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[54] **ENERGY ABSORPTION BY A RADIOISOTOPE PRODUCED PLASMA**

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[52] **U.S. Cl.** **343/18,** 60/201

[51] **Int. Cl.** **G01s 7/36**

[58] **Field of Search** .... 343/18, 18 A, 18 E; 102/87, 102/92; 60/201

[56] **References Cited**

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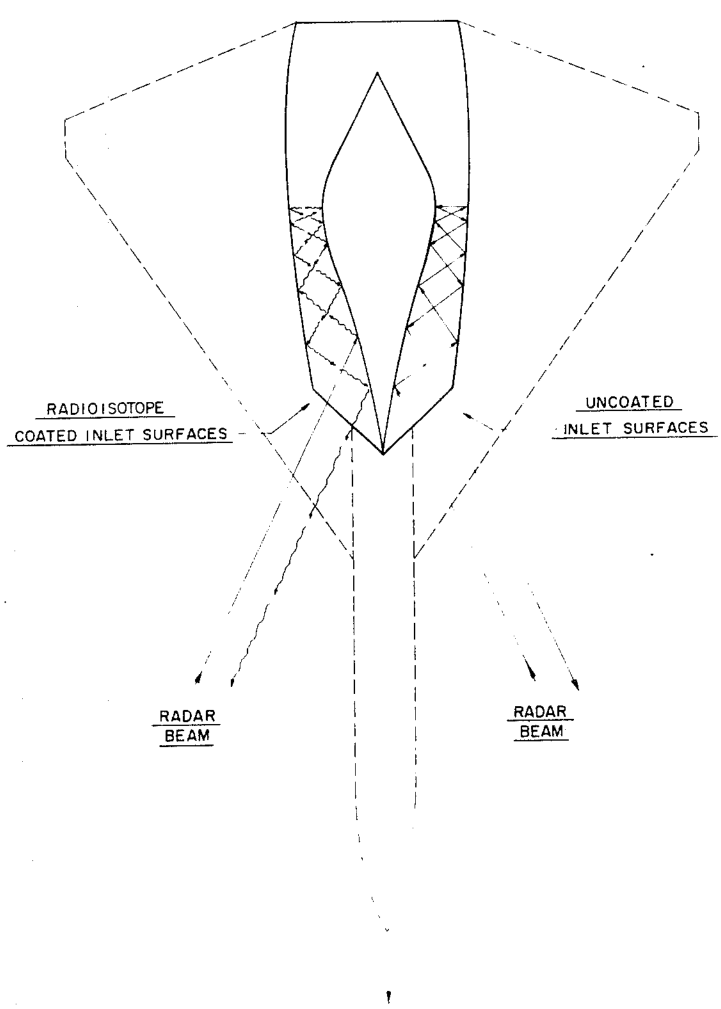
[57] **ABSTRACT**

This invention relates to an arrangement for producing an ionized plasma adjacent a surface and in particular it relates to providing a body with a coating capable of injecting kinetic energy into an adjacent gaseous medium thereby reducing the frictional drag of the body when traveling through such a medium, as well as being capable of producing an ionized plasma sheath that will absorb or attenuate the transmission of eletromagnetic and longitudinal type energy therethrough.

