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Massie

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[54] HYBRID ROCKET

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[52] **U.S. Cl.** **60/251,** 60/254
[51] **Int. Cl.** **F02k 9/06**
[58] **Field of Search**.................................60/251, 254

[56] **References Cited**

UNITED STATES PATENTS

3,325,998	6/1967	Novotny	60/251
3,142,152	7/1964	Sessums, Jr.	60/251
3,177,657	4/1965	Strauss et al.	60/251
3,274,771	9/1966	Lieberman et al.	60/251
3,097,481	7/1963	Silver	60/254

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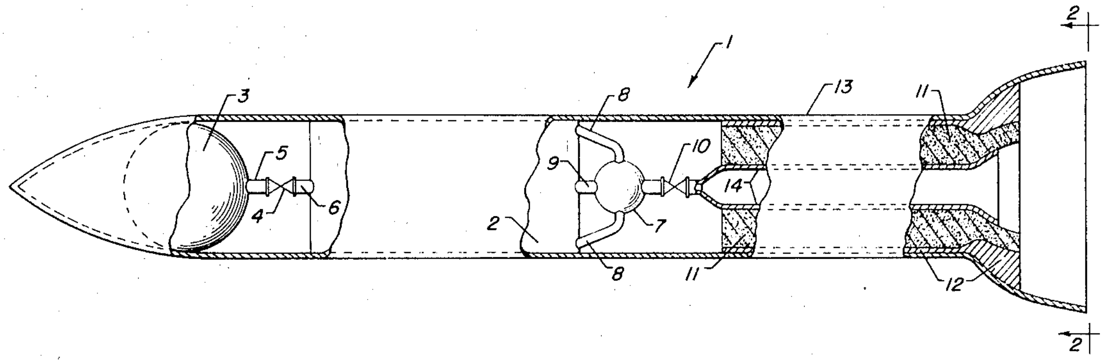
[57] **ABSTRACT**

An improved hybrid rocket, wherein a tube for conducting liquid oxidizer to a solid fuel charge passes through the solid fuel charge and is constructed so as to structurally disintegrate when subjected to the heat produced by the reaction of the solid fuel and liquid oxidizer. Disintegration of the tube proceeds at approximately the same axial rate as does consumption of the solid fuel during operation of the rocket. As a result, the liquid oxidizer is continually supplied to the appropriate location in the solid fuel charge so as to increase the uniformity and thoroughness of burning. The burn time of the rocket may thereby be extended and the thrust may be varied by utilizing a tube of varied cross section and varied wall thickness.

