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(54) HIGH TEMPERATURE RESISTANT AIRFOIL APPARATUS FOR A HYPERSONIC SPACE VEHICLE

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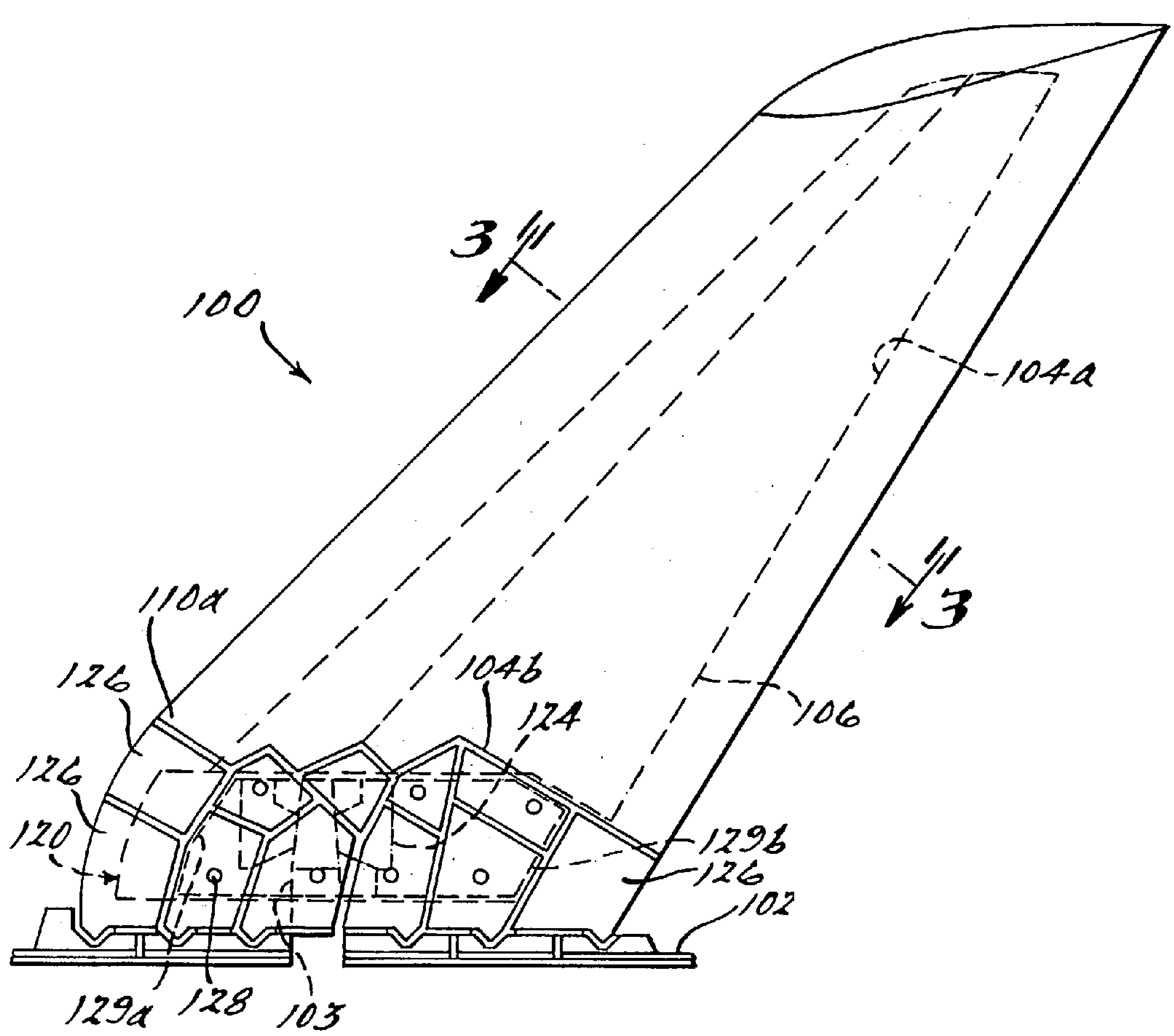
(57) **ABSTRACT**

A ruddervator for an aerospacecraft including a monolithic, one-piece, oxide/oxide-based ceramic matrix composite (Oxide-CMC) shell having a hollowed interior area. A graphite composite structural member is inserted into the hollowed interior area and bonded thereto. The Oxide-CMC shell is comprised of one or more plies of Oxide-CMC fabric which are fused over a thick substrate of rigid ceramic foam insulation to form the monolithic shell. An outer mold line ply of the Oxide-CMC shell is further infused with a high-emissivity coating such as reaction-cured glass (RCG) to provide plasma heating re-radiation outward to reduce internal temperatures in the ruddervator. A torque box transition structure is secured to the graphite composite structural member to interface the ruddervator to a fuselage actuator spindle of the aerospacecraft. The ruddervator is reusable and formed from a reduced number of independent component parts, and weighs less than previously developed ruddervators. The manufacturing cost of the ruddervator is reduced by utilizing the reduced tooling complexities of Oxide-CMC over CMC fabrication processes.



