A hypervelocity impact (HVI) Whipple Shield and a method for shielding a wall from penetration by high velocity particle impacts where the Whipple Shield is comprised of spaced apart inner and outer metal sheets or walls with an intermediate cloth barrier arrangement comprised of ceramic cloth and high strength cloth which are interrelated by ballistic formulae.

22 Claims, 2 Drawing Sheets
FIG. 1

1.35 CM AL
7 KM/SEC, 0 DEG.

0.19 CM
AL 6061-T6

0.19 CM
AL 2219T87

TOTAL A.D. 2.73

FIG. 2

1.2 CM AL
7 KM/SEC, 0 DEG.

0.19 CM
AL 6061-T6

0.32 CM
AL 6061-T6

0.48 CM
AL 2219T87

TOTAL A.D. 2.80
FIG. 4

FIG. 3
ENHANCED WHIPPLE SHIELD

BACKGROUND OF THE INVENTION

Protection from penetration of a wall by debris in space or particle impacts caused by collision of a particle in space with the wall of a space vehicle is a particular concern which must be addressed by designers of space vehicles. This is particularly true of manned vehicles or structures such as the space station. The parameters for protection against orbital debris or impact particles have been defined in terms of the critical diameter, velocity and impact angle relative to the bumper and disperse it in a spray form.

SUMMARY OF THE INVENTION

The present invention is a system for enhancing the protection capabilities of existing Whipple Shield structures against penetration by hypervelocity impact matter and for enabling greater protection capabilities for new Whipple Shield structures against penetration by hypervelocity impact matter at reduced structural weight and/or stand off (spacing) distances.

In the present invention, layered cloth elements are disposed and located intermediate of the outer bumper wall and the rearward wall. The layered cloth elements include a ceramic cloth disposed in a facing relationship to the bumper wall. “Ceramic cloth” is herein defined as a pliable material made by weaving, felting, embedding or knitting ceramic fibers, threads and/or filaments in to a fabric. “Ceramic” is defined herein as a material composed of metal oxides such as aluminum oxide, silicon dioxide, boron oxide and other metal oxides. The ceramic cloth provides an impact shock layer which has significant strength and flexibility at high temperatures for extended time periods. The purpose of the ceramic cloth is to shock and break up an incoming particle and disperse it in a spray form.
penetration of the ceramic cloth before impact with the low weight as defined herein is a fiber, thread and/or low weight fibers, threads and/or filament. “High strength/boron oxide and other metal oxides. The ceramic cloth disposed in facing relationship to the rear wall. Knitting ceramic fibers, threads and or filaments in to a filament having a specific strength greater than 9~10^5 inches (where specific strength=strength/density). The high strength cloth provides the capability to slow down or retard the impact particle which, at a given impact velocity, will just penetrate containment or rear wall. Reference can be made to FIG. 4 which illustrates a chart of specific strength of various materials. Materials suitable for the high strength cloth should have a specific strength of about 9x10^5 in. or more. “SPECTRA” cloth made by Allied Signal, Inc. of Petersburg, Va. is suitable. SPECTRA cloth is made from extended polyethylene fibers.

The layered MLI blanket, ceramic cloth and high strength cloth are flexible and tests have shown that the relative positioning between the bumper wall and the rear wall does not significantly offset the performance of penetration resistance although the blanket barrier structure is preferably not in contact with either of the walls for optimum performance. The ceramic cloth and high strength cloth are sometimes referred to herein as a blanket barrier.

With respect to FIG. 1, as an example of a practical application, a spacing “S” from the outer surface of the bumper wall to the inner surface of the containment or rear wall is 11.4 cm for a habitable module on a space station. The bumper wall thickness ranges from 0.127 cm to 0.19 cm and is A16061-T6 aluminum. The wall 12 (rear pressure wall) has a wall thickness ranging from 0.32 cm to 0.48 cm and is A12219-T87 aluminum. The ceramic cloth structure consists of six layers of woven threads of AF62 “NEXTEL” (“NEXTEL” is a trademark product available from 3M Ceramic Materials Department). The high strength cloth structure consists of six layers of woven threads of “KEVLAR” 710 (“KEVLAR” is a trademark product available from DuPont). “KEVLAR” style 710 is a dense maximum filling fabric made from 1500 denier KEVLAR 29. As designated in the drawing the areal density of the various components illustrated in FIG. 2 in g/cm^2 is as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Areal Density (g/cm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bumper wall</td>
<td>0.517</td>
</tr>
<tr>
<td>MLI</td>
<td>0.06</td>
</tr>
<tr>
<td>NEXTEL</td>
<td>0.600</td>
</tr>
<tr>
<td>KEVLAR</td>
<td>0.190</td>
</tr>
<tr>
<td>rear wall</td>
<td>1.361</td>
</tr>
</tbody>
</table>