5 Claims, 5 Drawing Figures



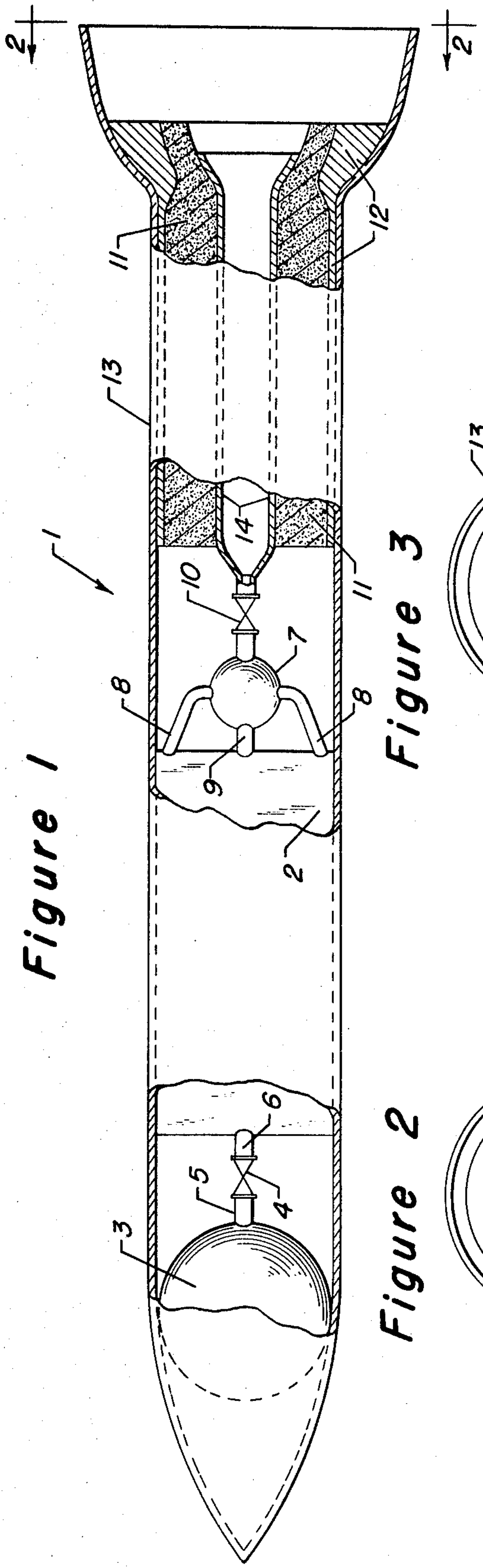


Figure 1

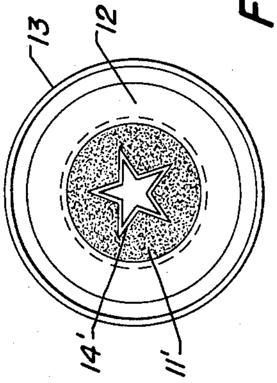


Figure 3

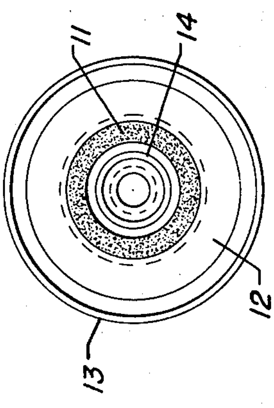


Figure 2

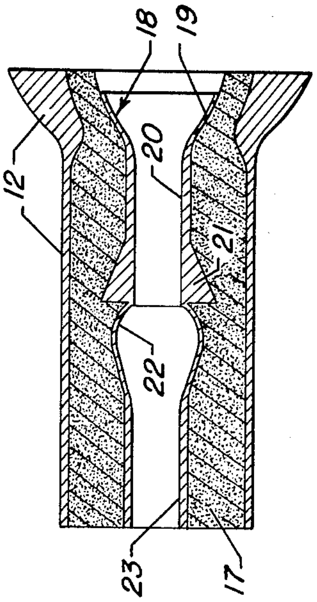


Figure 5

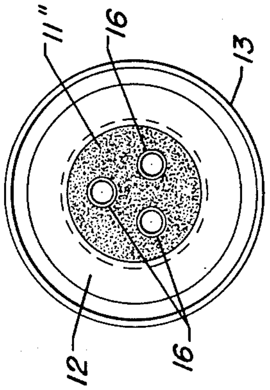


Figure 4

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HYBRID ROCKET

This invention relates to an improved hybrid rocket. More particularly, the invention involves a tube for conducting liquid oxidizer to a solid fuel charge which passes through the solid fuel charge and is constructed so as to structurally disintegrate when subjected to the heat produced by the reaction of the solid fuel and liquid oxidizer. Disintegration of the tube proceeds at approximately the same axial rate as does consumption of the solid fuel during operation of the rocket. As a result, the liquid oxidizer is continually supplied to the appropriate location in the solid fuel charge so as to increase the uniformity and thoroughness of burning. The burn time of the rocket may thereby be extended and the thrust may be varied by utilizing a tube of varied cross section and varied wall thickness.

A principal disadvantage of hybrid and solid fuel rockets, as compared with liquid fuel rockets, is that rockets operating on solid fuel tend to be somewhat unpredictable and unreliable in operation. This unpredictability is due primarily to the uncontrolled burning in the rocket engine which occurs once the rocket fuel has been ignited. Conventional rockets having a solid fuel utilize either a solid or a liquid oxidizer to sustain combustion of the fuel. A rocket using a solid oxidizer and a solid fuel is a true solid fuel rocket. A rocket utilizing a solid fuel with a liquid oxidizer is commonly termed a hybrid rocket. While hybrid rockets may be controlled in flight more accurately than true solid fuel rockets by regulating the supply of oxidizer to the solid fuel, the degree of control attainable is insufficient to render this type of rocket at all predictable in operation when compared with a liquid fuel rocket. The reason that solid fuel rockets are unpredictable in operation is that once the solid fuel is ignited, there is no control over irregularities in burning in the rocket except through regulation of the quantity of oxidizer supplied in a hybrid rocket. Erratic and unpredictable thrust occurs because of the different burning patterns that occur in the solid fuel as influenced by a multitude of uncontrollable conditions. For example, intense burning at one point in the fuel charge may structurally isolate an unburned portion of the solid fuel charge to the extent that it becomes dislodged and is carried out of the exhaust of the rocket without having been consumed in combustion. Similarly, uneven burning of the rocket fuel may result in channeling so that liquid oxidizer supplied to the solid fuel is channeled away from unburned portions of the fuel and is discharged from the rocket exhaust without having reacted with the solid fuel. Various attempts have been made to overcome these problems, but none has heretofore proved successful enough to render solid fuel rockets sufficiently predictable in operation.