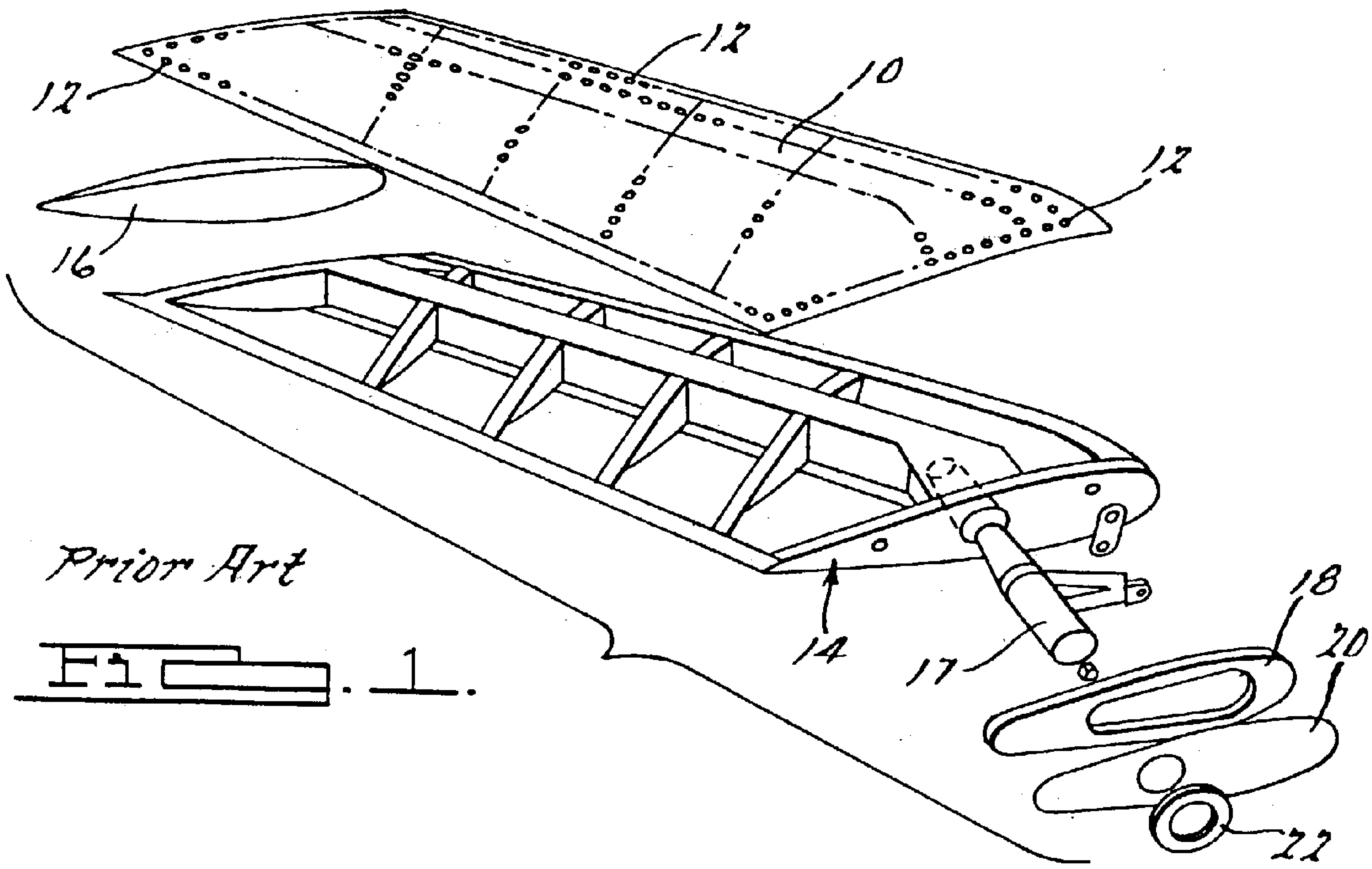


FIG. 1.

FIG. 2.

