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

REPLY TO ATTN OF: GP

(NASA-Case-LAR-10578-1) APPARATUS AND METHOD FOR GENERATING LARGE MASS FLOW OF HIGH TEMPERATURE AIR AT HYPERSONIC SPEEDS Patent (NASA) 6 p CSCL 20D

N73-25262

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

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

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

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,731,528

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) : ____________

NASA Patent Case No. : LAR-10578-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes [ ] No [x]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter

Elizabeth A. Carter
Enclosure
Copy of Patent cited above

NASA-HQ

United States Patent [19]

Boatright

[11] **3,731,528**

[45] **May 8, 1973**

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

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[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, D.C.

[22] Filed: **Mar. 9, 1972**

[21] Appl. No.: **233,098**

[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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Primary Examiner—S. Clement Swisher
Attorney—Howard J. Osborn et al.

[57] **ABSTRACT**

High temperature, high mass 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 atm. The air is heated to temperatures of 7,000°R to 8,000°R prior to introduction into said tank by passing said air through an electric arc heater. The air cools to 5,500°R to 6,000°R while in the tank and then it is rapidly released through a Mach number 8–10 nozzle.

As an embodiment of the invention cold air or hot driver gas under pressure is injected simultaneously with the release of said pressurized hot air and regulated to enter the tank at the same rate the hot air is leaving. This holds pressure in the tank constant during the test. Alternatively, the driver gas is introduced into the tank prior to the discharge of the hot air to thereby increase the pressure in the tank and permit tests at higher pressures than can be handled by the arc heater.

14 Claims, 3 Drawing Figures

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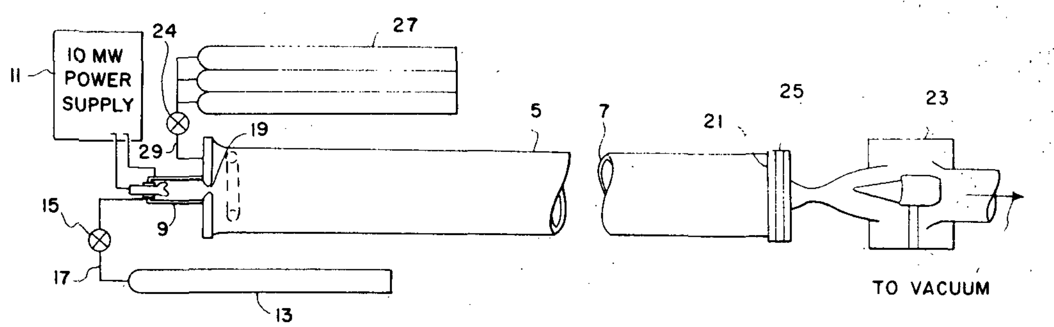

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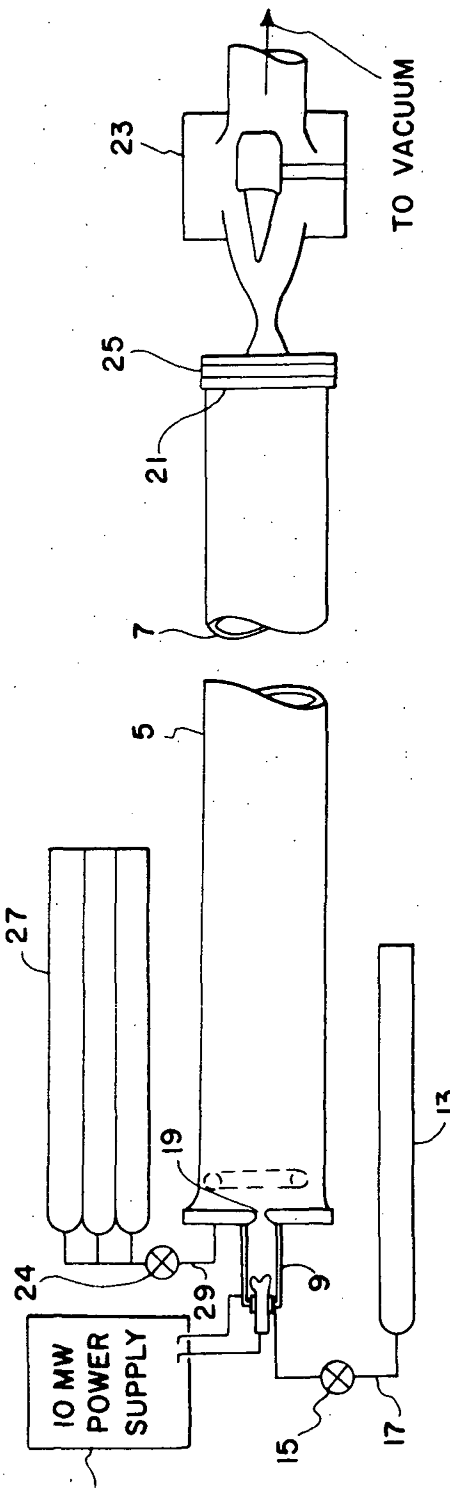
23
TO VACUUM
25
21
7
5
27
19
13
24
29
9
10 MW POWER SUPPLY
11
15
17