16 Claims, 10 Drawing Figures



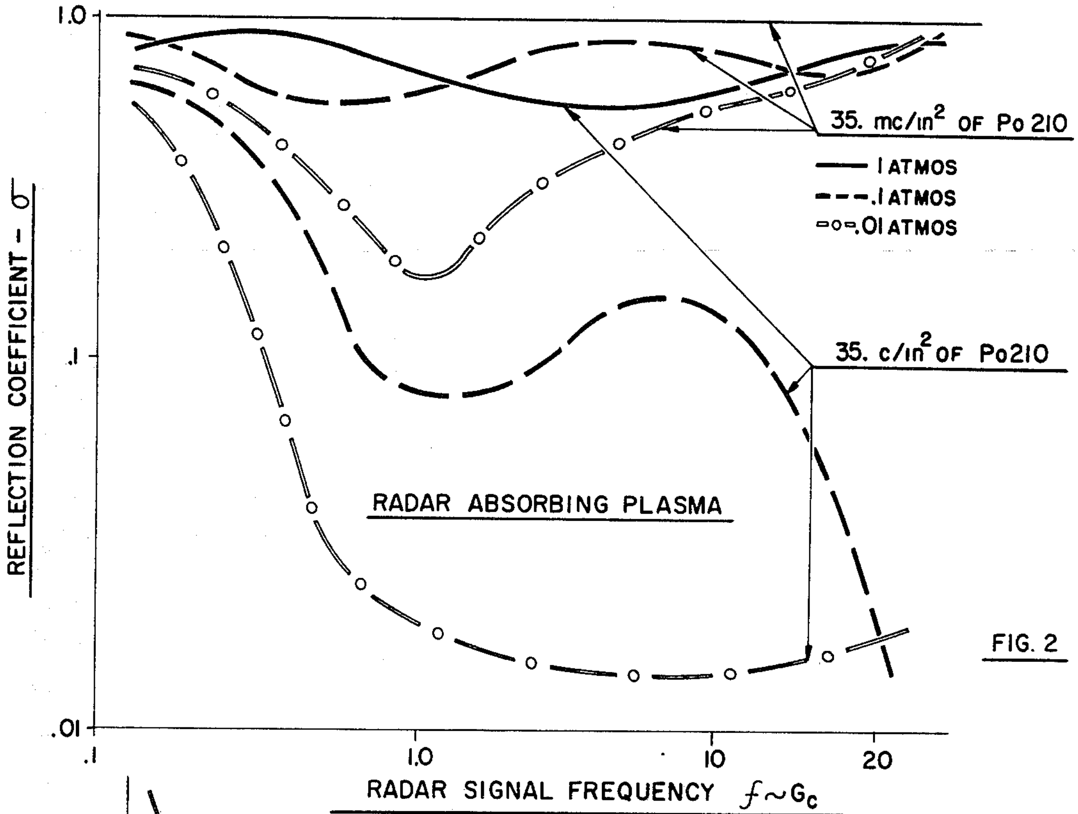


FIG. 2

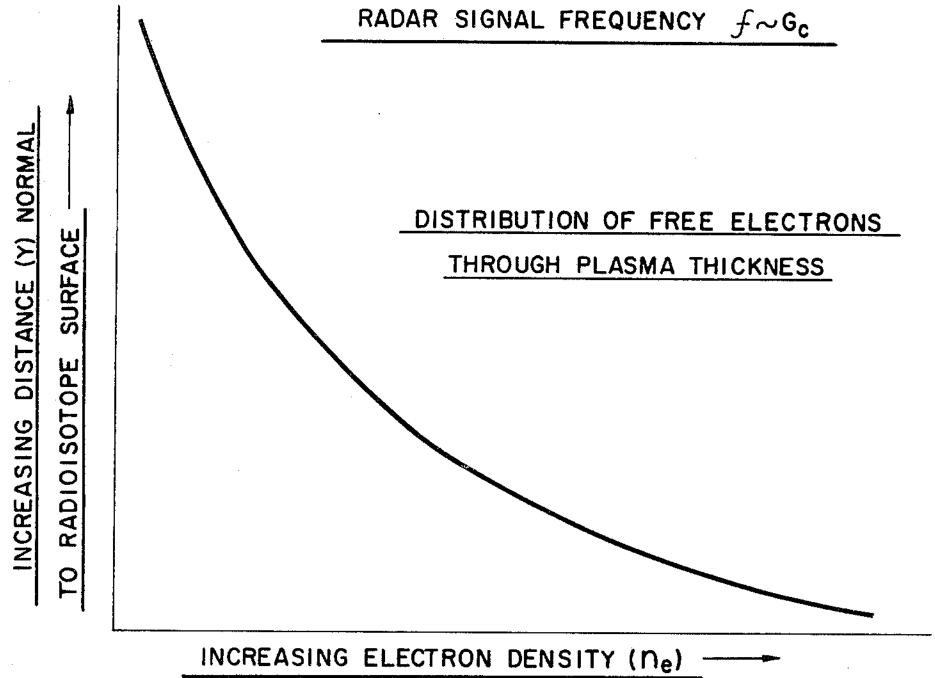


FIG. 1

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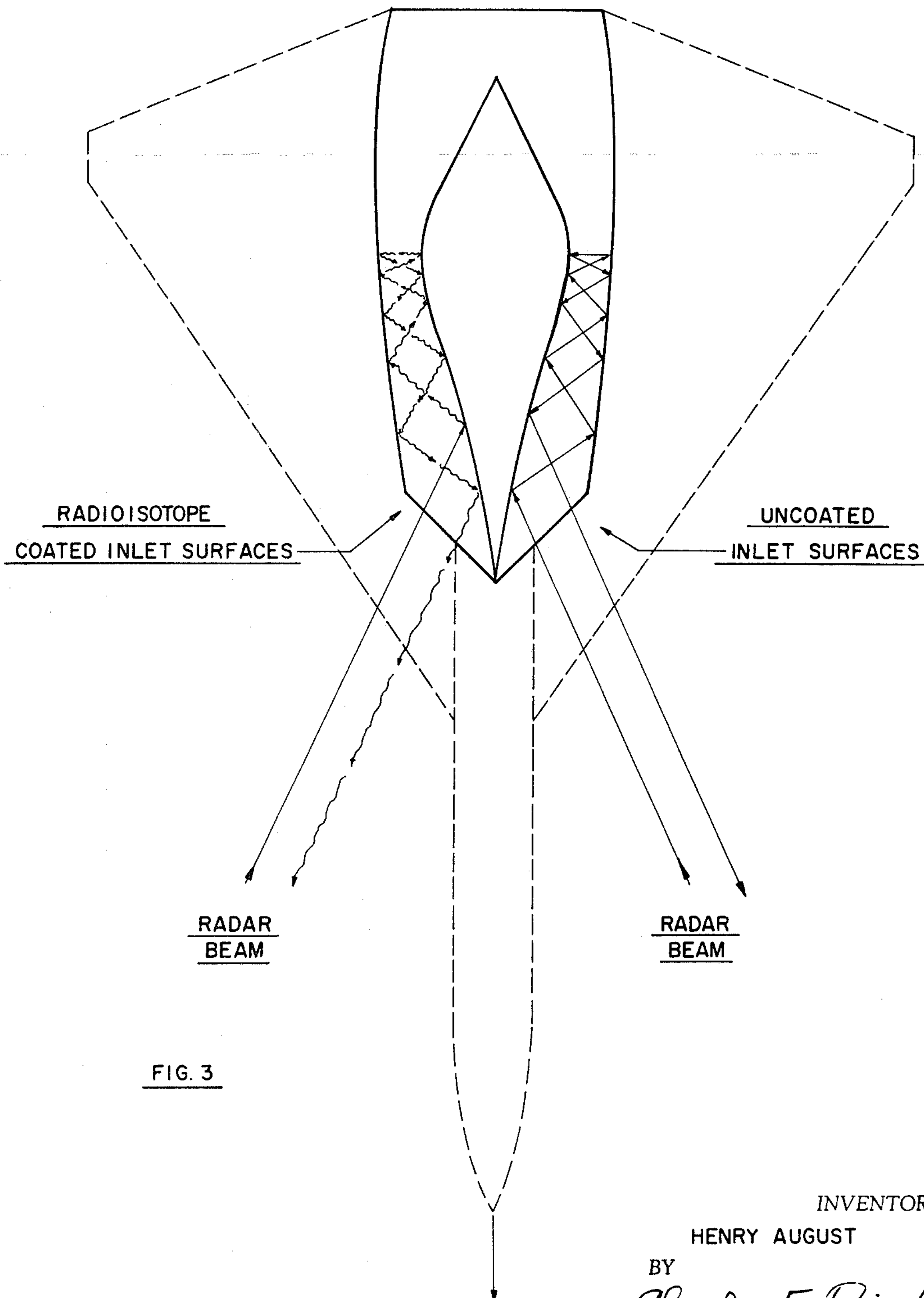

FIG. 3

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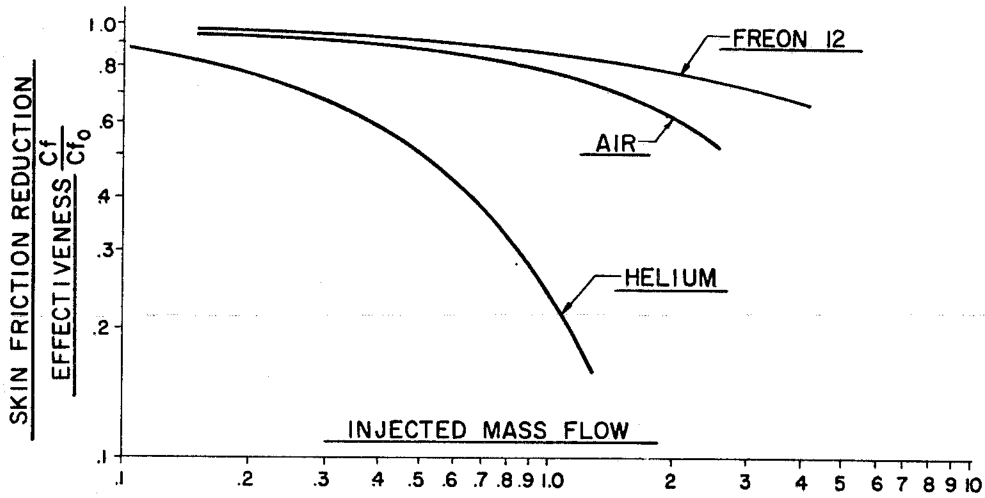

