction along steered paths such that the magnitude of their respective orientations exceeds 45 degrees for regions of ϕ wherein circumferential loads incident on the shell exceed longitudinal loads incident thereon by a selected amount.

35. The aircraft of claim 33, wherein the first angled and second angled plies are laid down around the shell during its construction along steered paths such that the magnitude of their respective orientations is less than 45 degrees for regions of ϕ wherein longitudinal loads incident on the shell exceed circumferential loads incident on the shell by a selected amount.

5 36. The aircraft of claim 32, wherein additional longitudinal plies having orientations in a range of zero degrees, plus or minus 20 degrees relative to the local fuselage surface axis system are placed in at least one of a crown and a keel region of the fuselage during its construction for efficiently reacting fuselage bending moments induced by horizontal tail loads or elevator loads or nosegear slapdown loads incident thereon.

10 37. The aircraft of claim 19, further comprising at least one additional composite ply layer in a crown region of the shell for reducing a risk of hail damage in the fuselage crown area.

 38. The aircraft of claim 19, further comprising at least one additional composite ply layer in a window belt area of upper sides of the shell.

15 39. The fuselage structure of claim 7, wherein a local frame depth of the circumferential frames in a crown region of the fuselage is increased relative to an average frame depth.

 40. The fuselage structure of claim 7, wherein a local frame depth of the circumferential frames in a keel region of the fuselage is increased relative to an average frame depth.

20 41. The fuselage structure of claim 7, wherein a local frame depth of the circumferential frames in left and a right side regions of the structure in a passenger cabin portion of the structure are decreased relative to an average frame depth.

 42. The aircraft of claim 7, wherein each of the circumferential frames have a varying depth as defined by an outer edge of the frame lying substantially along a first elliptical path and an inner edge lying substantially along a second elliptical path, and wherein the ratio of the major axis to the minor axis is greater for the second elliptical path than for the first elliptical path.

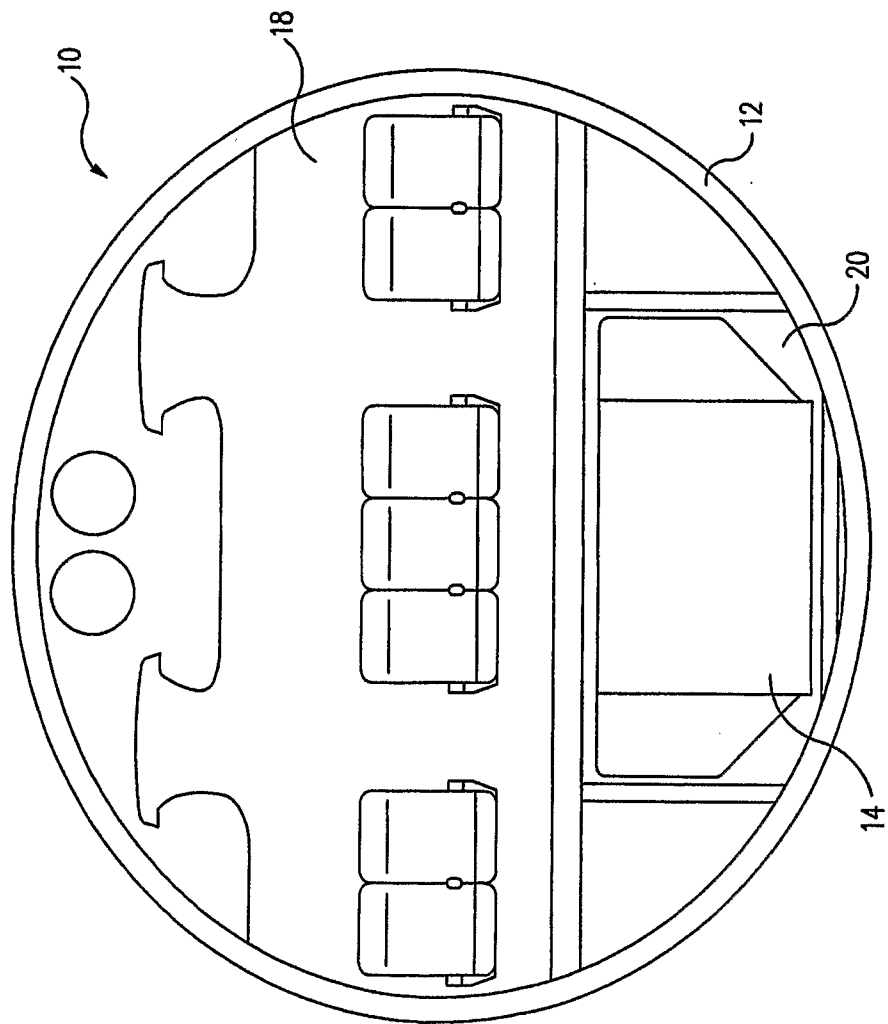


FIG. 1A
(PRIOR ART)

