NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: GP

October 15, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned
U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,277,375

Corporate Source : Langley Research Center

Supplementary
Corporate Source :

NASA Patent Case No.: XLA-01552

Gayle Parker

Enclosure:
Copy of Patent

NASA-HQ

07

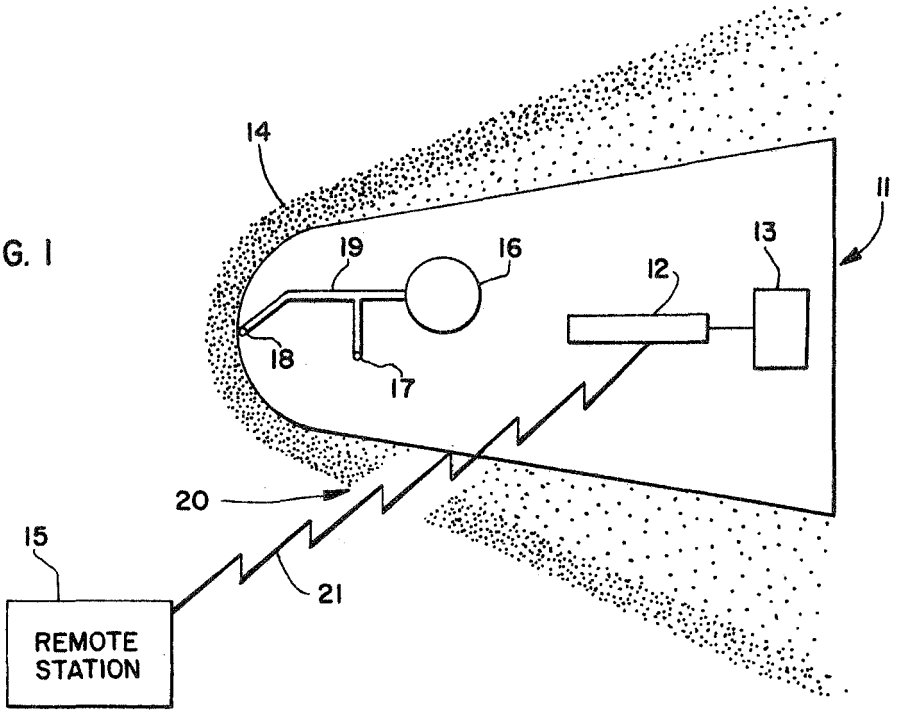
N71-11284

Oct. 4, 1966 C. H. NELSON ETAL 3,277,375

REENTRY COMMUNICATION BY MATERIAL ADDITION

Filed Dec. 19, 1963

FIG. 1



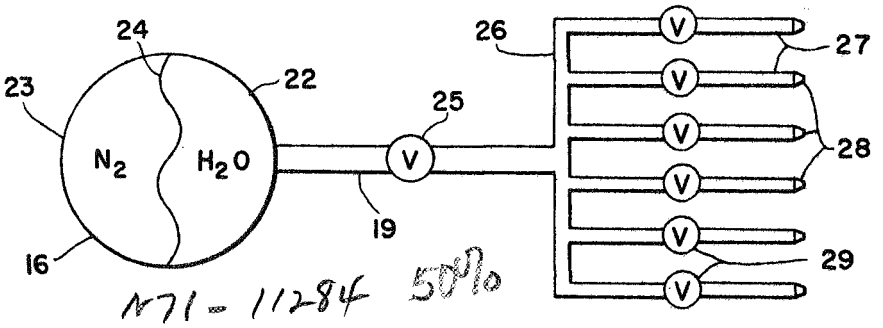


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FIG. 2

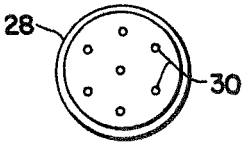

FIG. 3

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$5.00

United States Patent Office

3,277,375
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3,277,375

REENTRY COMMUNICATION BY MATERIAL ADDITION

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Filed Dec. 19, 1963, Ser. No. 332,339
2 Claims. (Cl. 325—65)

This invention relates to radio-frequency communication to and from a space vehicle and more particularly concerns a method and apparatus for accomplishing radio-frequency communication through the plasma formed around a space vehicle as it enters or leaves a planetary atmosphere.

Whenever a space vehicle traveling at a hypersonic speed (Mach 10 or above) enters or leaves a planetary atmosphere, it is surrounded by a shock-induced layer of ionized gases. This energized layer of gases or plasma prevents radio-frequency signals from passing through it. The radio-frequency signals are either reflected or absorbed by the plasma. Consequently, radio-frequency communication to and from the space vehicle is either partially or totally obstructed during the times that the space vehicle is surrounded by a layer of plasma. Since a layer of plasma is formed around a vehicle during critical phases of its flights (while leaving and entering a planetary atmosphere), it is desirable to be able to communicate through the plasma.

