



(51) International Patent Classification:

*B64D 37/06* (2006.01)    *B60K 15/03* (2006.01)  
*B64D 37/32* (2006.01)    *F41H 5/04* (2006.01)

(21) International Application Number:

PCT/GB2015/051322

(22) International Filing Date:

6 May 2015 (06.05.2015)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1408013.9                    7 May 2014 (07.05.2014)                    GB  
14275102.3                   7 May 2014 (07.05.2014)                    EP

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(81) Designated States (unless otherwise indicated, for every kind of national protection available):

AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available):

ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

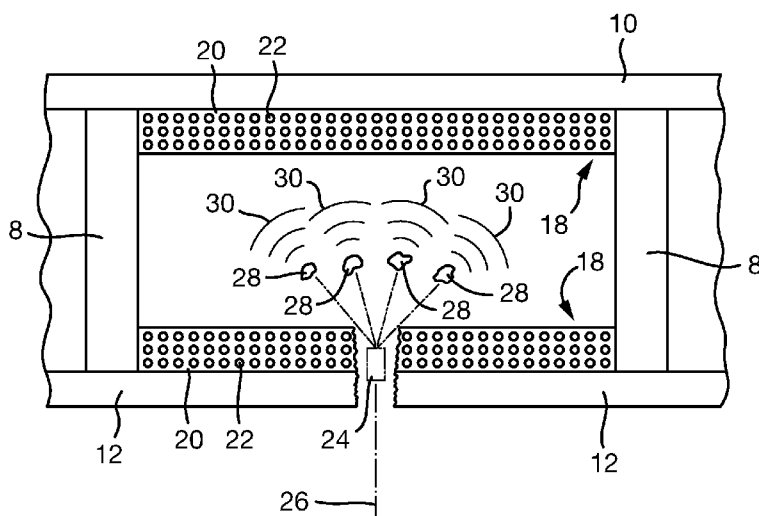
— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

Published:

— with international search report (Art. 21(3))

(54) Title: LIQUID STORAGE SYSTEM

Fig. 3



(57) Abstract: A liquid storage system comprising: a tank (16) for containing a liquid, said tank (16) enclosing a liquid storage space (14); and a tank liner (18) fixedly attached to an internal surface of the tank (16). The tank liner (18) comprises: a plurality of elements (22), each element (22) having a hardness value of 2GPa or above; and a binder material (20) in which the plurality of elements (22) are embedded. The elements (22) have a higher hardness value than the binder material (20). A distance between a first element and the internal surface of the tank (16) in a direction normal to the internal surface of the tank (16) is different to a distance between a second element and the internal surface of the tank (16) in the direction normal to the internal surface of the tank (16), the first element being different to the second element.

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## LIQUID STORAGE SYSTEM

## FIELD OF THE INVENTION

The present invention relates to liquid storage systems.

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## BACKGROUND

A high speed projectile on impact with and penetration into a liquid containing tank generates very high pressure in the liquid. This phenomenon, known as hydrodynamic ram, typically includes the generation of shock waves and subsequent pressure pulses in the liquid. These pressures, combined with the penetration damage from the projectile, can cause damage to the tank structure and frequently are the cause of catastrophic failure of the tank. The hydrodynamic ram pressure pulses are intense but of short duration which propagate through the liquid in the tank.

15 There is thus a need for means for reducing hydrodynamic ram pressure in the liquid in such a tank and for a generally improved tank which has an improved ability to sustain projectile impact without catastrophic failure.

## SUMMARY OF THE INVENTION

20 In a first aspect, the present invention provides a liquid storage system comprising: a tank for containing a liquid, said tank enclosing a liquid storage space; and a tank liner fixedly attached to an internal surface of the tank. The tank liner comprises: a plurality of elements, each element having a hardness value of 2GPa or above; and a binder material in which the plurality of elements are embedded. The elements have a higher hardness value than the binder material. A distance between a first element and the internal surface of the tank in a direction normal to the internal surface of the tank is different to a distance between a second element and the internal surface of the tank in the direction normal to the internal surface of the tank, the first element being different to the

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second element. Thus, the hard elements are distributed within the binder matrix at different depths of the tank liner. A distance between a first element and the internal surface of the tank may be different to a distance between a second element and the internal surface of the tank, i.e. multiple different  
5 elements may have different respective depths with the tank liner. The depth of the tank liner may be a dimension that points from a proximal surface of the liner to a distal surface of the liner.

The elements may be substantially uniformly distributed throughout the binder material. The elements may be distributed throughout the entire bulk of  
10 the binder material, i.e. throughout the entirety of the binder material.

The binder material may be more flexible than walls of the tank, for example, such that loads carried in use by the binder material are very small (preferably zero, or insignificant) compared to loads carried by the structure of the tank.

The fuel tank liner may comprises a proximal surface fixedly attached to  
15 an internal surface of the tank, and a distal surface opposite to the proximal surface. The elements may be arranged as multiple layers of elements between the proximal surface and the distal surface. A distance between the proximal surface and the distal surface (i.e. a thickness of the tank liner) may be between  
20 10mm and 25mm. The tank liner may have a uniform thickness.

A diameter of each of the elements may be in the range 2mm to 6mm. Each element may have a hardness value of 20GPa or above. The elements may be made of ceramic, metal, or a metal alloy. The elements may be substantially spherical in shape. The binder material may be a rubber or a  
25 polymer. The tank may be an aircraft fuel tank.

In a further aspect, the present invention provides a vehicle comprising a liquid storage system in accordance with any of the above aspects.