It is an object of the present invention to increase the thoroughness of burning of the solid fuel in a hybrid fuel rocket. This is accomplished by sustaining combustion at the downstream portion of the solid fuel charge and by preventing premature ignition upstream from the rocket exhaust. Premature burning causes portions of unburned solid fuel to become structurally isolated from the solid fuel charge and from the fuel case, whereupon the unburned solid fuel is dislodged and carried off in the exhaust. This problem commonly exists in solid fuel charges which burn radially outward, that is, outward toward the fuel case and the rocket shell.

Another object of this invention is to increase the degree of control exerted over the burning of the solid fuel in the rocket during flight, and thereby allow the performance of hybrid rockets to be stabilized by proper design. This maintenance of control after ignition is exerted by establishing a high level of uniformity in the burning of the fuel by preventing premature contact of the oxidizer with the solid fuel. The oxidizer is supplied to specific locations within the solid fuel at specific moments during the time of rocket operation, as predetermined during the rocket construction. Erratic burning patterns in portions of the solid fuel charge are thereby prevented from achieving a cumulative effect to cause significant deviations from the predicted flight pattern or other motion pattern in rockets which are not designed for flight. Control of the effects of isolated combustion irregularities promotes the stability and predictability of the operation of the rocket during flight.

In a broad aspect, this invention is, in a hybrid rocket utilizing a solid fuel and a liquid oxidizer for propulsion, the improvement comprising a solid fuel charge encompassing at least one tube means parallel to the rocket axis through which oxidizer is conducted to said solid fuel charge and which is structurally unstable when subjected to the heat produced by the reaction of said solid fuel and said liquid oxidizer, whereby disintegration of said tube means proceeds at approximately the same axial rate as does consumption of said solid fuel during the operation of said rocket. The term axial rate refers to the rates at which the zone of disintegration of the tubes means and the zone of fuel combustion advance from the exhaust section of the rocket toward the rocket nose.

The construction of the rocket of this invention allows the tube means through which oxidizer is supplied to the solid fuel to disintegrate at an axial rate approximately equal to the axial rate of fuel consumption so that the point of oxidizer-fuel contact is at the downstream extremity of the unburned fuel charge. This prevents the oxidizer from prematurely reacting with the fuel upstream in the rocket engine, thereby isolating portions of fuel and causing it to be ejected unburned. By the same token, oxidizer is not injected too far downstream from where it would be ejected without having reacted with the fuel.

In one preferred form of the invention, a single tube is aligned with the rocket axis to serve as the tube means. For ease and economy of construction, the solid fuel charge is molded about the tube during the manufacture of the rocket. In one preferred embodiment of this invention, the tube has a star-shaped cross-sectional configuration. While this configuration is normally associated with radial burning solid fuel rockets, it is useful in this invention because radial burning does take place throughout the relatively short distance that exists between the downstream tube end and the downstream extremity of the fuel charge.

In a refinement of this invention, the cross-sectional area occupied by the tube varies, thereby influencing the rate of fuel consumption which, in turn, affects the rocket thrust. Similarly, the thickness of the tube wall may be varied along the tube axis in order to influence the rate of fuel consumption. By varying either the tube cross section or wall thickness, the rocket may be constructed so as to predictably accelerate and decelerate at predetermined intermediate times during the rocket flight. It should be pointed out that at any given location along the tube axis, the tube wall is uniform.

