Aug. 23, 1966 J. E. LINDBERG, JR 3,267,856

NOSE-CONE COOLING OF SPACE VEHICLES

Original Filed April 5, 1962 2 Sheets-Sheet 1

FIG. 1

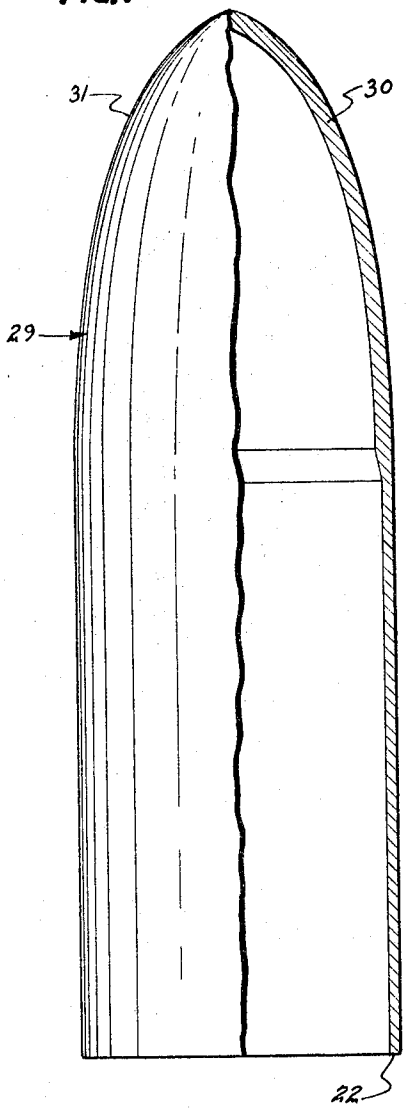
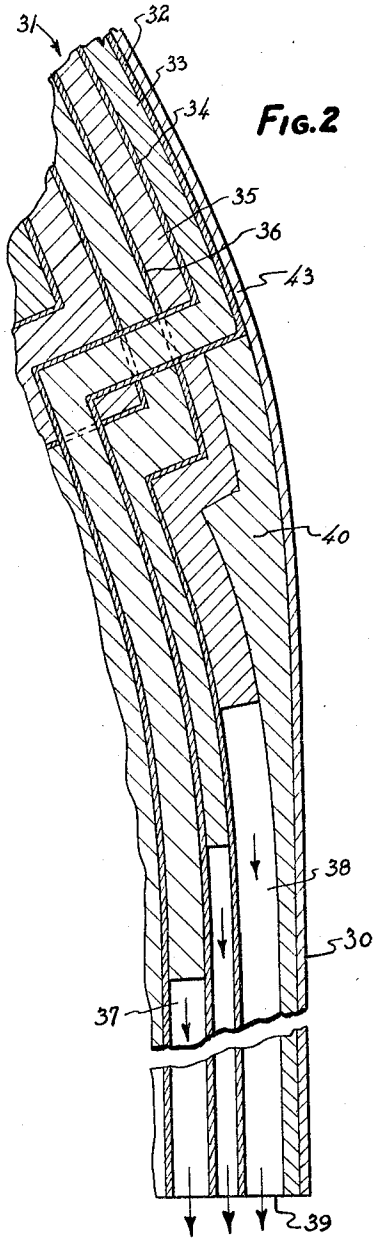


FIG. 2



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NOSE-CONE COOLING OF SPACE VEHICLES