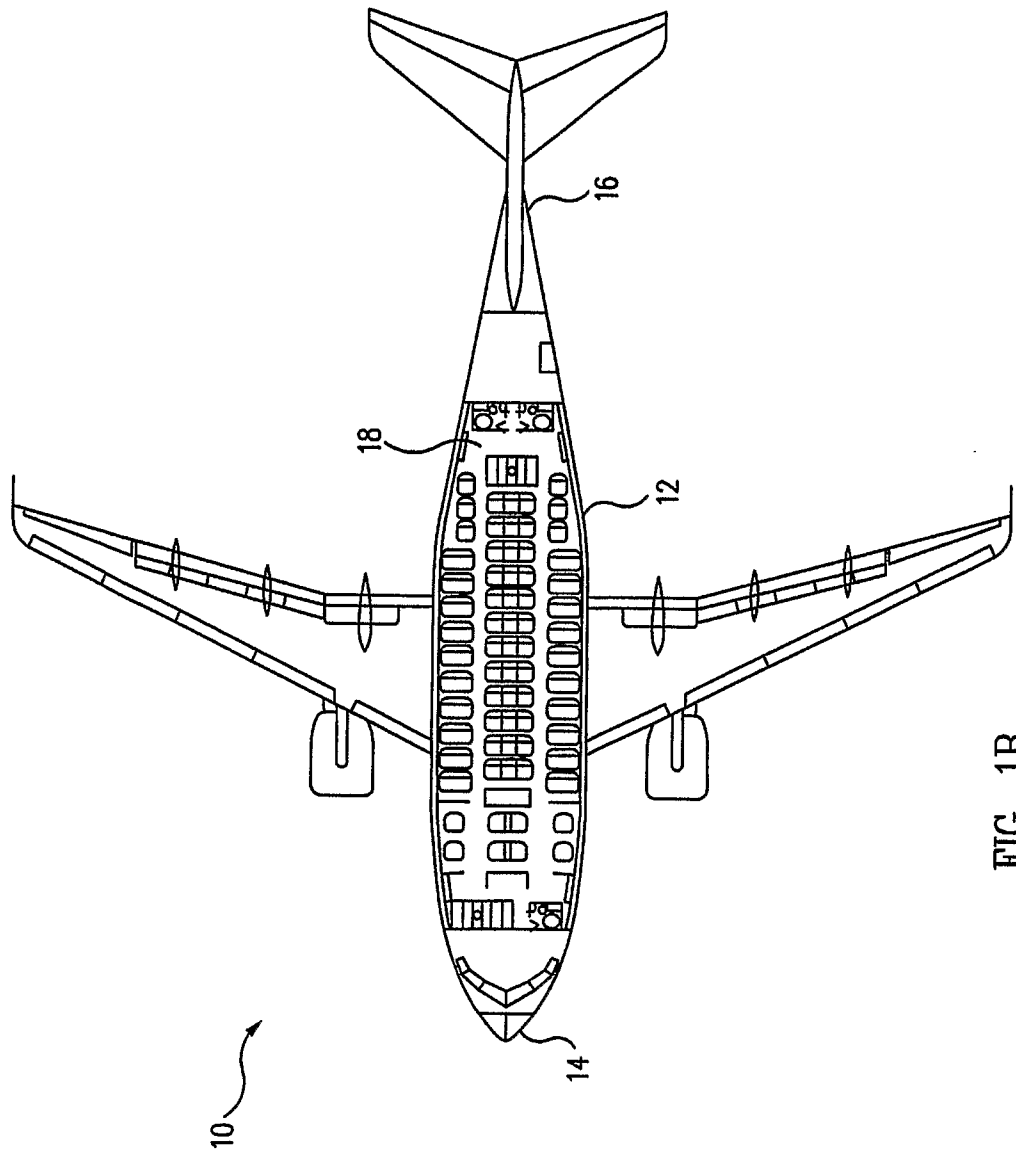


FIG. 1B
(PRIOR ART)