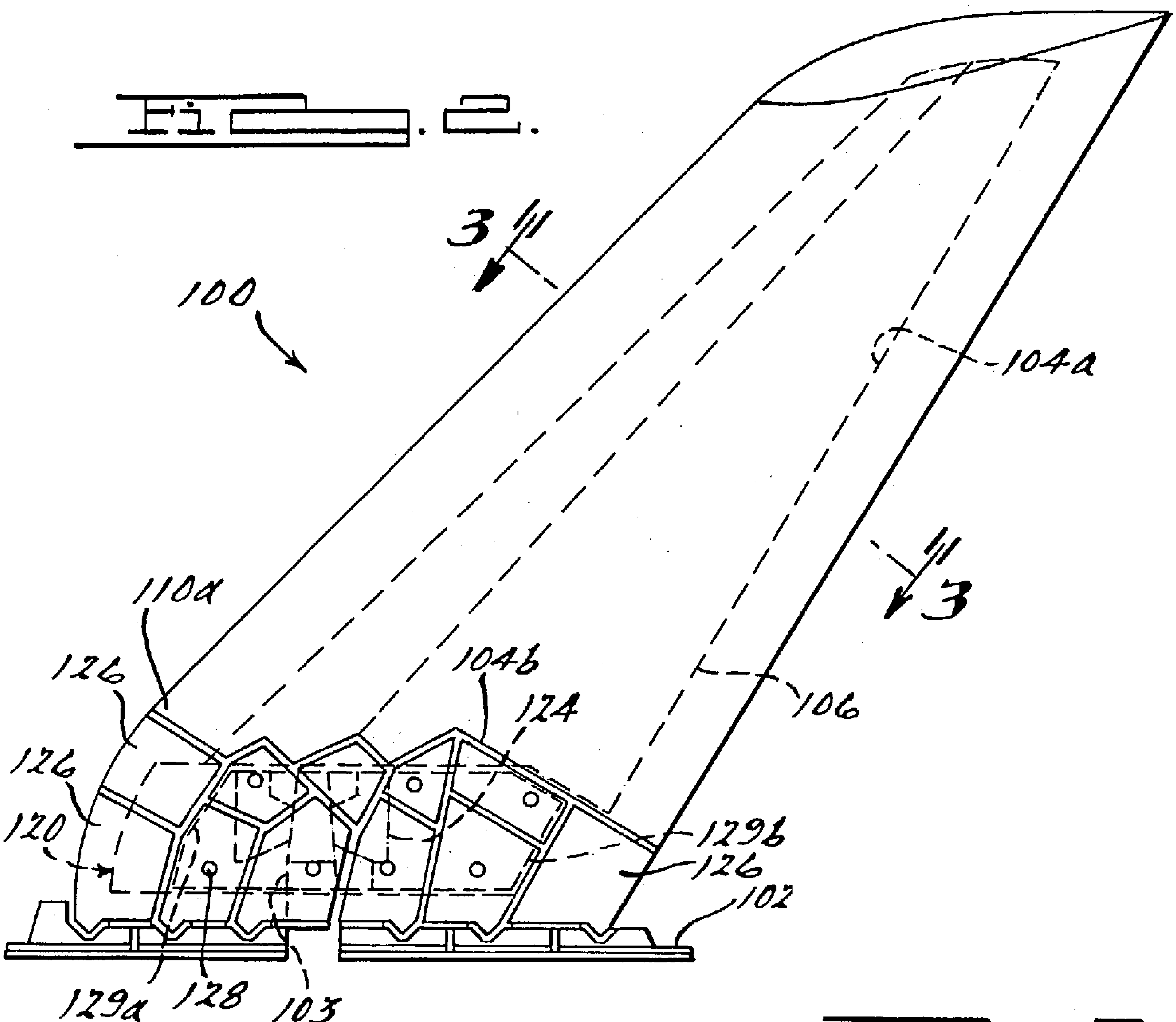
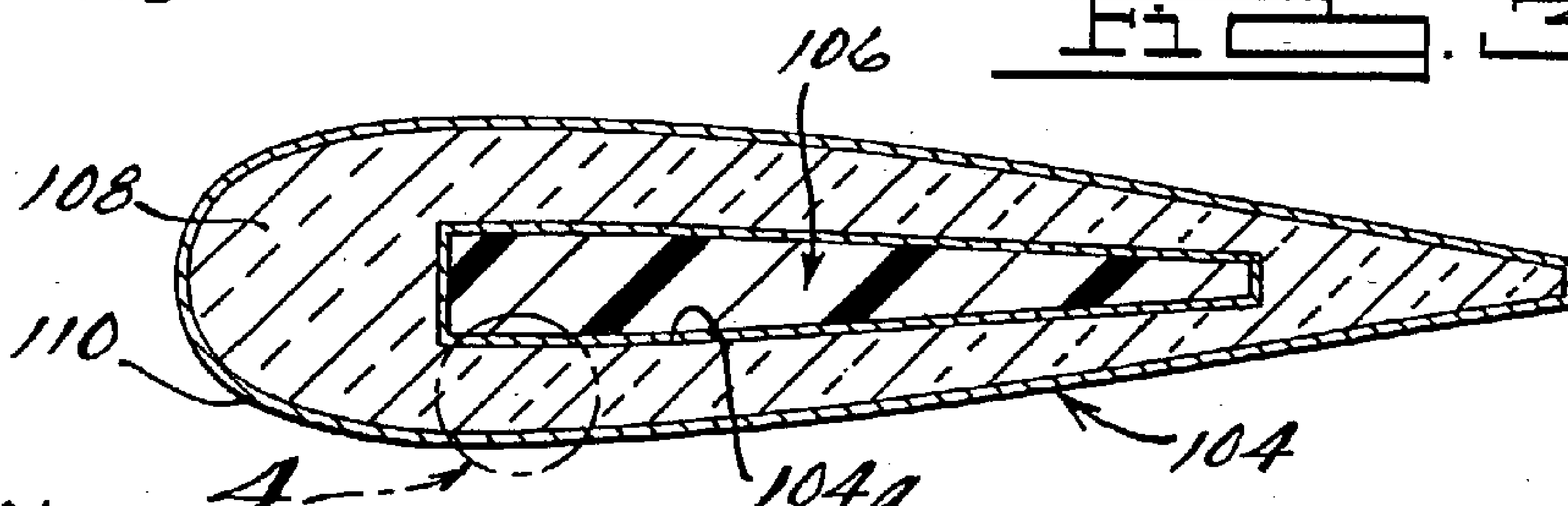