Original Filed April 5, 1962 2 Sheets-Sheet 2

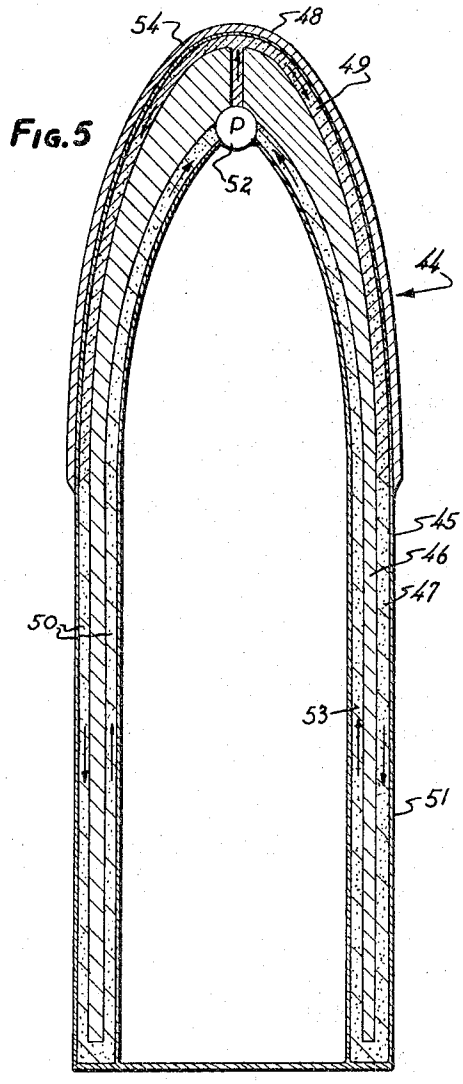


FIG. 5

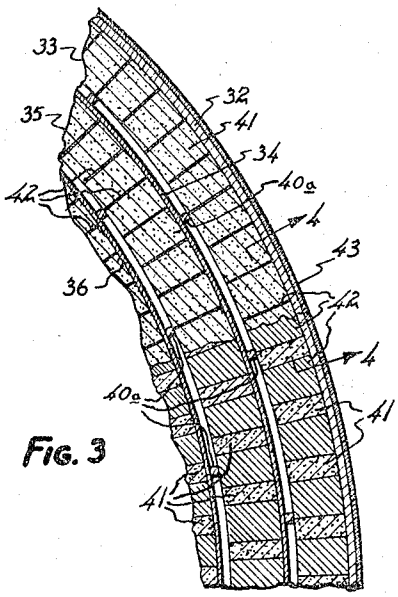


FIG. 3

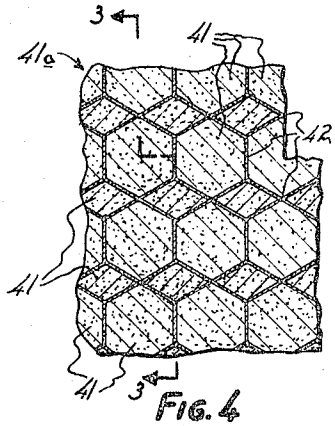


FIG. 4

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3,267,856

NOSE-CONE COOLING OF SPACE VEHICLES

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Original application Apr. 5, 1962, Ser. No. 186,600. Divided and this application Aug. 12, 1964, Ser. No. 389,103

1 Claim. (Cl. 102—92.5)

This invention relates to the nose-cone cooling of space vehicles including missiles and more particularly to missiles whose nose structures incorporate means for dissipating heat therefrom. This application is a division of application Serial No. 186,600, filed April 5, 1962, which is a continuation-in-part of application Serial No. 725,110, filed March 31, 1958, now abandoned.

It is well known that an object entering the earth's atmosphere at even moderate speed is heated considerably by the attendant aerodynamic conditions at the surface of the object. Such heating occurs when vehicles re-enter the atmosphere and is a serious problem, forcing drastic limitations on the maximum re-entry speed which a structure of given design can attain without being severely damaged or even destroyed. This heat is primarily developed and is largely concentrated at the nose.

An important object of the present invention is to efficiently dissipate the heat developed at the nose. By achieving this object, the invention makes it possible to use higher re-entry speeds and therefore gives greater freedom in missile design and increases the missile's ability to avoid interception.

Another object of this invention is to provide a missile structure wherein the heat developed at the nose surface is carried to other parts of the missile and dissipated there, thereby lowering the nose temperature.

Other objects and advantages of the invention will appear from the following detailed description of some preferred embodiments thereof.

In the drawings:

FIG. 1 is a view in elevation and half in section of the shell of the forward portion of a missile.

FIG. 2 is a greatly enlarged fragmentary view in elevation and in section of a portion of the shell of FIG. 1 showing incorporation therein of one form of the present invention.

FIG. 3 is a further enlarged fragmentary view of a portion of FIG. 2 showing one type of lamination structure suitable for use in the shell of FIG. 2.