The number of layers of ceramic cloth and high strength cloth or their thickness can vary according to the areal density desired. For example, the rear wall member (tw) can be selected so that the combined weight of the barrier blanket (mb) and the selected rear wall is less than or equal to the weight of a rear wall member with a greater thickness as required to protect an un-enhanced Whipple Shield.

To illustrate the significance of the present invention comparative tests were conducted with various other Whipple Shield configurations. The best configuration of other Whipple Shields in testing was a Whipple Shield as shown in FIG. 2 where an aluminum intermediate bumper wall 22 had a thickness of 0.32 cm and was disposed between the primary bumper wall and the rear wall 12. All other dimensions were similar to FIG. 1 and the total areal density was 2.80 g/cm^2 as compared to 2.728 g/cm^2 for the structure illustrated in FIG. 1.

Tests were conducted with light-gas guns and shaped charges with respect to the structures shown in FIG. 1 and FIG. 2 for an aluminum particle and the protection against penetration was plotted in terms of critical particle diameter as a function of impact velocity and impact angle as shown in FIG. 3. Critical particle diameter is the diameter of a particle which, at a given impact velocity, will just penetrate the containment wall 12. Particles with diameter less than the critical diameter will not penetrate through the containment.
d Particle diameter (cm)
d_0 Minimum particle diameter causing failure; i.e., "critical" particle that just results in complete penetration of the shield's rear wall or containment wall 12 of FIG. 1 (cm)
\( \delta \) Density (g/cc)
m Areal density (g/cm²)
\( \Theta \) Containment wall 12 yield stress (ksi)
t Thickness (cm)
\( \Theta \) Impact angle measured from surface normal (deg)
V Particle impact velocity (km/sec)

Subscripts:
b All bumpers and intermediate layers
\( \text{p} \) Particle
w Rear wall or Containment wall 12 of FIG. 1

With Equations 1 and 2, for a given size and material impact particle, velocity and impact angle, a Whipple Shield with a barrier blanket can be designed with the design parameters as desired. Conversely, for an given Whipple Shield incorporating the present invention, the protection afforded by the shield can be analyzed to determine its protection performance characteristics.

The design parameters for a Whipple Shield with a blanket barrier of the present invention can be defined for the intermediate velocity range in terms of a critical diameter and impact velocity for a given particle material by the following relationship:

**Intermediate Velocity Equation**

\[
2.7/(\cos \Theta)^{0.5} < V < 6.5/(\cos \Theta)^{0.5},
\]

then:

\[
d_0 = 1.031 \delta_\text{p}^{0.5} \left( \rho \cos \Theta \, \delta_\text{w} \right)^{0.5} \left( 6.5/(\cos \Theta)^{0.5} \right) + 0.321 \left( \rho \cos \Theta \, \delta_\text{w} \right)^{0.5} \left( (V - 2.7)/(\cos \Theta)^{0.5} \right) (6.5/(\cos \Theta)^{0.5} - 2.7/(\cos \Theta)^{0.5})
\]

where the parameter
S Overall spacing from the front of outer bumper to the back of rear wall (cm)

With Equations 3 and 4 for a given size and material impact particle, velocity and impact angle, the Whipple Shield can be designed with the desired design parameters for intermediate velocity projectiles. Conversely, a given Whipple Shield incorporating the present invention can be analyzed to determine its protection performance characteristics.

The design parameters for a Whipple Shield with a blanket barrier of the present invention can be defined for the high velocity range in terms of a critical diameter and impact velocity for a given particle material by the following relationship:

**High-Velocity Equation**

\[
V \geq 6.5/(\cos \Theta)^{0.5} \ldots
\]

then:

\[
d_0 = 0.6 \left( \rho \delta_\text{p} \right)^{0.5} \left( \cos \Theta \right)^{0.5} \left( \delta_\text{p} \right)^{0.5} \left( V \right) \ldots
\]

With Equations 5 and 6, for a given size and material impact particle, velocity and impact angle, the Whipple Shield can be designed with the desired design parameters for a high velocity projectile. Conversely, a given Whipple
Shield incorporating the present invention can be analyzed to determine its performance characteristics.

