May 2, 1967 W. A. WEBB 3,316,718

HONEYCOMB STRUCTURED PROPELLANT FOR ROCKET MOTORS

Filed Jan. 13, 1965

3 Sheets-Sheet 1

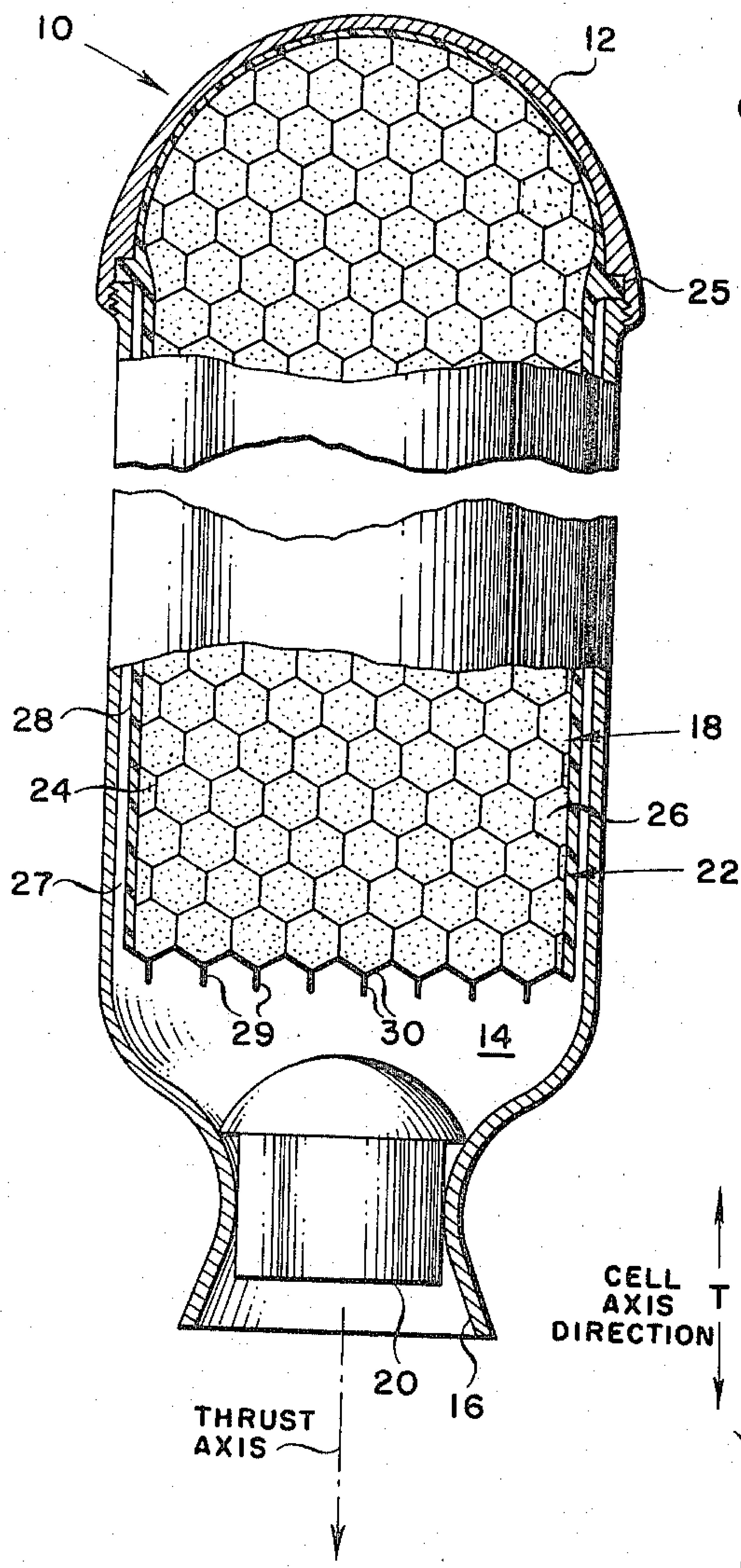

FIG. 2

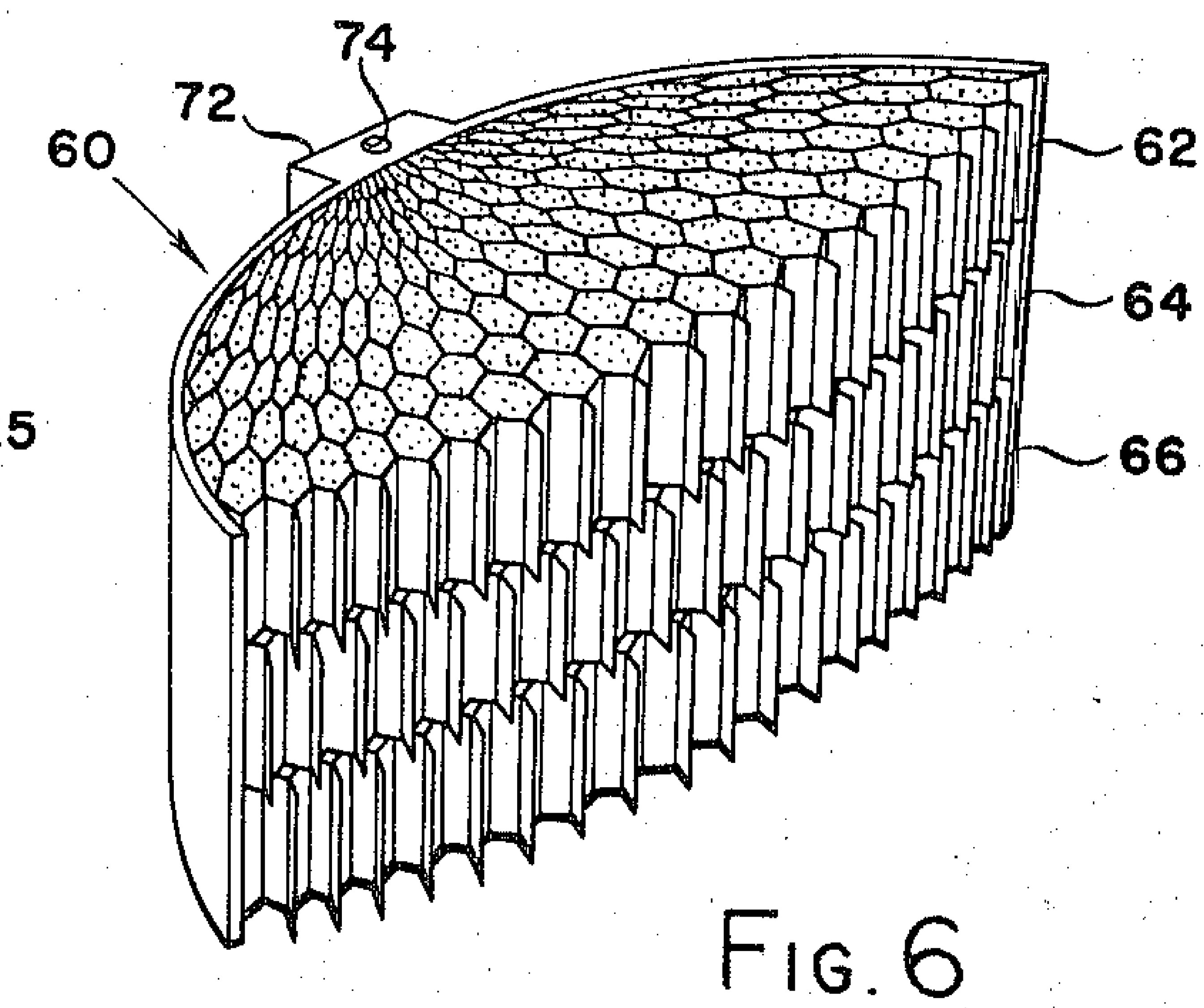

FIG. 6

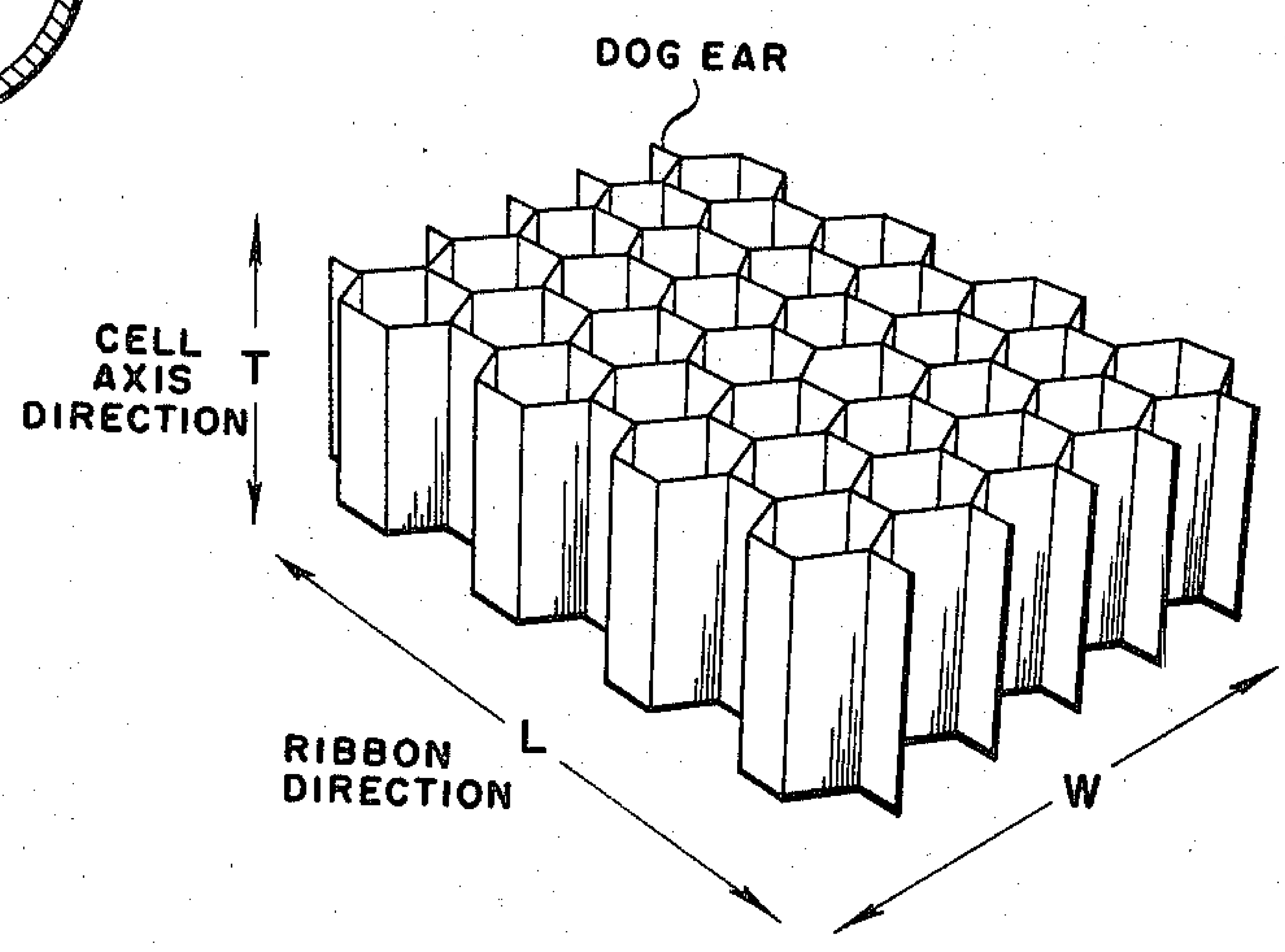