FIG. 4

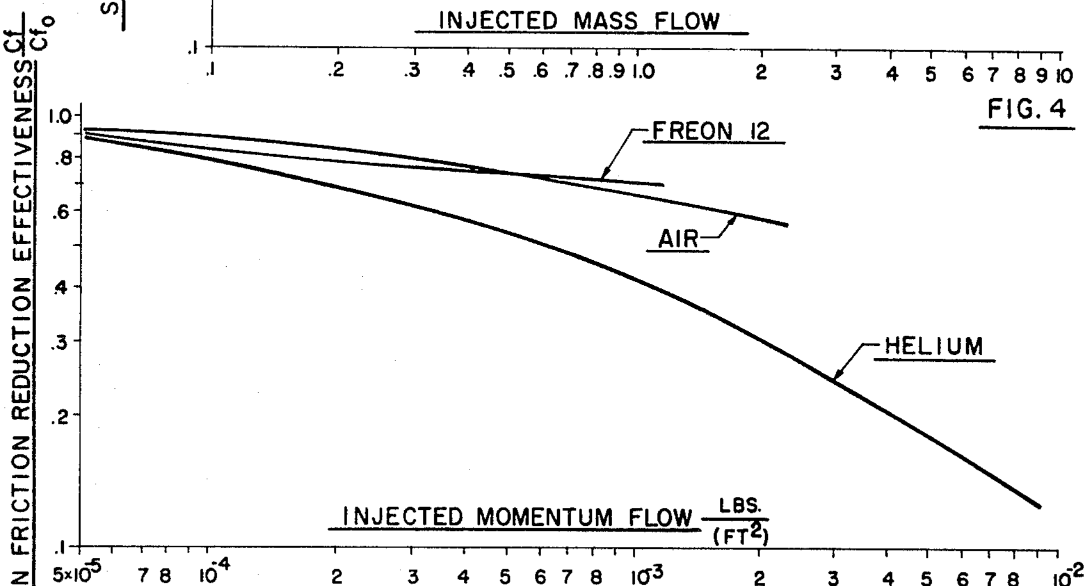

FIG. 5

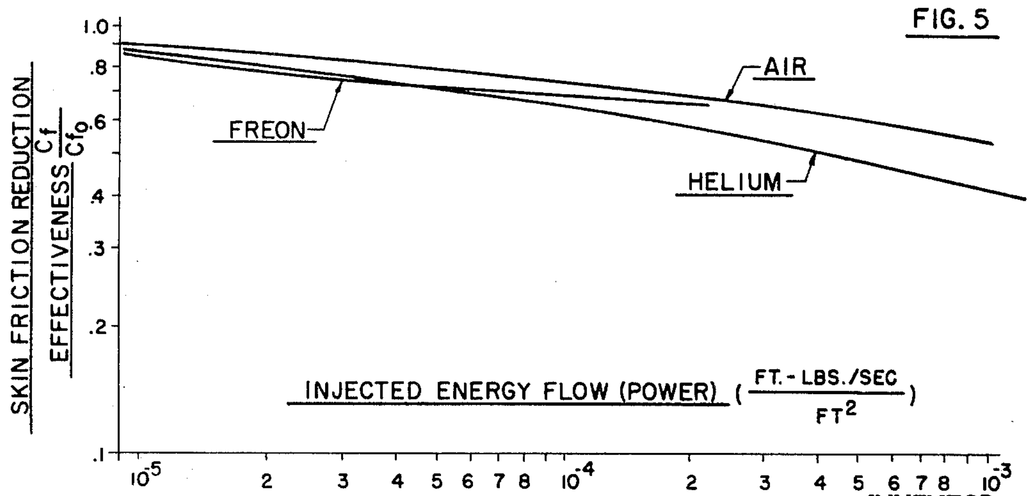

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FIG. 6

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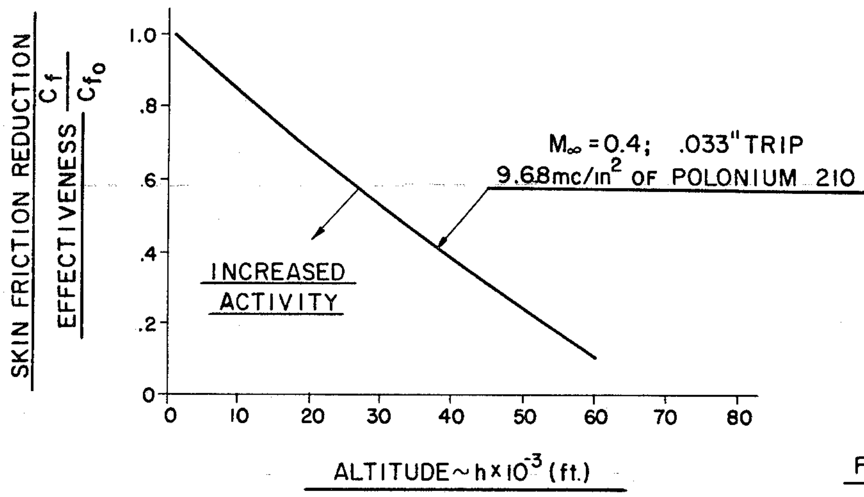

FIG. 10

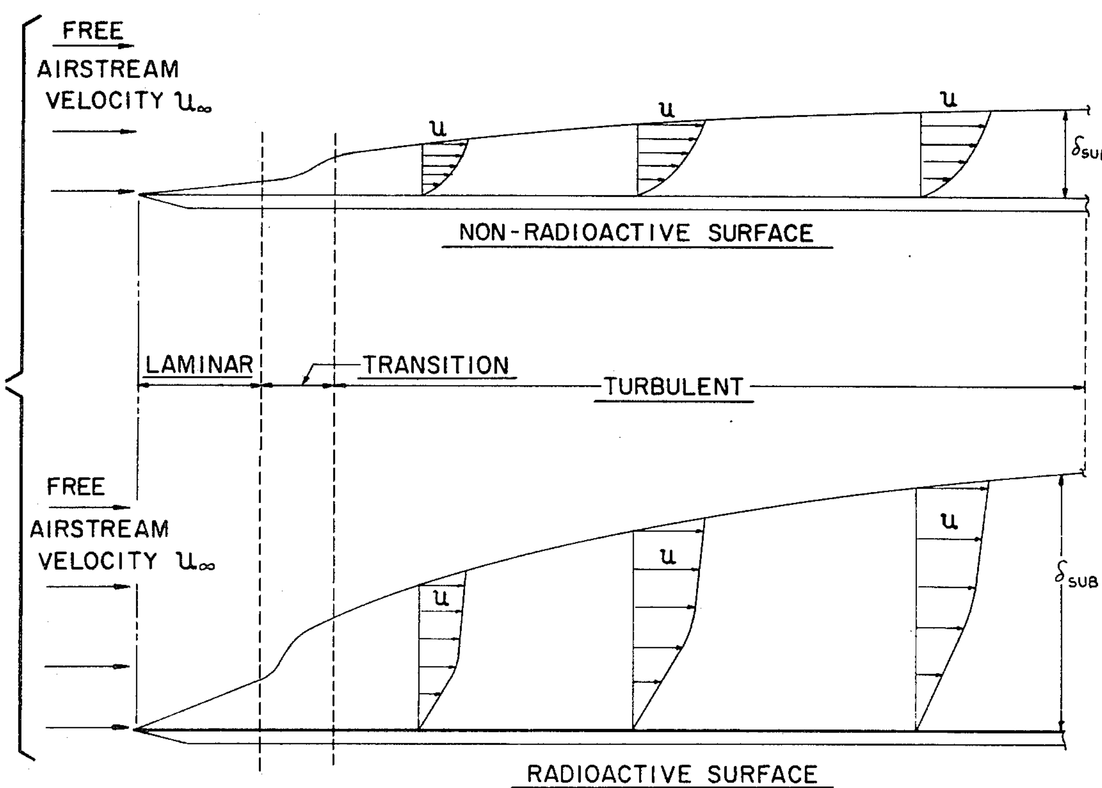

FIG. 7

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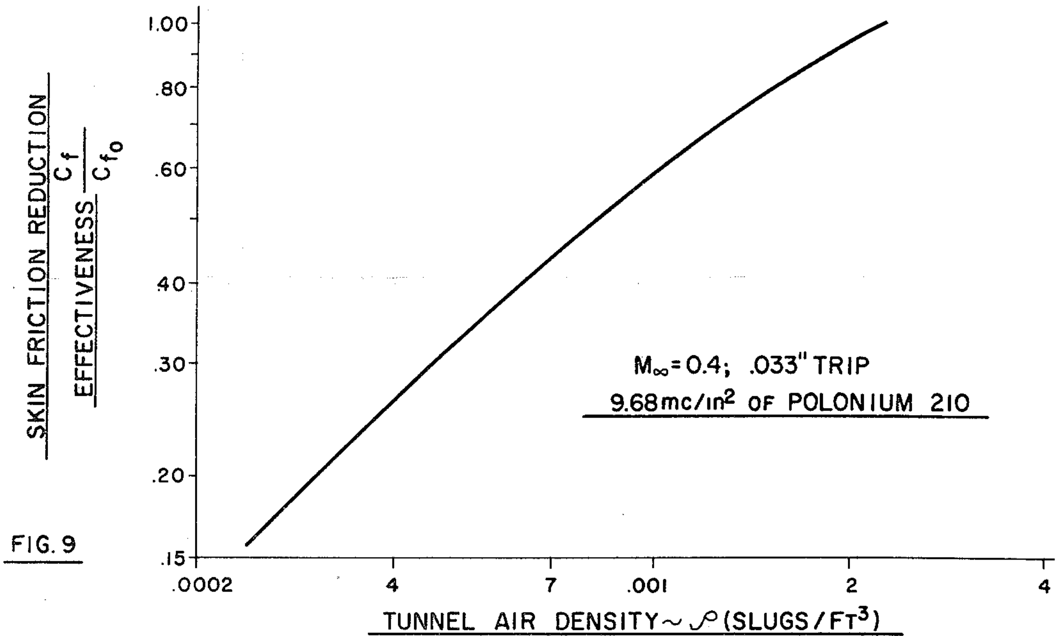