The present invention which provides an intermediate blanket barrier enhances the protection performance of existing Whipple Shields with relatively short standoffs or wall spacing. The blanket barrier has great protection effectiveness as compared to a solid-aluminum second bumper of equal mass per unit area as shown in FIG. 2. The ceramic cloth is more effective than an aluminum barrier at shocking and disrupting fragments of the impact object and the bumper wall. The high strength cloth has a greater strength to weight ratio than aluminum and provides superior capability to slow the expansion speed of the debris cloud before impact with the inner wall of the shield. The blanket barrier of the present invention also upon impacts produce short fibers of low density and low size that are less damaging to the container wall 12 in FIG. 1 as compared to large aluminum metal fragments produced by an aluminum barrier.

The data providing the basis for formulating ballistic limit equations 1–6 that define the maximum particle size that a blanket barrier Whipple Shield is capable of protecting against as a function of projectile velocity includes the various parameters noted above. These equations are useful for assessments of meteoroid/orbital debris penetration probability for spacecraft protected by the blanket barrier Whipple Shield. The equations are also useful to size shields for a given and/or desired protection level.

Tests using light-gas guns (LGG), shaped-charge launcher (SCL), and SNL hypervelocity launcher (HVL), all indicate that the barrier Whipple Shield provides better protection than an aluminum double-bumper shield of equivalent weight.

In the comparison of the ballistic limit curves for a double bumper shield and the present invention as given in FIG. 3, the data indicates that the aluminum double-bumper shield at a 45° impact angle will protect against a 0.98 cm particle at 7 km/sec (point 71) while the blanket barrier in a Whipple Shield can protect against a 1.54 cm aluminum projectile at the same impact conditions (point 41). This is a clear indication that the blanket barrier Whipple Shield scops particles with about 3 times greater mass than the aluminum shield 22 at these impact conditions.

In other tests, we have established that the rear wall of an aluminum shield was completely perforated by a 1 g shaped charge projectile at 11 km/sec and a 45° impact angle while the rear wall of a Whipple Shield having a blanket barrier was not penetrated by a 1.5 g SCL projectile (50% heavier). A shaped-charge particle diameter was calculated assuming a sphere with an equivalent mass to that measured for the cylindrically shaped-charge projectile. Shaped-charge data collected indicates the blanket barrier Whipple Shield ballistic limit curves are conservative at high velocities. In addition, tests on the all-aluminum shield of FIG. 2 failed the shield’s rear wall 12 while tests under similar impact conditions on the barrier Whipple Shield did not fail the rear wall 12. This relative performance advantage for blanket barrier in the Whipple Shields compared to all-aluminum barrier is shown in the comparison below.

<table>
<thead>
<tr>
<th>Shield Type</th>
<th>Impact Angle</th>
<th>Proj. Mass (g)</th>
<th>Proj. Velocity (km/sec)</th>
<th>Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-Al</td>
<td>0</td>
<td>0.84</td>
<td>11.03</td>
<td>Shield FAILED</td>
</tr>
</tbody>
</table>

Using ballistic limit equations for Whipple Shields and supporting data, a Whipple Shield would weigh about 2–3 times more than the barrier Whipple Shield of the present invention for protecting from a 1.4 cm diameter aluminum projectile at 7 km/sec with a 11 cm standoff.

The blanket barrier in the Whipple Shield of the present invention using fabric cloth blanket as the intermediate bumper (i.e., second bumper) represents an innovative, low-weight technique to provide protection when spacing is constrained (for example, when S/d<15 for V=6.5 km/sec & 0° normal impact).

The blanket barrier in a Whipple Shield provides better protection than double-aluminum bumper shields of equal weight (by stopping 50% to 300% more massive particles). Shield performance is improved (compared to aluminum) because ceramic fabric is better at shocking projectile fragments than aluminum, and high strength fabric is better at slowing debris cloud expansion than aluminum. In addition, the fragments of bumper materials within the debris cloud (“secondaries”) are smaller for cloth bumpers than aluminum, which results in less rear wall damage compared to the larger fragments produced by aluminum bumpers.