In a further aspect, the present invention provides a method of producing a liquid storage system. The method comprises: providing a tank for containing  
30 a liquid, said tank enclosing a liquid storage space; providing, in a liquid or

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semiliquid form, a binder material; adding a plurality of elements to the liquid or semiliquid binder material, each element having a hardness value of 2GPa or above; solidifying the binder material so as to embed the plurality of elements in the binder material; and fixedly attaching, to an internal surface of the tank, the solidified binder material with the elements embedded therein, thereby proving  
5 a tank liner for the tank. The tank liner is such that a distance between a first element and the internal surface of the tank in a direction normal to the internal surface of the tank is different to a distance between a second element and the internal surface of the tank in the direction normal to the internal surface of the  
10 tank, the first element being different to the second element.

The method may further comprise: applying the mixture of the liquid or semiliquid binder material and the plurality of elements to the internal surface of the tank (while the binder material is in its liquid or semiliquid form); and, thereafter, solidifying the mixture of the liquid or semiliquid binder material and  
15 the plurality of elements that has been applied to the internal surface of the tank, thereby bonding the binder material with the elements embedded therein to the internal surface of the tank.

The method may further comprise: providing a mould, the mould having a shape complementary to the internal surface of the tank; applying the mixture  
20 of the liquid or semiliquid binder material and the plurality of elements to the mould (while the binder material is in its liquid or semiliquid form); thereafter, solidifying the mixture of the liquid or semiliquid binder material and the plurality of elements that has been applied to the mould; and fixedly attaching, to the internal surface of the tank, the solidified binder material with the elements  
25 embedded therein.

In a further aspect, the present invention provides at least part of a wall of a tank for containing a fluid, the at least part of the wall comprising a plurality of elements, each element having a hardness value of 2GPa or above, and a binder material in which the plurality of elements are embedded. The elements  
30 have a higher hardness value than the binder material.

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Each element may have a hardness value of 5GPa or above. Each element may have a hardness value of 10GPa or above. Each element may have a hardness value of 15GPa or above. Each element may have a hardness value of 20GPa or above.

- 5           The elements may be arranged in the binder material such that, when the at least part of the wall of the tank is impacted by a projectile having sufficient kinetic energy for at least part of the projectile to fully penetrate the at least part of the wall, the projectile impacts with at least one of the elements.

The elements may be made of ceramic, metal, or a metal alloy.

- 10           The elements may be substantially spherical in shape.

A diameter of each of the elements may be in the range 2mm to 6mm

- The binder material may be a rubber or a polymer. For example, the binder material may be a polymer matrix in which is also embedded a fibre-based such as carbon fibres. Thus, the at least part of a wall may be a carbon  
15 fibre composite (CFC) panel (e.g. an outer skin of an aircraft), in which is embedded the relatively hard elements.

The at least part of a wall of a tank may be a liner for a tank which is configured to be applied to an internal surface of a tank.

- In a further aspect, the present invention provides a tank for containing a  
20 liquid, wherein at least part of a wall of the tank is in accordance with the preceding aspect.

- The at least part of the tank wall may be a liner for the tank which is applied to an internal surface of the tank. The total cavity volume of the tank liner in the tank may be less than or equal to 15% by volume of the tank  
25 volume.

The tank may be an aircraft fuel tank.

In a further aspect, the present invention provides a vehicle (e.g. an aircraft) comprising a tank for containing a liquid in accordance with the preceding aspect.

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## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic illustration (not to scale) of an exploded view of an example aircraft wing in which an embodiment of a fuel tank liner is implemented;

Figure 2 is a schematic illustration (not to scale) showing a cross section through a fuel tank located in the aircraft wing; and

Figure 3 is a schematic illustration (not to scale) illustrating effects of a projectile impacting with an external surface of the fuel tank.

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## DETAILED DESCRIPTION

In the following description, like reference numerals refer to like elements.

The following description is based on embodiments of the invention and should not be taken as limiting the invention with regard to alternative embodiments that are not explicitly described herein. Structural material types and methods of construction identified are examples only.

It will be appreciated that relative terms such as top and bottom, upper and lower, and so on, are used merely for ease of reference to the Figures, and these terms are not limiting as such, and any two differing directions or positions and so on may be implemented.

Figure 1 is a schematic illustration (not to scale) of an exploded view of an example aircraft wing 2 in which an embodiment of a fuel tank liner is implemented.

The aircraft wing 2 comprises a substructure 4 comprising a plurality of spars 6 and ribs 8. The spars 6 are spaced apart from one another and are aligned along the length of the aircraft wing 2. The spars 6 are coupled together by the spaced apart ribs 8 which are substantially perpendicular to the spars 6. The spars 6 and ribs 8 are connected together by fasteners (not shown in the

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Figures). The spars 6 and ribs 8 are made of carbon fibre composite (CFC) material, i.e. a composite material comprising a polymer matrix reinforced with carbon fibres. In other examples, the spars 6 and ribs 8 are made of a different appropriate material, for example, aluminium.

5           The aircraft wing 2 further comprises external skins, namely an upper skin 10 and a lower skin 12. The upper skin 10 comprises a plurality of panels made of CFC material. The upper skin 10 is attached to an upper surface of the substructure 4 by fasteners (not shown in the Figures). The lower skin 12 comprises a plurality of panels made of CFC material. The lower skin 12 is  
10 attached to a lower surface of the substructure 4 by fasteners (not shown in the Figures). The external skin 10, 12 may each be, for example, 8mm thick.

When the substructure 4 and the external skins 10, 12 are attached together (and, for example, bonded with a sealant), a cavity defined by the substructure 4 and skins 10, 12 is formed. Such a cavity is used as a fuel tank  
15 for storing aircraft fuel and is indicated in Figure 1 by the reference numeral 14. The fuel tank is described in more detail later below with reference to Figure 2.

The aircraft wing 2 further comprises a leading edge structure, a trailing edge structure and a wing tip structure, which are not shown in Figure 1 for reasons of clarity.