FIG. 1

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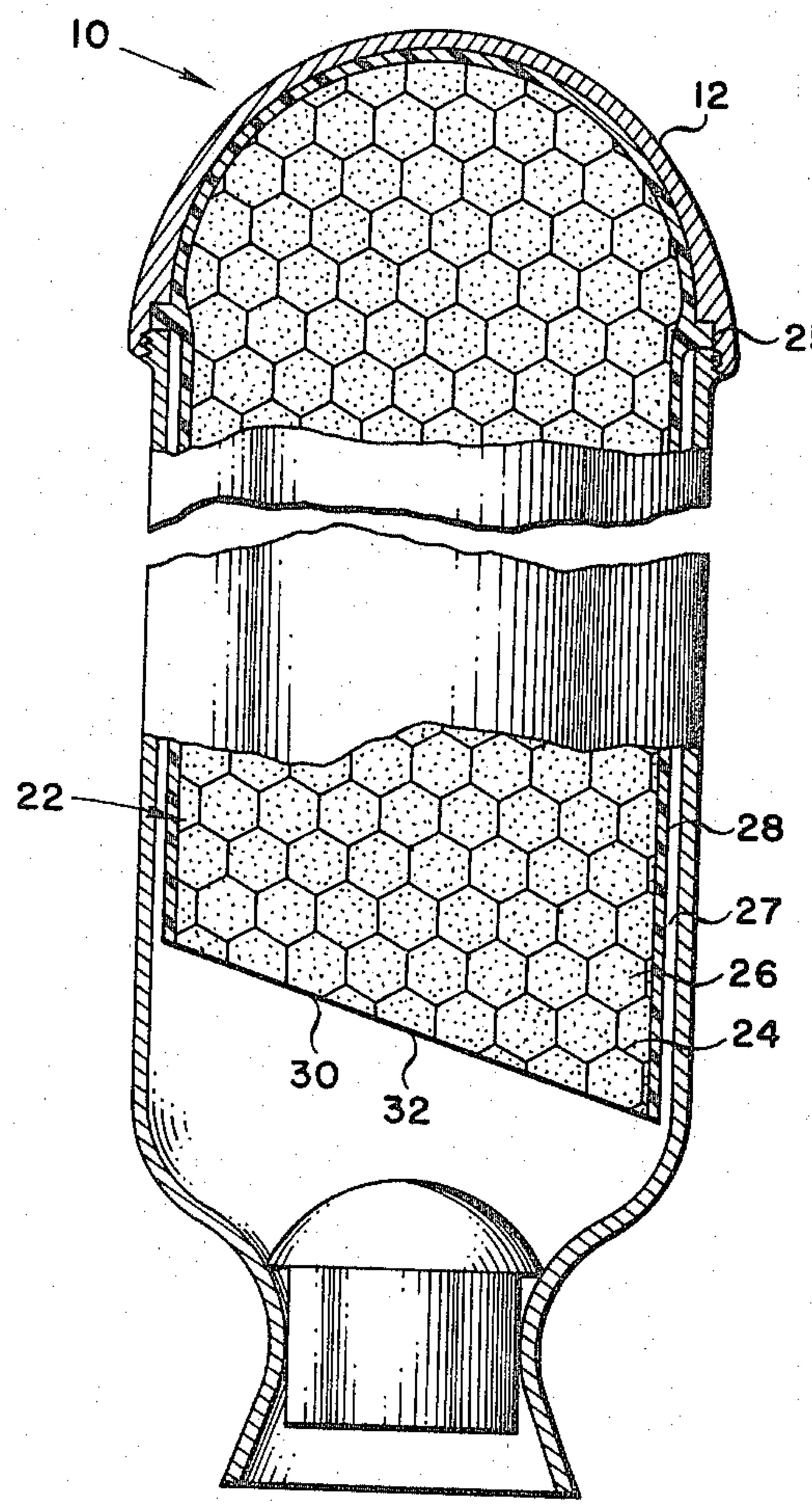