The ballistic limit equations 1–6 define performance of blanket barriers for Whipple Shield configurations and these equations are based on extensive test and analysis results. It will be apparent to those skilled in the art that various changes may be made in the invention without departing from the spirit and scope thereof and therefore the invention is not limited by that which is disclosed in the drawings and specifications but only as indicated in the appended claims.

We claim:

1. An enhanced hypervelocity Whipple Shield for protecting a wall member from penetration by impact particles having interrelated factors of velocity and critical diameter where a critical diameter is the minimum diameter of a particle which would just penetrate the wall member at a given density and velocity and impact angle, said shield comprising:

a wall member and a bumper wall member constructed from a selected metal material and respectively having a wall thickness and spacing from one another for dissipating the energy developed by a high velocity impact of a particle of a selected metal material where the particle has a first critical diameter and velocity and for preventing penetration of the wall member;
a flexible barrier blanket disposed intermediate of said bumper wall member and said wall member, said blanket barrier including a ceramic cloth facing said bumper wall member for shocking fragments of a particle penetrating said bumper wall member and having a high strength cloth facing said wall member for retarding the fragments penetrating said ceramic cloth whereby said Whipple Shield can withstand high velocity impact particles of said selected metal material.
at critical diameters and velocities greater than said first critical diameter and velocity; and wherein the critical diameter and velocity are interrelated for velocities less than 2.7/(\cos \Theta)^{0.5} by the following relationship of parameters

\[ d_c = 2.1 \left[ (a/(40)^{0.5} + 0.37 m_b) \left( \cos \Theta \right)^{-0.5} \right] \]

where the parameters are defined as follows:

- \( d_c \): Minimum particle diameter causing failure; i.e., "critical" particle that just results in complete penetration of the shield's rear wall (cm)
- \( \delta_c \): Density (g/cc)
- \( m_b \): Areal density (g/cm²)
- \( \Theta \): Impact angle measured from surface normal (deg)
- \( V \): Particle impact velocity (km/sec)
- \( S \): Overall spacing from the front of outer bumper to the back of rear wall (cm)

and where the Subscripts are:

- \( b \): All bumpers and intermediate layers
- \( p \): Particle
- \( w \): Rear wall.

3. An enhanced hypervelocity Whipple Shield for protecting a wall member from penetration by impact particles having interrelated factors of velocity and critical diameter where a critical diameter is the minimum diameter of a particle which would just penetrate the wall member at a given density and velocity and impact angle, said shield comprising:

- a wall member and a bumper wall member constructed from a selected metal material and respectively having a wall thickness and spacing from one another for dissipating the energy developed by a high velocity impact of a particle of a selected metal material where the particle has a first critical diameter and velocity and for preventing penetration of the wall member;
- a flexible barrier blanket disposed intermediate of said bumper wall member and said wall member, said blanket barrier including a ceramic cloth facing said bumper wall member for shocking fragments of a particle penetrating said bumper wall member and having a high strength cloth facing said wall member for retarding the fragments penetrating said ceramic cloth whereby said Whipple Shield can withstand high velocity impact particles of said selected metal material at critical diameters and velocities greater than said first critical diameter and velocity; and wherein the critical diameter and velocity are interrelated for velocities greater than 6.5/(\cos \Theta)^{0.5} by the following relationship of parameters

\[ d_c = 0.61 \left[ \delta_c \right]^{0.37} 2.7/(\cos \Theta)^{0.5} \]

where the parameters are defined as follows:

- \( d_c \): Minimum particle diameter causing failure; i.e., "critical" particle that just results in complete penetration of the shield's rear wall (cm)
- \( \delta_c \): Density (g/cc)
- \( m_b \): Areal density (g/cm²)
- \( \Theta \): Impact angle measured from surface normal (deg)
- \( V \): Particle impact velocity (km/sec)
- \( S \): Overall spacing from the front of outer bumper to the back of rear wall (cm)

and where the Subscripts are:

- \( b \): All bumpers and intermediate layers
- \( p \): Particle
- \( w \): Rear wall.
selecting a first critical diameter and velocity of a hypervelocity particle which should be prevented from penetrating the rear wall member of the enhanced Whipple Shield having a bumper wall spaced from the rear wall; selecting a wall thickness for the rear wall member and the bumper wall member for a selected metal material and defining the spacing from one another for dissipating the energy upon penetration of the bumper wall member and determining the critical diameter and velocity of a hypervelocity particle of a selected metal material which would penetrate the rear wall member of a basic (un-enhanced) Whipple Shield; constructing a flexible barrier blanket to be disposed intermediate of said bumper wall member and said rear wall member where said blanket barrier includes a ceramic cloth facing said bumper wall member for shocking fragments of a particle penetrating said bumper wall member and has a high strength cloth facing said rear wall member for retaining the fragments penetrating said ceramic cloth so that said enhanced Whipple Shield can withstand said first critical diameter and velocity of such hypervelocity particles; and disposing said blanked barrier intermediate of said bumper wall and said rear wall member.