In the past, there have been several schemes suggested for accomplishing radio-frequency communication through the layer of plasma surrounding a space vehicle while it is reentering the earth's atmosphere. Among these schemes, is the scheme of selecting for use a signal frequency that will penetrate or pass through the hypersonically generated plasma. Extremely high or very low radio frequencies will pass through the plasma. However, since most communication equipment presently in use is designed for the VHF-UHF bands (30 mc. to 300 mc. and 300 mc. to 3,000 mc.) there is an equipment acquisition problem if either the extremely high or very low frequencies is used. Also, at the higher frequencies there is an atmospheric absorption problem and at the lower frequencies there are atmospheric noise and antenna problems.

Another scheme which has been suggested consists of altering the electromagnetic properties of the plasma by superimposing a static magnetic field. However, this scheme has a disadvantage in that it requires large magnetic-field producing systems for large space vehicles.

The present invention is concerned with injecting a material into the flow field of the plasma to open a hole in the plasma layer through which radio-frequency signals can be transmitted. This hole is produced by reducing the electron concentration of the plasma. The possible ways in which the material reduces the electron concentration is by cooling the plasma; by increasing the recombination rate of electrons and ions in the plasma; and by the attachment of electrons in the plasma to the injected material.

When a material such as gas is ejected at the surface of a space vehicle, the gas causes a great disturbance to the plasma flow field and instead of mixing tends to cause the flow field to bulge around the ejection site. Because of this bulging, a hole is not opened through the plasma and the surface of the layer of plasma is made larger. Therefore, it is desirable to use a material that can be

distributed into the plasma flow field with minimum flow field disturbances. It has been found that liquid droplets are good materials for this use. Also, in the use of liquid droplets evaporation and heat transfer can occur in the short residence time of the coolant in the vehicle vicinity. Water is a good liquid to use because it has a high heat capacity both as a liquid and a vapor and it has a high latent heat of vaporation. Water also increases the recombination rate, and has an affinity for electrons.

It is therefore an object of this invention to provide a method and apparatus for enabling radio-frequency communication through the layer of plasma formed around a space vehicle as it either leaves or enters a planetary atmosphere.

Another object of this invention is to provide a method and apparatus for injecting a material into the plasma flow field formed around a space vehicle while it is either leaving or entering a planetary atmosphere to accomplish radio-frequency communication through the plasma.

A further object of this invention is to provide a method and apparatus for injecting liquid droplets into the plasma flow field formed around a space vehicle while it is either leaving or entering a planetary atmosphere to accomplish radio-frequency communication through the plasma.

Other objects and advantages of this invention will further become apparent hereinafter and in the drawings; in which:

FIG. 1 shows a schematic diagram of a space vehicle and the apparatus that constitutes a preferred embodiment of this invention;

FIG. 2 shows a more detailed schematic diagram of the apparatus that constitutes a preferred embodiment of this invention; and

FIG. 3 shows an enlarged end view of a nozzle 28 shown in FIG. 2.

In describing the preferred embodiment of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, it is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

Turning now to the specific embodiment of the invention selected for illustration in the drawings, the number 11 designated generally a space vehicle with an antenna 12 attached to the outside srface thereof. Electrically connected to antenna 12 is communication equipment 13. This communication equipment consists of a transmitter and a receiver. When space vehicle 12 is entering or leaving a planetary atmosphere a layer of plasma 14 is formed around the vehicle which prohibits the vehicle from communicating with a remote station 15. Remote station 15 consists of a transmitter, a receiver and an antenna. A water supply 16 which is under pressure is connected to sites 17 and 18 on the outside surface of vehicle 11 by a tube 19 to spray water into the layer of plasma 14. This spray of water opens a hole 20 in the plasma 14 enabling radio-frequency signals 21 to pass between vehicle 11 and the remote station 15. Thus, radio-frequency communication is maintained between space vehicle 11 and remote station 15. Site 17 can be located anywhere on the side of vehicle 11 and there can be any desired number of these sites. Site 18 is located in the stagnation region and there can be any desired number of these sites. The stagnation region is that portion of the layer of plasma immediately adjacent to the vehicle's leading edge. The stagnation region has been proven to be the most effective site to spray water into the plasma on long slender space vehicles. However, it is doubtful that this will be true for blunt-nosed vehi-

cles—too much water might be required. Much more water is needed for a stagnation region spray than for a side spray because a stagnation region spray tends to eliminate the whole layer of plasma whereas a side spray tends to open only a hole in the layer of plasma.

Referring now to FIG. 2, there is shown in more detail the apparatus used to spray water into the plasma around the space vehicle **11**. A tank **16** is divided into two compartments **22** and **23** by a diaphram **24**. Compartment **22** is filled with water and compartment **23** is filled with N_2. The N_2 in compartment **23** is under pressure which pressure is exerted against diaphragm **24** putting the water in compartment **22** under pressure. Tube **19** connects compartment **22** to a manifold **26**. Located in tube **19** is a valve **25**. Valve **25** can be hand operated or it can be automatically operated by a preprogramed control. It can also be hand operated or preprogramed to turn "on" and "off" for short intervals of time to conserve the water supply. Any desired number of tubes **27** connect manifold **26** to nozzles **28**. Located in each tube **27** is a valve **29**. Valves **29** can be hand operated or they can be automatically operated by a preprogramed control. All or any number of the valves **29** could be turned on at any given time. Any number of nozzles **28** can be located at sites **17** and **18** or at any other desired site on the outer surface of space vehicle **11**.