FIG. 3

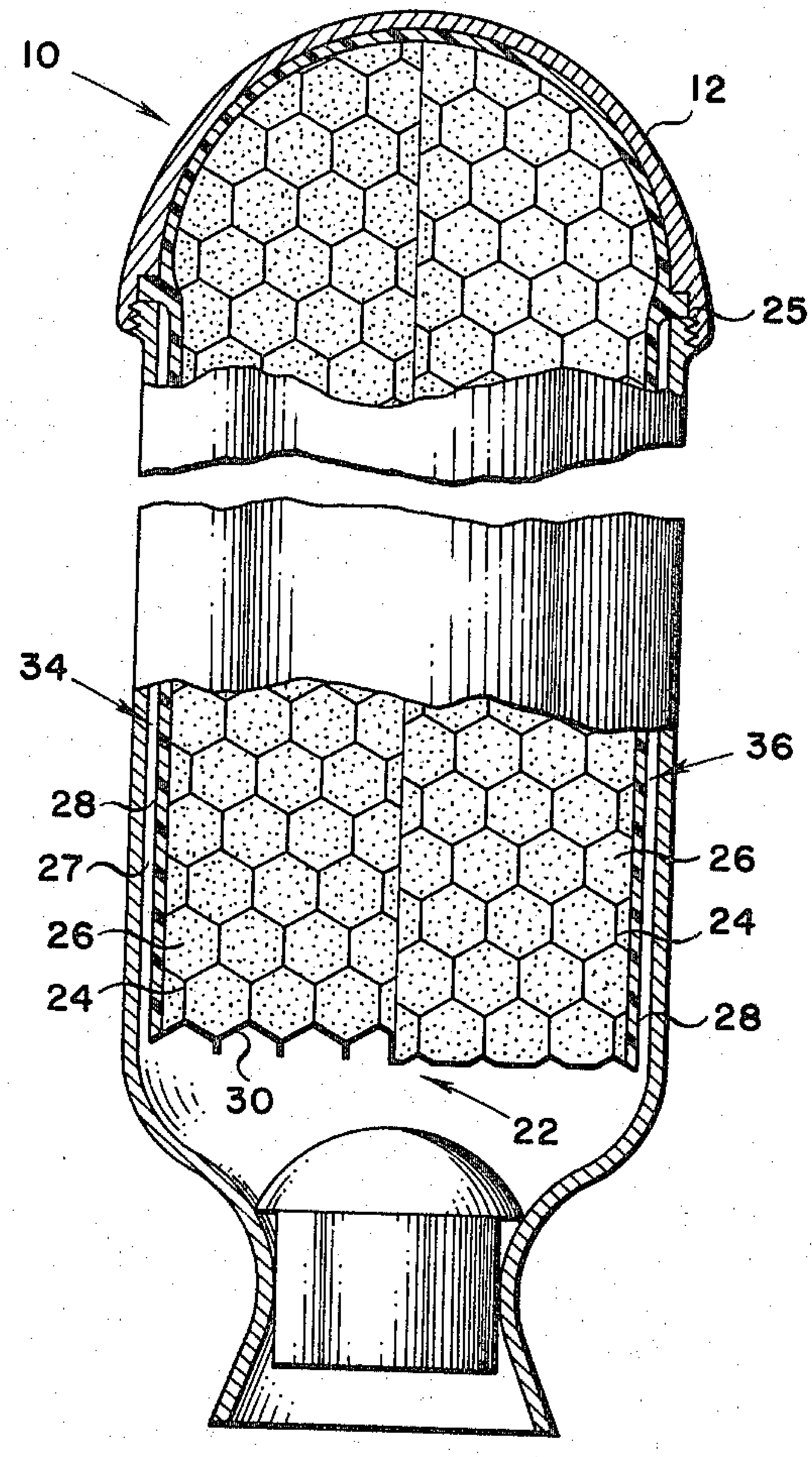

FIG. 4

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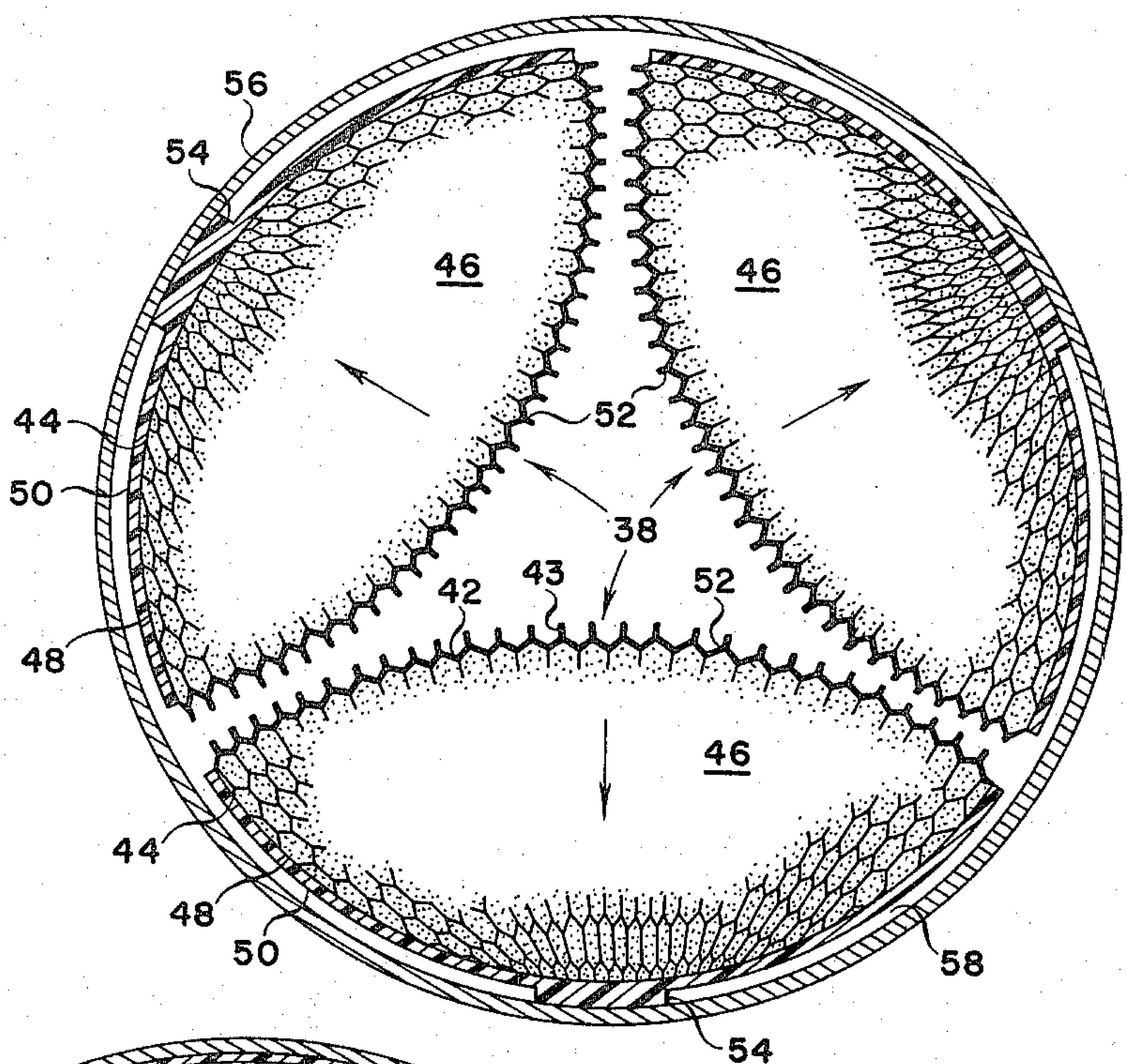
FIG. 5