5. The method as set forth in claim 4 wherein the critical diameter and velocity are interrelated for velocities less than $2.7/(\cos \Theta)^{0.5}$ by the following relationship of parameters $d_c = 0.6(t, 6, 5) - \tfrac{20}{\cos \Theta} - \sqrt{V/(6.5/(\cos \Theta)^{0.5})}$ where the parameters are defined as follows, $\delta_p$ Density (g/cc)

m Areal density (g/cm²)

$\sigma$ Rear wall yield stress (ksi)

$t$ Thickness (cm)

$\Theta$ Impact angle measured from surface normal (deg)

V Particle impact velocity (km/sec)

and where the Subscripts are:

b All bumpers and intermediate layers

p Particle

w Rear wall.

6. The method as set forth in claim 4 wherein the critical diameter and velocity are interrelated for velocities between $2.7/(\cos \Theta)^{0.5}$ and less than $6.5/(\cos \Theta)^{0.25}$ by the following relationship of parameters $d_c = 1.031 \delta_p^{0.25} \left[ t \delta_p (\cos \Theta)^{0.5} + 0.37 m_B (\cos \Theta)^{0.25} \{ 6.5/(\cos \Theta)^{0.25} \} - 1 \{ \sqrt{V/(6.5/(\cos \Theta)^{0.25})} - 2.7/(\cos \Theta)^{0.5} \} \right]^{0.5}$ where the parameters are defined as follows:

d Particle diameter (cm)

d_c Minimum particle diameter causing failure; i.e., “critical” particle that just results in complete penetration of the shield’s rear wall (cm)

$\delta_p$ Density (g/cc)

m Areal density (g/cm²)

$\sigma$ Rear wall yield stress (ksi)

$t$ Thickness (cm)

$\Theta$ Impact angle measured from surface normal (deg)

V Particle impact velocity (km/sec)

and where the Subscripts are:

b All bumpers and intermediate layers

p Particle

w Rear wall.

7. The method as set forth in claim 4 wherein the critical diameter and velocity are interrelated for velocities greater than $6.5/(\cos \Theta)^{0.25}$ by the following relationship of parameters $d_c = 0.6(t, 6, 5) - \tfrac{20}{\cos \Theta} - \sqrt{V/(6.5/(\cos \Theta)^{0.5})}$ where the parameters are defined as follows:

d Particle diameter (cm)

d_c Minimum particle diameter causing failure; i.e., “critical” particle that just results in complete penetration of the shield’s rear wall (cm)

$\delta_p$ Density (g/cc)

m Areal density (g/cm²)

$\sigma$ Rear wall yield stress (ksi)

$t$ Thickness (cm)

$\Theta$ Impact angle measured from surface normal (deg)

V Particle impact velocity (km/sec)

S Overall spacing from the front of outer bumper to the back of rear wall (cm)

and where the Subscripts are:

b All bumpers and intermediate layers

p Particle

w Rear wall.

8. A method for modifying a hypervelocity Whipple Shield to result in an enhanced Whipple Shield with the same or less shield weight to increase the resistance to penetration by impact particles having interrelated factors of velocity, impact angle and critical diameter where a critical diameter is the minimum particle diameter of a given particle material which would just penetrate a rear wall member at a given velocity and impact angle, said method comprising the steps of:

selecting a first critical diameter, velocity and impact angle of a hypervelocity particle which should be prevented from penetrating a rear wall member of an enhanced Whipple Shield which also has a bumper wall spaced from the rear wall member;

selecting a wall thickness for the rear wall member and the bumper wall member for selected metal materials and defining the spacing from one another for dissipating the energy upon penetration of the bumper wall member so that the said first critical diameter, velocity and impact angle of a hypervelocity particle of a selected metal material would just penetrate the rear wall member of this basic (un-enhanced) Whipple Shield;

