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[54] **APPARATUS AND METHOD FOR GENERATING LARGE MASS FLOW OF HIGH TEMPERATURE AIR AT HYPERSONIC SPEEDS**

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[52] **U.S. Cl.** **73/147**

[51] **Int. Cl.** **G01m 9/00**

[58] **Field of Search** 73/147

[56] **References Cited**

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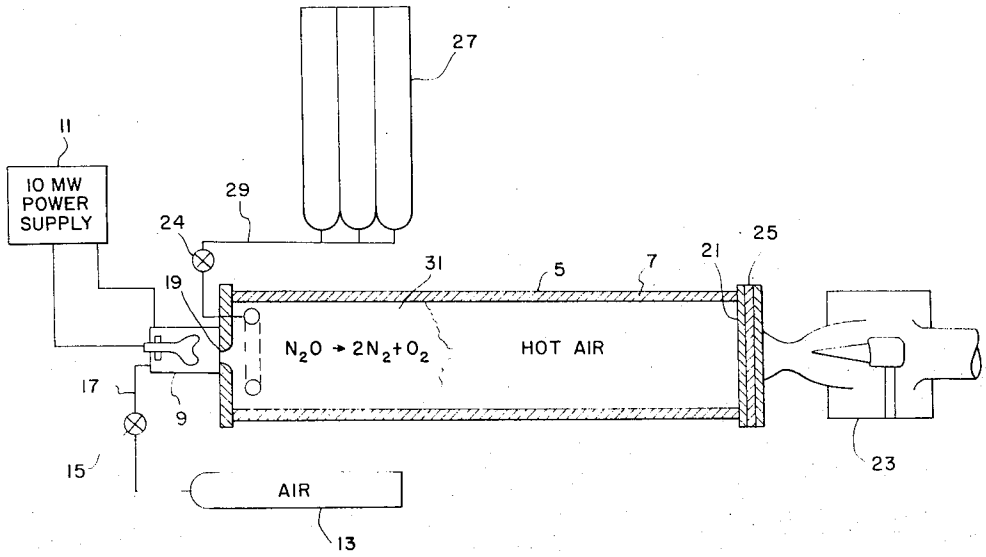
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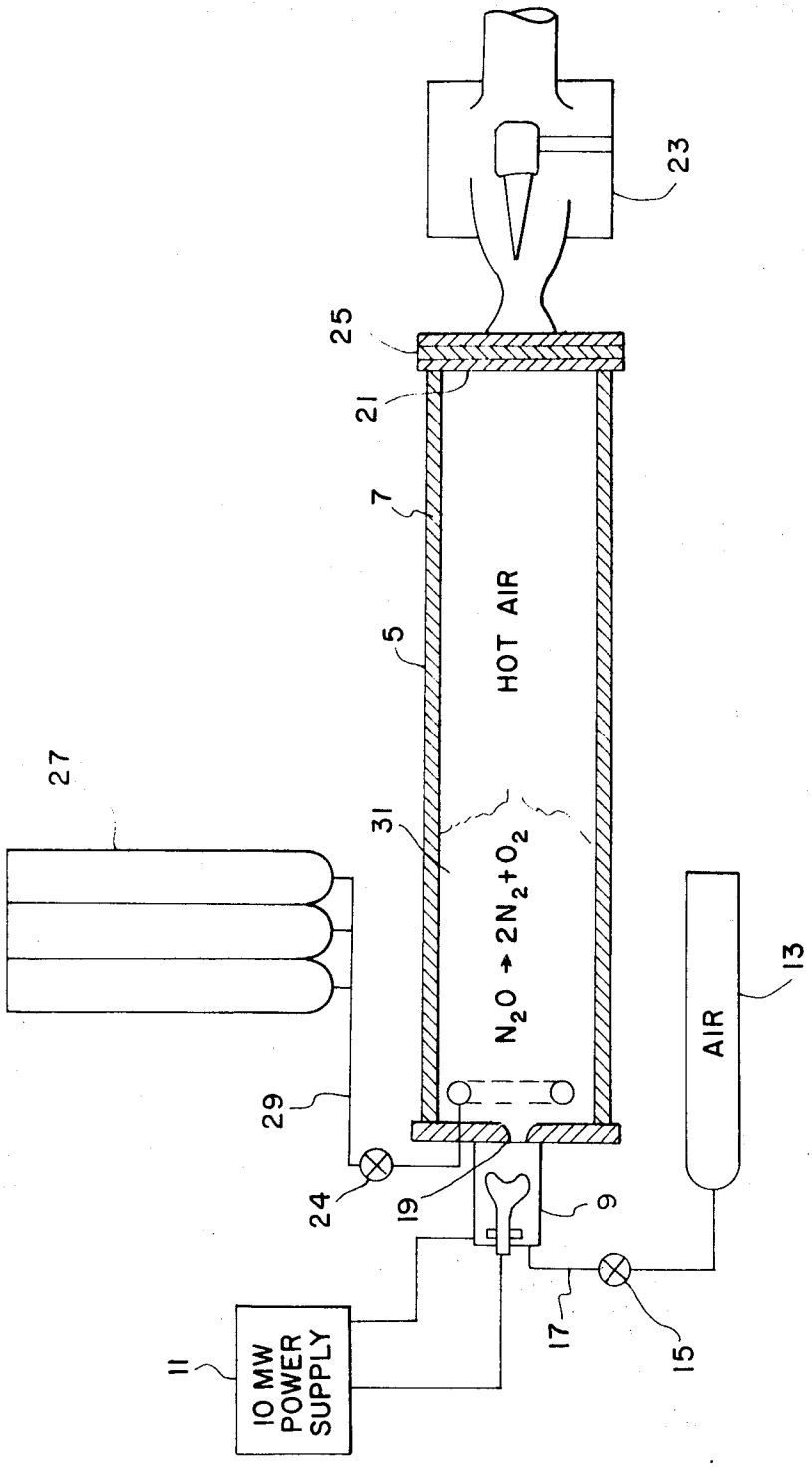
[57] **ABSTRACT**