Referring to FIG. 3, there is shown an end view of a nozzle **28**. Each of the nozzles **28** has several orifices **30** in it through which water will pass. The number and size of these orifices can be different for each nozzle **28**, depending on where the nozzle is to be located. For injection from the stagnation site **18**, up to seven 0.080-inch-diameter orifices **30** have been used with success; and for injection from the side site **17** up to ninety-eight 0.015-inch-diameter per side have been used with success. Two side sites on opposite sides of vehicle **11** were used.

The sizes of orifices **30** can be different than the specific sizes mentioned above. The sizes of the orifices depend on the ejection site, the antenna location and the size and shape of the space vehicle. It is necessary only that the orifices are small enough so that the water droplets ejected therefrom will vaporize before they leave the vehicle vicinity and will penetrate the plasma without bulging it. The amount of water ejected by orifices **30** will depend on the injection site and on the size and shape of the vehicle. For a vehicle having an eight-inch diameter nose, a velocity of approximately 17,800 ft./sec., and operating in the altitude range of 160,000 to 250,000 ft., water flow rates of 0.3 to 00.1 pound per second have been proven to be adequate to relieve plasma attenuation. These values were the lowest flow rates tested and even lower values may be effective. For larger vehicles and higher velocities, somewhat larger amounts may be needed. The amount of water used can be varied by opening different combinations of values **29**, or by varying the pressure of N_2 in compartment **23**.

The operation of the apparatus which constitute the preferred embodiment of this invention will be described while referring to FIGS. 1 and 2. Whenever space vehicle **11** is either entering or leaving a planetary atmosphere, a layer of plasma **14** is formed around the space vehicle which prohibits radio-frequency communication between the space vehicle and a remote station **15**. To alleviate this problem, the pilot or an automatic control opens valve **25** and any desired number of valves **29**. The water in compartment **22** of tank **16** is then forced through tube **19** by the N_2 in compartment **23**. The water is sprayed out through orifices **30** into the layer of plasma **14**, opening up a hole **20** therein. Now radio-frequency communication can be maintained between space vehicle **11** and remote station **15** through hole **20**. It is necessary only to vary the number of valves **29** that are open to vary the amount of water sprayed into the plasma. Water can be conserved by opening and closing valve **25** for short intervals of time to produce pulses of water out of orifices **30**.

The advantages of this invention are numerous. It allows the use of standard communication and telemetry gear on board a space vehicle during the times that it is leaving or entering a planetary atmosphere. It consists of equipment that is relatively simple and inexpensive and that can be installed on existing missiles and spacecraft. And it can utilize the excess water during reentry from fuel cells, waste, and surplus water supply that might be aboard the space vehicle.

It is to be understood that the form of the invention herewith shown and described is to be taken as a preferred embodiment. Various changes may be made in the shape, size and arrangement of parts. For example, equivalent elements may be substituted for those illustrated and described herein, parts may be reversed, and certain features of the invention may be utilized independently of the use of other features, all without departing from the spirit or scope of the invention as defined in the subjoined claims. The invention could be used on a passive communication satellite, thereby eliminating the need for communication equipment on board the space vehicle. The invention uses water as a means of cooling and modifying the plasma. Freon 12 (CCl_2F_2) has also been used and found to be effective. Other liquids or solids might also be used. In particular, liquids or solids with large latent heats and/or heat capacities such as liquid hydrogen and ice would be possible materials. Accordingly, it is to be understood that the term liquid as used in the subjoined claims is not necessarily restricted to water and the term nongaseous substances includes both liquids and solids.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. Apparatus for accomplishing radio-frequency communication between a space vehicle and a remote station during the times that the space vehicle is surrounded by a layer of plasma comprising: communication equipment located on board said space vehicle and at said remote station; a liquid supply located on board said space vehicle; and means located on said space vehicle for spraying small droplets of said liquid into said layer of plasma whereby substantial evaporation of the liquid and heat transfer between the liquid and the plasma occurs in the short residence time of the liquid in the vehicle vicinity and substantial numbers of electrons in said plasma attach to said liquid droplets thereby reducing the electron concentration of said layer of plasma to enable radio-frequency communication between said space vehicle and said remote station.

2. A method for altering the layer of plasma formed around a space vehicle while it is either entering or leaving a planetary atmosphere so that radio-frequency communication can be made through the layer of plasma comprising: the steps of providing a liquid supply on board said space vehicle; and spraying small droplets of said liquid into said layer of plasma whereby substantial evaporation of the liquid and heat transfer between the liquid and the plasma occurs in the short residence time of the liquid in the vehicle vicinity and substantial numbers of electrons in said plasma attach to said liquid droplets thereby reducing the electron concentration of said layer of plasma to enable radio-frequency communication through said layer of plasma.

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