FIG. 3.



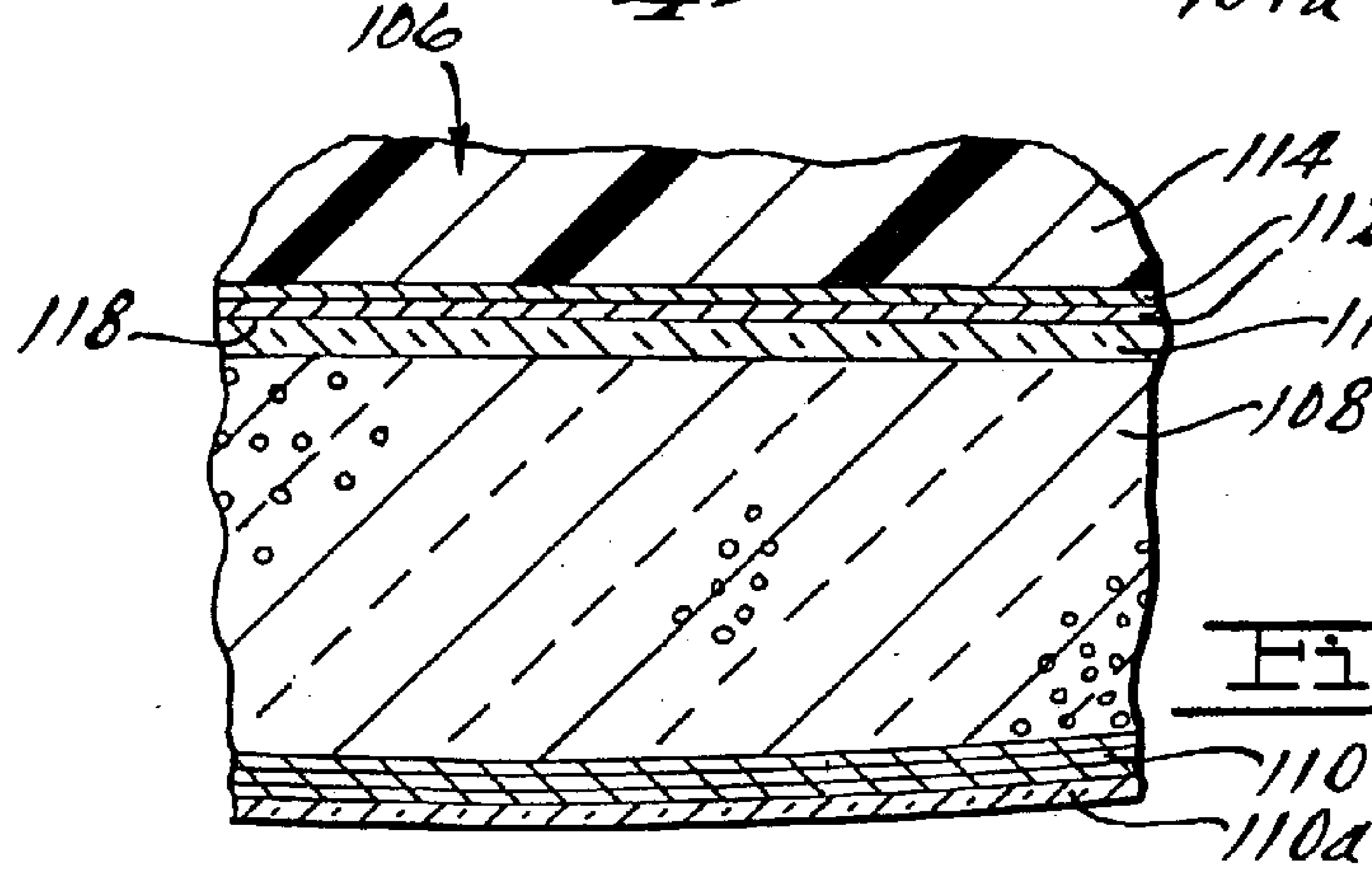


FIG. 4.

HIGH TEMPERATURE RESISTANT AIRFOIL APPARATUS FOR A HYPERSONIC SPACE VEHICLE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional of U.S. patent application Ser. No. 09/703,947 filed on Nov. 1, 2000, presently allowed. The disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] This invention relates to control surfaces for aerospacecraft, and more particularly to a ruddervator for an aerospacecraft incorporating a single piece, temperature resistant ceramic matrix composite shell secured over a composite structural member, wherein the structural member is adapted to be secured to a control element of the aerospacecraft.

BACKGROUND OF THE INVENTION

[0003] Current control surfaces for advanced aerospacecraft are formed by a carbon-based ceramic matrix composite (CMC) hot structure with conventional rib-stiffened structure and a mechanically fastened skin. The X-37 aerospacecraft presently in use uses a control surface termed a "ruddervator" with the above-described construction, and makes use of carbon/silicon carbide (C/SiC). This construction is shown in **FIG. 1**. The mechanically fastened upper skin **10** is secured by a high temperature metal, ceramic or ceramic composite fasteners at locations **12** to an integral C/SiC lower skin and substructure **14**. A C/SiC tail tip **16** is used to close the end of the ruddervator. A titanium spindle **16** is used to rotate the ruddervator as needed. Thermal protection system seals **18**, **20** and ring **22** are used to help mount the ruddervator to the fuselage of the aerospacecraft.

[0004] The X-37 ruddervator approach described above uses an expensive 2800° F. CMC system in a 2400° F. "hot structure" application and uses an aircraft-like structural approach at the elevated temperature. The term "hot structure" refers to the temperature of the primary load-carrying structure, in this case the CMC and supports used at 2400° F. This construction reduces the service life of the