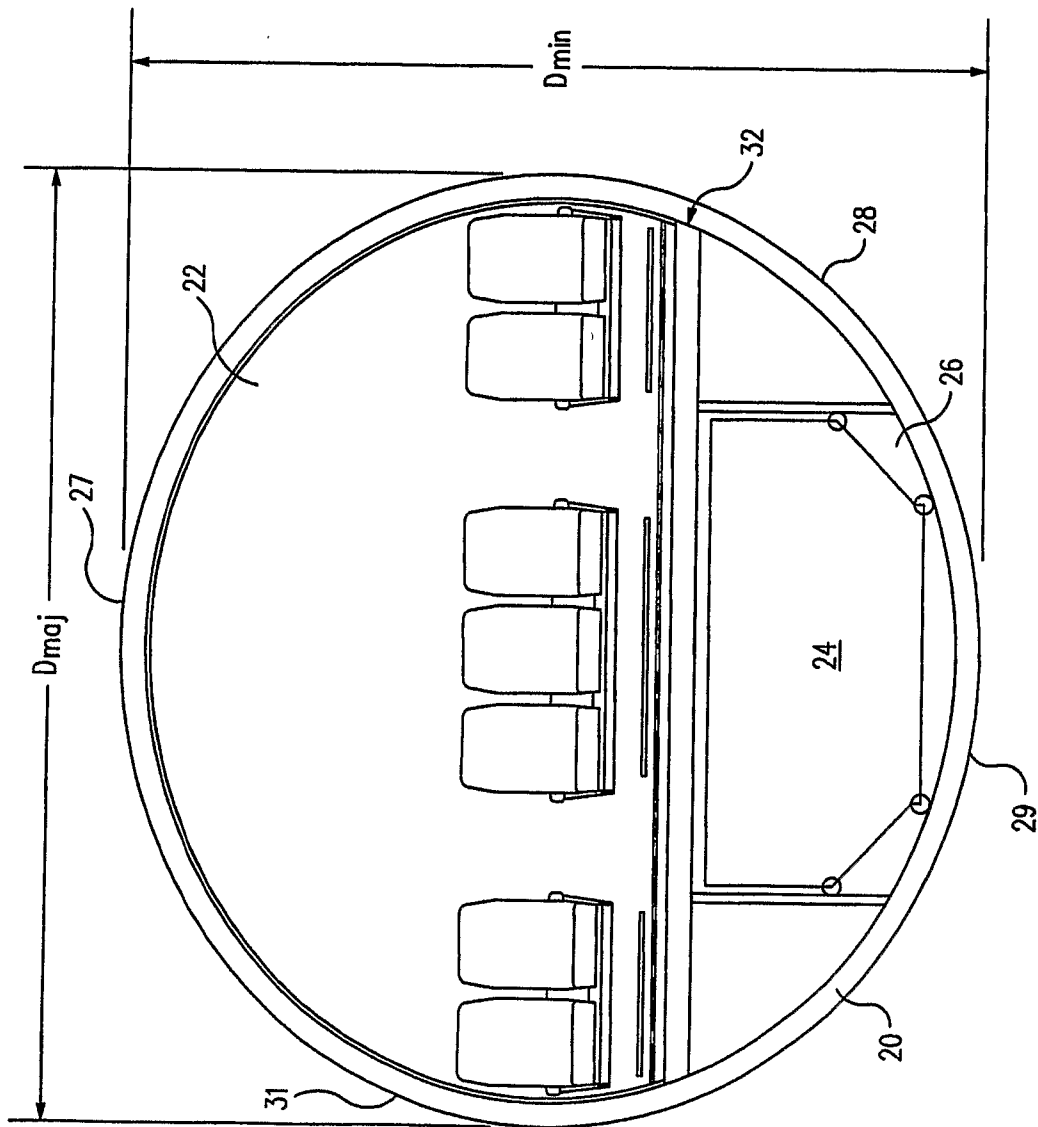


FIG. 2A

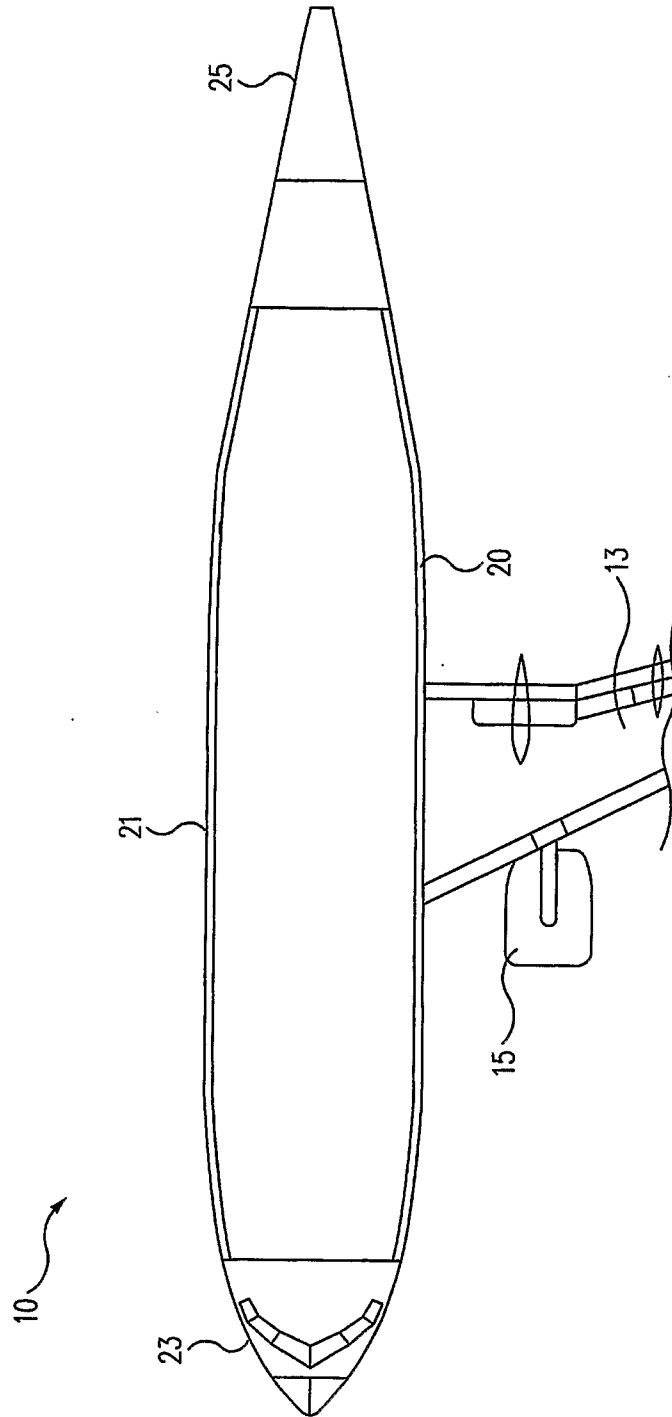


FIG. 2B

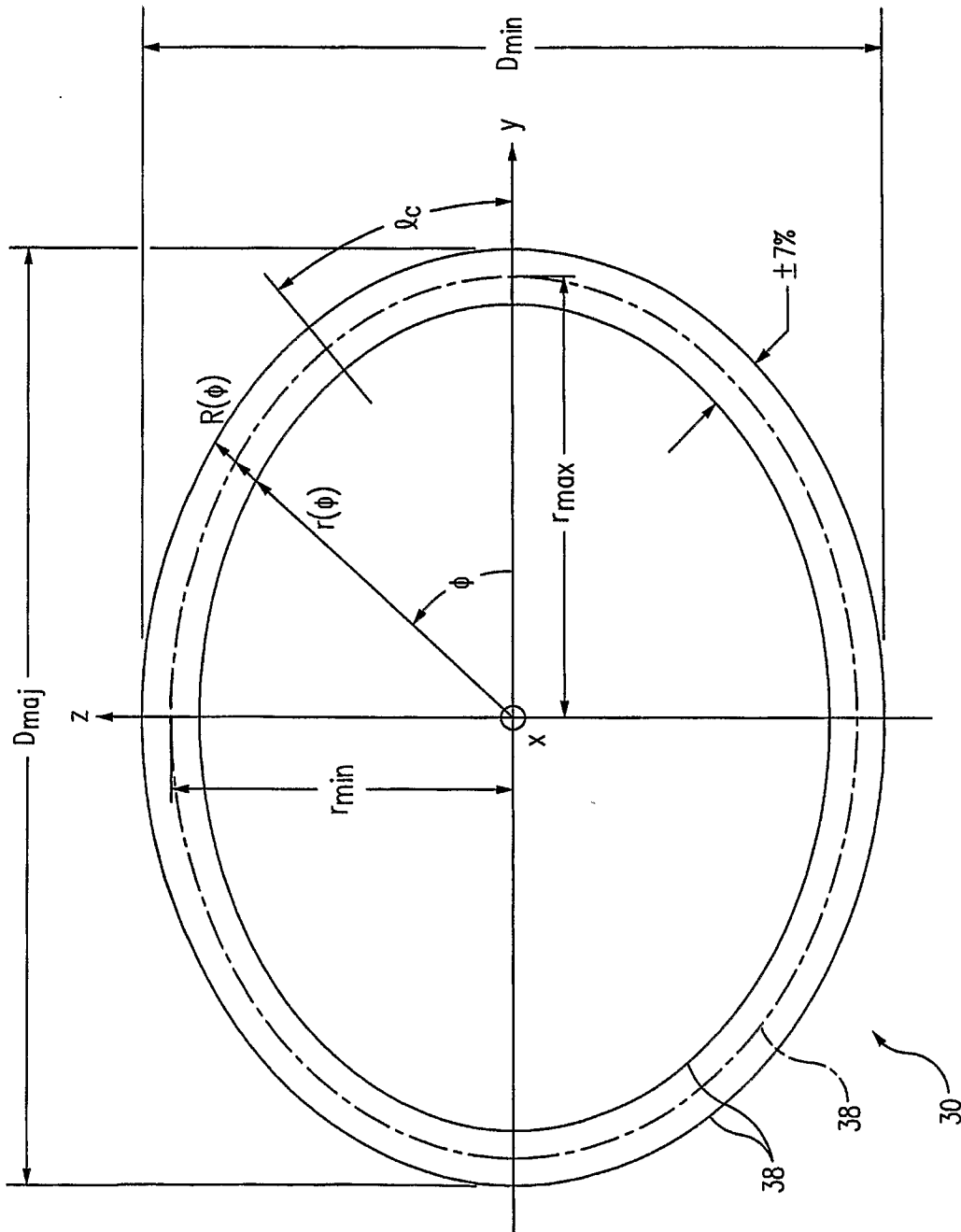


FIG. 3

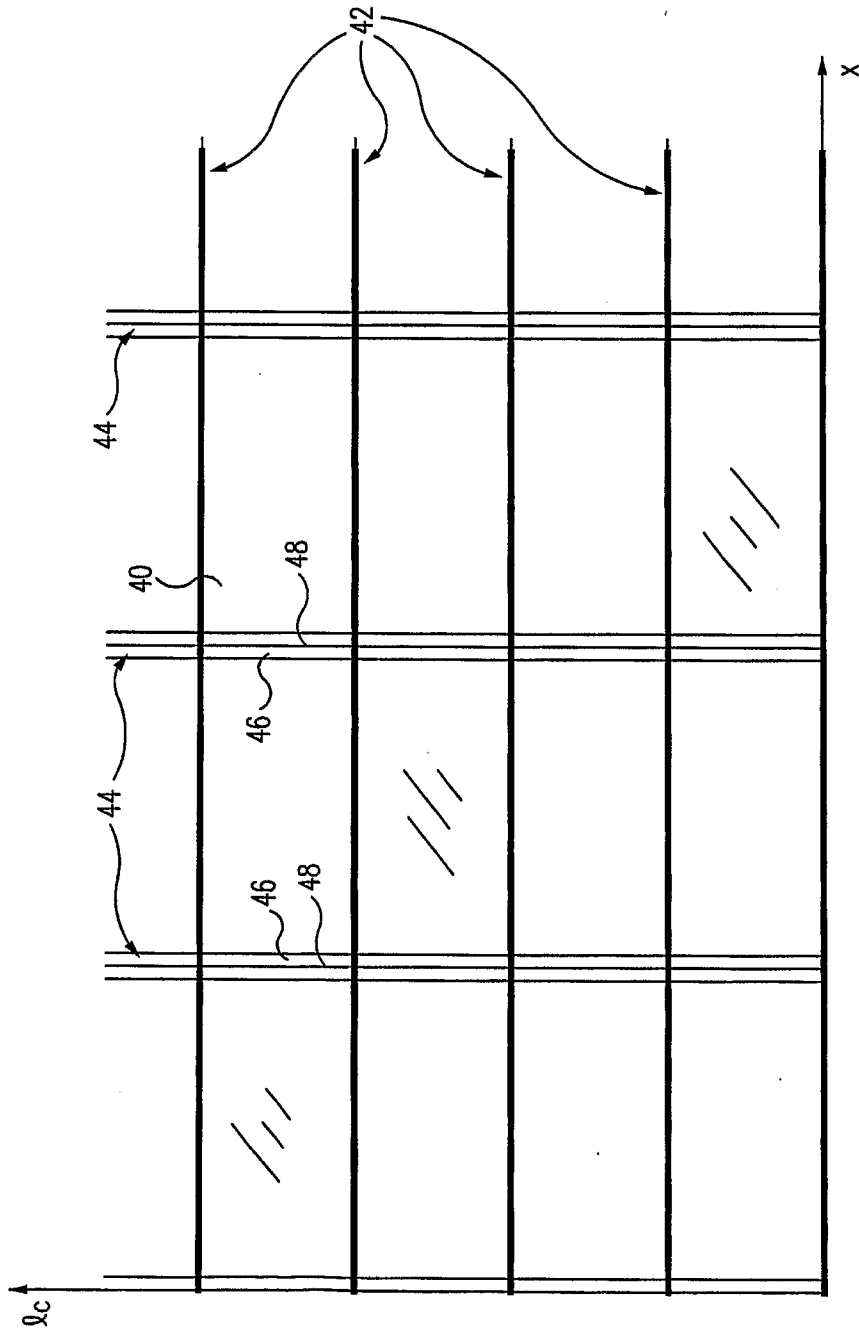


FIG. 4

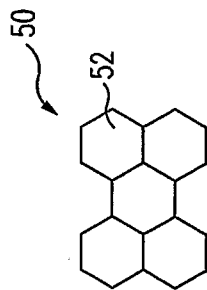


FIG. 5A

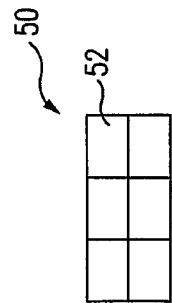


FIG. 5B

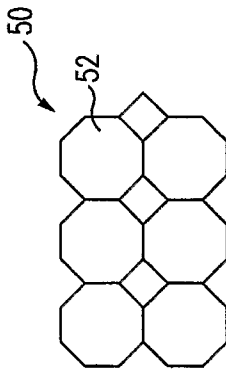


FIG. 5C

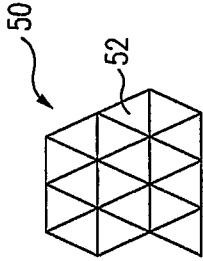


FIG. 5D

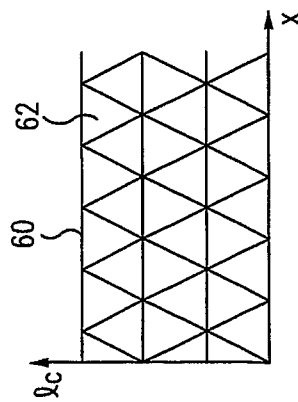


FIG. 6A

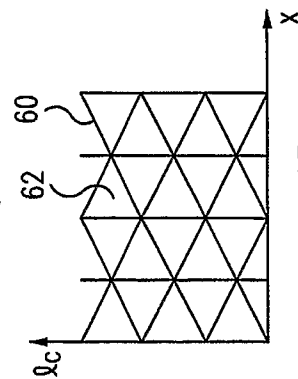


FIG. 6B

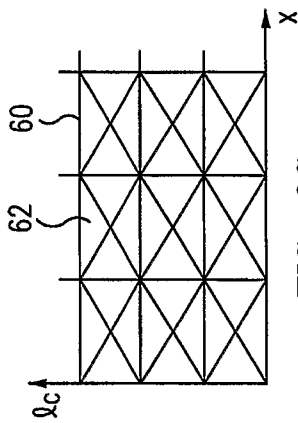


FIG. 6C

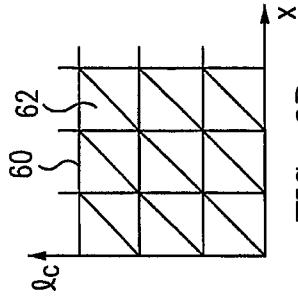


FIG. 6D

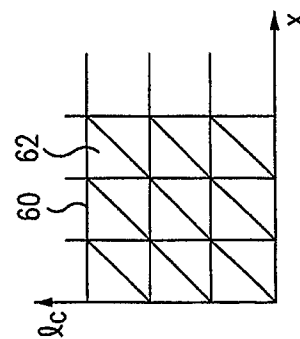


FIG. 6E

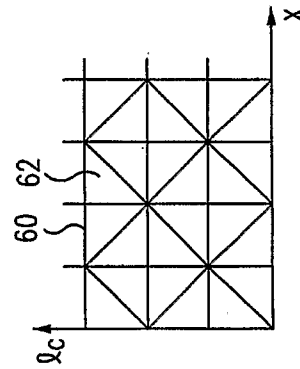


FIG. 6F

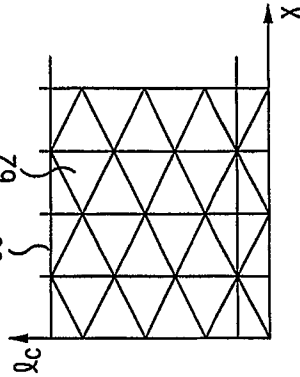


FIG. 6G

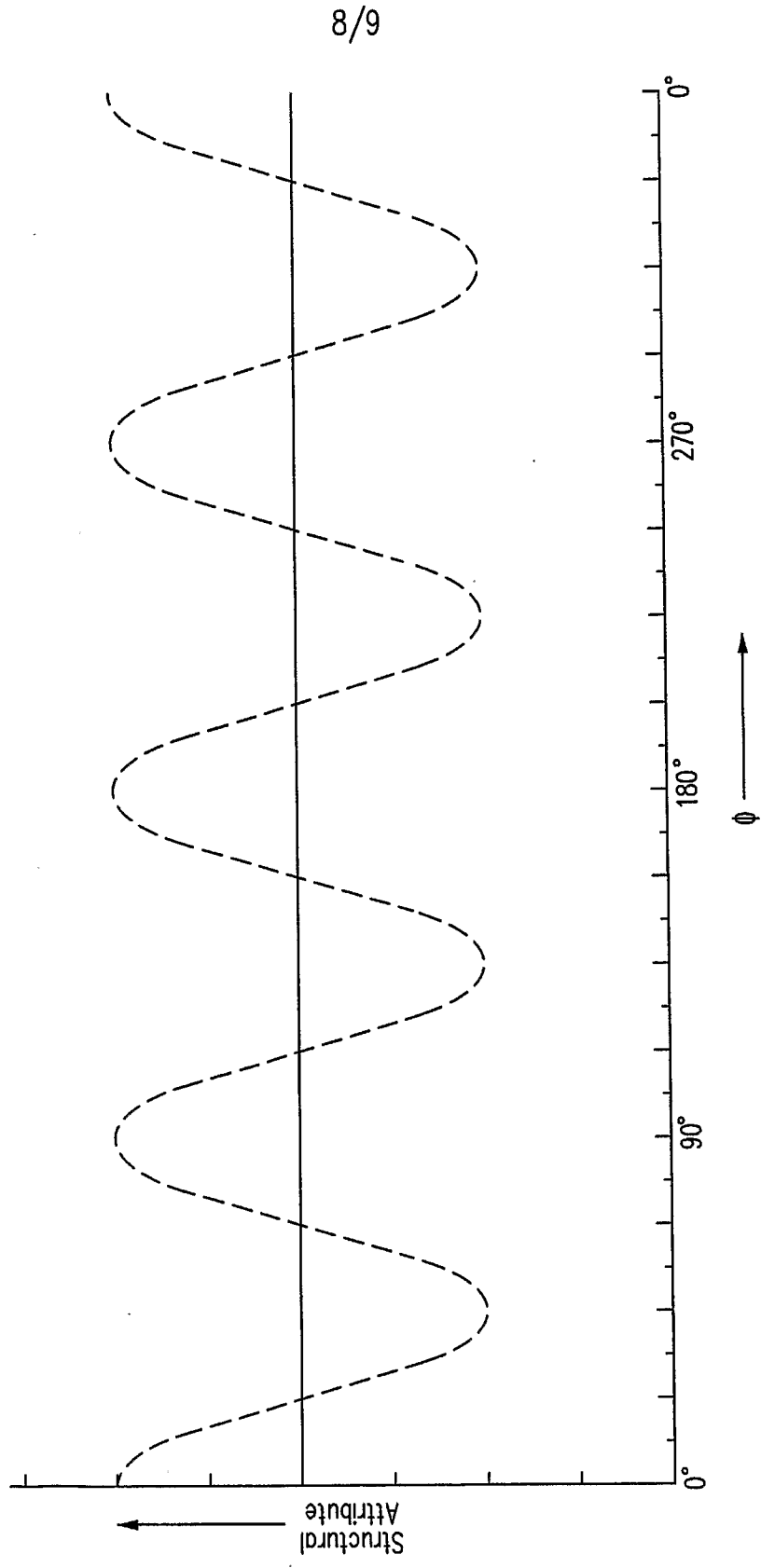


FIG. 7

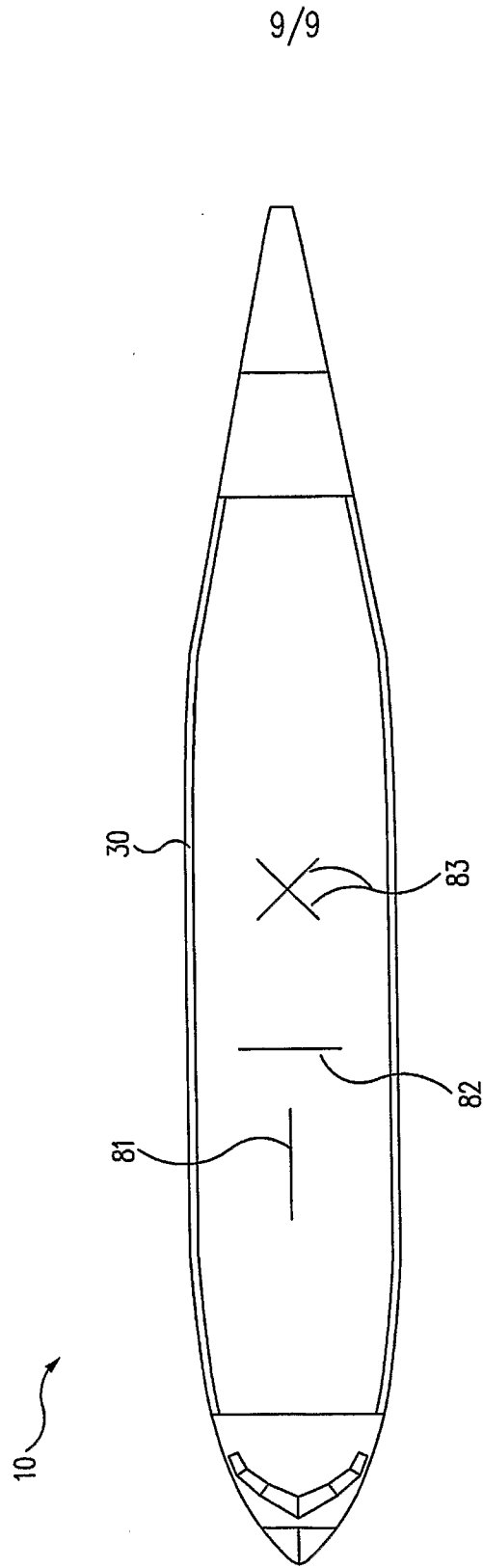


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/043742

