(NASA-Case-MFS-25843-1) METHOD AND APPARATUS FOR SUPPRESSING IGNITION OVERPRESSURE IN SOLID ROCKET PROPULSION SYSTEMS Patent Application (NASA) 15 p HC A02/MF A01 CSCL 21H G3/20

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NASA CASE NO. MFS-25,843-1

PRINT FIGURE 1

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Serial No. 444,125
Filed: 11/24/82

MSFC

NASA Case No. MFS-25843

Method and Apparatus for Suppressing Ignition Overpressure in Solid Rocket Propulsion Systems

Technical Abstract

This invention relates to suppression of the transient overpressure wave produced upon ignition of large solid rocket motors such as the motors of the Solid Rocket Booster.

The overpressure wave produced by exhaust plume 49 is suppressed by providing within launch platform 26 a plurality of pipes 42 and spray heads 44 around the periphery of the plume and spraying water into the upper end of the plume during ignition. A large amount of water, preferably equivalent in mass to 0.8 to 2.0 times the mass of plume exhaust products, is sprayed into the plume in a direction generally perpendicular to plume flow. The invention is used in combination with existing measures, in particular, exhaust deflector plates and open trenches for directing the flow of exhaust gases away from the launching pad.

Novelty of the invention is believed to reside in directing the water spray into the upper portion of the plume so as to suppress the transient wave at its source. This measure provides more than a threefold reduction in magnitude of the wave and minimizes the danger of damage from overpressure during launching.

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METHOD AND APPARATUS FOR SUPPRESSING IGNITION OVERPRESSURE IN SOLID ROCKET PROPULSION SYSTEMS

Origin of the Invention

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

Technical Field

This invention relates to rocket propulsion systems and more particularly to suppression of transient overpressure produced upon ignition of solid rocket motors.

Background Art

One of the problems presented in launching of space vehicles such as the Space Shuttle is to minimize destructive effects of rocket motor exhaust gas flows. The large rocket motors required for launching such vehicles eject vast quantities of exhaust gases at high velocities and high temperatures, creating powerful shock waves in the air. Two types of wave phenomena are of concern in the Space Shuttle launch environment -- steady-state acoustical waves produced over a period of ten seconds from ignition of liquid-fueled Space Shuttle Main Engines (SSME) until after liftoff and a transient overpressure wave that occurs upon ignition of large solid rocket motors of the two Solid Rocket Boosters (SRB) some five seconds after SSME ignition.

The need for suppression of acoustic waves in launching of the Shuttle arises from susceptibility of certain vehicle components, as well as payload experiment hardware, to damage from the combined effects of low-frequency and acoustically induced higher frequency loads. This requirement was recognized prior to the first Shuttle launch, and a noise-suppression system was developed to meet it. A major feature of the system provided for spraying of water on deflector plates located some fifty feet below the exhaust plane of the rocket motors, the water spray serving to protect the plates from thermal damage as well as to reduce acoustic levels.

In regard to transient overpressure, ignition of solid rocket motors results in a pressure wave having an amplitude and frequency determined by various factors, primarily the pressure rise rate of the motor chamber and the extent to which exhaust gases are confined by the exhaust trenches and other features of the launch pad structure. Shuttle SRB motors produce over 2½ million pounds of thrust each and are started up by a three-stage igniter system that induces a chamber pressure rate rise of 9,000 pounds per square inch per second in reaching a steady-state chamber pressure of about 850 psi. This rapid pressure rise results in expulsion of hot gases at a very high rate, creating a "piston" effect in the semi-confined, channelized volume underneath the launching pad. A transient overpressure wave originates from an apparent source region near the top of the exhaust deflector of the launch pad structure and moves upward across the Shuttle Orbiter vehicle before liftoff from the pad. Owing to the manner in which the Orbiter is mounted on the External Tank and SRB's, movement of the wave across the Orbiter is directional rather than symmetrical so that the effects of large pressure differentials across the Orbiter, in terms of vehicle loads, are accentuated. Certain regions of the Orbiter, in particular, wings, elevons, heat shield and payload bay, undergo a strong dynamic response approaching design limits. Although considerable knowledge regarding ignition overpressure waves had become available prior to the first Shuttle launch, the extent of the problem in terms of pressure differential imposed on the vehicle and its structural response was not fully recognized. Data from that launch, however, demonstrated a clear need for suppression of such waves.