FIG. 4 is a fragmentary view in section taken along the line 4—4 in FIG. 3.

FIG. 5 is a view in elevation and in section of pertinent portions of another missile, showing a different shell structure embodying a modified form of the invention.

In order to illustrate the invention more clearly, the figures have been made somewhat diagrammatic in form and do not show the contents within the shell since the undesirable heat is developed at the shell and must be dissipated therefrom. The invention is independent of the contents of the vehicle itself.

As an illustrative example of a space vehicle to which this invention applies, a missile **29** is shown in FIG. 1, which indicates the general form of its shell **30**. Referring next to FIG. 2, it will be noted that the nose portion **31** of the shell **30** may be laminated to provide layers **32**, **34**, and **36**, for example, of a suitable heat-conducting metal with alternate layers of heat-dissociable material **33** and **35** sandwiched therebetween. The metal layers **32**, **34**, and **36** are preferably between 0.005" and 0.050" thick, while the layers **33** and **35** may be between about 0.05" and 1.0" thick. Although only five layers **32**, **33**, **34**, **35**, and **36** are shown in the drawings, by way of example, the laminated shell **30** in the nose region **31** typically has dozens of such laminations.

The heat-dissociable material may be comprised of hydrides of the so-called getter metals. These hydrides, as explained in my copending application Serial No. 695,357, filed November 8, 1957, now Patent No. 3,075,-361, are valuable heat-transfer agents, because the metallic hydride is dissociated into metal and hydrogen in an endothermic reaction, absorbing a large amount of heat per unit weight and per unit volume, as illustrated in Tables I and II below.

TABLE I

Thermodynamic properties of typical alkaline and alkaline earth hydrides

Hydride	Heat of dissociation in gram-calories per gram of compound	Heat of dissociation in gram-calories per cubic centimeter of compound	Latent heat of fusion of the metal in calories per cubic centimeter	Latent heat of vaporization of the metal in calories per cubic centimeter	Specific heat of the metal in calories per cubic centimeter per ° C. near 20° C.
LiH	2,720	2,230	53	2,590	0.418
NaH	571	788	26	9,850	0.29
KH	339	492	13	426	0.15
CaH_2	1,070	2,030	80	1,490	0.23
SrH_2	426	1,382	67	1,070	0.46
BaH_2	294	1,238	47	1,080	0.08

TABLE II

Thermodynamic properties of typical Group B hydrides

Hydride	Heat of dissociation in gram-calories per gram of compound	Heat of dissociation in gram-calories per cubic centimeter of compound	Latent heat of fusion of the metal in calories per cubic centimeter	Latent heat of vaporization of the metal in calories per cubic centimeter	Specific heat of the metal in calories per cubic centimeter per ° C. near 20° C.
$TiH_{1.75}$	634	2,480	471	10,050	0.62
$ZrH_{1.92}$	418	2,275	392	10,150	0.45
$PdH_{0.59}$	237	255	456	12,400	0.70

Certain metals such as copper, tungsten, iron, and nickel which form hydrides of the class known as group A (others are listed in my referred-to patent application Serial No. 695,357) are suitable for use when combined with group B hydrides. The formation of a group A hydride is endothermic, and, since the dissociation of a group B hydride is also endothermic, the combination of a type A metal with a group B hydride will absorb heat as the temperature of the surrounding medium is elevated. Some properties of type A hydrides are listed in Table III.

TABLE III

Thermodynamic properties of typical hydrides of Group A materials

Hydride	Heat of formation in gram-calories per gram of compound	Heat of formation in gram-calories per cubic centimeter of compound	Latent Heat of fusion of the metal in calories per cubic centimeter	Latent heat of vaporization of the metal in calories per cubic centimeter	Specific heat of the metal in calories per cubic centimeter per ° C. near 20° C.
NiH_2	97.2	684	641	12,500	0.93
CuH	79.3	506	438	11,200	0.81

Suitable hydrides include the stoichiometric hydrides of the alkali and alkaline earth metals and the nonstoichiometric getter hydrides, some of which are listed above in Tables I and II. The stoichiometric metallic hydrides are those of lithium, sodium, potassium rubidium, cesium, francium, calcium, strontium, barium, and radium, all of which are suitable for this invention, except that some of them are currently expensive. Beryllium and magnesium form stoichiometric hydrides that decompose at low temperatures (beryllium hydride at about 125° C. and magnesium hydride at about 280° C. to 300° C.). Suitable nonstoichiometric hydrides, members of group B, are those of scandium, titanium, vanadium, ytterbium, zirconium, niobium, hafnium, tantalum, the rare-earth metals (atomic numbers 57–71), and the actinides (atomic numbers 89–103), though many of these are currently expensive and difficult to obtain in quantity.