20           Figure 2 is a schematic illustration (not to scale) showing a cross section through the fuel tank 16 in the aircraft wing 2.

In this embodiment, the outer walls of the fuel tank 16 are provided by spars 6, ribs 8, and the upper and lower skins 10, 12. Aircraft fuel is stored in the cavity 14 defined by the fuel tank outer walls.

25           In this embodiment, the fuel tank 16 comprises two fuel tank liners 18. A first of the fuel tank liners 18 is disposed on an internal surface of the upper skin 10, i.e. the surface of the upper skin 10 that is inside the fuel tank 16. A second of the fuel tank liners 18 is disposed on an internal surface of the lower skin 12, i.e. the surface of the lower skin 12 that is inside the fuel tank 16.

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Preferably, the fuel tank liners 18 cover the entirety of the internal surfaces of the external skins 10, 12 that define the fuel tank 16. Further, the fuel tank liners 18 may also cover the surfaces of the ribs 8 or spars 6.

In this embodiment, each fuel tank liner 18 is a layer of composite material that comprises a binder matrix 20 in which is embedded a plurality of objects 22.

The binder matrix 20 may be any appropriate material that may be used to bind together or retain the objects 22. For example, the binder material 20 may be rubber or a polymer.

Preferably, the binder matrix 20 is relatively flexible compared to the structure of the aircraft wing 2 to which it is to be attached. In other words, preferably, the binder matrix 20 is more flexible than the external skins 10, 12, the spars 6, and the ribs 8. The binder matrix 20 being more flexible than the aircraft structure advantageously tends to provide that, when the tank liner 18 is fixed into the fuel tank 16, the fuel tank liner 18 tends not to carry any load, or only an insignificant load, compared to the structure of the aircraft (i.e. compared to the spars 6, the ribs 8, and/or the external skins 10, 12). Thus, the tank liner 18 tends not to change, to any significant extent, the loading distribution of the aircraft wing 2. Thus, the design of the wing 2, and the structural design process performed in designing the aircraft wing 2, tend not to be undermined or invalidated by the application of the tank liner 18 to the wing 2. Thus, application of the tank liner 18 to a wing 2 (e.g. retrofitting to an existing wing) tends to be facilitated.

In some embodiments, the objects 22 may be included (i.e. embedded) directly within the composite layup of the tank structure, for example, within the skins 10, 12.

In this embodiment, the objects 22 are substantially spherical in shape, each having a diameter of approximately 2mm to 6mm. However, in other embodiments, one or more of the objects 22 may have a different shape and/or size, for example, an object 22 may be rod-shaped (i.e. elongate) or a cube (e.g. a rounded cube). In some embodiments, the objects 22 are larger than



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6mm in diameter, for example the objects 22 may have diameters between 6mm and 22mm. In this embodiment, the objects 22 are harder and/or denser than the binder matrix 18. In this embodiment, the objects 22 are harder and/or denser than the CFC material that forms the external skins 10, 12. In this  
5 embodiment, the objects 22 are made of ceramic, e.g. zirconia, silicon nitride, alumina, or silicon carbide. Preferably the objects 22 have a hardness value (e.g. a Vickers hardness or a Knoop hardness) of 2GPa or above. More preferably the objects 22 have a hardness value (e.g. a Vickers hardness or a Knoop hardness) of 5GPa or above. More preferably the objects 22 have a  
10 hardness value (e.g. a Vickers hardness or a Knoop hardness) of 10GPa or above, for example the objects 22 may be made of Zirconias and Aluminium Nitrides having a Knoop hardness in the range of 10GPa to 14GPa. More preferably the objects 22 have a hardness value (e.g. a Vickers hardness or a Knoop hardness) of 15GPa or above, for example the objects 22 may be made  
15 of Aluminas and Silicon Nitrides which typically have a Vickers hardness of 15GPa to 20GPa. More preferably the objects 22 have a hardness value (e.g. a Vickers hardness or a Knoop hardness) of 20GPa or above, for example the objects 22 may be made of a carbide having a Knoop hardness of over 20GPa, e.g. Silicon Carbides and Boron Carbides which typically have a Vickers  
20 hardness of about 20GPa to 30GPa.

In this embodiment, the concentration and arrangement of the objects 22 within the fuel tank liners 18 are such that a projectile passing through the thickness of a fuel tank liner 18 will tend to impact with at least one of the objects 22, and preferably multiple objects 22. In some embodiments, the  
25 objects 22 are arranged in the binder matrix 20 in layers e.g. between 3 and 5 layers. More preferably there are more than 5 layers of objects 22. The objects 22 within a fuel tank liner 18 may be more closely packed together closer to the external skin 10, 12 to which that fuel tank liner 18 is attached.

In this embodiment, the objects 22 are distributed substantially uniformly  
30 within a fuel tank liner 18. In other words, the objects 22 are evenly spread throughout the fuel tank liners 18. This advantageously tends to increase the

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likelihood of a projectile that impacts with and penetrates a fuel tank liner 18 impacting with at least one of the objects 22.

In this embodiment, a distance between an object 22 and the internal surface of the tank 16 in a direction normal to the internal surface of the tank 16 is different to a distance between at least one other object 22 and the internal surface of the tank 16 in the direction normal to the internal surface of the tank 16. In other words, multiple different objects 22 each have different respective depths in the fuel tank liner 18. The depth of a fuel tank liner 18 is understood to be the dimension of that fuel tank liner 18 along a direction that points from a proximal surface of the tank liner 18 (i.e., a surface of the tank liner 18 that is attached to the internal surface of the fuel tank 16), and a distal surface of the tank liner 18 (i.e. the surface opposite to the proximal surface), for example, in a direction normal to the proximal and/or distal surfaces. This may be due at least in part to the uniform distribution of the objects 22, and the sizes of the objects 22 relative to the thickness of a fuel tank liner 18. Thus, in effect, objects 22 may be arranged in multiple layers within a fuel tank liner 18. This advantageously tends to increase the likelihood of a projectile that impacts with and penetrates a fuel tank liner 18 impacting with multiple objects 22 as it passes through the liner 18.