A. CLASSIFICATION OF SUBJECT MATTER INV. B64C1/00 B64C1/12		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) B64C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/062449 A1 (SANKRITHI MITHRA M K V [US]) 3 April 2003 (2003-04-03) cited in the application	1-4, 19
Y	paragraphs [0001], [0004], [0016], [0020], [0021]; claim 12; figures	7-10, 25-30, 32-38
Y	----- US 2004/055349 A1 (EL-SOUDANI SAMI M [US]) 25 March 2004 (2004-03-25) paragraphs [0028], [0033]; figures	7-10
Y	----- US 2004/035979 A1 (MCCOSKEY WILLIAM ROBERT [US] ET AL) 26 February 2004 (2004-02-26) paragraphs [0010], [0011], [0046], [0065], [0066]; figures	7-10
	----- -/--	
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents :		
A document defining the general state of the art which is not considered to be of particular relevance *E* earlier document but published on or after the international filing date *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *O* document referring to an oral disclosure, use, exhibition or other means *P* document published prior to the international filing date but later than the priority date claimed		*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. *&* document member of the same patent family
Date of the actual completion of the international search 14 September 2007		Date of mailing of the international search report 21/09/2007
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016		Authorized officer Salentiny, Gérard

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2006/043742

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6 684 593 B2 (BRENNEIS HARTMUT [DE] ET AL) 3 February 2004 (2004-02-03) column 3, lines 29-34 column 6, lines 26-44; figures -----	7-10
Y	US 6 114 050 A (WESTRE WILLARD N [US] ET AL) 5 September 2000 (2000-09-05) the whole document -----	10,30, 32-38