High temperature, high mass air flow and a high Reynolds number test air flow in the Mach number 8–10 regime of adequate test flow duration is attained by pressurizing a ceramic-lined storage tank with air to a pressure of about 100 to 200 atmospheres. The air is heated to temperatures of 7,000° to 8,000°R prior to introduction into said tank by passing said air over an electric arc heater means. The air cools to 5,500° to 6,000°R while in the tank. A decomposable gas such as nitrous oxide or a combustible gas such as propane is injected into said tank after said pressurization and the heated pressurized air in said tank is rapidly released through a Mach number 8–10 nozzle. The injected gas medium upon contact with the heated pressurized air effects an exothermic reaction which maintains the pressure and temperature of the pressurized air during the rapid release.

The novel apparatus employed in the method comprises an elongated ceramic-lined storage tank having an inlet and an outlet, means for supplying air under presure to said tank through said inlet, electric arc heating means for heating said air prior to its introduction into said tank, a Mach number 8–10 hypersonic nozzle provided said outlet for discharging the heated and pressurized air from said tank, and means for supplying nitrous oxide near said inlet for supplying said heated air.

13 Claims, 1 Drawing Figure




23
25
21
7
5
HOT AIR
27
31
$N_2O \rightarrow 2N_2+O_2$
AIR
13
29
24
19
9
17
15
11
10 MW POWER SUPPLY

APPARATUS AND METHOD FOR GENERATING LARGE MASS FLOW OF HIGH TEMPERATURE AIR AT HYPERSONIC SPEEDS

ORIGIN OF 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 for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a device for producing air flow at hypersonic speed. More particularly, the present invention is directed to an improved method and apparatus for producing air flow at the speeds, high temperatures and high Reynolds numbers required to duplicate flight conditions at a Mach number of 8 to 10.

2. Description of the Prior Art

In air breathing propulsion research as, for instance, in ram jet, scramjet and air augmented rocket research, high temperature, high Reynolds number conditions in the Mach 8 to 10 regime are required to be duplicated in ground facilities. This is especially true for propulsion research since phenomena such as fuel mixing, ignition and combustion chemistry cannot be realistically studied with partial simulation in low temperature flow. Many aerodynamic and structural research areas would also benefit by the availability of a high Reynolds number, high temperature facility in this Mach number regime, particularly if the facility were of sufficient size to permit model testing with turbulent boundary layer conditions.

Currently, the limitations on ground facilities of this type result from a lack in ceramic-filled, gas-fired heaters of sufficiently high air temperature simulation or a lack of mass flow capability for electric arc-heated facilities. Impulse facilities such as shock tunnels have an inadequate test duration (5 to 10 milliseconds) for most types of propulsion or structural research problems. Propulsion facilities with true temperature simulation of the gas-fired, ceramic-filled type are limited to about a Mach number of 7. Electric arc-heated facilities wherein the air under high pressure gas is passed through an electric arc and then directly through a hypersonic nozzle, although able to reproduce air temperatures far in excess of those required for Mach number 8 to 10 simulation, are not contemplated for use if facilities of a size required for engine propulsion testing because of the very large values of mass flow and power required. Generation of power at these levels necessitates the use of very expensive power equipment.