Various measures have been used previously for suppression of acoustic and thermal effects of rocket motor exhausts. As pointed out above, the launching system for the first Shuttle launch included provisions for spraying large amounts of water at locations well below the rocket motor exhaust plane, and principally at the crest of the deflector used to direct exhaust gases into trenches leading away from the launch pad. This approach, while useful for control of acoustic levels, has no effect on transient ignition overpressure waves. Water sprays have also been applied further upstream of a jet motor exhaust to control acoustic levels, as disclosed by Burdett et al in U. S. Patent 2,692,024. This patent deals with an unconfined jet blast of a liquid-fueled motor, with water being sprayed into the exhaust plume from openings in pipes located within the confines of the plume. The teachings of this patent differ from the present invention in that the patent is concerned only with reduction of acoustic levels in an unconfined jet blast of a liquid-fueled motor, and not with reduction of the magnitude of an ignition overpressure wave from a solid-fueled motor in a semi-confined environment. Placement of spray hardware directly in the exhaust plume as taught by Burdett et al would not be feasible because of the extreme conditions produced by Shuttle motors. The hardware would serve to "choke" the gas stream, accentuating rather than suppressing the overpressure wave, and/or to disintegrate, creating destructive debris. Covering of exhaust ducts, which serves to further confine the exhaust gas stream, has also been used to reduce acoustic levels, but this measure as applied to large solid motors would intensify the "piston" effect involved in ignition overpressure and thus increase the magnitude of the wave. In the case of solid rocket motors fired in a closed or confined environment such as from a silo, water sprays have been found to increase, rather than decrease, the magnitude of ignition overpressure waves.

Statement of Invention

In the present invention the transient overpressure wave produced upon ignition of a solid rocket motor under conditions whereby the exhaust gas stream is deflected and directed outward through open trenches is suppressed by spraying an effective amount of water into the upper portion of the exhaust gas plume of the rocket motor from means disposed outside the plume. The water spray for Space Shuttle launchings is delivered through piping and nozzles located in the launch platform and disposed around the periphery of the solid rocket motor plume areas and well above the location previously used for suppression of acoustic levels. Spraying water into solid rocket exhaust plumes in accordance with the invention produces more than a threefold reduction in the magnitude of transient ignition overpressure waves and thus diminishes the possibility of damage from this source.

It is an object of the invention to provide a method for suppressing the transient overpressure wave produced upon ignition of solid rocket motors.

Another object is to provide a method of protecting space vehicles from damage due to ignition overpressure waves from large solid rocket motors.

Still another object is to provide apparatus for use in suppressing such waves.

Brief Description of the Drawings

Figure 1 is a side view, partly in section and with parts removed, showing the Space Shuttle and its launch environment shortly after ignition of Solid Rocket Booster motors.

Figure 2 is a top view looking down into one of the SRB exhaust holes in the launch platform and showing piping for delivery of a water spray in accordance with the invention.

Figure 3 is a graph showing the effect on overpressure suppression of varying the exhaust stream density function by varying the amount of water sprayed.

Figures 4a, 4b, and 4c are graphs showing actual SRB ignition overpressure data from two Shuttle launchings, one with and the other without use of suppression measures of the present invention.

Detailed Description of the Invention

Referring to the drawings, Figure 1 shows the Space Shuttle 10 in its launch environment, with features unrelated to the invention being removed for the sake of clarity. The Shuttle at launching is made up of the Orbiter vehicle 12 powered by SSME engines 14; External Tank 16, to which the Orbiter is secured by releasable supports 18; and two Solid Rocket Boosters 20, secured to the External Tank on opposite sides thereof, only one of the two identical SRB's being shown in the side view of Figure 1. The structure of each SRB includes an aft skirt 22 near the bottom end and a rocket nozzle 24 extending axially past the aft skirt. The assembled Shuttle is disposed for launching on Mobile Launch Platform 26, which, along with a launch tower (not shown) serves to support the Shuttle and associated launch equipment. Directly underneath each SRB the floored metal framework of the platform has extending therethrough an exhaust hole 28 for passage of exhaust gases, and a similar hole 30 is located below the Orbiter for passage of SSME exhaust gases. The launching platform is located well above ground level and is supported by pedestals, not shown. Side deflector plates, only one of which 32 is shown in Figure 1, are disposed between the platform and trenches below so as to direct the flow of exhaust gases in the desired direction. A large uncovered trench of generally rectangular cross-section is provided underneath each exhaust hole, the trenches serving to facilitate removal of exhaust gases away from the launch area during the critical period prior to liftoff. In the view shown

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trench 34 for SRB 20 extends outward horizontally to the right and trench 36 for SSME exhausts extends horizontally in the opposite direction. Exhaust gas flow from the respective rocket motors is directed into the trenches by means of deflectors 38 and 40 disposed diagonally in opposite directions.