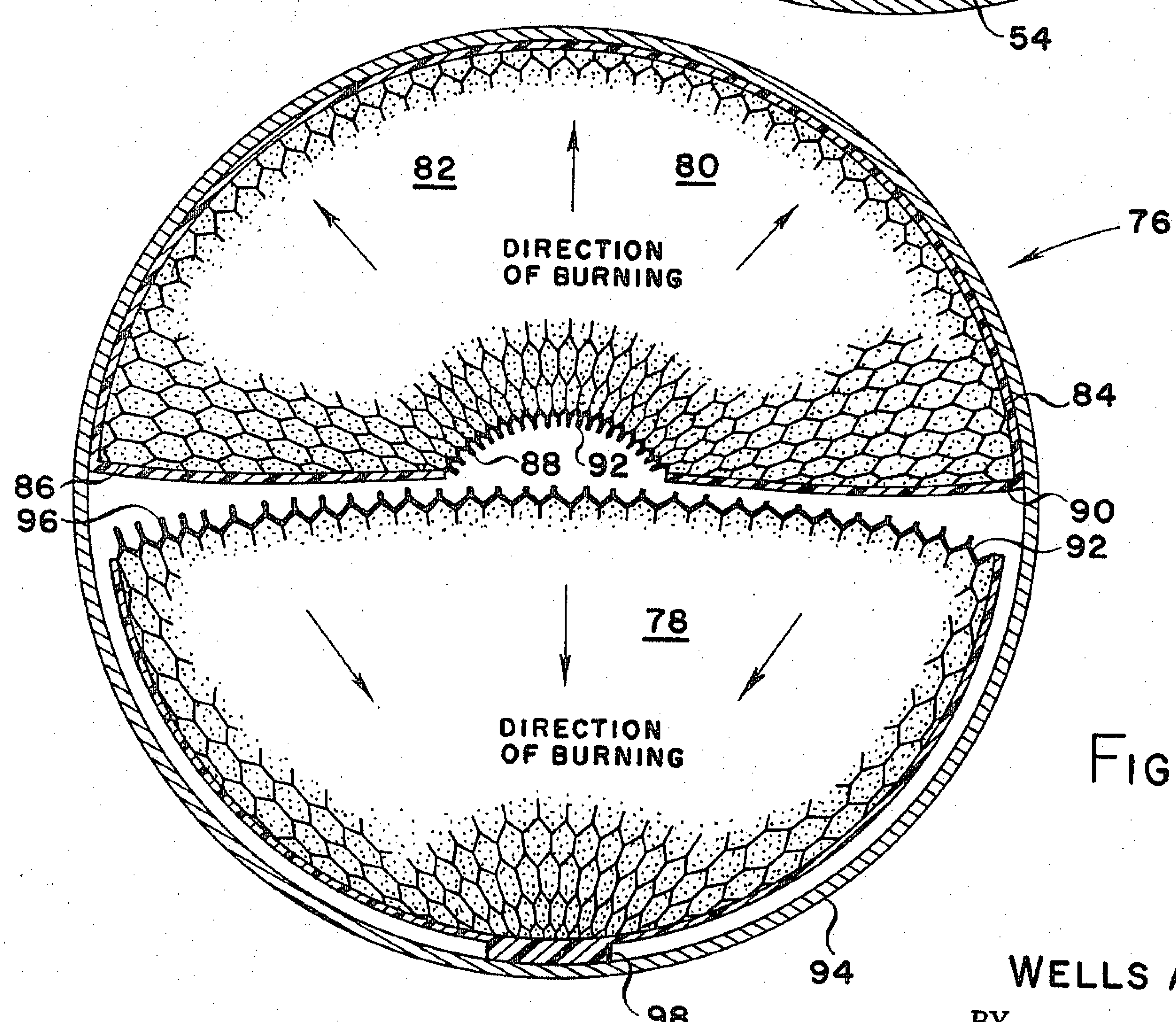


FIG. 7

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HONEYCOMB STRUCTURED PROPELLANT FOR ROCKET MOTORS

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11 Claims. (Cl. 60—255)

This invention relates to propellant grains for rocket motors, and more particularly to improvements in solid propellant grains which are reinforced with a honeycomb cellular structure.