Each fuel tank liner 18 may have any appropriate depth (i.e. thickness), for example, 10mm to 20mm, or 15mm to 19mm. Preferably, the thicknesses of the fuel tank liners 18 are such that the fuel tank liners 18 occupy less than or equal to 15% (e.g. approximately 10%) of the fuel tank capacity. In other embodiments, the fuel tank liners 18 are a different thickness that provides that the fuel tank liners 18 occupy a different proportion of the fuel tank capacity. Preferably, the fuel tank liners 18 are of uniform thickness.

The fuel tank liners 18 may be attached to the external skins 10, 12 by any appropriate means for example using an adhesive or by performing a bonding process.

In some embodiments, a fuel tank liner 18 is formed and attached to an internal surface of the fuel tank as follows. Firstly, the binder material 20 is

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provided in a liquid (e.g. molten) or semiliquid state. Secondly, the objects 22 are added to, and thoroughly mixed with, the liquid binder material 20. The mixing of the objects 22 into the liquid binder material 20 tends to substantially uniformly distribute the objects 22 within the binder material 20. Thirdly, the liquid binder material 20 with the object 22 therein is spread across a surface of the aircraft component to which the fuel tank liner 18 is to line. For example, the mixture of the binder material 20 and the objects 22 may be poured over a surface of an aircraft panel 10, 12 that is to form an internal surface of the fuel tank 16. The mixture of the binder material 20 and the objects 22 may be applied to an aircraft component before, during, or after assembly of the aircraft wing 2. Lastly, the mixture of the binder material 20 and the objects 22 is solidified, for example, the liquid binder material 20 may be allowed to harden (e.g. by cooling), or may be cured. This solidification of the mixture of the binder material 20 and the objects 22 tends to bond the binder material 20 to the aircraft component to which the mixture has been applied. Thus, a solid fuel tank liner 18 is formed on an aircraft component. In some embodiments, a cast or mould may be used to shape the fuel tank liner 18 on the aircraft component. This cast or mould may be removed after solidification of the mixture of the binder material 20 and the objects 22.

In some embodiments, a fuel tank liner 18 is formed and attached to an internal surface of the fuel tank as follows. Firstly, the binder material 20 is provided in a liquid (e.g. molten) or semiliquid state. Secondly, the objects 22 are added to, and thoroughly mixed with, the liquid binder material 20. The mixing of the objects 22 into the liquid binder material 20 tends to substantially uniformly distribute the objects 22 within the binder material 20. Thirdly, the liquid binder material 20 with the object 22 therein is applied to a mould tool or cast in a desired shape (i.e. a shape that conforms to the shape of the surface to which the fuel tank liner 18 is to be applied). The mixture of the binder material 20 and the objects 22 is then solidified, for example, by cooling or curing. Thus, a solid fuel tank liner 18 is formed. The fuel tank liner may be removed from the cast or mould after solidification. The solidified fuel tank liner

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18 may be attached to an internal surface of the fuel tank 16, for example, using a layer of adhesive.

As will now be described in more detail, the fuel tank liners 18 are operable to reduce hydrodynamic ram pressure in the fuel contained within the fuel tank 16 resulting from impact of a projectile with an external surface of the fuel tank 16.

Figure 3 is a schematic illustration (not to scale) illustrating effects of a projectile 24 impacting with the lower skin 12 of the fuel tank 16. The path of the projectile through the lower skin 12 is indicated in Figure 3 by the reference numeral 26.

The projectile 24 may be any appropriate projectile or foreign object such as a bullet, warhead fragment, a vehicle part, a rock, a maintenance tool, hail, ice, a bolt, etc. An example projectile has a weight of approximately 3.5g, is substantially spherical in shape having a diameter of approximately 9.5mm, and travels with a velocity of 1500m/s. A further example projectile is a 44g 12.5mm bullet that travels with a velocity of 500m/s.

In this example, the projectile 24 initially impacts with an external surface of the lower skin 12 and travels through the lower skin 12. The projectile 24 causes high strain rate shear damage to the lower skin 12 resulting in a hole in the lower skin 12 approximately the size of the projectile 24.

After passing through the lower skin 12, the projectile 24 impacts with the fuel tank liner 18 disposed on the lower skin 12.

The projectile 24 impacting with one or more of the objects 22 in the fuel tank liner 18 tends to retard the passage of the projectile 24 into the fuel tank 16. Impact kinetic energy of the projectile 24 tends to be absorbed at least to some extent by the fuel tank liner 18 and also transferred to the objects 22 which may be ejected into the fluid volume.

Also, projectile 24 impacting with one or more of the objects 22 in the fuel tank liner 18 may cause the projectile 24 to break up, or fragment, or be eroded into smaller parts prior to it entering the cavity 14. To facilitate this, preferably

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the objects 22 are harder and/or denser than the projectile 24. In some embodiments, the size of the objects 22, the hardness size of the objects 22, the density size of the objects 22, the concentration size of the objects 22 within the binder matrix 20, and or any other attribute of the objects 22 and/or binder matrix 20 may be determined (e.g. by experimentation or modelling) so as to maximise the likelihood of fragmentation of the projectile 24. The impact of the projectile 24 with objects 22 in the fuel tank liner 18 may also cause fragmentation of a portion of the fuel tank liner 18 disposed on the lower skin 12. The fragments into which the projectile 24 is broken up, and the fragments of the fuel tank liner 18, are hereinafter collectively referred to as "fragments" and are indicated in Figure 3 by the reference numerals 28. Thus, impact energy of the projectile 24 is absorbed at least to some extent by the fuel tank liner 18 disposed on the lower skin in the fragmentation of the projectile and/or the fuel tank liner 18.