Water spray into SRB plumes is supplied from a source and headers (not shown) through pipes 42 and spray heads 44 disposed around the periphery and near the top of the plume 46 ejected from rocket nozzle 24. Only two of the eight spray heads and pipes actually used are shown in Figure 1 for the sake of clarity. The water spray 48 is directed generally perpendicularly into the exhaust plume in order to obtain maximum mixing and overpressure suppression.

Troughs 50 filled with water are provided at the top of exhaust hole 28 in a manner such as to cover any open space, the water troughs serving to block the reflection of energy upward into the Shuttle before liftoff. No water spray is directed into the corresponding portion of plume 52 from SSME motors 14 inasmuch as ignition overpressure is not a significant problem for these liquid-fueled motors.

Figure 2 shows the arrangement of pipes and spray heads actually used to deliver water spray to Shuttle SRB plumes. In this view, looking down into SRB exhaust hole 28 of launch platform 26, two water pipes 42 are shown disposed on each of the four sides of the hole, with each pipe being connected to a spray head 44. The heads are positioned so that water 48 from each one is sprayed horizontally toward the center of the hole. Two of the spray heads 44(a) are disposed at a lower level than the other six; this is because of the presence of haunches 54 for supporting columns 56, which in turn support the SRB. One of the water troughs 50 covering the remainder of hole 28 is also shown in this view. Ideally, equal amounts of water spray would be delivered to the top portion of the plume 49 from all sides of the hole; however, in the arrangement shown in Figure 2 less water is delivered through heads 44c than through heads 44b and 44d, and the water provided through heads 44a is delivered at a lower region of the plume because the presence of the haunches and other hardware interfered with equal sizing and spacing of the required piping. The arrangement shown, while not ideal, is nontheless effective.

Figure 3 of the drawings graphically shows the effects of the amount of water sprayed, in terms of water injection rate, on Density Rate Function (DRF) which in turn correlates, within limits, with the extent of overpressure suppression. The DRF in this graph is defined as the ratio of initial exhaust stream density ρD, without water addition, to the stream Density ρW, achieved with water addition, and the water injection rate ωD is defined as the ratio of water mass flow rate W_W to propellant mass flow rate W_ρ. At the lower water injection rates, that is, below 1, curve 58 shows a decrease in DRF values with increasing water injection rates that correlates directly with the extent of overpressure suppression and thus reflects the inverse relationship of maximum amplitude of ignition overpressure to exhaust stream density. At higher water injection rates no further suppression is obtained owing to a "choking" effect characterized by incomplete mixing of water and exhaust gases and formation of a "wall" of water having unpredictable or even adverse effects on suppression. The result is a band of uncertainty shown by shaded area 60 of the graph. The optimum range of water injection rates, and thus the preferred range for suppression in accordance with the invention is from .8 to 2.0 as shown by line 61 in the figure. At very high injection rates, as shown by the right hand portion of the graph, little suppression is obtained and uncertainty of result is increased. The results depicted in this graph have been verified analytically and have been found to be consistent with actual test data.

The effects of spraying water by the method of the invention on the magnitude of transient overpressure waves in actual Shuttle firings may be seen by reference to Figures 4a, 4b, and 4c. Figure 4a shows at data curve 64 pressure measurements with time obtained from a pressure guage located at the top of SRB hole 50 on the launching platform during launch of the first Shuttle (STS-1). A strong positive pressure peak or peaks occurred at 4.1 seconds after SSME igniton, which corresponds to 165 milliseconds after SRB ignition. The positive peak in turn was followed by a strong negative peak. A pressure wave of this magnitude approaches design limits of various components of the Orbiter vehicle and thus is a matter of great concern. Data curve 63 shows pressure measurements taken at the same location during launching of STS-2 and under the same conditions except that 100,000 gallons per minute of water were sprayed into the top of each SRB plume by means of the apparatus shown in Figure 2. Use of the water spray resulted in highly effective suppression of the transient overpressure wave, leaving only a slight variation, well within design limits.