Metal honeycomb cellular structures, or cores, have been previously proposed for use in end-burning, solid propellant grains to give better mechanical properties and to increase the burning rates of the grains. However, these proposals have not been entirely successful, and it has now been determined that the difficulties encountered were due in large measure to the cell orientation of the honeycomb core with respect to the combustion front, or burning surface. In the previous proposals, the cells were oriented so that the ribbons comprising the cell walls were perpendicular to the combustion front; i.e., the general direction of burning was in the direction of the cell axis, or T direction. Thus, if there should be a separation of the solid propellant from the cell wall in some localized area due perhaps to shrinkage of the propellant upon cure, the flame could advance down the gap ahead of the normal combustion front and cause uneven burning or, in some cases, failure of the rocket motor. The use of viscous liquid propellants prevented this kind of failure, but introduced other problems involving the control of the liquid in the honeycomb core which still remain to be solved.

Another difficulty of the previously proposed end-burning, solid-propellant grains which burned in the T direction was a low initial chamber pressure and a relatively slow buildup of such pressure due to the fact that the ignition surface was flat and consisted primarily of solid propellant. Upon ignition, there was a time lag before the flat propellant surface in each cell could be converted into a conical, or dentated surface characteristic of the steady state burning condition.

In accordance with the present invention, the previous problems have been overcome by orienting the honeycomb core so that burning takes place in the ribbon or L direction; i.e., the cell orientation has now been turned 90° from the previous proposals. Now, the solid fuel mass within each cell is completely surrounded by the cell walls, and the advancing flame must first consume the overlying cell wall portions before the underlying solid fuel mass can be burned. Any cracks or gaps which might develop in the fuel are now confined to a single layer or row of cells, and there is no possibility that the flame can advance prematurely through the entire grain.

The present cell orientation also produces a quicker buildup of chamber pressure by providing for initial exposure of the honeycomb cell walls and dog ears. These are cleaned of propellant and then coated with a special igniter composition. Because of the higher heat conductivity of the metal surfaces initially exposed, there is very little time lag between the ignition stage and the steady state burning stage, the latter being characterized by a corrugated burning surface.

Also, as in the previous proposals, it has been found that the present mode of cell orientation gives the same advantages of reinforcement of the solid fuel and of increased burning rate. Generally, the present grains burn at about three times the rate of burning of the same propellant without the honeycomb core.

These advantages and other features of the present invention will be further described in detail in conjunction with the accompanying drawings wherein:

FIGURE 1 is a perspective, schematic view of a portion of a honeycomb core, illustrating core nomenclature and directions;

FIGURE 2 is a fragmentary, schematic, sectional view of a rocket motor containing an end burning propellant grain of the present invention;

FIGURE 3 is a fragmentary, schematic, sectional view of a rocket motor containing another end burning propellant grain of the present invention, said grain having a truncated ignition surface;

FIGURE 4 is a fragmentary, schematic, sectional view of a rocket motor containing another end burning propellant grain of the present invention;

FIGURE 5 is a sectional view of an internal burning, segmented propellant grain of the present invention;

FIGURE 6 is a perspective view of a segment of another internal burning, segmented propellant grain of the present invention, showing the honeycomb core pieces comprising the segment in staggered relationship; and

FIGURE 7 is an end view of still another internal burning, segmented propellant grain of the present invention.

FIGURE 2 shows a rocket motor **10** with a forward or head end **12**, a generally cylindrical combustion chamber, or case, **14**, and an exhaust nozzle **16**. Case **14** contains an end burning solid propellant grain **18** of the present invention. Grain **18** may be ignited at the aft end by any conventional means, such as an electrically-actuated squib **20**, and produces combustion gases which are discharged through nozzle **16** to propel the motor forward in well known manner.

Grain **18** is prepared for loading into motor **10** by machining a honeycomb core **22**, preferably aluminum, into cylindrical shape with the cell walls, or ribbons **24**, running in the direction of burning and with the cells being ⅔ expanded or fully expanded depending on whether propellant **26** is a soft cure material or an uncured material. Propellant **26** is cast into the cells under vacuum and then cured. A combustion inhibiting liner **28** is then applied on the cylindrical and head end surfaces and cured. Such a liner may be comprised of multiple coats of any suitable combustion inhibitor such as one containing 30% by weight epoxy adhesive, 68% polyamid, and 2% carbon black. The aft, or ignition, surface is cleaned of all propellant **26**, and the exposed cell walls and dog ears **29** are coated with a suitable igniter composition **30**, such as one containing 60 parts by weight magnesium powder, 25 parts potassium perchlorate, 15 parts barium nitrate, and 5 parts polyisobutylene binder in a volatile vehicle such as petroleum ether. The grain thus prepared is then loaded into the motor as a free-standing structure, with the cell axis perpendicular to the thrust axis.

The free-standing grain may be fastened to the motor by any suitable means, such as that shown in FIGURE 2 wherein an annular flange **25** is provided on liner **28**. Flange **25** is adapted to be held in clamped relationship between the case **14** and the head end **12**, the latter being screwed onto the case. As is known, the free standing structure allows for a gap **27** between the case and the grain. The gap permits small movements of the grain due to thermal expansion and contraction, thereby relieving any stresses which may be set up in the grain. The gap is pressurized with static gases when the motor is fired.