Y	US 6 692 681 B1 (LUNDE GERALD A [US]) 17 February 2004 (2004-02-17) the whole document -----	25-28
Y	US 5 902 535 A (BURGESS ROGER [US] ET AL) 11 May 1999 (1999-05-11) the whole document -----	29
X	WO 97/43176 A (REDWOOD AIRCRAFT CORP [US]) 20 November 1997 (1997-11-20) figures -----	1,19
X	US 3 854 679 A (SMETHERS R) 17 December 1974 (1974-12-17) figures -----	1,19
A	EP 1 108 646 A2 (EADS AIRBUS GMBH [DE] AIRBUS GMBH [DE]) 20 June 2001 (2001-06-20) -----	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2006/043742

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.: 5, 6, 11-18, 20-24
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest.
- No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 5,6,11-18,20-24

Claims 5, 6, 11-18 and 20-24 attempt to define the claimed subject-matter by reference to a product which itself is not claimed and the technical features of which are not clearly identifiable. These claims do indeed claim an improvement by comparing the result thereof to a product for which the assumed weight saving process hasn't been applied. The tailoring process itself is not clearly defined as it merely addresses the modification of the shape of a structural attribute which itself is either not novel or inventive. The way of claiming therefore amounts to the definition of the claimed product and/or process entirely by the result to be achieved. The fuselage structure or the method involving the design thereof is indeed claimed by comparison to a fuselage structure for which the process hasn't been applied. In fact, an attempt is made herewith to claim a product/process providing a weight improvement compared to any fuselage structure known so far. Such a product and/or process may not be searched as no clear technical features related thereto are indicated.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.5), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2006/043742