Figures 4b and 4c show pressure values obtained for the same launchings, STS-1 and STS-2, respectively, measured on the Orbiter vehicle at a heat shield located between SSME's. Remaining traces of the transient overpressure wave are more clearly seen in this view. Suppression at this location, however, was also highly effective, a five fold reduction in magnitude being obtained.

While the invention has been described relative to specific embodiments, it is evident that modifications and changes may be made with regard thereto without departing from the scope of the invention.

METHOD AND APPARATUS FOR SUPPRESSING IGNITION OVERPRESSURE IN SOLID ROCKET PROPULSION SYSTEMS

ABSTRACT

The transient overpressure wave produced upon ignition of a solid rocket booster (20) is suppressed by providing within the launch platform (26) a plurality of pipes (42) and spray heads (44) disposed around the periphery of the exhaust gas plume (49) near its upper end and spraying water into the upper end of the plume during ignition. A large amount of water, preferably equivalent in mass to 0.8 to 2.0 times the mass of exhaust products being ejected, is sprayed into the plume in a direction generally perpendicular to plume flow.

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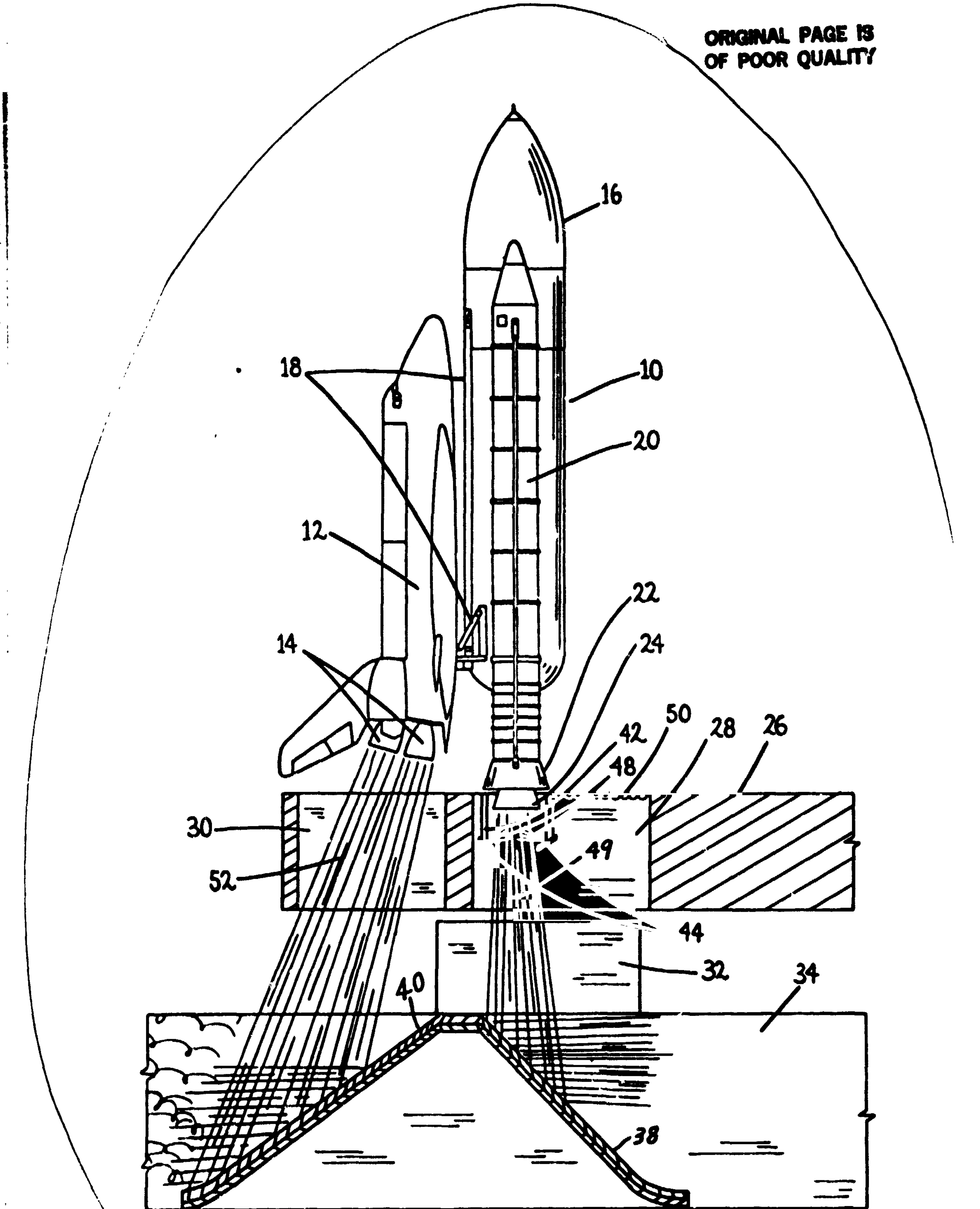