Impact with one or more of the objects 22 may cause the projectile 24 to have increased tumble when travelling through the fluid.

In this example, on impact of the fragments 28 with the fuel, the fragments tend to generate respective high pressure shock waves 30. Each of these shock waves 30 tend to be of significantly lower energy than a shock wave or shock waves that would have been generated if the projectile 24 had not fragmented. Thus, pressures resulting from the shock waves 30 exerted on the walls of the fuel tank 16 tend to be lower than the shock wave pressures that would have been exerted on the walls of the fuel tank 16 if the projectile 24 had not fragmented. Thus, the likelihood of damage to the walls of the fuel tank 16 (e.g. decoupling of the external skin 10, 12 from the spars 6 or ribs 8 tends to be reduced.

In this example, as a fragment 28 passes through the fuel, a cavitation "wake" may form behind that fragment 28, i.e. a region of low pressure (e.g. a vapour or a vacuum) may form in the wake of a fragment 28. This causes a fluid displacement and an increase in the pressure of the fluid in the fuel tank 16. The increased fuel pressure resulting from cavitation caused by the fragments

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28 tends to be significantly lower than the pressure increase that would have been caused by cavitation if the projectile 24 had not fragmented. Thus, pressures resulting from cavitation exerted on the walls of the fuel tank 16 when the projectile 24 is fragmented tend to be lower than the pressures that would  
5 have been exerted on the walls of the fuel tank 16 if the projectile 24 had not been fragmented. Thus, the likelihood of damage to the walls of the fuel tank 16 (e.g. decoupling of the external skin 10, 12 from the spars 6 or ribs 8 tends to be reduced.

In this example, when travelling through the fuel, the fragments 28 tend  
10 to experience a greater overall drag force compared to that that would be experienced by the projectile 24 if the projectile 24 had not fragmented. This tends to be at least in part due to the increased surface area of the fragments 28 compared to the non-fragmented projectile 24. Thus, the passage of the projectile/fragments through the fluid in the fuel tank 16 tends to be retarded.  
15 The retardation of the passage of the projectile/fragments through the fluid tends to decrease the likelihood of the projectile/fragments impacting with the upper skin 10. Thus, the likelihood of a hole being formed in the upper skin tends to be reduced. Furthermore, the increase in drag on the projectile/fragments tends to mean that a greater portion of the impact energy is  
20 absorbed by the fluid in the fuel tank 16. Thus, forces exerted on the walls of the fuel tank 16 tend to be reduced.

Additionally, in this example, the fuel tank liner 18 disposed on the upper skin 10 is located within the fuel tank 16 such that the shock waves 30 resulting from compression of the fuel in the fuel tank 16 resulting from impact of the  
25 projectile 24 with the lower skin 12 impinge on the fuel tank liner 18 disposed on the upper skin 10 and so that the shock waves 30 interact with the fuel tank liner 18 disposed on the upper skin 10 before impinging on the upper skin 10. The fuel tank liner 18 disposed on the upper skin 10 tends to reflect incident shock waves 30 at least to some extent. Also, the fuel tank liner 18 disposed on  
30 the upper skin 10 tends to be a relatively poor transmitter of impinging shock waves 30. Thus, the amplitude of the shock waves 30 impinging upon the upper

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skin 10 tends to be reduced and consequently the pressure experienced by the upper skin 10 tends to be diminished by the presence of the fuel tank liner 18 disposed on the upper skin 10. The fuel tank liners 18 advantageously tend to decouple the fuel from walls of the fuel tank 16.

5           Furthermore, were any of the fragments 28 (or even the non-fragmented projectile 24) to continue through the cavity 14 and impact with the fuel tank liner 18 disposed on the upper skin 10, the fuel tank liner 18 disposed on the upper skin 10 would tend to cause further break-up or fragmentation of the impinging fragment 28 (or the non-fragmented projectile 24), thereby further  
10       reducing impact energy and reducing force experienced by at least the upper skin 10.

          An advantage provided by the above described fuel tank liner is that hydrodynamic ram damage to a fuel tank caused by an object impacting with an external surface of the fuel tank tends to be reduced or eliminated.  
15       Hydrodynamic pressures and their associated structural responses tend to be reduced or eliminated. Thus, the likelihood of catastrophic failure of the fuel tank and corresponding aircraft loss tends to be reduced or eliminated.

          The above described fuel tank liner advantageously tends to be relative easy and cheap to manufacture.

20           The above described fuel tank liner tends to be relatively easy to retrofit to existing aircraft fuel tanks.

          The above described fuel tank liner tends to provide protection against hydrodynamic ram damage whilst occupying a relatively small amount of the fuel tank's capacity.

25           In the above embodiments, the fuel tank liners are used to line the surfaces of an aircraft wing fuel tank. However, in other embodiments, the fuel tank liners are a different type of liner and may be used to line an internal or external surface of a different type of container for containing fluid. In some embodiments, one or more walls of the container may be made of a different  
30       material to that described above.

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In the above embodiments, fuel tank liners are disposed on the internal surfaces of the upper and lower aircraft skins. However, in other embodiments a fuel tank liner may be disposed on a different surface of the fuel tank instead of or in addition one or both of the internal surfaces of the upper and lower aircraft skins. For example, in some embodiments, all internal surfaces of the fuel tank are covered by fuel tank liners. In some embodiments, a fuel tank liner is only disposed on a single surface of the fuel tank, for example, on only the internal surfaces of the lower aircraft skin.