FIG. 9

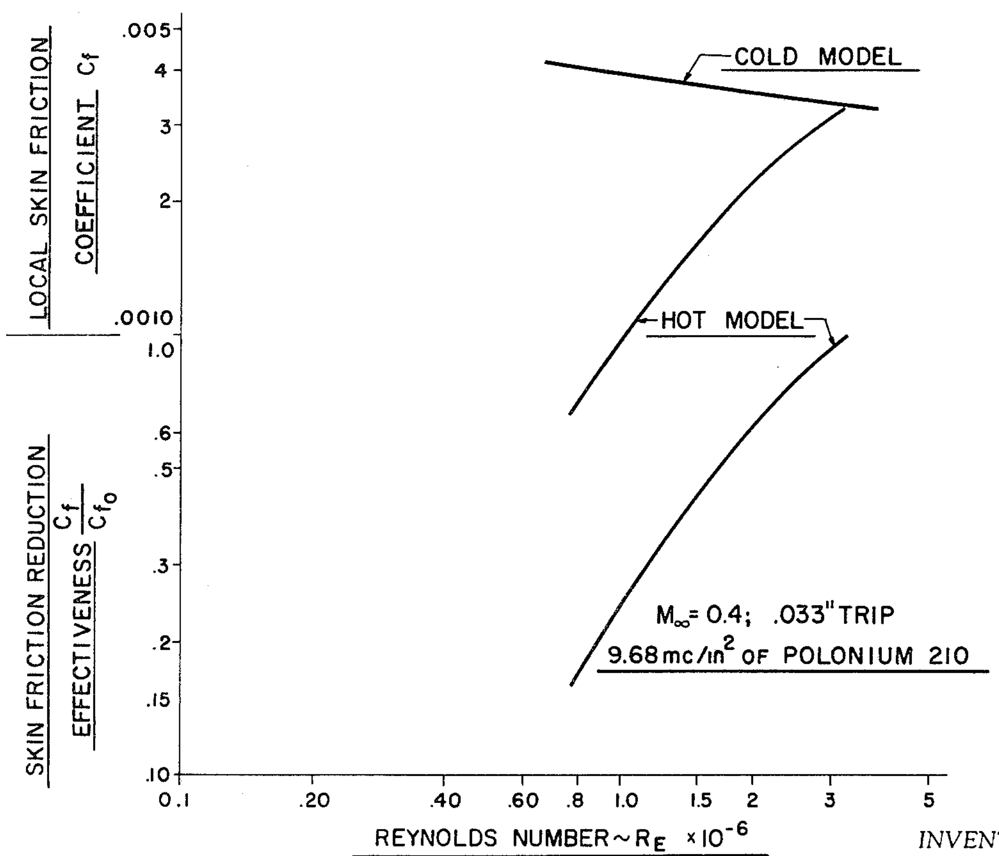

FIG. 8

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ENERGY ABSORPTION BY A RADIOISOTOPE PRODUCED PLASMA

In order to effectively carry out military missions, aerospace vehicles such as aircraft and suborbital and orbital reentry vehicles must be able to penetrate space and air corridors at high speeds without being detected. The probability that a mission will be satisfactorily completed is reduced because of the inherent susceptibility of these vehicles to radar detection. Currently, "early warning" radar systems are capable of sighting such vehicles as they approach over the horizon. They can then be tracked by radar and become the objective of defensive weapons launched against them. Any means, therefore, by which such vehicles can be rendered undetectable by radar would give them a significant advantage.

Methods of accomplishing this goal can be divided into two types. One involves the use of active countermeasures wherein the vehicle transmits electronic energy to disrupt the radar signal return or launches decoys to confuse it. The second method involves passive countermeasures which rely on some characteristic of the vehicle's configuration or construction to reduce the radar return. Examples of active methods are noise jamming, track braking and electronic decoys. An example of a passive method is the use of radar absorbing materials on the vehicle's surface. However, while such materials can be effective in reducing the radar cross-section of a vehicle, they introduce weight, strength and temperature limitations that are undesirable.

Recently the possibility of absorbing radar by utilization of an ionized plasma to absorb electromagnetic energy propagating through it has been under consideration. Much evidence of this absorption phenomenon is available at radio frequencies. For instance, the difficulty of propagating electromagnetic wave energy through an ionized media has raised many recent problems in the field of space vehicle communications. This is particularly evident in the telemetering of information by way of radio frequency waves transmitted from an aerospace body, moving at hypersonic velocity during its reentry phase into the earth's atmosphere, to a receiver stationed at the earth's surface. As the vehicle penetrates into the atmosphere, its velocity is reduced and the kinetic energy given up by it is transferred to the surrounding air in the form of heat, thereby heating the air to a high temperature. This heated air is confined to a region close to the body between the shock wave pattern, which is defined by the air and vehicle characteristics and the body shape of the vehicle. The high temperature to which the air in this region is raised causes effects such as excitation of electron energy levels, dissociation of molecules, and ionization of the molecular and atomic constituents of the air. The attenuating effects of this ionized sheath surrounding the vehicle on the propagation of electromagnetic phenomena has been found to be a combination of absorption, reflection, refraction and diffraction. Under certain conditions of reentry, the attenuation may be so pronounced that complete "-blackout," or loss of received signal is encountered. The plasma of a rocket engine exhaust flame, during powered flight of such a vehicle, has also been found to cause the same effect on electromagnetic wave propagation through the exhaust. However, the plasma sheath conditions adequate to alter or prevent electromagnetic wave propagation occurs naturally around a reentry body or within rocket engine exhaust gases only during a limited period of the vehicle's flight. Consequently, the provision of a means for providing an ionized plasma sheath in a controlled manner, as required, would have significant advantages in the avoidance of radar detection of an aerial vehicle.

U.S. Pat. No. 3,127,608 discloses an early arrangement whereby an attempt was made to provide an electron cloud or plasma around an aerial vehicle by means of a high energy electron beam gun carried by the vehicle and directed below the vehicle. However, such an arrangement is not practical since, due to the low efficiency of an electron beam gun in converting power into a stream of electrons, an extremely large powerplant would have to be provided to operate the electron gun. The weight and volume of such a powerplant would be prohibitive for an aerial vehicle to carry. Furthermore, the energy level of the electrons produced was not high enough to prevent an excessive rate of electron attachment to neutral oxygen molecules and too rapid depletion of the plasma.

Thus, the present invention has as one of its primary objects a practical arrangement for producing an ionized plasma about an aerial vehicle for the purpose of modifying and/or attenuating an electromagnetic detection signal emanating from a remote source.

Another principal object of the present invention resides in the provision of means for injecting momentum energy into a fluid boundary layer medium (gaseous or liquid) surrounding a moving vehicle to cause local alteration of the boundary layer with a consequent reduction in the local and mean skin friction coefficients, thereby increasing the maximum velocity and/or maximum altitude attainable by the vehicle. By the so-called concept of "blowing boundary layer control" it has been demonstrated that the thickness of the natural boundary layer may be increased, with a resulting decrease in the skin friction coefficient, by means of injecting a foreign gas at a relatively low velocity through a porous surface into the natural boundary layer, thereby causing its thickness to grow by the mixing process which results between the local stream fluid of the natural boundary layer and the injected gas. By the present invention, the same result is achieved by means of the injection of high energy particles or energy quanta, i.e., small particles of mass at high velocities, into the natural boundary layer.

Another object of the present invention is the provision of an ionized plasma sheath about a surface to modify and attenuate electromagnetic waves propagating therethrough and particularly the radar, infrared and visible light ranges of the electromagnetic spectrum.

Still another object of this invention is the provision of an ionized plasma sheath about a sound-producing body to modify and attenuate the longitudinal sound waves propagating through the plasma from such body.

Yet another object of the present invention is the provision for generation of an ionized plasma adjacent a surface by means of the application of a coating of a radioactive material on such surface for the emission of particles and energy of the alpha, beta or gamma type or other particles or energy quanta.

A still further object is the reduction of the radar cross-section of an aerial vehicle by means of the application of a radioisotope surface coating thereto.

In accordance with these objects, the present invention envisions the injection of energy quanta, e.g., alpha, beta or gamma particles by the application of a thin paint-like coating of a radioactive energy emitting substance, such as a radioisotope material, to a surface of a body to generate an ionized plasma adjacent such surface for the absorption, refraction and diffraction of electromagnetic and longitudinal waves propagating through the plasma, as well as for the energization of the boundary layer adjacent such surface with a consequent reduction in skin friction when the surface has relative motion with respect to a surrounding fluid medium.

These and other objects of the present invention will become apparent from the following detailed description taken in connection with the accompanying drawings, in which:

FIG. **1** is a non-dimensional plot of the distribution of free electrons through a radioisotope produced plasma above a flat surface of infinite extent;

FIG. **2** is a plot of the coefficient of reflection σ against frequency for a radar absorbing plasma for flat plate geometry of infinite extent;

FIG. **3** is a schematic view of an aircraft engine air induction system illustrating the reflection of a radar signal from wall to wall of the system before being returned to its source when the walls are uncoated and the resulting diffusion and scattering of the incident signal when the wall surfaces are coated with a radioisotope.

FIGS. **4**, **5** and **6** are logarithmic plots of the improvement effected in respect of the skin friction reduction effectiveness, CF/CF_o, for injection of air, Freon **12** and helium gases into a turbulent air boundary layer. These FIGS. are plotted from the same experimental data (Institute of Aeronautical Sciences Report No. 59–78) but to different abscissa, i.e., injected mass flow, injected momentum flow and injected energy flow, respectively, for a Mach No. of 3.21.