One very important determination which must be made in the construction of the tube of this invention is the determination of compatible substances to be used for the solid fuel, the oxidizer, and the oxidizer supply tube means. While it is important that this determination be made, there is no lack of workable combinations of fuel, oxidizer, and tube structural materials. Some of the conventional liquid oxidizer-solid fuel hybrid propellant systems include: chlorine trifluoride-lithium hydride; chlorine trifluoride-lithium; nitrogen tetroxide-beryllium hydride; hydrogen peroxide-beryllium hydride; fluorine-beryllium hydride; oxygen-beryllium hydride; and fluorine-aluminum hydride. Other possible liquid oxidizers in hybrid rockets include: difluoroamine, trifluoroamine, and oxygen difluoride.

Stainless steel, Monel, and nickel are all compatible with those propellant systems utilizing chlorine trifluoride as an oxidizer. The term Monel includes several nickel alloys, all comprising about **66** percent nickel, about **0.12** to **0.18** percent carbon, about **0.60** to **0.90** percent manganese, about **1.00** to about **1.35** percent iron, about **0.15** percent silicon, about **29.5** to **31.5** percent copper, and in some instances small proportions of sulfur, aluminum, or titanium. Pure aluminum is known to be a good container for hydrogen peroxide and dry fluorine may be safely handled in nickel and Monel, since a protective fluoride film quickly develops. Dry nitrogen tetroxide can be used with nickel, aluminum, stainless steel, Inconel, and carbon steel. Inconel includes nickel alloys containing anywhere from about **32** to about **76** percent nickel, about **0.04** percent carbon, about **0.20** to **0.75** percent manganese, from **6.75** to **46** percent iron, from **0.20** to **0.35** percent silicon, from **0.10** to **0.30** percent copper, from **15** to **20.5** percent chromium, and in some instances small quantities of aluminum, titanium, molybdenum, or columbium. Oxygen difluoride can be used with those structural materials compatible with chlorine trifluoride. Difluoroamine and trifluoroamine can be used with borosilicate glass, polyethylene, polypropylene, or those structural materials compatible with chlorine trifluoride.

Specific combinations of oxidizers, solid fuels, and tube structural materials include:

chlorine trifluoride-lithium hydride-Monel tube,
nitrogen tetroxide-beryllium hydride-carbon steel tube,
hydrogen peroxide-beryllium hydride-aluminum tube,
oxygen-beryllium hydride-glass tube, and
fluorine-aluminum hydride-nickel tube. These examples are not meant to be inclusive, as other substances may also be used as long as the oxidizer and the solid fuel are suitable as a propellant system for a hybrid rocket, and as long as the tube is constructed of a material which is unstable when subjected to the heat produced by the reaction of the liquid oxidizer with the solid fuel. That is, as long as the heat generated by the reaction of the oxidizer and solid fuel is sufficient to melt, disintegrate, or otherwise decompose the structural material of which the tube is constructed. The tube should be of a material which disintegrates slightly upstream along the rocket axis from the zone where the most intense combustion occurs. In this manner, oxidizer is supplied to the solid fuel at or just upstream from the fuel currently being consumed in combustion at any given time. The combustion of the solid fuel follows the disintegrating end of the tube as both proceed axially upstream throughout the length of the solid fuel charge. The axial rate of combustion and decomposition must be approximately equal. If the tube disintegrates too readily, that is, if the tube disintegrates well upstream from the zone of combustion at a given point in time, premature contact between the oxidizer and upstream sections of the solid fuel charge will occur. Conversely, if the heat from the reaction of the oxidizer with the solid fuel does not cause the tube to disintegrate until combustion is occurring right at the tube end, the oxidizer will be supplied downstream from the portion of the solid fuel charge which is to be ignited next. This will result in an unnecessary consumption of liquid oxidizer and an incomplete combustion of the solid fuel which will cause a portion of the thrust potential of the rocket to go unrealized.

This invention may be further illustrated in the accompanying drawings in which:

FIG. **1** is a side view of one embodiment of the improved rocket of this invention partially broken away and in partial section.

FIG. **2** is an end view of FIG. **1** of the rocket exhaust along the lines **2—2**.

FIG. **3** is an alternate embodiment of the rocket exhaust of FIG. **2**.

FIG. **4** is an alternate embodiment of the rocket exhaust of FIG. **2**.

FIG. **5** is an alternative embodiment of a portion of the rocket engine of this invention.