fasteners. Additionally, carbon-based CMCs generally require complex and costly tooling, unique and expensive infiltration/furnace facilities, and fabrication cycles of six months or more. The use of new materials under development, such as oxide fibers/oxide-matrix based CMC (oxide-CMC), provide opportunities to design control surfaces in novel and more cost-effective ways including, but not limited to, maintaining internal supports and attachments below 600° F.

[0005] For present and planned reusable hypersonic vehicles there are also size constraints on control surfaces due to available volume which restrict the use of conventional, lower cost structure insulated with bonded tile thermal protection. The current solution is to use the CMC for control surface hot structure in areas which do not require their extreme high temperature properties. The result is high initial and recurring costs for these parts as well as weight penalties and high part counts. Without an order of magnitude reduction in thermal structure costs, commercial reusable access to space will be difficult, if not impossible, to achieve.

[0006] It is therefore a principal object of the present invention to provide a new construction for a ruddervator for an aerospacecraft which can be produced more inexpensively from a simpler fabrication process, and which has improved life and reliability over the conventional mechanically fastened upper skin-to-substructure approach presently in use for ruddervator applications.

[0007] It is another object of the present invention to provide a hybrid control surface for an aerospacecraft which can be manufactured more economically, which is simpler to repair, and which does not make use of typical mechanical fasteners to secure an upper skin to a substructure.

[0008] It is still another object of the present invention to provide a ruddervator for an aerospacecraft having a simplified design which requires significantly fewer independent component parts being needed in the construction of the ruddervator.