In copending application Ser. No. 233,098 to William B. Boatright there is described a method and device for producing a high temperature, high density, high Reynolds number test air flow in the Mach number 8 to 10 regime. According to the disclosure of the copending application, electric arc-heated air is used to pressurize a ceramic-lined, high pressure storage vessel. After pressurization (requiring several minutes) a valve is opened at the downstream end of the storage vessel and the hot air in the storage vessel is discharged at a high mass flow rate through a hypersonic (M=8 to 10) nozzle. As embodiments of the invention of the copending application there are disclosed two methods

for holding the stagnation pressure constant during the test period when the hot gas is being discharge through the hypersonic nozzle. This is accomplished by simply dumping cold air or hot driver gas into the upstream end of the tank at the same rate that hot pressurized air is being exhausted from the vessel. Because of concern over the large degree of mixing of hot air and dumping gas with their widely different temperatures and densities, it was also proposed as a preferred embodiment of the invention that a traveling separator be positioned transverse to the longitudinal axis of the vessel or tank which separator has peripheral edges in sliding engagement with the internal walls of the tank.

In yet another mode described in the copending application the cold air or hot driver gas is introduced into the tank after pressurizing with the arc heater but prior to discharge of the hot air, thereby increasing the pressure in the tank and permitting tests at higher pressures than can be handled by the arc heater.

Although the methods of the copending application utilizing the injection of cold air or hot driver gas into the upstream end of the tank and preferably a traveling separator within the tank provide surprising advantages, they are not entirely without shortcomings. For example, when a free piston such as a traveling separator is used, close tolerances between it and the walls of the tank must be maintained, which for a large vessel can be difficult. Moreover, since the interior of the storage tank would generally be lined with a heat insulating refractory, this refractory would experience severe heat stresses as the piston or separator moved through the chamber. Also on injection of cold gas, severe heat stresses can result from the exposure to a rapid change in temperature and these stresses could then give rise to large ruptures in the refractory material.

In addition, because of the large difference in gas density between cold driven gas and hot driven gas, the cold gas would spill under the testing gas. This effect would reduce the available quantity of test gas. The problem is less severe when an elongated storage vessel is placed vertically and the incoming cold gas is introduced at the bottom, although diffusion of the two gases may present a problem.

It is an object of this invention, therefore, to provide an improved method for holding the pressure in the tank constant after pressurizing with the arc heater and during the test period when the storage vessel air is being exhausted through the hypersonic nozzle.

It is also an object of the invention to provide an improved method for increasing the pressure in the tank.

A further object of the invention is to accomplish the aforementioned objects while alleviating or eliminating the heat stresses in the insulating ceramic lining of the tank which can occur with the cold air injection method described in the copending application.

Yet another object of the invention is to achieve the aforementioned objects while reducing spilling of injected gas under the test gas as is likely to occur in the cold air injection method because of the large difference in gas density between the cold gas and the hot gas.

A further object of the invention is to accomplish the aforementioned objects without the need of a traveling separator.

BRIEF SUMMARY OF THE INVENTION

These and other objects of the invention are obtained by utilizing an elongated ceramic-lined storage tank having an inlet and an outlet, means for supplying air under pressure to said tank through said inlet, electric arc heating means for heating said air flow prior to its introduction into said tank, a Mach number 8 – 10 hypersonic nozzle provided said outlet for discharging the heated and pressurized air from said tank, and means for supplying gaseous medium near the tank inlet for the heated air, said gaseous medium upon contact with said hot pressurized air in said tank effecting an exothermic reaction that maintains the pressure and temperature of the pressurized air in the tank during said discharge.

Thus, according to the method of the invention, high temperature, high mass air flow and a high Reynolds number test air flow in the Mach number 8 – 10 regime of adequate test flow duration is obtained by pressurizing a ceramic-lined storage tank with air to a pressure of about 100 to 200 atmospheres and an average temperature after the storage period of about 5,500° to 6,000°R, heated prior to introduction into said tank by passing said air over an electric arc heater means, injecting said gaseous medium into the tank after said pressurization and rapidly releasing said heated pressurized air in said tank through a Mach number 8 – 10 nozzle.