Referring now to FIG. **1** there is shown a simple rocket **1**. Rocket **1** is made up of three general sections, namely, a forward section containing a pressurizing gas storage tank **3** at the left end of FIG. **1**, a central section containing the liquid oxidizer storage tank **2**, and a rocket engine and exhaust section containing the solid fuel charge **11** and the single conducting tube **14** of the tube means of this invention. Tube **14** conducts liquid oxidizer to the solid fuel charge **11** from the oxidizer storage tank **2** while rocket **1** is in flight.

The tank **3** contains a suitable pressurizing gas, such as helium, under relatively high pressure. This gas is conducted by a conduit **5** through a valve **4** and another conduit **6** to the adjacent end of oxidizer tank **2**. When the valve **4** is opened, gas under pressure pressurizes the liquid oxidizer in tank **2**. From oxidizer tank **2** there is a central conduit **9** and peripheral conduits **8** which lead to a chamber **7**. Within conduits **8** and **9** are rupture disks which retain the oxidizer within tank **2** before launch. Upon pressurization of tank **2**, however, the disks in conduits **8** and **9** are ruptured, whereupon liquid oxidizer flows through conduits **8** and **9** into chamber **7** and through control valve **10** toward the tube **14** and the solid fuel combustion charge **11**. Since the pressurizing tank **3**, the oxidizer tank **2**, and the related conduits and valves are conventional, they need not be described in detail herein.

The oxidizer is conducted from the oxidizer tank 2 to the solid fuel via tube **14**. Tube **14** is a single tube axially aligned with the rocket **2** and constructed of a material which is structurally unstable when subjected to the heat produced by the reaction of the solid fuel and the liquid oxidizer. When combustion of the solid fuel occurs, that portion of tube **14** in the vicinity of the combustion area disintegrates. For some oxidizer-fuel combinations, ignition occurs spontaneously upon contact of the oxidizer with the fuel. Other oxidizer fuel combinations require a conventional ignition means to initiate combustion. Such an ignition means is not illustrated in the drawings. Disintegration of the tube **14** proceeds at approximately the same axial rate as does consumption of the solid fuel charge **11** during the operation of the rocket. Tube **14** disintegrates slightly upstream (toward the left along the axis of rocket **1**) from the point of most intense combustion at any given time. The disintegration of tube **14** thereby precedes the most intense zone of combustion in the solid fuel charge **11** axially upstream at a relatively short and a relatively fixed axial distance. Since the oxidizer is able to contact the solid fuel charge **11** in that area in which the tube **14** has disintegrated, the liquid oxidizer is supplied to the solid fuel charge **11** just upstream from where existing combustion is taking place. This results in a steady uniform fuel consumption from the rear of the solid fuel charge **11** in exhaust section **15** towards the front of the solid fuel charge **11** adjacent the valve **10**. The oxidizer from tank **2** is prevented from prematurely contacting the solid fuel charge **11** because of the separation provided between the oxidizer and the solid fuel by the wall of tube **14**.

As is conventional, the solid fuel charge **11** is molded within a resin impregnated fiberglass wound fuel case **12**. Prior to molding, however, the tube **14** is axially positioned within the engine case **12**. The solid fuel is thereby molded uniformly about the tube **14** within the rocket engine case **12**.

Referring now to FIG. **3**, there is shown an alternative embodiment of the tube means of this invention. In FIG. **3**, the tube means is a single tube **14'** constructed with a star-shaped cross-sectional configuration. This configuration assists in maintaining a uniform radial burn rate once the solid fuel has been ignited downstream from the end of the disintegrating tube means **14'**. The solid fuel charge **11'** of FIG. **3** is molded within rocket engine case **12** and is positioned within the rocket shell **13** in exactly the same manner as is the solid fuel charge **11** of FIG. **2**. The same is true of the solid fuel charge **11''** of FIG. **4**. In FIG. **4**, however, the tube means of this invention is comprised of three individual tubes **16**. Tubes **16** are parallel to the rocket axis, but none of the tubes **16** is axially aligned with the rocket axis. That is, none of the tubes has an axis which is aligned with or coincides with the rocket axis. The various cross-sectional configurations of the solid fuel charges in FIGS. **2**, **3**, and **4**, are given for purposes of illustrating the conventional configurations, and are not intended to be restrictive as to the scope of this invention.