FIG. 1

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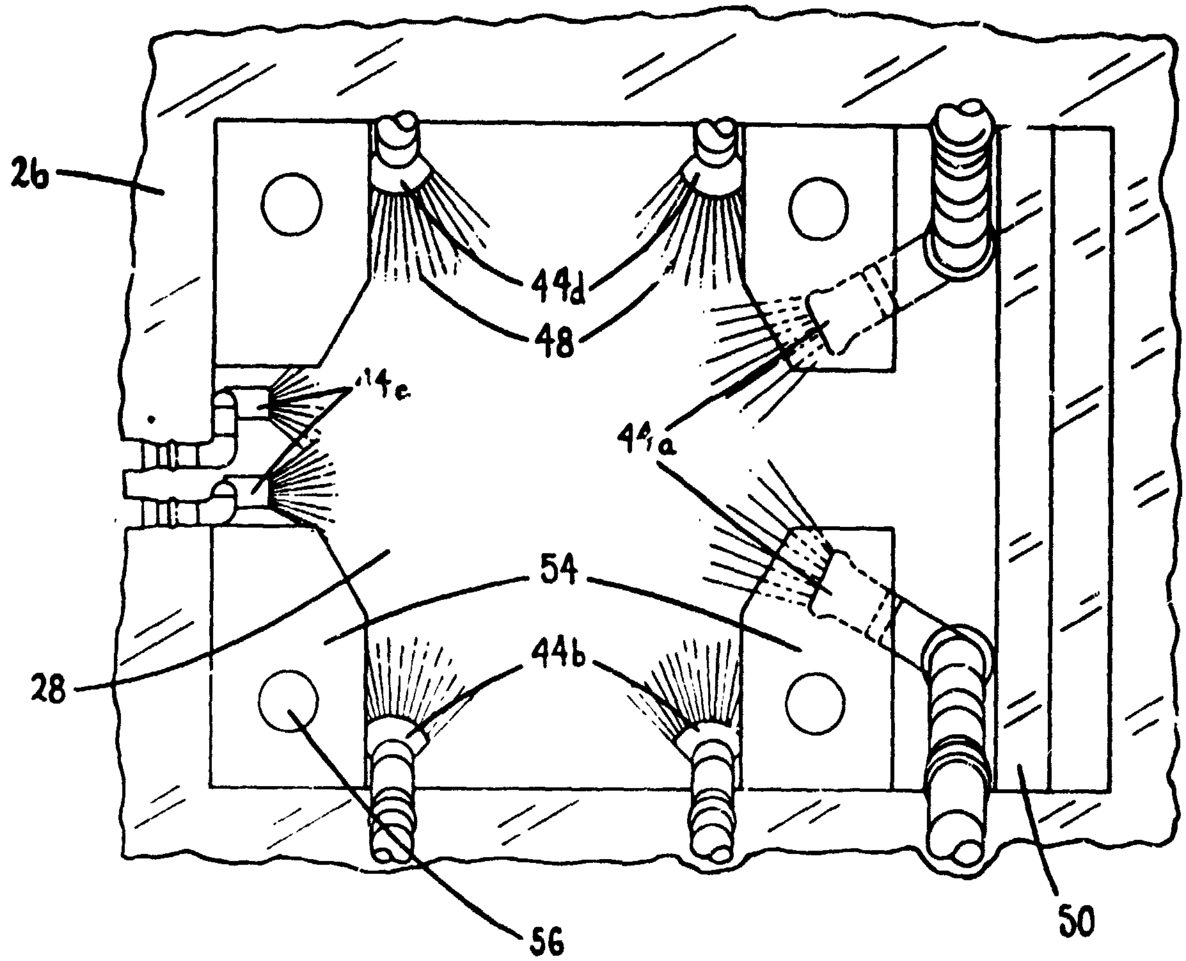