The gaseous medium injected into the tank after pressurization may be a gas or a mixture of gases which decompose or combust under the temperature and pressure conditions inside the hot air pressurized tanks and effect an exothermic reaction that maintains the temperature and pressure of the tank during release of the pressurized hot air. Illustrative of a suitable decomposable gas is nitrous oxide. Suitable combustible gases are hydrocarbon gases such as propane, preferably in combination with stoichiometric proportions of free oxygen.

According to one embodiment of the invention, the gaseous medium under pressure is injected simultaneously with the release of the pressurized hot air and regulated to enter the tank at the same rate that hot air is leaving. In this way the tank pressure and temperature is held constant during the test period. Alternatively, the gaseous medium can be introduced prior to discharge of the hot air thereby increasing the pressure in the tank beyond that which a given arc heater can operate.

The gaseous medium is introduced into the storage tank below its ignition or decomposition temperature. In the case of a decomposable gas such as the nitrous oxide, when it enters the tank the high temperature of the hot pressurized air in the tank causes spontaneous decomposition of the nitrous oxide gas in a exothermic manner into nitrogen and oxygen. When a combustible gas is injected, on the other hand, the high temperature of the hot air in the tank causes the gas to ignite and burn forming products of combustion such as CO_2 and H_2O. In either case, the resulting exothermic reaction creates a gas volume in the tank of substantially increased temperature, the final temperature of the decomposed or combustion products upon completion of the reaction being about 3,000°R higher than the temperature of the gas introduced. The pressure generated by the continuous chemical decomposition or combustion maintains a constant storage pressure in the tank during the test period.

Generally the pressurizing period is about 2 to 4 minutes and the discharge period about 10 to 30 seconds. The concept of storing arc-heated air at high pressure is new and exploits the fact that even with appreciable heat losses of the air to the walls of the tank, the air temperature will still remain well above the temperature of the ceramic-lined walls of the tank. By contrast, the air in a gas-fired, ceramic-filled heater will always be less than the temperature of the ceramic brick since the bricks are used to heat the air. In addition, the high velocity air flowing between the bricks of a ceramic heater picks up dust from the bricks as they rub against each other due to thermal expansion and this causes a contamination problem. In the present invention, only low velocity air is in contact with the ceramic-lined walls of the tank.

BRIEF DESCRIPTION OF THE DRAWING

The invention will be further described with reference to the accompanying drawing which is a schematic diagram of the high enthalpy air tank apparatus of the invention in horizontal arrangement.

DETAILED DESCRIPTION OF THE INVENTION

The drawing represents an arrangement partially in section of components of a Mach number 9 facility capable of duplicating flight conditions in the air breathing corridor at this Mach number. Although the drawing shows the arrangement wherein the tank is vertical it should be understood that the invention also contemplates an arrangement wherein the tank is horizontal. This facility is sized for a 10 megawatt arc heater and should furnish a test duration of 5 to 10 seconds for a test section about 3 feet in diameter. Alternately, a smaller test section size can be used and this results in a longer running time for a given tank size. Also, if a higher powered arc heater or multiple heaters are used, then a larger tank might be used or the tank pressurization time might be decreased.

For a typical case shown in the drawing, the tank **5** is about 35 feet long and 4 feet in diameter and is lined with ceramic **7.** Its volume is 440 cubic feet and if the tank is pressurized to 100 atmospheres at an average temperature of 5,700°R at the end of the storage period, then the mass of the air in the tank would be 306 pounds. The tank is provided at one end with an arc heater **9** to which is connected a 10 megawatt power supply indicated diagramatically as **11** and an air supply **13.** A valve **15** is provided line **17** connecting the air supply **13** with arc heater **9.** Between the arc heater **9** and the tank **5** is an inlet **19** in the form of a water-cooled throat section about **0.5** inch in diameter. At the opposite end of the tank **5** an outlet **21** communicates with a hypersonic nozzle **23.** The outlet **21** is provided with a water-cooled gate valve **25.** A typical hypersonic nozzle **23** is characterized by the following specifications: Mach No. = 9; throat = 1.55 in diameter; Test section = 3.2 feet diameter; Total enthalpy = 1,740 B/lb.; Total pressure = 150 – 200 ATM; Total temperature = 5,760°R; Mass flow rate = **35** lb./sec.