[0009] It is a further object of the present invention to provide a ruddervator for an aerospacecraft which can be constructed even more cost effectively, and which is reusable.

[0010] It is still another object of the present invention to provide a ruddervator for an aerospacecraft wherein the ruddervator employs a one piece, highly temperature resistant outer shell which is bonded to a composite structural member to provide a highly temperature resistant, lightweight and yet easy to manufacture assembly.

SUMMARY OF THE INVENTION

[0011] The above and other objects are provided by an airfoil in accordance with preferred embodiments of the present invention. The airfoil is specifically adapted to withstand the high temperatures encountered during hypersonic flight and is particularly suited for use as a ruddervator on an aerospacecraft.

[0012] The airfoil is comprised of a temperature resistant, ceramic matrix composite shell having an opening at one end and a hollowed out interior area. A structural member is inserted into the hollowed out interior area and bonded to an interior surface of the shell to form a structurally rigid airfoil assembly. A transition structure is secured to the structural member for interfacing the airfoil assembly to a control element of the space vehicle to permit the airfoil assembly to be controlled by the control element.

[0013] In one preferred embodiment the shell is comprised of a one-piece, oxide/oxide-based ceramic matrix composite (Oxide-CMC) shell. The structural member comprises a graphite composite structure having a graphite composite face sheet and a honeycomb core element.

[0014] During manufacture, the structural member is inserted into the hollowed out opening of the Oxide-CMC shell and is bonded thereto. The transition structure may be secured to the structural member either after the structural member is inserted into the shell or before attachment of the structural member to the shell. Finally, the transition structure is secured to a fuselage actuator spindle of the aerospacecraft.

[0015] The airfoil apparatus of the present invention thus forms a highly temperature resistant, easy to manufacture assembly. The assembly further reduces the cost and weight over present day ruddervator designs as a result of reducing the total number of parts required to form the ruddervator, in addition to providing a higher specific strength and stiffness of the materials used with the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The various advantages of the present invention will become apparent to one skilled in the art by reading the following specification and subjoined claims and by referencing the following drawings in which:

[0017] **FIG. 1** is an exploded perspective view of a prior art ruddervator;

[0018] **FIG. 2** is a side view of a ruddervator of an aerospacecraft in accordance with a preferred embodiment of the present invention;

[0019] **FIG. 3** is a cross sectional end view of the ruddervator of **FIG. 2** taken in accordance with section line **3-3** in **FIG. 2**; and

[0020] **FIG. 4** is an enlarged view of a portion of the ruddervator of **FIG. 3** corresponding to circled area **4** in **FIG. 3**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Referring to **FIG. 2**, there is shown a ruddervator **100** for a hypersonic vehicle such as an aerospacecraft. The ruddervator **100** is secured to a fuselage actuator spindle **103** of an aerospacecraft **102** so as to be movable by the spindle.

[0022] With reference to FIGS. 2-4, the ruddervator **100** includes a shell **104** and an internal structural member **106**. The shell **104** is formed as a single-piece, monolithic structure having a hollowed out portion **104***a*. The shell **104** is comprised of a highly temperature resistant material, such as oxide/oxide-based ceramic matrix composite (Oxide-CMC) fabric **110** fused over a substrate of rigid ceramic foam insulation **108**. Preferably, a plurality of plies of Oxide-CMC fabric are incorporated, with the outer mold line (OML) ply being infused with a high-emissivity coating **110***a* such as reaction-cured glass (RCG). The high-emissivity coating provides plasma heating re-radiation outward to reduce internal temperatures within the ruddervator **100**.

[0023] With further reference to **FIGS. 3 and 4**, the structural member **106** comprises one or more graphite composite face sheets **112**, such as graphite/epoxy, and a honeycomb core **114**. The honeycomb core **114** may be formed from Nomex®, commercially available from E.I. du Pont de Nemours and Company. The hollowed out portion **104***a* is formed in the foam insulation **108** to permit the direct room temperature vulcanizing (RTV) adhesive bonding, as indicated at **116**, of the inner mold line **118** of the foam insulation onto the graphite face sheet **112** of the structural member **106**. The Oxide-CMC face sheets **110** provide a continuous shear flow around the OML of the ruddervator and, in concert with the directly bonded graphite composite structural member **106**, provide a quasi-torque box structure. The low thermal expansion property of the graphite minimizes the thermal mechanical stresses experienced due to thermal expansion differences between the ceramic foam insulation **108** and the structural member **106**.