Aluminum alloy 5052 or some other alloy containing from about ½% to 5% magnesium is preferred for the honeycomb core because of the higher burning efficiencies obtained. Aluminum alloys without magnesium may also be used, but the burning efficiencies are lower. The burning efficiency is also dependent upon the thickness or gauge of the honeycomb foil material. Generally, as thin a gauge as possible, consistent with strength requirements, is selected, with gauges in the range of 0.9 to 2 mils being preferred.

Propellant **26** may be any propellant having a viscosity which is now enough to permit flow into the honeycomb cells. Generally, the viscosity of such a propellant will be below 200,000 centipoises, with viscosities in the range of 40,000 to 140,000 centipoises being preferred. Typical examples of such propellants contain a solid oxidizing salt, such as ammonium perchlorate crystals, as a major component and a polymerizable organic compound, such as polysulfide, polyurethane, and polybutadiene, as a minor component.

Examples of specific propellant formulations suitable for use in the present invention are shown below:

EXAMPLE I

Ingredient:	Percent by weight
Polybutadiene	7
Aluminum powder	13
Aluminum perchlorate	69
Polyester plasticizer	8
Epoxy resin	1
Burning rate catalyst	2
	100

EXAMPLE II

Ingredient:	Percent by weight
Ball powder (nitrocellulose-nitroglycerine)	15
Nitrate esters	32
Aluminum powder	17
Ammonium perchlorate	26
Ethyl centralite	0.5
Resorcinol	0.5
Cyclotetramethylene tetranitramine	9
	100

Test strands made of the propellant shown in Example I above burned at the rate of 1 inch per second at a pressure of 1,000 pounds per square inch, producing a pressure exponent, n, equal to 0.29 in the burning rate equation:

$$r=Cp^n$$

where r is the burning rate, C is a function of the grain temperature, and p is chamber pressure. When the same propellant was cast into a honeycomb core, the burning rate increased to 3 inches per second at 1,000 pounds per square inch and the pressure exponent dropped to 0.20, showing that the honeycomb core produces an accelerated burning rate and a greater safety and stability of chamber pressure. The threefold increase in apparent burning rate is accounted for by the fact that the steady state burning surface is corrugated and has approximately three times the area of surface found in the conventional grains without honeycomb.

It has been found that the combustion time versus chamber pressure curve for grain **18** of FIGURE 2 shows regularly occurring undulations in pressure which apparently result from the burning through of overlying cell walls in successive cell layers. In applications requiring a smoother pressure curve, grain **18** may be modified as shown in FIGURE 3 by providing for an inclined, planar ignition surface **32**. Here, the fact that the burning front advances at an angle to the longitudinal axis of the rocket motor assures that the overlying cell walls in the successive cell layers are burned through at different times, thus smoothing out the chamber pressure.

The same effect of smoothing out the pressure curve may be obtained by modifying the grain as shown in FIGURE 4. Here, the cylindrical core of FIGURE 2 has been divided longitudinally and the respective halves

34, 36 have been bonded together with the cells staggered or offset approximately one-half of the cell length. With this core structure, the burning through of successive cell layers in the two halves is out of phase with each other and a smoother pressure curve is obtained.

FIGURE 5 shows a typical end section of an internal, or central, burning propellant grain comprised of three longitudinal segments **38**, each having opposing convex surfaces **42, 44** and the general configuration shown in FIGURE 6. These segments are made by fan-wise expansion of the honeycomb core **46** with the cell ribbons running generally in the direction of burning, as shown. After shaping to form the convex surface **44**, segments **38** are filled with a suitable solid propellant **48** in the same manner as described for grain **18**. Multiple coats of a suitable burning inhibitor **50** are then applied to surface **44** and to the end surfaces (not shown) of the grain. Surface **42** including dog ears **43** is cleaned of propellant and a suitable igniter composition **52** is applied thereto and cured. Segments **38** are then bonded longitudinally along a central portion **54** to a sleeve **56**, as shown in FIGURE 5. Sleeve **56** thus assembled is adapted to be nested within combustion chamber **14**. Or alternatively, central portion **54** may be bonded directly to the motor case, thus eliminating sleeve **56**.

Burning of segments **38** starts on the surface **42**, progresses in the L direction, and terminates at the bonded portions **54**. The gap **58** between sleeve **56** and the unbonded portions of surface **44** allows for the relief of thermal stresses during combustion, and the inhibitor **50** applied on surface **44** assures that the flames do not reach the propellant until substantially all of the segment is burned in the L direction.

It has been determined from the combustion time versus chamber pressure curve made with this segmented grain that there are regularly occurring undulations in the pressure, apparently due to the simultaneous combustion through the overlying cell walls in successive layers of honeycomb cells. To smooth out these undulations, the individual segments may be modified in the manner shown in FIGURE 6. Here, the individual segments are made up of segment pieces **62, 64, 66**, each of whose cell walls are staggered with respect to the walls of the adjacent piece. This can be done by providing a tab **72** on each segment piece and drilling a hole **74** through the tab after aligning the pieces in staggered relationship. For final assembly of the pieces, a rod (not shown) can be inserted in the hole and then the pieces can be bonded together by stringing them on the rod. Tab **72** is then cut off and the composite segment **60** can then be filled with propellant and treated in the same manner as previously described for segment **38**.

The previously described internal burning propellant grains burn regressively; that is, the combustion chamber pressure decreases as the time of burning increases. This type of burning is due to the fact that burning fronts become progressively smaller and thus less gas is produced with increasing time.