FIG. **7** is a schematic representation of the laminar sublayer portion of boundary layer flow over a non-radioactive surface and over a radioactive surface illustrating the increase in thickness δ of the laminar sublayer and the favorable distortion of the local velocity profiles at different locations therein that occur over the radioactive surface;

FIG. **8** is a logarithmic plot of the local skin friction coefficient of a radioactive and non-radio-active boundary layer test model and of the skin friction reduction effectiveness (Cf/C_{fo}), all as a function of Reynolds Number;

FIG. **9** is a logarithmic plot of skin friction reduction effectiveness (Cf/C_{fo}) of the test model of FIG. **8** as a function of wind tunnel air density; and

FIG. **10** is a linear plot of skin friction reduction effectiveness as a function of altitude for the same test model of FIGS. **8** and **9**.

The concept of the present invention resides in the application of a thin, paint-like coating of a suitable radioisotope material to an external surface of an aerial vehicle. Such a vehicle may be an aircraft or an orbital or suborbital reentry-type vehicle such as a rocket, missile, nose cone or the like. The high energy particles or quanta and energy emitted from the isotope, primarily in the form of alpha or beta particles or gamma rays, continuously ionize a layer of air adjacent to the coated surfaces. This action is highly efficient in that a large percentage of the emitted energy produces ionization of the air. No internal power source is required on board the vehicle, little or no radiation shielding is required and the paint-like surface coating produces negligible penalties in volume and weight. A plasma cloud of ionized air may thus be generated to envelop any aerial vehicle, or a portion thereof, under nearly any flight condition.

The radioisotope-produced plasma provides a particularly desirable feature in that it contains an electron density distribution that is high near the surface and gradually decreases in magnitude with increasing distance from the coated surface, as shown by FIG. **1**. The plasma thus is of a low intensity at its outer edge. This presents a very good impedance match to an electromagnetic wave, such as a radar beam, as it propagates from the non-conducting air or space regime into the plasma. No sharp discontinuities in dielectric properties are encountered by the wave and consequently little of the electromagnetic energy is reflected at the edge of the plasma, thereby allowing nearly all of the energy to pass into the plasma where at least a portion thereof is subject to absorption.

In addition to radar energy attenuation, other desirable countermeasure effects are produced on electromagnetic energy by the plasma. Diffraction, refraction and reflection in the plasma cause signal cross-modulation and distortion such that the return signal may be shifted in frequency and phase. Radar tracking of reentry vehicles having a thermal plasma generated therearound during the reentry phase often results in false indications of vehicle position, velocity and bearing during reentry due to such frequency and phase shifts. This additional means of confusing a radar detection signal provides this concept with added anti-detection capability with respect to an electromagnetic radar signal detection system.

Vehicles reentering the earth's atmosphere at high velocities can generate long narrow trailing wake flow fields behind them. These wakes consist of ionized air and ionized ablative materials (ceramics, graphite, and the like) that melt, evaporate or sublime while absorbing the thermal energy developed at the stagnation regions on the vehicle. These long narrow conducting gaseous columns are highly reflective to a radar beam. By adding radioisotope material to the ablative material in a mixture or compound form which carries downstream as part of the wake flow field during reentry a radioisotope generated plasma can be made to envelop the trailing wake with a relatively thick attenuating plasma and thereby prevent radar detection of such wake.

Hypothetically, the incidence of an electromagnetic wave upon an electron plasma will result in oscillation of the electrons at the same frequency as the wave. In actuality, however, the presence of neutral particles and ions in the paths of the electrons results in random collisions which disturb the orderly re-radiating process. The disordered electromagnetic energy emitted retains little identity with the incident wave and is effectively lost or absorbed in the plasma. This phenomena will prevail in a plasma regardless of the means by which the electrons are liberated. Attenuation and absorption can take place over the full electromagnetic bandwidth in various degrees and the plasma is not narrow band frequency limited because a graded dielectric is generated which is effective over a wide range of frequencies. It is believed that the thickness of the plasma is important for successful absorption and attenuation as well as the magnitude of plasma frequency and that a plasma thickness of at least a quarter wave length of the incident energy is probably required. However, the total number of free electrons encountered by the wave, that is, the product of the number of free electrons per unit length and the wave propagation length thru the plasma, is the ultimate criterion determining the absorption characteristics of the plasma and the total radar cross-section reduction.

A radioisotope produced plasma is in a state of extreme thermal non-equilibrium. Even in the case where molecules, atoms and ions of the air are at standard temperature and pressure, the electrons, which have been freed by collisions with the very high energy particles emitted from a radioisotope surface coating, possess a spectrum of kinetic energy that includes an energetic range from a low of 4 electron volts to a high of 2,000 electron volts which was transferred to them by collision with the emitted particles. The liberated fast electrons are so energetic that they are capable, in turn, of ionizing other molecules and atoms. Thus, secondary and even tertiary ionizations occur.

Of the many radioisotopes available, the alpha emitters appear to be most significant because they dissipate their kinetic energy in smaller air volumes than beta or gamma rays due to their relatively shorter penetration range. Thus, alpha particles more densely ionize the air. Polonium 210 is a preferred isotope, since it is practically a pure alpha emitter and has many desirable characteristics including a half-life of 138 days, alpha particles that possess 5.3 million electron volts of kinetic energy and commercial availability. Such an alpha particle passing through a thin metallic seal with 70 percent efficiency with a resulting energy off 3.71×10^6 electron volts in standard temperature air will, by direct and indirect collisions, theoretically influence 10^8 gas molecules of the air before thermalization is achieved. Of these collisions, 10^5 will be ionizing collisions. Indirect collisions are the chain reaction collisions between the gas molecules of the air resulting from the initial direct collision of the alpha particle and air gas molecules. Thermalization is the condition wherein the kinetic energy of the air particles which have been energized by the alpha particle are reduced by successive collisions to an energy level corresponding to the gas temperature. Another α-emitter of considerable interest for practical coating applications is Curium 242. The maximum range of the emitted alpha particles is an inverse function of the density of the medium through which they travel. The maximum range of such particles in air at standard temperature and pressure (STP) is 1.5 inches and from a health and safety standpoint they cannot penetrate through more than the first few dead layers of a person's skin.

Because of the many high energy electrons (Polonium 210 alpha particles are capable of transferring as much as 2,000 electron volts of kinetic energy to the particles as they are freed) produced by the radioisotope emission, it is considered that the electron attachment process, i.e., the attachment of the free electrons to a neutral particle such as an oxygen molecule, does not play a significant role in the decay of a radioisotope generated plasma in air. This is contrary to the conditions pertaining in a thermal plasma, such as is generated by a reentry vehicle, wherein the free electrons possess kinetic energies of less than one electron volt and the electron attachment process contributes significantly to the decay of such a plasma. Thus, the radioisotope generated plasma of the present invention tends to persist and to resist rapid decay.

Computations for a flat surface coated with 35 millicuries of Polonium 210 per square inch, with 70 percent energy transmission through a protective gold seal, show that the energy available for ionizing air is 3.71×10^6 electron volt per α-particle and the free electron production rate is 7.5×10^{13} electrons/sec/in^2 or 1.16×10^{17} electrons/sec/meter^2. Even for such a low surface coating concentration this emission rate is comparable to the 1.35×10^{17} electrons/meter^2 that is set forth in U.S. Pat. No. 3,127,608 as the requirement for 100 decibel attenuation at 10,000 megacycles (10 Gigacycles). For 70 percent transmission the maximum range of the α-particles at S.T.P. is about 1 inch.

A test program run at a frequency of one GC (one Gigacycle = 10^9 cycles per second) corresponding to the so-called radar L-band and using a monostatic back-scattering range has verified the validity of the present concept of electromagnetic wave absorption by a radioisotope produced plasma. For this test only the normal incidence measurements were considered meaningful. The test model consisted of a copper-plated 5 inch diameter × ⅜ inch thick stainless steel flat disk. The copper layer was used as a substrate to which 30 millicuries per square inch of Polonium 210, an alpha-emitter, was electroplated on one surface of the 5 inch diameter disk. For safety reasons a flash of gold material 0.000001 inch thick was applied over the polonium to assure that the radioisotope remains secured to the surface of the disk and to eliminate any health hazards resulting from direct contact, ingestion and the like. An 18 inch I.D. plexiglass sphere having an average wall thickness of one-half inch which is transparent to radar energy served as a vacuum chamber to simulate altitude conditions. The background return, including the sphere, was about 13.6 decibels below the 5 inch diameter targets and at least 28.9 decibels below the 18 inch diameter targets. By first running a "dummy" target that did not have a radioisotope coating, then the radioisotope-coated target, and then repeating the same level of radar cross-section measurement of the "dummy" target, in that order, the transmitted power was indicated to have held constant throughout the test series. The 18 inch target diameter was achieved by centrally positioning the 5 inch diameter "active" test model in an 18 inch diameter aluminum plate. Table I summarizes the results of this preliminary test program.