A high pressure storage tank **27** for a gaseous medium such as nitrous oxide or propane is connected via line **29** with the tank **5** at the end where the arc heater is located. A valve **24** is provided line **29.** When propane is utilized as the gaseous medium in tank **27** it is

preferred to provide in addition means (not shown) foran oxidizer such as free oxygen and to have propane gas and oxygen mix just prior to entry in tank **5.**

In operation of the facility, the tank **5** is first evacuated and the down stream gate valve **25** is closed. Valve **15** is opened and introduced into the arc heater **9.** The arc heater **9** is operated at a pressure higher than in tank **5.** If the heater is operated at **105** atm, then with a tank pressure of 100 atm, there results an air mass flow of 1.5 lb./sec through throat **19** (0.55 inch diameter) into the tank **5.** The air exhausted from the heater is initially at a temperature on the order of 7,000° to 8,000°R. Due to heat losses to the tank walls, this temperature will decrease to temperature levels on the order of 5,500° to 6,000°R during the pressurization period.

At the end of the pressurization period, valve **24** is opened at the same instant as valve **25,** and the decomposable or combustible gas is injected into the tank at the same rate that hot air is being exhausted through hypersonic nozzle **23** to the test section (not shown). The gas introduced is heated by means not shown to a temperature below the ignition or decomposition temperature thereof. In general, this temperature is approximately 1,350°R. As this gas enters tank **5** the high temperature in the tank causes the gas in the case of nitrous oxide to spontaneously decompose or in the case of propane to combust in an exothermic manner. The chemical reaction takes place and creates a hot gas volume **31.** The final temperature of the decomposed products in the case of nitrous oxide or the gaseous products of combustion in the case of propane is 3,000°R higher than the preheated temperature of the undecomposed or unburned gas. The pressure generated by the continuous chemical decomposition maintains a constant storage pressure in tank **5** during the dumping or test period. The test gas leaves the tank **5** through valve **25.**

Alternately, after pressurizing the tank wih the arc-heated air, the opening of valve **25** is delayed as valve **24** is opened to introduce combustible or decomposable gas into the tank **5.** This increases the pressure in the tank above that obtainable with the arc heater.

It is claimed:

1. An apparatus for generating air flow at hypersonic speeds of Mach number 8 to 10 comprising an elongated ceramic lined storage tank having an inlet and an outlet, means for supplying air under pressure to said tank through said inlet, electric arc heating means for heating said air prior to its introduction into said tank, a Mach number 8 – 10 hypersonic nozzle provided said outlet for discharging the heated and pressurized air from said tank, and means for supplying a gaseous medium near said inlet for supplying said heated air, which gaseous means upon contact with said heated and pressurized air in said tank effects an exothermic reaction.

2. The apparatus of claim **1** wherein the electric arc heater means is a 10 megawatt arc heater.

3. The apparatus of claim **1** wherein the storage tank is horizontal and the inlet and outlet are located at the respective ends of said tank.

4. The apparatus of claim **1** wherein the storage tank is vertical and the outlet is located on the side of the tank near one end and the inlet located at the opposite end.

5. The apparatus of claim **1** wherein the inlet is through the side of the tank near one end and the outlet is at the opposite end of the tank.

6. A method of generating high temperature, high mass air flow and a high Reynolds number test air flow in the Mach number 8 – 10 regime of adequate test flow duration comprising pressurizing a ceramic lined storage tank with air to the pressure of about 100 to 200 atmospheres and an average temperature of about 5,500° to 6,000°R, heated prior to introduction into said tank by passing said air over an electric arc heater means, injecting a gaseous medium into the tank after said pressurization and rapidly releasing said heated pressurized air in said tank through a Mach number 8 – 10 hypersonic nozzle, said gaseous medium upon contact with the heated pressurized air in said tank effecting an exothermic reaction that maintains the pressure and temperature of said pressurized air during said rapid release.

7. The method of claim **6** wherein the pressurizing period of about 5 to 10 minutes and the discharge period is about 5 to 15 seconds.

8. The method of claim **6** wherein the gaseous medium is injected simultaneously with the release of said pressurized hot air and regulated to enter the tank at the same rate that said hot air is leaving to thereby hold constant the stagnation pressure in said tank.

9. The method of claim **6** wherein the gaseous medium is introduced into said tank prior to discharge of said hot air to thereby increase the pressure in said tank.

10. The method of claim **6** wherein said gaseous medium is a combustible gas and said exothermic reaction is obtained by combustion of said gas.

11. The method of claim **10** wherein said combustible gas is propane.

12. The method of claim **6** wherein said gaseous medium is a gas decomposable under the conditions inside said hot air pressurized tank.

13. The method of claim **12** wherein the decomposable gas is nitrous oxide.

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