constructing a flexible barrier blanket to be disposed intermediate of said bumper wall member and said rear wall member where said barrier blanket includes a ceramic cloth facing said bumper wall member for shocking fragments of a particle penetrating said
bump	ter wall member and has a high strength cloth facing said rear wall member for retarding the fragments penetrating said ceramic cloth; selecting a second reduced thickness for the rear wall member such that the combined weight of the said blanket barrier and the said second rear wall member is less than or equal to the weight of the first rear wall member, so that said enhanced Whipple Shield can withstand said first critical diameter, velocity and impact angle of such hypervelocity particles; and disposing said blanket barrier intermediate of said bumper wall member and said second rear wall member.

9. The method as set forth in claim 8 wherein the critical diameter and velocity are interrelated for velocities less than 2.7/\cos \theta \leq 0.35 by the following relationship of parameters:

\[ d_c = \frac{1}{2} \left( \frac{V}{6.5/\cos \theta} \right)^{0.3} \]

where the parameters are defined as follows:

- \( d \): Particle diameter (cm)
- \( d_c \): Minimum particle diameter causing failure; i.e., "critical" particle that just results in complete penetration of the shield's rear wall (cm)
- \( \delta \): Density (g/cc)
- \( m \): Areal density (g/cm²)
- \( \sigma \): Rear wall yield stress (ksi)
- \( t \): Thickness (cm)
- \( V \): Particle impact velocity (km/sec)
- \( \theta \): Impact angle measured from surface normal (deg)

wherein the critical 35

\[ V \leq 6.5/\cos \theta \]

10. The method as set forth in claim 8 wherein the critical diameter and velocity are interrelated for velocities greater than 2.7/\cos \theta \leq 6.5/\cos \theta \leq 2.7/\cos \theta \leq 0.35 by the following relationship of parameters:

\[ d_c = \frac{1}{2} \left( \frac{V}{6.5/\cos \theta} \right)^{0.3} \]

where the parameters are defined as follows:

- \( d \): Particle diameter (cm)
- \( d_c \): Minimum particle diameter causing failure; i.e., "critical" particle that just results in complete penetration of the shield's rear wall (cm)
- \( \delta \): Density (g/cc)
- \( m \): Areal density (g/cm²)
- \( \sigma \): Rear wall yield stress (ksi)
- \( t \): Thickness (cm)
- \( V \): Particle impact velocity (km/sec)
- \( \theta \): Impact angle measured from surface normal (deg)

11. The method as set forth in claim 8 wherein the critical diameter and velocity are interrelated for velocities greater than 6.5/\cos \theta \leq 2.7/\cos \theta \leq 0.35 by the following relationship of parameters:

\[ d_c = \frac{1}{2} \left( \frac{V}{6.5/\cos \theta} \right)^{0.3} \]

where the parameters are defined as follows:

- \( d \): Particle diameter (cm)
- \( d_c \): Minimum particle diameter causing failure; i.e., "critical" particle that just results in complete penetration of the shield's rear wall (cm)
- \( \delta \): Density (g/cc)
- \( m \): Areal density (g/cm²)
- \( \sigma \): Rear wall yield stress (ksi)
- \( t \): Thickness (cm)
- \( V \): Particle impact velocity (km/sec)
- \( \theta \): Impact angle measured from surface normal (deg)

12. An enhanced hypervelocity Whipple Shield for protecting a wall member in the enhanced Whipple Shield from penetration by impact particles having a velocity (\( v_p \)) and critical diameter (\( d_c \)) greater than a velocity (\( v_p \)) and critical diameter (\( d_c \)) at which impact particles would normally penetrate an unenhanced Whipple Shield, where such critical diameter (\( d_c \)) of such an impact particle is the minimum diameter of such particle which would just penetrate the wall member for a given density, velocity (\( v_p \)) and impact angle of such particle, said enhanced Whipple Shield comprising:

a. a rear wall member and a first bumper wall member constructed from selected metal materials and respectively having a wall thickness and spacing from one another for dissipating the energy developed by a high velocity impact of such particle of a selected material at said velocity (\( v_p \)) and critical diameter (\( d_c \));

b. a flexible barrier blanket disposed in the space intermediate of said bumper wall member and said rear wall member, said barrier blanket including a ceramic cloth which acts as a second bumper wall member and faces said first bumper wall member for shock absorbing the energy of such a particle penetrating said first bumper wall member, and said barrier blanket also having a high strength cloth facing said rear wall member for retarding the fragments penetrating said ceramic cloth whereby said enhanced Whipple Shield can withstand high velocity impact of such particles of such selected material at said velocities (\( v_p \)) and diameters (\( d_c \)) greater than the velocity (\( v_p \)) and diameters (\( d_c \)) without penetration of the rear wall member; and

c. said Whipple Shield having a ratio of the spacing between the rear member and the second bumper wall member to said critical diameter (\( d_c \)) of 15 or less.