FIG. 2

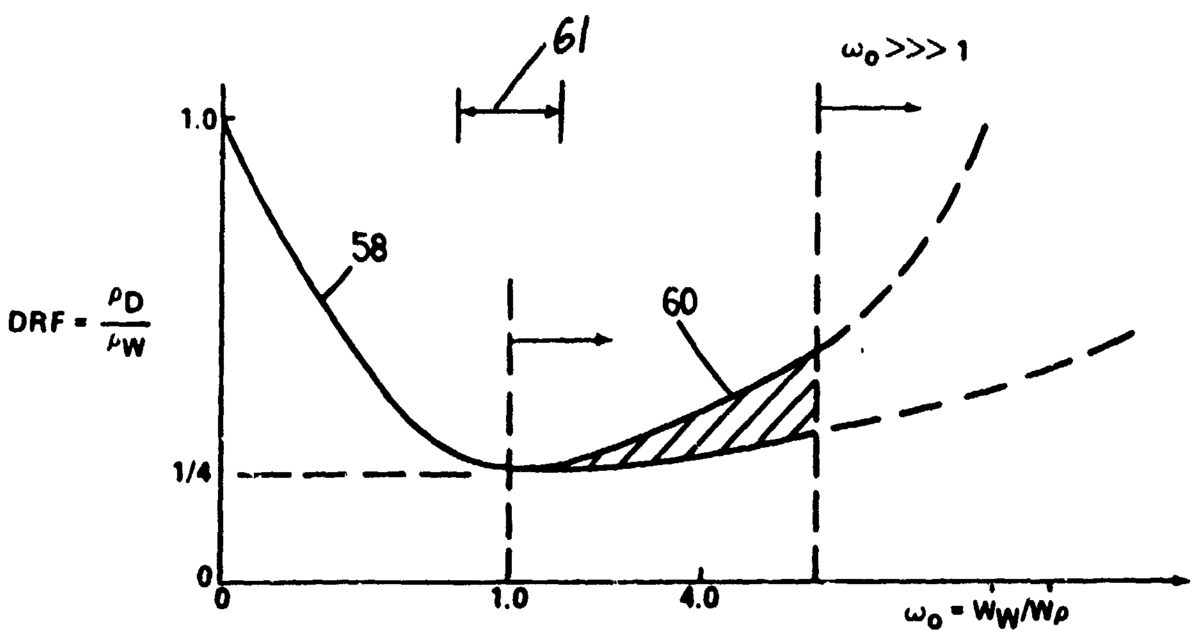

FIG. 3

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