Also useful are the borohydrides—compounds of metals with the borohydride radical BH_4. Examples are the borohydrides of aluminum, beryllium (decomposes at 123° C.), lithium (decomposes at 275° C.), sodium, zirconium, etc. Of course, for most applications, some of these are much more useful than others while still others are impractical in some situations. The selection can be made to accommodate the desired operating conditions.

Alloys of hydrides are also useful, including alloys of alkaline or alkaline earth hydrides alone, alloys of the nonstoichiometric hydrides, alloys comprised of members of each group, and alloys of or with borohydrides therewith. Hereafter the generic term type "B" hydride shall be used to designate the alkaline earth and alkaline hydrides as well as the group B nonstoichiometric getter hydrides.

In additions to the endothermic processes described previously as means of heat transfer, utilization may be made of the latent heats of fusion and vaporization of the metals involved in the hydride and of a carrier for the hydride, such as ceramic or graphite. Fusion and vaporization are, of course, endothermic processes; fusion requiring on the order of a few hundred calories per cc. of metal and vaporization requiring about 5 to 15 kilocalories per cc. of metal. Similarly the heats of dissociation and of ionization of the liberated hydrogen may also, under favorable conditions, be used for the heat transfer process. The magnitude of heat of dissociation of hydrogen is on the order of 100 k.cal./mole H_2 and that for the ionization is on the order of 300 k.cal./mole hydrogen ions. In addition, when metallic vapor is present, it may also be possible to utilize its heat of dissociation and of ionization as valuable heat transfer mechanisms. Most gases are fully dissociated above 8000° K. and are ionized above

16,000° K. at one atmosphere of pressure. Whether the aforementioned properties are useful in a particular application, depends upon the actual temperature of the nose cone in that application. This temperature, in turn, depends upon the velocity of the vehicle and the medium in which it is moving. These conditions determine to some extent the optimum choice of heat transfer material and of engineering design. The examples to be described will illustrate this. The gas temperature near the surface of the nose cone may be found from the following approximate formula

$$T-T_o=\left(\frac{v}{100}\right)^2$$

where:

v=vehicle velocity in miles per hour
T_o=initial temperature of the atmosphere in ° C.
T=temperature of the gas near the surface of the nose cone in ° C.

As an example of the use of the formula let:

T_o=0° C.
v=10,000 miles per hour

then

$$T=\left[\frac{10,000}{100}\right]^2=10,000° \text{C.}$$

In the event it is decided that advantage may be taken of the heats of dissociation and of ionization of the liberated gas, it may be desirable to employ "deuterides" instead of hydrides since the heats of dissociation and of ionization for deuterium are larger than those of hydrogen. For example, palladium deuteride, whose general properties correspond to those of palladium hydride, may be used.

The first examples of my invention to be discussed are particularly applicable when the aerodynamic conditions at the nose cone produce temperatures below that required for appreciable ionization of a gas. These conditions will be experienced when a relatively small magnitude of heat is generated over a relatively long period of time. Under these conditions oxidation of any or all oxidizable unprotected surfaces or fluids released may take place, and oxidation is an undesirable exothermic reaction.

In the embodiment of FIGS. 1 and 2, each layer **33**, **35** (and so on) of heat-dissociable material is connected to a duct **37**, **38** (and so on) which in turn extends to and exhausts at the aft end **39** of the missile shell **30**. The metal layers **32**, **34**, **36** (and so on) may be special alloy steels or any highly heat-resistant metal which is also a good heat conductor and may be coated or processed to prevent or retard oxidation. For example, the layers **32**, **34**, **36** may be siliconized molybdenum, i.e., molybdenum which has been processed to convert the skin to molybdenum disilicide to protect it from oxidation.