[0024] With further reference to **FIG. 2**, the ruddervator **100** includes a torque box transition structure **120** for interfacing the ruddervator **100** to the fuselage actuator spindle **103** of the aerospacecraft **102**. The torque box transition structure **120** is sized to be slightly longer and wider than the graphite composite structural member **106** to provide space for fittings to attach the end of the member to the transition structure. The torque box transition structure **120** consists of a honeycomb sandwich torque box **122** with an access panel **124**. The access panel **124** allows access to the lower end of the graphite composite structural member **106** and also to machined internal fittings on the transition structure **120** to permit attachment of the ruddervator **100** to the actuator spindle. To limit the temperature of the transition structure **120** to a maximum temperature of about 250° F.-500° F., the transition structure is covered with a plurality of external, rigid insulation tiles **126**. Due to the lower temperatures at the base **100***a* of the ruddervator **100**, current or advanced tile systems can be utilized such as RCG and toughened uni-piece fibrous insulation (TUFI) coated alumina-enhanced thermal barrier (AETB) tile. The tile over the transition structure **120** is attached using standard RTV, strain isolation pads (SIP) and fillerbar (F/B). However, to provide access to the spindle axis panel **124** and the attachments for the graphite composite structural member **106**, specific tiles **126** are preferably bonded to intermediate carrier panels **129***a* and **129***b* and specific tiles have removable ceramic plugs **128** for access to carrier panel fasteners. The carrier panels are preferably fastened to inserts in the honeycomb sandwich transition structure **120** and thus permit easier removal of the tiles for damage replacement.

[0025] The ruddervator **100** also includes a serrated shape at a base portion **104***b* of the Oxide-CMC shell **104**. The tiles **126** at the interface of the Oxide-CMC shell **104** and the torque box transition structure **120** match the serrated end of the Oxide-CMC shell. The serrated interface minimizes direct high temperature plasma flow to the aft portions of the ruddervator **100**. It also permits direct access to the graphite composite structural member **106** when the transition structure **120** tile **126** are removed so that side attachments (not shown) between structural member **106** and structure **120** can be accessed.

[0026] It is an important advantage of the ruddervator **100** that the Oxide-CMC shell **104** is formed with the hollowed out interior area **104***a* defined by the outer mold line of the graphite composite structural member **106** in **FIG. 3**. This hollowed out interior area **104***a* allows a monolithic Oxide-CMC slab of material to be used to form the Oxide-CMC shell **104**, and allows insertion of the graphite composite structural member **106** into the hollowed out area and subsequent direct bonding of the shell to the structural member.

[0027] To further improve the structural integrity of the ruddervator **100**, the graphite composite structural member **106** preferably has a slight wedge shape, as indicated in **FIG. 2**, and also comprises open angles in all three dimensions, as indicated in **FIG. 3**. This feature permits air to escape during insertion of the structural member **106** into the hollowed out opening **104***a* of the Oxide-CMC shell **104** during manufacture to minimize the amount of air trapped in the RTV bond line **116** (**FIG. 4**). Excessive amounts of trapped air would reduce bond line strength to below acceptable levels. The wedge shape also permits pressure to be applied to the exposed end of the graphite composite structural member **106** and distributed throughout the Oxide-CMC shell **104** during bond curing to increase the adhesive joint strength and further reduce trapped air. The wedge shaped feature also provides an increasing thickness of CMC insulation between the outer mold line and inner mold line of the Oxide-CMC shell **104** to match the increasing temperature gradient to the ruddervator tip **100***b* (**FIG. 2**), while at the same time optimizing the ruddervator **100** overall structure to minimize weight. However, the individual panel surfaces creating the wedge shaped structural member **106** are all flat to minimize panel fabrication costs with the aerodynamic outer mold line insulation **108** cast directly into the Oxide-CMC.

[**0028**] The Oxide-CMC insulation **108** is further preferably uncoated at the open end (i.e. at serrated edge **104***b*) to allow the shell to vent during ascent. This reduces the risk of material fracture due to trapped air pressure differentials inside the insulation **108**.

[**0029**] The ruddervator **100** of the present invention provides an assembly of reduced cost and weight over present day ruddervator constructions by reducing the total number of parts required and by using higher specific strength and stiffness materials. The number of independent parts is significantly reduced by the use of the Oxide-CMC shell **104** and the single graphite composite structural member **106**, as compared with numerous built-up pieces of CMC hot structure and/or the traditional cold structure covered with numerous external tiles. The cost of the ruddervator **100** is also reduced by utilizing the reduced tooling complexities of Oxide-CMC over CMC fabrication processes, as well as the ability to implement more simple repair processes. Eliminating the need for oxidation protection coatings on the ruddervator also improves its life and reliability.