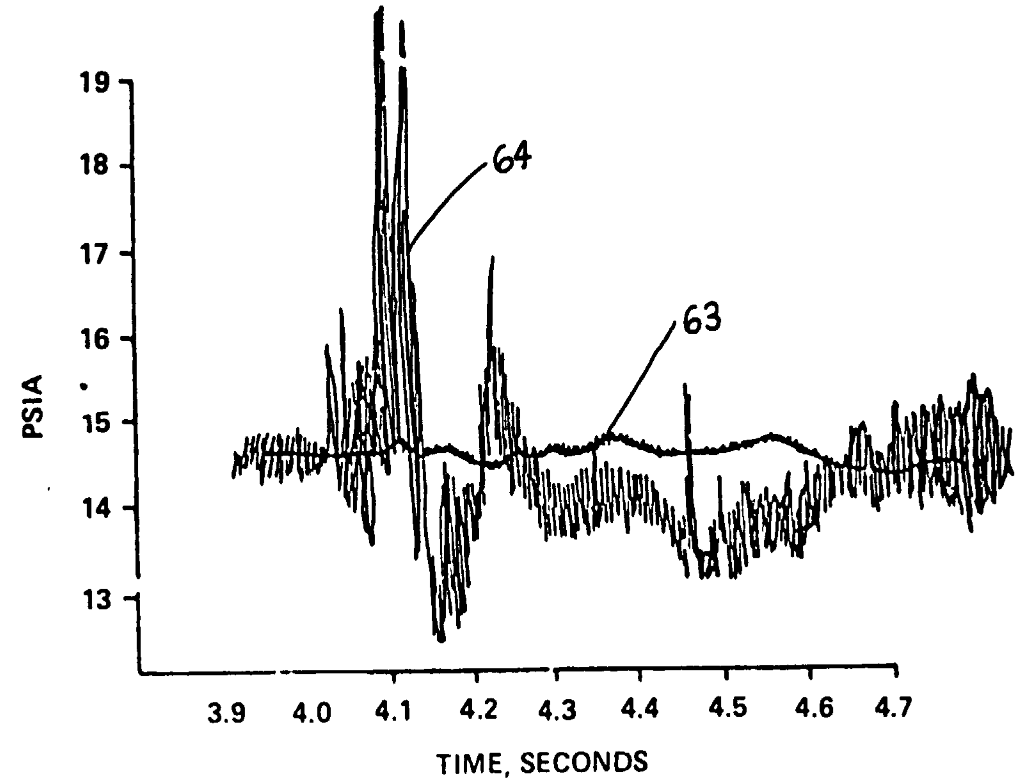

FIG. 4a

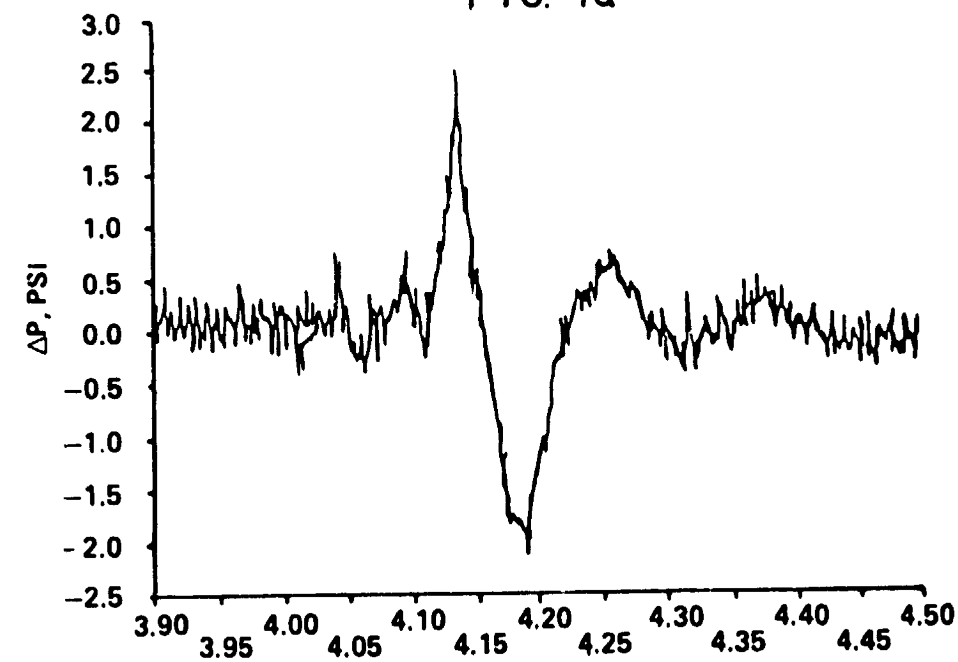

FIG 4b

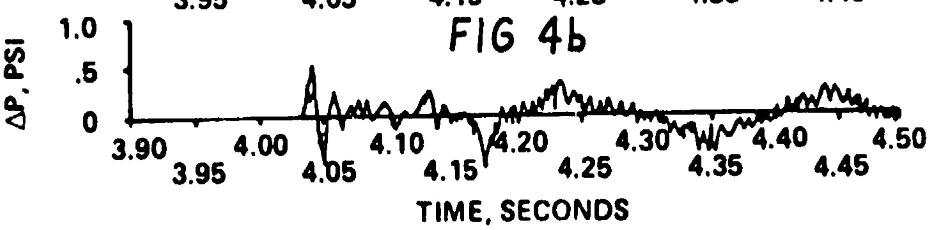

FIG. 4c