As heat is generated at the first metal lamination **32**, the first layer of heat-dissociable material **33** receives most of the transferred heat. The result, particularly when a

type "B" hydride is used, is an endothermic reaction wherein hydrogen is outgassed, removing a large quantity of heat as heat of dissociation (see Table II), and the hydrogen is then passed through the duct **37** and carried aft to the exhaust point **39**, carrying with it some of the developed heat contained in the hydrogen by virtue of its relatively high specific heat. At the exhaust point **39**, the hydrogen may oxidize and be used as desired or expelled. As the layer **33** becomes fully outgassed and can no longer transfer heat away from the metal **32** by outgassing hydrogen in an endothermic reaction, the first thin layer **32** of metal will melt away. The metal layer **32** may possibly oxidize but not before heat transfer has been carried out by the endotherm of the heat dissociable reaction. This melting is also endothermic and will cool the nose **31** somewhat, exposing the first layer **33** of the heat-dissociable material. This layer **33**, having outgassed, is now substantially metal, and it too is carried away, as by melting, in another endothermic reaction that tends to cool the nose **31**. Table IV shows the melting points of typical metals.

TABLE IV

Melting and boiling points of the metals of Tables I, II, and III

Compound	Melting point at 1 atm. of the metal, ° C.	Boiling point at 1 atm. of the metal, ° C.
LiH	180	1,370
NaH	98	892
KH	63.4	770
CaH_2	850	1,440
SrH_2	770	1,380
BaH_2	704	1,640
$TiH_{1.75}$	1,812	3,535
$ZrH_{1.92}$	1,852	5,000
$PdH_{0.59}$	1,552	4,000
NiH	1,453	2,730
CuH	1,083	2,600

The heat is now transferred chiefly by the next metal lamination **34** to the next layer of heat-dissociable material **35**, which outgasses through its duct **38** to the end **39** of the missile. Since, as stated before, there may typically be dozens of such layers, the process of heat transfer via the heat of transformation of the heat-dissociable material, the transportation of hydrogen, the melting of the metal layer, and the melting and dissipation of the outgassed metal, continues from layer to layer always aiding in the cooling of the nose of the missile except for possible oxidation, which, in any case, because of structural design, will be limited in its capacity to oppose the desired heat transfer characteristics. The number, thickness, and composition of the metal layers and the heat-dissociable material layers may be adjusted by design to insure that all aerodynamic heating developed by the re-entry of the missile into the atmosphere will be dissipated before all these protective laminations have been destroyed. The heat dissociable materials are so chosen that the dissociation endotherm is approximately completed before temperatures are attained at which fusion of the metals involved takes place.

At some given portion **40** (see FIG. 2) the layers are adjusted in thickness so that the nose **31** of the missile will always be a smooth contour of proper shape as each layer is destroyed. Also, the ducts **37**, **38**, etc., are so arranged that they are cleared of hydrogen upon the dissolution of the getter layers to which they are connected. The inner layers of the getter material preferably terminate at progressively greater distances down the side of the nose cone, insuring that the outgassed material will not burn too near to a duct that is then carrying hydrogen from a lower outgassing layer. This is shown in the stepped construction of FIG. 2.

The laminations may be constructed as shown in FIGS. 3 and 4. Each layer **33**, **35**, etc., of heat-dissociable material may be constructed by packing hydride **41** into cells **42** of sheets **41***a* of metal which have a honeycomb form, such as "Hexcell" honeycombed metal. Other cells **41** are empty to give gas passages. The metal forming the honeycomb sheet **41***a* may be the same as the metal in the layers **32**, **34**, and **36** or may be another metal, but in either case the metal should be one which has a melting point above the temperature required for completion of the dissociation endotherm of the heat-dissociable material. One side of each honeycomb sheet **41***a* may then be intimately bonded to its outer layer **32**, **34**, etc., while the unbonded side gives a gas passage **37**, **38** between laminations. Structural members **40***a* which may be constructed of metal or ceramic are provided to maintain the fabricated layers **33**, **35**, etc., rigidly in place. They are small and do not obstruct gas flow through the passages **37**, **38**. The laminations thus formed possess an advantage in that there is more rapid transfer of heat through the metal **41***a* to the getter material **41**, and this rapid heat transfer increases the efficiency of the nose cooling operation.