TABLE I.—TEST RESULTS OF RADIOISOTOPE PRODUCED PLASMA RADAR ANTIDETECTION SYSTEM
(f=1 Gc., Normal Incidence)

Test No.	Gas density	Target diameter	Dummy (db.)	α-Emitter (db.)	Radar cross section reduction (percent)
1	Air at 100% atmos	5″	−21.70	−22.70	20.6
2	do	5″	−21.75	−22.70	19.6
3	Air at 3% atmos	18″ plus sphere	−6.90	−7.30	8.9
4	Air at 10% atmos	do	−6.90	−7.40	10.9
5	Air at 100% atmos	do	−6.90	−7.30	8.9
6	do	do	−1.00	−1.70	14.9
7	Air at 3% atmos	do	−1.00	−1.70	14.9
8	Air at 10% atmos	do	−1.00	−1.60	12.9
9	Air at 100% atmos	do	−2.00	−2.70	14.9
10	Argon at 3% atmos	do	−2.00	−2.50	10.9
11	Argon at 10% atmos	do	−2.00	−2.50	10.9
12	Argon at 100% atmos	do	−2.00	−2.70	14.9

Reduction in radar cross-section of from 10 percent to 20 percent was consistently realized with the Polonium 210-coated model compared to the "dummy" model. The 20 percent reduction was obtained for the test conditions where the target surface (5 inch diameter target) was entirely coated with Polonium 210. Lesser reductions were obtained for the conditions where the target surface (18 inch diameter target) was only partially covered with Polonium 210. While this degree of radar cross-section reduction is, in and of itself, relatively small because of the low power source utilized, it shows the efficacy of the applicant's inventive concept. With higher strength sources, i.e., 35 curies per square inch, much greater radar cross-section reduction is potentially available from this system. FIG. 2 depicts the tremendous potential to be gained by the higher (1,000x) activity surface distribution as determined analytically.

The above tests were without airflow. However, while the velocity of the flowing air particles can be considered negligible compared to the initial velocity of the radioisotope emitted particles, the volume of air bombarded per unit time increases with increasing freestream velocity. Thus, it is of interest to consider the possible flight condition of an aerial vehicle traveling at Mach 3 (36,100 in/sec) at an altitude of 58,500 feet (0.1 standard atmosphere) with a coating of 35 millicuries of Polonium 210 per square inch over a 1 inch wide strip on a wing mean aerodynamic chord length of 942 inches. The α-particle range at 0.1 atmosphere is 15 inches. For the 942 inch strip 7.19×10^{16} free electrons are produced per second. The electron density production rate $q = 8.11 \times 10^9$ electrons/cm³/sec. Accounting for the recombination rate of air at 0.1 atmosphere the equilibrium electron density $n_e = (q/r)^{1/2} = (8.11 \times 10^9/1.1 \times 10^{-7})^{1/2} = 1.97 \times 10^8$ electrons/cm³ where q is the electron production rate per unit volume and r is the electron-ion recombination rate.

In addition to α-emitting Polonium 210, a small disk coated with 1.9 curies per square inch of Promethium 147, a beta emitter was also tested. Only nominal radar cross-section reduction was realized in these tests. However, more powerful β sources will undoubtedly show worthwhile results similar to the alpha emitter even if not as powerful or significant. Thorium **204** may be suitable in this regard.

About the same radar cross-section reduction was obtained with the plasma produced in an argon atmosphere as was obtained with the plasma produced in an air atmosphere. This result is highly significant since it shows that electron attachment is a negligible factor in the decay process of a radioisotope produced plasma in air since the electrons freed by the bombardment of high energy particles emitted from the radioisotope source possess such high velocities that they probably do not attach to the oxygen molecules of the air until after becoming thermalized as a result of undergoing many collisions with air particles. Argon has no ability to attach electrons regardless of the velocity of the free electrons and also has about the same ionization potential as air. If electron attachment was a significant factor in the decay process of the plasma produced by alpha particle emission in air (as it is in the decay process of the low energy plasma generated by the electron beam gun) then a lower electron density would have been sustained in the air plasma than in the argon plasma and a larger radar cross-section reduction would have resulted with the argon plasma compared to that with air. The test results show comparable radar cross-section reduction with either air or argon, thus demonstrating the apparently negligible role of electron attachment in the air plasma generated by Polonium 210.

Even the lower levels of cross-section reduction demonstrated by these relatively low energy tests can be effectively utilized to attenuate a radar wave that is subject to multiple reflections before being returned so that the efficiency of the radioisotope coated walls is effectively multiplied. Thus, the absorption effectiveness of a given plasma can be greatly increased for the case of a typical air induction inlet system or other types of intersections of external surfaces, i.e., a wing-body juncture. A radar beam, after entering a duct, bounces from wall to wall many times before it is returned from the duct. If each wall of the duct is coated with radioisotope material, then additional absorption of the radar electromagnetic energy can be realized upon each reflection. However, since the wave undergoes absorption, refraction, diffraction and reflection as it propagates into and out of the plasma during a single bounce, the reflection coefficients for each of the various surfaces will not be identical even if the plasma and incidence angle are identical. Such an application is shown in FIG. **3** wherein the radar wave enters the air induction system of an aircraft and is reflected a number of times before being returned. In such an arrangement the radioisotope-coated walls of the induction inlet would be particularly effective to absorb and attenuate such radar detection signals. Thus, the intersection of two external surfaces forming a corner such as a wing-fuselage intersection, and particularly the air induction inlet ducts, are the areas deriving the most benefit of radar cross-section reduction from the radioisotope-produced plasma. Since these regions account for the major portion of the returned radar signal from an aircraft, the significant countermeasure advantage resulting from the present invention is clearly evident. Since the radar signal from the ground or airborne detection station passes through the plasma twice in being reflected from a simple surface, the wave passes through four plasma thicknesses for an intersection, and in the case of the induction system duct of a supersonic aircraft, it may, for example, easily pass through as many as 14 or more plasma thicknesses, depending on the design of the inlet, before it returns to the receiving station.

The above test results have all been for normal incidence on the test surface. The angle that a radar beam from a ground station makes with a surface of an aerial vehicle would usually not be normal to the surface. This will increase the propagation length of the electromagnetic wave through the plasma and decrease the gradients of plasma properties along the path of the beam as compared to normal incidence. Thus, the reflection coefficient in such instances will be lower than that for normal incidence.

Additional means of producing higher electron densities and thereby increasing the radar absorption of a given radioisotope-produced plasma include the use of an artificial atmosphere having a lower ionization potential than air, such as ethyl chloride. Theoretical considerations also indicate that the attenuation of a radar beam can be enhanced if the cyclotron frequency, ω_c, of the free electrons of the plasma is set equal to the radar signal frequency by means of a superimposed DC magnetic field. The effect of an electrostatic field superimposed on a thermal plasma through which an electromagnetic wave is propagating may also be expected to increase the attenuation of the wave in the plasma. This field will force the free electrons to maintain high velocities even after collisions with many atoms and molecules that are tending to thermalize the electrons. Thus, the decay process, consisting primarily of electron recombination and attachment, of a given plasma may be slowed down, thereby resulting in higher electron densities being sustained in the plasma.

From the above tests, it is clear that an alpha emitter such as Polonium 210 can be applied as a thin coating over a flight vehicle's surfaces and will remain effective as a radar absorbing plasma generator for a period of years. FIG. 2 depicts the fact that a 35 millicurie per square inch distribution of Polonium 210 will absorb substantial percentages (0–40 percent) of the incident radar energy upon a single reflection from its coating and analytically shows that a 35 curie per square inch distribution of Polonium 210 will absorb very large percentages of the incident energy upon a single reflection over a wide band of frequencies at high altitudes (approximately 106,000 feet). Thus, it can be concluded that the radar absorption effectiveness of a given radioisotope surface coating distribution is increased at greater vehicle flight altitudes.