13. The apparatus as set forth in claim 12 wherein said ceramic cloth is comprised of metal oxides having high impact resistance at high temperatures.

14. The apparatus as set forth in claim 12 wherein said high strength cloth is comprised of a pliable material which has a specific strength greater than 9x10⁶ inches.

15. The apparatus as set forth in claim 12 wherein said ceramic cloth is comprised of fibers of metal oxides having high impact resistance at high temperatures and said high strength cloth is comprised of a pliable material which has a specific strength greater than 9x10⁶ inches.
16. The apparatus as set forth in claim 15 wherein said ceramic cloth is aluminum oxide, silicon dioxide or boron dioxide.

17. The apparatus as set forth in claim 15 wherein said high strength cloth is made from Spectra\textsuperscript{TM} or Kevlar\textsuperscript{TM} fibers.

18. The apparatus as set forth in claim 15 wherein said ceramic cloth is comprised of fibers of aluminum oxide, silicon dioxide or boron dioxide and wherein said high strength cloth is comprised of fibers of Spectra\textsuperscript{TM} or Kevlar\textsuperscript{TM} material.

19. The apparatus as set forth in claim 15 wherein said ceramic cloth is comprised of fibers of aluminum oxide, silicon dioxide or boron dioxide and wherein said high strength cloth is comprised of fibers of Spectra\textsuperscript{TM} or Kevlar\textsuperscript{TM} material.

20. The apparatus as set forth in claim 12 wherein the layers of said ceramic cloth member are comprised of fibers of metal oxides having impact resistance at high temperatures and wherein the layers of said high strength cloth member are comprised of a pliable material which has a specific strength greater than 9\times10^6 inches.

21. The apparatus as set forth in claim 20 wherein said ceramic cloth member is comprised of fibers of aluminum oxide, silicon dioxide or boron dioxide and wherein said high strength cloth member is comprised of fibers of Spectra\textsuperscript{TM} or Kevlar\textsuperscript{TM} material.

22. A method for modifying a hypervelocity Whipple Shield to result in an enhanced Whipple Shield with the same or less shield weight to increase the resistance to penetration by impact particles having interrelated factors of velocity, impact angle and critical diameter, where a critical diameter is the minimum particle diameter of a given particle material which would just penetrate a rear wall member at a given velocity and impact angle, said method comprising the steps of:

- selecting a first critical diameter, velocity and impact angle of a hypervelocity particle which should be prevented from penetrating a first rear wall member of an enhanced Whipple Shield which has a bumper wall member at a location spaced from the first rear wall member;

- selecting a wall thickness for the first rear wall member and the bumper wall member for selected metal materials and defining the spacing from one another for dissipating the energy upon penetration of the bumper wall member so that said first critical diameter, velocity and impact angle of a hypervelocity particle of a selected metal material would just penetrate the first rear wall member of this unenhanced Whipple Shield;

- constructing a flexible barrier blanket to be disposed intermediate said bumper wall member and said first rear wall member where said barrier blanket includes a ceramic cloth member facing said bumper wall member for shocking fragments of a particle penetrating said bumper wall member, said ceramic cloth member being comprised of layers of woven fibers of metal oxides having impact resistance at high temperatures, said barrier blanket further including a high strength cloth member facing said rear wall member for retarding the fragments penetrating said ceramic cloth member, said high strength cloth member being comprised of layers of fibers which have a specific strength greater than 9\times10^6 inches;

- substituting a second rear wall with a reduced wall thickness relative to the first rear wall member such that the combined weight of said barrier blanket and said second rear wall member is less than or equal to the weight of said first rear wall member, so that said enhanced Whipple Shield can withstand said first critical diameter, velocity and impact angle of such hypervelocity particles; and

- disposing said barrier blanket intermediate of said bumper wall member and said substituted second rear wall member.

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