FIG. **5** illustrates a specialized modification of the tube means and solid fuel charge of this invention. The tube means of FIG. **5** is unique in that the cross-sectional area occupied by the tube **18** varies along the tube axis as does the thickness of the tube wall. These variations influence the rate of fuel consumption in the rocket and make possible predictable periods of acceleration and deceleration before the total consumption of the fuel charge **17**. The extreme downstream portion **19** of the tube **18** is constructed with a very thin tube wall. Upon the initial ignition of the fuel charge **17**, this extreme downstream portion **19** of the tube **18** will rapidly disintegrate, thereby exposing a substantial area of the fuel charge **17** to the oxidizer coming from the upstream portion of the tube **18**. After the extreme downstream portion **19** of tube **18** has disintegrated, the rate of fuel combustion decreases somewhat because of the thickened walls of the portion **20** of the tube **18**. The thicker walls of portion **20** require greater heat for total disintegration, so that the distance along the rocket axis between the downstream edge of the tube **18** and the zone of most intense combustion of the fuel charge **17** is much shorter than it was after initial fuel ignition. The result is that less fuel is exposed to the liquid oxidizer than was the case when the rocket was first ignited so that the combustion rate and the rocket thrust are decreased. As the combustion proceeds upstream, the thick-walled portion **20** gives way to a portion **21** of the tube **18** having still thicker walls. As the area of most intense combustion in fuel charge **17** reaches the vicinity of the portion **21** of tube **18**, the increased thickness of the tube walls at portion **21** slows disintegration of the tube in this area until the zone of most intense combustion of the fuel charge **17** is practically in the same general plane perpendicular to the rocket axis as is the downstream extremity of the tube **18**. During this portion of the rocket flight, the fuel consumption is minimal and the rocket will decelerate due to the forces of gravity and air friction. Once past this thickened portion **21**, however, the thickness of the tube walls abruptly decreases and the cross-sectional area of the tube **18** widens at the portion **22** of tube **18**. The increased cross-sectional area and the thin tube walls causes the rate of consumption of the fuel charge **17** to markedly increase, since there is greater timely contact of the oxidizer with the unburned fuel. During the time the fuel charge **17** is being consumed in the vicinity of portion **22** of tube means **18**, the rocket will accelerate due to the increased fuel consumption. At portion **23** of tube **18**, the tube walls again thicken and the cross-sectional area occupied by the tube decreases, thereby decreasing the rate of fuel consumption. This transition is quite similar to the transition that occurred when the portion **19** of tube **18** had disintegrated and the slower more time consuming disintegration of portion **20** of tube means **18** was begun.

It is to be understood that the foregoing descriptions of several of the embodiments of this invention are intended to be illustrative only, and that numerous conventional alterations in the rocket design can be made without departing from the spirit of the invention as defined in the claims.

I claim as my invention:

1. A hybrid rocket utilizing a solid fuel and a liquid oxidizer for propulsion comprising a solid fuel charge encompassing at least one tube means, the thickness of said tube means wall varying along the tube means axis, said tube means being disposed parallel to the rocket axis through which tube means oxidizer is conducted to said solid fuel charge and which tube means is structurally unstable when subjected to the heat produced by the reaction of said solid fuel and said liquid oxidizer, whereby disintegration of said tube means proceeds at approximately the same axial rate as does consumption of said solid fuel during the operation of said rocket.

2. The rocket of claim **1** further characterized in that said liquid oxidizer is chlorine trifluoride, said solid fuel is lithium hydride, and the aforesaid tube means is constructed of Monel.

3. The rocket of claim **1** further characterized in that said liquid oxidizer is hydrogen peroxide, said solid fuel is beryllium hydride, and the aforesaid tube means is constructed of glass.

4. The rocket of claim **1** further characterized in that said liquid oxidizer is fluorine, said solid fuel is aluminum hydride, and the aforesaid tube means is constructed of nickel.

5. A hybrid rocket utilizing a solid fuel and a liquid oxidizer for propulsion comprising a solid fuel charge encompassing at least one tube means parallel to the rocket axis, the major portion of said tube means having a star-shaped cross-sectional configuration, through which tube means oxidizer is conducted to said fuel charge and which tube means is structurally unstable when subjected to the heat produced by the reaction of said solid fuel and said liquid oxidizer, whereby disintegration of said tube means proceeds at approximately the same axial rate as does consumption of said solid fuel during the operation of said rocket.

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