The thickness of the radioisotope generated plasma, which is the maximum distance an emitted particle travels normal to the radioisotope coated surface, is inversely proportional to the density of the medium through which it is propagating. Assuming 70 percent energy transmission through the protective gold flash coating on the Polonium 210 test articles, the maximum range of the emitted alpha particles is about 1, 10 and 100 inches at respective atmospheric densities of 1.00 (sea level), 0.10 (58,500 foot altitude) and 0.01 (106,000 foot altitude). If a thick plasma is required at low altitudes, the combination of an alpha and beta emitter may be desirable since the beta particles have a longer range in air than the alpha particles. Similarly, under certain circumstances, it may even be desirable to use a combination of alpha, beta and gamma ray emitters or other energy quanta to achieve the requisite plasma characteristics.

In the present invention the radioactive material can be applied to internal as well as external surfaces. Such surfaces may be of metal, plastic, ceramic, glass or other structural materials. The radioactive material may be plated, bonded, painted or otherwise attached, i.e., as by diffusion bonding, to the surface of the structural material. It may also be applied as a component of an ablative material such as a fired on ceramic or graphite surface coating layer.

While the absorption of electromagnetic wave energy has been specifically discussed with respect to radar wave lengths, it is equally applicable to the infrared portion of the electromagnetic spectrum and affords a means of avoiding detection by infrared sensors whether that infrared energy emanates from the vehicle or from a remote source.

Another important aspect of the present invention relates to the reduction of the skin friction and heat transfer from a surface having relative movement with respect to an enveloping or contacting fluid medium. The fact that the local skin friction coefficient C_f of a surface moving relative to an adjacent fluid is smaller at higher Reynold's numbers, R_e, where the thickness δ of the laminar sublayer portion of the turbulent boundary layer is greater has suggested the idea of artificially causing the laminar sublayer to grow thicker than the natural occurrence provides and thus yield a decrease in the local (C_f) and means (C_f) skin friction coefficient. So-called blowing boundary layer control has been used toward this end and consists of injecting a foreign gas, such as air, Freon 12, helium or hydrogen, through a porous surface into the natural boundary layer, thereby causing its thickness to grow by the mixing process which ensues between the local stream fluid of the natural boundary layer and the injected gas. The effect of the injected gas on the boundary laminar sublayer thickness has proven to be effective as a method of reducing skin friction as determined by force measurements and by total pressure surveys of the sublayer. Analytical and empirical studies of the gas injection method of blowing boundary layer control show that distortion of the natural shape of the sublayer's velocity profile occurs as well as the thickening effect and that the velocity profile distortion is in a direction such as to decrease the wall shear. The Stanton number, which is an indication of heat transfer to the wall, ($S_t = h/(\rho_1 \mu_1 C_p)$ where h is the local heat transfer coefficient, ρ_1 is the fluid mass density, μ_1 is fluid viscosity and C_p is the specific heat at constant pressure) and the local wall temperature are also decreased, primarily because the skin friction is reduced and also because the foreign gas is a hot sink. It has also been proven that, for equal mass flows, the greatest reduction of skin friction can be obtained with the lighter gases such as helium and hydrogen, which are injected at higher velocities, than for higher density gases injected at lower velocities. The injected energy does work upon the particles of the local stream fluid (laminar sublayer of the boundary layer) by molecular collisions and results in moving the local stream fluid particles through a distance away from the surface thereby causing the desired reduction in velocity gradient at the wall. A given quantity of injected kinetic energy can be supplied by large mass flows at low velocities or by low mass flows at large velocities with the injected energy being proportional to the square of the velocity.

It has been shown in the prior art (Institute of Aeronautical Sciences Report No. 59–78, 1959) that greater benefits, i.e., a decrease in the ratio of the average skin friction coefficient with gas injection (C_F) to the average skin friction coefficient without injection (C_{Fo})—a ratio defining the skin friction reduction effectiveness—can be attained by smaller particles of mass at higher velocities based on equal mass flow of the injected gases. Reducing the injected mass flow data of FIG. 4 (taken from IAS Report No. 59–78) for air, Freon 12 and helium to an equal momentum basis brings the three curves for the respective gases closer together, FIG. 5. Further reduction of the data to an equal energy basis results in substantially a single line representation for the three gases (within experimental limits) or at least a narrow bandwidth representation thereof (FIG. 6). Thus, it appears that skin friction reduction for the injection of different gases or particles may be correlated to the injected energy on a kinetic energy flux basis.

A surface coating of a radioactive material will by natural emission phenomena emit alpha particles, beta particles and gamma rays, as well as other particles or energy, and can thus be used to inject mass, momentum, and energy into the sublayer portion of the boundary layer of a fluid in motion relative to the radioactive surface. Such small particles emitted from the radioactive material at very high velocities may be injected into the sublayer to thicken and distort it in a manner similar to the gas injection method discussed above such that the local (C_f) and mean (C_F) skin friction coefficient and the Stanton number (St) are reduced. The alpha, beta and other particles emitted from a radioactive material are electrically charged and will ionize the local boundary layer fluid particles. This is desirable because Coulomb forces between the ionized particles further enhance the mixing process due to molecular collisions, thereby yielding favorable results. As shown in FIG. 7, this accomplishes the same desirable results, i.e., laminar sublayer thickening and velocity profile distortion so as to decrease the wall shear, as the blowing boundary layer gas injection technique, while eliminating the ducting, large pumping power, weight and structural requirements that complicate the gas injection method. The results of wind tunnel tests accomplished at a freestream Mach number of 0.4 and nominal total pressures of 0.10, 0.25, 0.50 and 1.00 atmospheres are shown in FIGS. 7, 8 and 9. In these tests an "active" model having a test surface coated with Polonium 210 to a density of 9.68 mc/in^2, with a protective gold flash coating (approx. 0.000001 inch thick) electroplated over the radioisotope, was housed in a splitter plate positioned flush with the tunnel wall. Static pressure taps were used to determine the local Mach number. A boundary layer trip of 0.033 inch height (sized to provide transition at the lowest Reynolds number test condition) was located on the tunnel wall 2.39 feet upstream of the test model's spanwise centerline to insure a turbulent boundary layer condition over the model surface.

The laminar sublayer velocity profiles were measured by means of a boundary layer rake from a point just forward of the test surface to just aft of the surface. This rake consisted of six total pressure probes and six total temperature probes having a maximum probe height of 0.30 inch. The decrement in velocity from just forward of the test model to just aft of the model is a measure of skin friction drag of the test model's surface.

Based on the measured boundary layer thickness naturally developed on a dummy model having no radioisotope coating, the boundary layer transition point (transition from laminar to turbulent flow) was computed to be 13.7 inches upstream of the model's spanwise centerline thereby assuring a turbulent boundary layer at the test specimen. Local skin friction coefficients computed at the chordwise center of both the dummy and active test models as a function of the wind tunnel Reynold's Number are shown in FIG. 7.

Local skin friction reduction effectiveness due to the flux of kinetic energy from the radioisotope coating as a function of tunnel air density is shown in FIG. 8. Drastic skin friction reductions of as much as 80 percent were realized at the lower air density test conditions due to the alpha bombardment, however, no significant effect was noted for the low radioisotope concentration utilized in this test at a tunnel density of 1.0 atmosphere. This variation is in agreement with the predictable trend of effectiveness that a given rate of injected kinetic energy flux from a surface would provide greater skin friction reduction effectiveness as the atmospheric density of the airflow is reduced. A physical appreciation of this condition may be arrived at by visualizing that the emitted kinetic energy flux is doing work on the air particles and altering the boundary layer profile (particularly in the sublayer region) thereby reducing the velocity gradient at the wall. The fewer air particles contained in the boundary layer flow (lower air density) the more effective will be a given quantity of energy flux.

Thus, it is evident that a significant skin friction drag reduction can be achieved at high altitude for any air vehicle having a radioisotope surface coating. FIG. 9 depicts, as a first approximation, this effect based on ambient air density variation with altitude. Actually, on a more rigorous basis, the local skin friction reduction effectiveness is a function of local air density, which is also dependent on the vehicle's configuration, attitude and velocity as well as flight altitude.

Although the test results herein were obtained at low speed, they are indicative of turbulent skin friction reductions that can be realized at supersonic and hypersonic velocities. Unlike the inviscid flow field, no abrupt changes occur in boundary layer phenomena as the Mach number is increased from subsonic to supersonic or from supersonic to hypersonic regimes. Only slight differences in skin friction reduction effectiveness should result due to compressibility. This essential independence of Mach number peculiar to boundary layer flow has been demonstrated by low and high speed boundary layer control data obtained for gas injection through porous walls.

While the above discussion has been limited to turbulent flow, similar effects should result when applied to laminar boundary layers. In application to laminar flow, however, care must be taken not to trip the boundary layer into turbulence by the injection of too much kinetic energy flux. Such destabilizing laminar flow effects have been noted in studies utilizing gas injection through porous walls.