In contrast to the above internal burning grains, segmented grain **76** shown in FIGURE 7 provides a grain having a substantially neutral burning curve. Segment **78** is made in the same manner as segment **38** in FIGURE 5 and has substantially the same characteristics as segment **38**. Segment **80** is made by expanding the honeycomb core **82** fanwise so as to describe a semi-cylindrical surface **84** and a slightly concave surface **86** with a central depression, or concave portion **88**. After filling core **82** will propellant, surfaces **84** and **86** are coated with a suitable burning inhibitor **90** and surface **88** is coated with a suitable igniter composition **92**. Segment **80** is then bonded along semi-cylindrical surface **84** to a sleeve **94** in opposing relationship to segment **78**. Sleeve **94** is adapted to be fitted into combustion chamber **14**.

Upon ignition, segment **78** burns initially on the relatively large surface **96**, and the combustion front becomes progressively smaller as it advances toward the bonded area **98**. On the other hand, segment **80** burns initially on the relatively small surface **88**, and its combustion front becomes progressively larger. The combination of these two segments, **78** with a regressive burning curve and **80** with a progressive burning curve, results in a composite grain with a substantially neutral burning curve.

While various embodiments of the present invention have been specifically described, other variations will be apparent to those skilled in the art, and it is to be understood that the scope of the present invention is to be limited only by the appended claims.

I claim:

1. A rocket motor comprising: a combustion chamber; an end-burning solid propellant grain in said chamber; a cellular structure in the form of a honeycomb for supporting and reinforcing the grain, said structure being so disposed in the grain that the cell axes are perpendicular to the general direction of burning of said grain.

2. A rocket motor comprising: a substantially cylindrical combustion chamber; an end-burning solid propellant grain in said chamber; a cellular structure in the form of a honeycomb for supporting and reinforcing the grain, said structure being so disposed in the grain that the cell axes are substantially perpendicular to the general direction of burning of said grain and to the combustion chamber wall, said grain having an inclined, planar ignition surface so that ignition and end-burning takes place simultaneously across several rows of the honeycomb cells.

3. A rocket motor comprising: a substantially cylindrical combustion chamber; an end-burning solid propellant grain in said chamber, said grain being comprised of semi-cylindrical half-portions bonded together, each of said portions being supported and reinforced by a cellular structure in the form of a honeycomb, said structures being disposed in each portion so that the cell axes are substantially perpendicular to the general direction of burning of said grain and said structures in each portion being disposed with relation to each other so that the respective cells are offset.

4. An end-burning solid propellant grain for a rocket motor comprising: a cylindrical metal honeycomb core having its cell axes perpendicular to the general direction of burning, said core being constituted of semi-cylindrical half-portions bonded together in such manner that the cells in one half-portion are offset with respect to the cells in the other half-portion; a solid propellant contained within said core to comprise said grain; a burning inhibitor on the cylindrical and forward surfaces of said grain; and an igniter composition on the aft surface of said grain.

5. A rocket motor comprising: a substantially cylindrical combustion chamber; a sleeve member nesting within said chamber; a plurality of internal burning propellant grain segments disposed longitudinally in said chamber; each of said segments having opposing convex surfaces, the first of said surfaces being bonded along a central portion thereof to the sleeve member, the second of said convex surfaces forming a central port; and each of said segments being reinforced with honeycomb cellular structures which are expanded fan-wise from the central portion of said first surface and in such manner that the cell ribbons are disposed in the general direction of burning.

6. A rocket motor according to claim **5**, wherein the second convex surfaces are coated with an ignition composition and the unbonded portions of the first convex surfaces are coated with a burning inhibitor.

7. A rocket motor according to claim **5**, wherein the respective segments are formed by a series of separate sections, each section having the walls of the honeycomb cellular structure in staggered relationship to the walls of the cellular structure in the immediately adjacent sections.

8. A rocket motor comprising: a combustion chamber; a plurality of internal burning propellant grain segments disposed longitudinally in said chamber; each of said segments having opposing convex surfaces, the first of said surfaces being bonded along a central portion thereof to the combustion chamber wall, the second of said surfaces forming a central port; and each of said segments being reinforced with honeycomb cellular structures which are expanded fan-wise from the central portion of said first surface and in such manner that the cell ribbons are disposed in the general direction of burning.

9. A rocket motor according to claim **8**, wherein the second convex surfaces are coated with an ignition composition and the unbonded portions of the first convex surfaces are coated with a burning inhibitor.

10. A rocket motor according to claim **8**, wherein the respective segments are formed by a series of separate sections, each section having the walls of the honeycomb cellular structure in staggered relationship to the walls of the cellular structure in the immediately adjacent sections.

11. A rocket motor comprising: a substantially cylindrical combustion chamber; a sleeve member nesting within said chamber; a segmented, internal burning solid propellant grain having first and second segments each reinforced with a honeycomb core and disposed in the sleeve member in opposing relationship; said honeycomb cores having the cell ribbons running in the general direction of burning; said first segment having a generally semi-cylindrical surface bonded to the sleeve member and an opposing generally concave surface with a central, longitudinal depression therein; said second segment having opposing first and second convex surfaces, said first convex surface having a curvature approximating the curvature of the sleeve member and being bonded to the sleeve member along a central, longitudinal portion; an igniter composition applied to the longitudinal depression of the first segment and to the second convex surface of the second segment; and a combustion inhibitor applied to the unbonded portion of the first convex surface of the second segment, to the generally concave surface of the first segment, and to the semi-cylindrical surface of the first segment prior to bonding to the sleeve member.

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CARLTON R. CROYLE, *Primary Examiner.*