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003062449	A1	03-04-2003	NONE
US 2004055349	A1	25-03-2004	AU 2003268301 A1 19-04-2004 WO 2004028719 A1 08-04-2004
US 2004035979	A1	26-02-2004	AU 2003296880 A1 25-05-2004 WO 2004039670 A2 13-05-2004
US 6684593	B2	03-02-2004	AT 299460 T 15-07-2005 CA 2337725 A1 22-08-2001 DE 10007995 A1 06-09-2001 EP 1127785 A2 29-08-2001 ES 2245329 T3 01-01-2006 US 2001015043 A1 23-08-2001
US 6114050	A	05-09-2000	DE 69734616 D1 22-12-2005 DE 69734616 T2 22-06-2006 EP 0783960 A2 16-07-1997 JP 9193296 A 29-07-1997 JP 2007191148 A 02-08-2007 US 5866272 A 02-02-1999
US 6692681	B1	17-02-2004	NONE
US 5902535	A	11-05-1999	NONE
WO 9743176	A	20-11-1997	CA 2254880 A1 20-11-1997 US 5769358 A 23-06-1998
US 3854679	A	17-12-1974	NONE
EP 1108646	A2	20-06-2001	AT 305881 T 15-10-2005 CA 2328653 A1 16-06-2001 ES 2249223 T3 01-04-2006 US 2001004096 A1 21-06-2001