The results described herein have been attained by the use of relatively low specific surface activities of Polonium 210 (9.68 millicuries/in.^{2}). Such specific surface activity may be readily increased manyfold, thus resulting in still greater skin friction and base drag reductions, including the 1.0 atmospheric density condition. Furthermore, in practical use, a single application of a relatively long lived radioisotope, suitably protected by a thin seal coating, will be capable of effective boundary layer control for a period of years.

In the flow regime of rarefield gases, in near free molecular flow as well as in actual free molecular flow, where the Knudsen Number, Kn, (ratio of mean free path between free stream fluid particles to the characteristic length of the vehicle) is equal to or greater than one, the drag of the vehicle caused by the resistance of the fluid to the vehicle's relative motion to the fluid results from the impact of the stream particles on the vehicle surfaces. A radioactive coating on the surfaces of such a vehicle can emit high energy particles and waves which will interact with the oncoming stream particles before or after they collide with the vehicle's surfaces and thus reduce the drag of the vehicle. In these flow regimes, no region of the flow field is defined as a boundary layer, as such, but the effect of high energy particles or waves emitted from a radioactive material surface coating will yield the same favorable result of a reduction in drag.

The radioisotope coating of the present invention also has the favorable result of reducing the base drag of vehicles having blunt base shapes. Base drag results from the entrainment, by aspirator effect of the boundary layer flow, of the fluid particles in the base region. As a consequence of this entrainment process, the static pressure acting on the base of the vehicle is reduced thereby reducing the force acting on the vehicle base that tends to push the vehicle through the fluid. This reduction in the base force is generally referred to as "base drag." Thus, thickening of the boundary layer and reduction of the flow velocity of the boundary layer fluid particles by means of the present invention also serves to reduce base drag, as well as skin friction.

In addition to base drag reduction by means of a radioisotope coating, it should be pointed out that it has not heretofore been recognized that a similar result, i.e., base drag reduction, may be achieved by the more conventional injection of gases or heat energy into the boundary layer as it flows over the surfaces upstream of the base region.

It is known that the frequency of an ionized media is the lower frequency limit for the propagation of longitudinal waves through such a media and that a longitudinal wave whose frequency is less than the plasma frequency can not be transmitted through the plasma (*Conduction of Electricity Through Gases*, Volume 2, Cambridge Press, 1933, Thomson, Sr., J. J. and M. A. Thomson). Thus, the application of a suitable radioisotope coating on a body or system that is either generating or receiving longitudinal waves may be utilized to attenuate and absorb such waves. The radioisotope should be selected to produce a plasma frequency high than the longitudinal wave frequency to be attenuated and capable of producing an electron density sufficient to result in the required attenuation. All longitudinal waves regardless of frequency, wavelength, amplitude or the mediums involved are capable of being thus attenuated. This includes the spectrum of audible sound waves. Thus, longitudinal waves from a reflecting or radiating body can be made to oscillate differently or not at all. In this fashion sound waves may be attenuated so as to be prevented from impinging on the human ear, deformation and rupture of structural materials exposed to acoustical vibrations may be lessened or eliminated and sonar type acoustic detection systems may be effectively nullified.

Another significant aspect of the present invention is that it provides a means for effectively shielding the human body from the harmful physical effects of the increasing amounts of high energy electromagnetic radiation generated by man in the utilization of various high frequency systems. Experiments on animals have shown that high level electromagnetic radiation produces heat within the organs as well as at the skin of such animals thereby increasing body temperature with particularly severe effects on the viscous materials of the eyeballs. Temporary sterility also resulted from such exposure. By enveloping such a harmful electromagnetic generating system in a suitable radioisotope produced plasma sheath the transmitted radiation may be greatly reduced regardless of the frequency, wavelength, amplitude or types of mediums involved. Since visible light is within the spectrum of electromagnetic waves, this means that visible light radiated or reflected from a body may be attenuated and made to appear differently to the human eye.

In recent years consideration has been given to providing high speed reentry vehicles with a means of flight control by utilizing magnetohydrodynamic (MHD) principles wherein an electric or a magnetic field is generated around the nose region of the reentry vehicle. Such control systems, however, are dependent on the interaction between the electric or magnetic field and the thermal plasma generated within the flow field surrounding the vehicle solely during reentry. By using a radioisotope generated plasma to interact with a MHD flight control system, such a system can be made independent of atmospheric altitude or flight speed.

In addition to the many significant advantages set forth above which result from a radioisotope surface coating, the plasma sheath produced by such a coating will also prevent the static electricity buildup on the external surfaces of an aerial vehicle which results from air friction on such surfaces as well as free electron generation in jet engine combustion chambers. Since the plasma sheath changes the air from a poor conductor to an excellent conductor of electricity, static charges will be conducted away through the plasma and thus prevent the buildup of such charges on a vehicle.

While particular embodiments of this invention have been illustrated and described herein, it will be apparent that various changes and modifications may be made therein without departing from the spirit and scope of this invention in its broader aspects or as defined in the following claims.

I claim:

1. An arrangement for altering the kinetic and electrical properties of a fluid medium adjacent a surface comprising a body having a surface in contact with a fluid medium and a coating on said surface emitting energy quanta into the fluid medium to ionize and to inject kinetic energy into such medium whereby the propagation of electromagnetic and longitudinal wave energy through the fluid medium is attenuated and the frictional drag on said surface of such fluid medium when moving relative to the surface is reduced.

2. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 1 wherein said coating comprises a thin film coating of a radioisotope material.

3. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 2 and further including a thin coating of a protective material deposited over said radioisotope material to prevent dislodgment of such material.

4. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 2 wherein said coating comprises a thin film coating of an alpha emitting radioisotope material.

5. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 2 wherein the majority of the electrically charged particles generated by the radioisotope material have an energy level of from 4 to 2,000 electron volts.

6. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 1 wherein said coating comprises a thin film of Polonium 210 plated onto a metal substrate.

7. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 6 and further including a thin flash coating of gold plated over said Polonium 210.

8. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 1 and further including means for injecting into the fluid medium to be ionized a material of a lower ionization potential level than that of the fluid medium to assist in initiation and enhancement of the ionization process.

9. An arrangement for altering the kinetic and electrical properties of a fluid medium as set forth in claim 1 and further including means for superimposing a DC magnetic field on the ionized fluid medium to enhance the ionization process.

10. A method for decreasing the electromagnetic and longitudinal wave transmission properties of a gaseous medium adjacent a surface comprising providing a body having a surface capable of generating or reflecting electromagnetic and longitudinal wave energy and coating onto said surface a radioisotope material for producing an ionized plasma adjacent said coating for decreasing the amount of radiated energy passing through said plasma.

11. A method for decreasing the wave transmission properties of a gaseous medium adjacent a surface as set forth in claim 10 wherein said coating is selected from the group consisting of Polonium 210, Promethium 147, Curium 242, or Thorium 204.

12. A method for reducing the radar and infrared cross section of a surface subjected to impingement of electromagnetic wave energy comprising providing a body capable of reflecting electromagnetic wave energy and applying a radioisotope coating onto said body for producing an ionized plasma sheath adjacent to and extending outwardly from said coating for decreasing the amount of electromagnetic wave energy radiated to and reflected from said body through said plasma sheath.

13. A method for reducing the skin friction and heat transfer from a surface having relative movement of a fluid thereover comprising applying to said surface a material, said material undergoing a nuclear transformation resulting in the emission of high kinetic energy particles into the boundary layer adjacent said surface and moving said surface relative to said fluid whereby the skin friction and heat transfer from said surface are thereby reduced.

14. As an article of manufacture, an aerospace vehicle surface adapted to be exposed to the adjacent atmosphere having a thin film coating of a radioisotope material capable of emitting particles having sufficient energy to ionize the adjacent atmosphere.

15. A method for reducing the radar and infrared cross section of a surface as set forth in claim 12, including the step of absorbing, refracting and diffracting the generated or reflected electromagnetic wave energy in said ionized sheath so that the electromagnetic energy radiated to and reflected from said body is decreased.

16. A method for reducing the radar and infrared cross section of a surface as set forth in claim 12, including the step of generating an electron gradient in said sheath which gradually decreases with increasing distance from the coating to create a substantial impedance match to incident electromagnetic energy so that no substantial sharply defined outer boundary to said plasma sheath exists to act as a reflective surface to said electromagnetic wave.

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