In the above embodiments, the fuel tank liners include objects embedded in the binder material. These objects are substantially spherical in shape, are made of ceramic, and have a diameter of 4mm to 5mm. However, in other embodiments, one or more of the objects may be a different shape, e.g. an irregular shape. In other embodiments, one or more of the objects may be made of a different appropriate material, e.g. metal or alloy such as hardened steel, for example the objects may be made of stainless steel which typically has a Vickers hardness of about 5GPa or cemented carbide which typically has a Vickers hardness of above 15GPa. Also, in other embodiments one or more of the objects may have a different size, for example, in some embodiments, some or all of the objects are larger than 5mm in diameter. Similarly, in other embodiments, some or all of the objects are smaller than 4mm in diameter. Preferably, the objects have diameters between 3mm and 5mm.

In the above embodiments, the liner material is a layer of material which may be applied to an internal surface of the fuel tank. However, in other embodiments, the fuel tank liner may be integral to one or more of the walls of the fuel tank. For example, in some embodiment, the objects may be directly embedded in one or more of the walls of the fuel tank. For example, in some embodiment, the objects are embedded in the portion of the lower skin that forms a wall of the fuel tank, i.e. the objects are directly embedded in the CFC material that forms the lower skin.



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## CLAIMS

1. A liquid storage system comprising:
  - a tank (16) for containing a liquid, said tank (16) enclosing a liquid storage space (14); and
  - 5 a tank liner (18) fixedly attached to an internal surface of the tank (16), wherein
    - the tank liner (18) comprises:
      - a plurality of elements (22), each element (22) having a hardness value of 2GPa or above; and
      - 10 a binder material (20) in which the plurality of elements (22) are embedded; wherein
        - the elements (22) have a higher hardness value than the binder material (20); and
        - 15 a distance between a first element and the internal surface of the tank (16) in a direction normal to the internal surface of the tank (16) is different to a distance between a second element and the internal surface of the tank (16) in the direction normal to the internal surface of the tank (16), the first element being different to the second element.
- 20 2. A liquid storage system according to claim 1, wherein the elements (22) are substantially uniformly distributed throughout the binder material (20).
3. A liquid storage system according to claim 1 or 2, wherein the binder material (20) is more flexible than walls of the tank (16).
- 25 4. A liquid storage system according to any of claims 1 to 3, wherein:

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the fuel tank liner (18) comprises a proximal surface fixedly attached to an internal surface of the tank (16), and a distal surface opposite to the proximal surface;

the elements (22) are arranged as multiple layers of elements between  
5 the proximal surface and the distal surface.

5. A liquid storage system according to any of claims 1 to 4, wherein:

the fuel tank liner (18) comprises a proximal surface fixedly attached to an internal surface of the tank (16), and a distal surface opposite to the proximal  
10 surface;

a distance between the proximal surface and the distal surface is between 10mm and 25mm.

6. A liquid storage system according to any of claims 1 to 5, wherein a  
15 diameter of each of the elements (22) is in the range 2mm to 6mm.

7. A liquid storage system according to any of claims 1 to 6, wherein each element (22) has a hardness value of 20GPa or above.

20 8. A liquid storage system according to any of claims 1 to 7, wherein the elements (22) are made of ceramic, metal, or a metal alloy.

9. A liquid storage system according to any of claims 1 to 8, wherein the elements (22) are substantially spherical in shape.

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10. A liquid storage system according to any of claims 1 to 9, wherein the binder material (20) is a rubber or a polymer.

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11. A liquid storage system according to any of claims 1 to 10, wherein the tank (16) is an aircraft fuel tank.
- 5 12. A vehicle comprising a liquid storage system in accordance with any of claims 1 to 11.
13. A method of producing a liquid storage system, the method comprising:  
providing a tank (16) for containing a liquid, said tank (16) enclosing a  
10 liquid storage space (14); and  
providing, in a liquid or semiliquid form, a binder material (20);  
adding a plurality of elements (22) to the liquid or semiliquid binder material (20), each element (22) having a hardness value of 2GPa or above;  
solidifying the binder material (20) so as to embed the plurality of  
15 elements (22) in the binder material (20); and  
fixedly attaching, to an internal surface of the tank (16), the solidified binder material (20) with the elements (22) embedded therein, thereby providing a tank liner (18) for the tank (16), the tank liner (18) being such that a distance  
20 between a first element and the internal surface of the tank (16) in a direction normal to the internal surface of the tank (16) is different to a distance between a second element and the internal surface of the tank (16) in the direction normal to the internal surface of the tank (16), the first element being different to the second element.
- 25 14. A method according to claim 13, wherein the method further comprises:  
applying the mixture of the liquid or semiliquid binder material (20) and the plurality of elements (22) to the internal surface of the tank (16); and

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solidifying the mixture of the liquid or semiliquid binder material (20) and the plurality of elements (22) that has been applied to the internal surface of the tank (16), thereby bonding the binder material (20) with the elements (22) embedded therein to the internal surface of the tank (16).

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15. A method according to claim 13, wherein the method further comprises:

providing a mould, the mould having a shape complementary to the internal surface of the tank (16);

10 applying the mixture of the liquid or semiliquid binder material (20) and the plurality of elements (22) to the mould; and

solidifying the mixture of the liquid or semiliquid binder material (20) and the plurality of elements (22) that has been applied to the mould; and

thereafter, fixedly attaching, to the internal surface of the tank (16), the solidified binder material (20) with the elements (22) embedded therein.