[**0030**] Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification and following claims.

What is claimed is:

1. A high temperature resistant airfoil apparatus for a hypersonic space vehicle, comprising:

a temperature resistant ceramic matrix composite shell having an opening at one end and a hollowed interior area;

a structural member inserted into said hollowed interior area and secured to an interior surface of said shell to form a structurally rigid airfoil assembly; and

a transition structure secured to said structural member for interfacing said airfoil apparatus to a control element of said space vehicle to permit said airfoil apparatus to be controlled by said control element.

2. The apparatus of claim 1, wherein said shell comprises an oxide/oxide-based ceramic matrix composite (Oxide-CMC) shell.

3. The apparatus of claim 2, wherein a top outer mold line (OML) ply of said Oxide-CMC shell is infused with a high-emissivity coating.

4. The apparatus of claim 1, wherein said structural element comprises a graphite composite structural member having a graphite composite facesheet and a honeycomb core element.

5. The apparatus of claim 1, further comprising a plurality of thermal barrier tiles secured over said transition structure.

6. The apparatus of claim 2, wherein said shell comprises an Oxide-CMC fabric fused to an outer surface of a rigid ceramic foam insulation member; and

wherein said insulation member is RTV bonded to said structural member.

7. The apparatus of claim 1, wherein said structural member is wedge-shaped when viewed chord-wise to help eliminate air being trapped within said hollowed interior area of said shell as said structural member is inserted into said hollowed interior area during manufacturing of said airfoil.

8. The apparatus of claim 1, wherein said structural member is wedge-shaped when viewed from one side thereof to help eliminate air being trapped within said hollowed interior area of said shell as said structural member is inserted therein during manufacturing of said airfoil.

9. The apparatus of claim 1, wherein a lower end of said shell comprises a serrated edge to minimize high temperature flow to an aft portion of said airfoil assembly.

10. A high temperature resistant ruddervator apparatus for a hypersonic space vehicle, comprising:

a one piece, temperature resistant oxide/oxide-based ceramic matrix composite (Oxide-CMC) shell having an opening at one end and a hollowed interior area, said Oxide-CMC shell comprising an Oxide-CMC fabric fused to a rigid ceramic foam insulation member;

a structural member inserted into said hollowed interior area of said Oxide-CMC shell and bonded to an interior surface of said Oxide-CMC shell to form a structurally rigid ruddervator assembly; and

a transition structure secured to said structural member for interfacing said ruddervator assembly to a control element of said space vehicle to permit said ruddervator assembly to be controlled by said control element.

11. The apparatus of claim 10, wherein said structural member comprises a graphite composite structural member having a graphite/epoxy facesheet secured to a honeycomb core element.

12. The apparatus of claim 10, wherein said Oxide-CMC fabric is comprised of a plurality of plies of Oxide-CMC fabric fused to an outer surface of said rigid ceramic foam insulation member.

13. The apparatus of claim 10, wherein an outer surface of said Oxide-CMC fabric is infused with a high emissivity coating to reduce internal temperatures experienced by said rigid ceramic foam insulation and said structural member.

14. The apparatus of claim 13, wherein said high emissivity coating comprises reaction cured glass (RCG).

15. A method of manufacturing a ruddervator for a hypersonic space vehicle, comprising the steps of:

forming a one piece shell comprised of oxide/oxide-based ceramic matrix composite (Oxide-CMC) material, said Oxide-CMC shell being open at one end and having a hollowed interior area;

inserting a structural member into said one end and into said hollowed interior area of said Oxide-CMC shell, said structural member being shaped generally in accordance with a shape of said hollowed interior area such that said structural member fits snugly with said hollowed interior area; and

securing an interior surface of said Oxide-CMC shell to an outer surface of said structural member.

16. The method of claim 15, further comprising the step of securing a transition structure to a lower end of said structural member, said transition structure being adapted to be secured to a control element of said hypersonic space vehicle.

17. The method of claim 15, further comprising the step of forming said Oxide-CMC shell from an Oxide-CMC fabric fused over a rigid ceramic foam insulation substrate.

18. The method of claim 15, further comprising the steps of:

forming said Oxide-CMC shell from an Oxide-CMC fabric and a rigid ceramic foam insulation substrate, wherein said foam insulation substrate comprises said hollowed interior area; and

using an RTV bonding process to secure said foam insulation substrate to said structural member.

19. The method of claim 15, further comprising the step of forming said hollowed interior area and said structural member each with a wedge shape to reduce the chance of air being trapped inside said hollowed interior area during insertion of said structural member therein.

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