If desired, a relatively thick coating of ceramic or vitreous material **43** may be applied over each layer of metal or over at least the outer layer **32** to delay heating and thereby delay destruction of a given layer of the lamination. Such a coating **43** is preferably applied to the side of the layer receiving the heat, and is illustrated in FIG. 2 where a ceramic coat **43** is shown over the outer metal layer **32**. There may be coatings over the layers **34** and **36** also, although these are not illustrated in this view.

A modified form of my invention employing endothermically heat-dissociable material for nose cooling of missiles is illustrated in FIG. 5. This structure is also useful for relatively small heat generation over a relatively long period of time. Here, a missile **44** has a thin metal shell **45** which is separated from the inner body **46** by a duct **47**. Typically, the shell **45** may be constructed of siliconized molybdenum or steel, as before. Toward the missile's nose **48** the duct **47** may be filled with suitable heat-dissociable material **49** having a low melting point, such as lithium hydride, for example, which has been fully ingassed. The remainder of the duct **47** may then be filled initially with metal **50** native to the hydride **49**. For example, if lithium hydride is used, the metal will be lithium.

Heat generated at the nose cone **48** of the missile is transferred through the metal shell **45**, heating the hydride **49** adjacent thereto. If lithium hydride is used, this hydride will become liquefied, because of its low melting point, and dissociated, each of these processes being endothermic. Similarly the remaining lithium metal **50** in the duct **47** will become liquefied. A pump **52** will pump the liquefied material in the duct **47** along pipes **53** to the nose **48** of the missile **44**. This forces the dissociated lithium and hydrogen to a region **51** lying to the rear of the nose cone **48**, where they recombine exothermically and release heat along the sides of the missile **44**, where it is dissipated by radiation. The liquid hydride thus formed is circulated by the pump **52** through the pipes **53** to the nose **48** of the missile for reuse. In this application it is necessary to choose hydrides which have low melting points or which will be in the liquefied state at temperatures below those for which heat generation at the nose cone becomes a serious problem. This is so in order that the material may be continuously pumped by the pump **52**.

In applying this method of nose cooling, some of the heat transferred from the nose **48** via the endothermic dissociation of the lithium hydride may be utilized to generate power to drive the pump **52**, instead of dissipating this heat entirely. Thus, useful work may be gained from the transferred heat.

This method of nose-cone cooling possesses the advantage that the heat-transfer medium is not destroyed or exhausted from the missile but is reused in a cyclic process. Also, the heat generated at the nose **48** may be transferred by the heat-transfer medium described to any location desired, for use in doing work or for dis-

sipation, depending upon the intention of the designer of the missile. For example, the liquid metal and the hydrogen may be carried from the nose by separate ducts and allowed to recombine and liberate heat only over a relatively small area such as at the tail of the missile where the heat may be used beneficially. The recombination being an exothermic reaction, most of the heat will be carried as stored chemical energy and dissipated in the recombination reaction.

The nose shown in FIG. 5 may also be provided with an external ceramic or vitreous coating **54**. This coating **54** serves to protect the metal shell **45** from oxidation in the region of greatest heating and also serves to delay heating of the missile.

To those skilled in the art to which this invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the spirit and scope of the invention. The disclosures and the description herein are purely illustrative and are not intended to be in any sense limiting.

I claim:

In a space vehicle, a nose having an imperforate outer surface and incorporating adjacent said surface a heat-

dissociable metallic hydride belonging to the group of metals consisting of lithium, sodium, potassium, rubidium, cesium, francium, calcium, strontium, barium, radium, beryllium, magnesium, scandium, titanium, vanadium, ytterbium, zirconium, niobium, palladium, hafnium, tantalum, the rare earth metals (atomic numbers 57–71), and the actinides (atomic numbers 89–103), said hydride emitting hydrogen gas by dissociation when heated by atmospheric friction against said nose, and means to convey the emitted gas away from the nose upon dissociation of said hydride, said means to convey including a pump for moving both the hydrogen and the metal back away from the nose after after dissociation, means providing a cooling portion to which they are moved by said pump and where they recombine as a metallic hydride, and means for recirculating said cooled hydride to said nose.

No references cited.

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