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Fig. 1

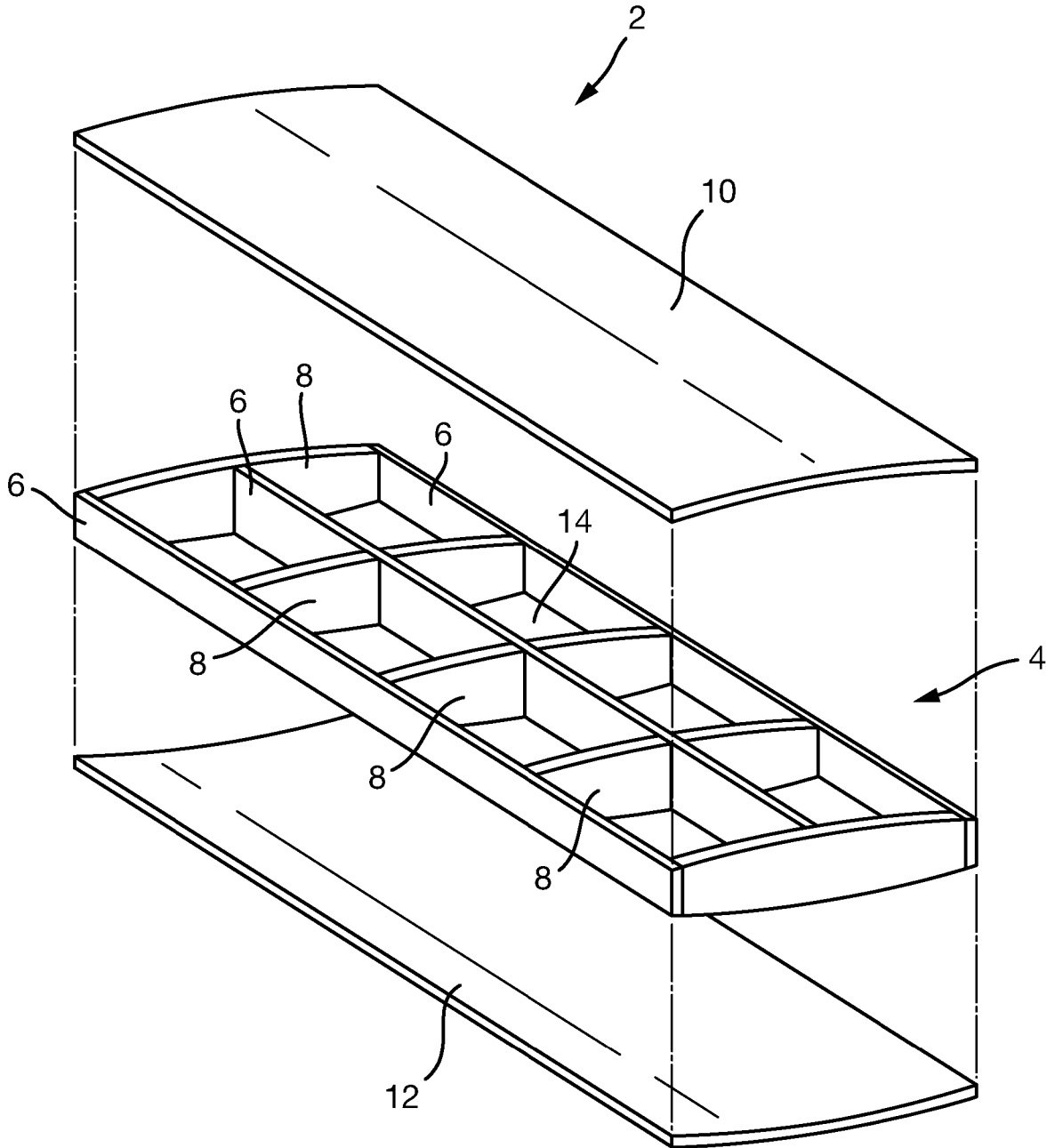


Fig. 2

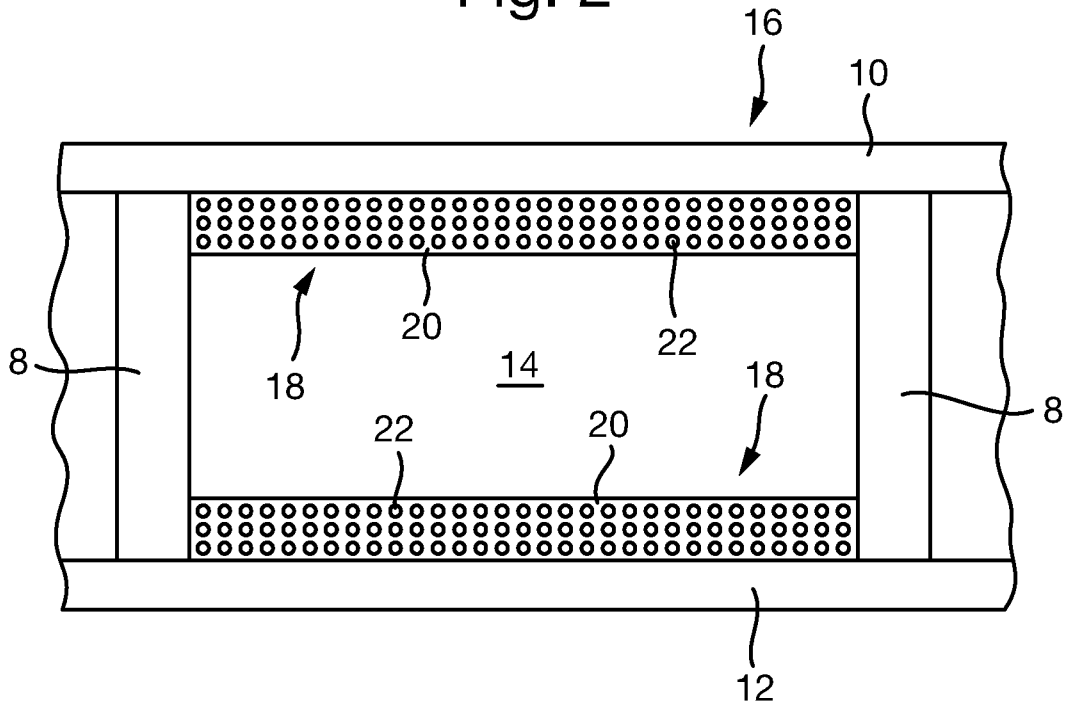
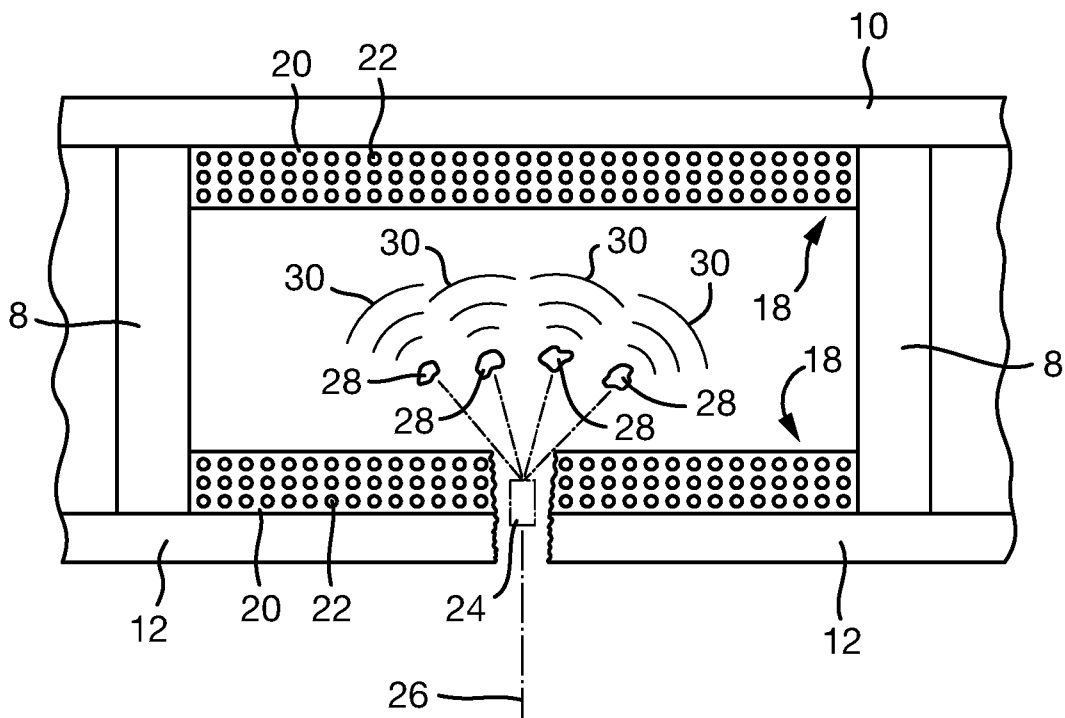


Fig. 3



# INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2015/051322

**A. CLASSIFICATION OF SUBJECT MATTER**  
 INV. B64D37/06 B64D37/32 B60K15/03 F41H5/04  
 ADD.

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)  
 B64D B60K F41H

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 practicable, 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.
Y	US 5 738 925 A (CHAPUT ARMAND JOSEPH [US]) 14 April 1998 (1998-04-14) column 2, line 37 - column 4, line 31; figures 1-3 -----	1-15
Y	US 8 096 223 B1 (ANDREWS MARK D [US]) 17 January 2012 (2012-01-17) The following figures, as well as related description text;; figures 1E, 2A-C, 3A, 3B -----	1-6,8-15
Y	US 4 360 124 A (KNAUS ERNEST ET AL) 23 November 1982 (1982-11-23) the whole document ----- -/--	14

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search

2 July 2015

Date of mailing of the international search report

10/07/2015

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## INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2015/051322

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	"CHARACTERISTICS OF KYOCERA TECHNICAL CERAMICS",  30 June 2004 (2004-06-30), XP055149244, Retrieved from the Internet: URL:http://americas.kyocera.com/kicc/pdf/Kyocera_Material_Characteristics.pdf [retrieved on 2014-10-28] Graph "Hardness"; page 1 Column "Sapphire"; page 4  -----	7
Y	US 3 969 563 A (HOLLIS SR RUSSELL E) 13 July 1976 (1976-07-13) column 2, lines 24-38; figure 1 column 7, line 25 - column 8, line 66; figure 8 column 9, line 64 - column 10, line 45; figure 11  -----	1-15
Y	US 2007/017359 A1 (GAMACHE RAYMOND M [US] ET AL) 25 January 2007 (2007-01-25) The following figures, as well as related description text:: figures 4A-C, 9  -----	1-6,8-15
A	US 2009/090236 A1 (MISENCIK STEPHEN [US] ET AL) 9 April 2009 (2009-04-09) paragraphs [0037], [0043]; figure 6  -----	1-15
A	US 2012/266745 A1 (WARREN DAVID H [US]) 25 October 2012 (2012-10-25) The following figures, as well as related description text:: figures 1A-D  -----	1-15



# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2015/051322

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5738925	A	14-04-1998	NONE
US 8096223	B1	17-01-2012	NONE
US 4360124	A	23-11-1982	NONE
US 3969563	A	13-07-1976	NONE
US 2007017359	A1	25-01-2007	NONE
US 2009090236	A1	09-04-2009	NONE
US 2012266745	A1	25-10-2012	NONE