FIG. 1

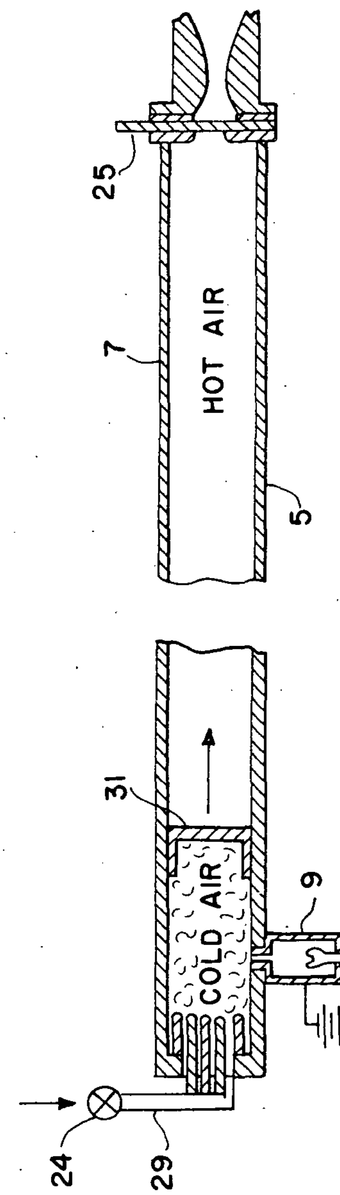
25
7
HOT AIR
5
31
COLD AIR
9
24
29

FIG. 3

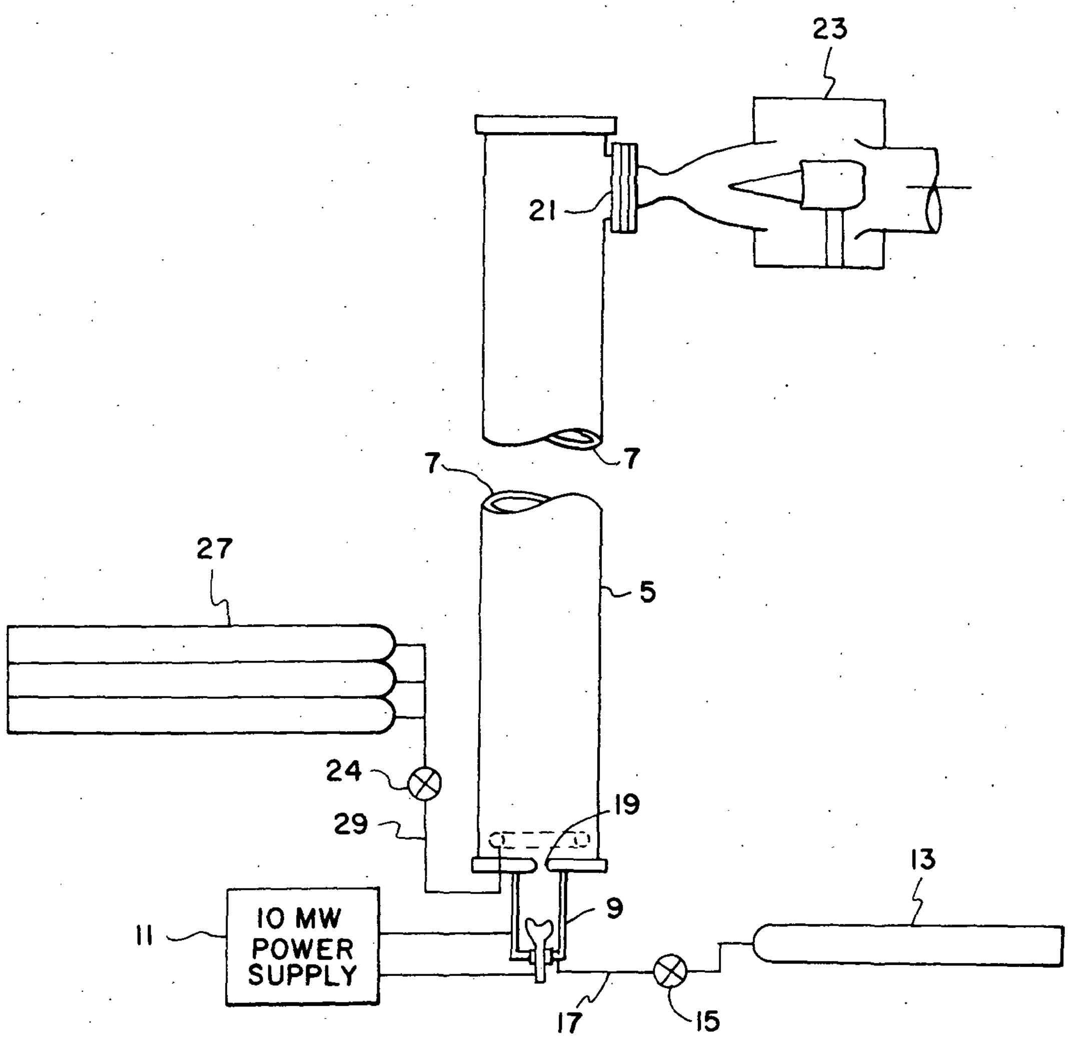

FIG. 2

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 an employee 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 a 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 temperatures, 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, ceramicfilled type are limited to about a Mach number of 7. Electric arc-heated facilities wherein the air under high pressure is passed through an electric arc and then directly through a hypersonic nozzle, although able to produce air temperatures far in excess of those required for Mach number 8 to 10 simulation, are not contemplated for use in 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.

It is an object of the invention, therefore, to provide a method and device for producing a high temperature, high density or mass flow, high Reynolds number test air flow in the Mach number 8 to 10 regime.

One object of the invention is to furnish an arrangement of components of a Mach number 8 – 10 facility capable of duplicating flight conditions in the air breathing corridor at these Mach numbers.

A further object of the invention is to provide a high temperature, high mass flow, high Reynolds number test flow in the Mach 8 – 10 regime which flow is of adequate test duration.

Yet another object of the invention is to attain the preceding objectives for producing the large flow rate of hot air by using an electric arc-heater to achieve the high air temperatures desired and storing the air momentarily (about 2 minutes) before exhausting it through the nozzle, thus avoiding the economic restrictions imposed by large power requirements of existing electric arc-heater facilities which discharge directly from the arc heater to the nozzle.

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.

In another aspect of the invention, the apparatus includes means for supplying cold air or hot gas near the tank inlet for the heated air. As an alternate embodiment of this aspect of the invention, a traveling separator element is positioned transverse to the longitudinal axis of the tank which separator element has peripheral edges nearly in contact with the internal walls of the tank and slides on longitudinal rails slightly protruding from the ceramic liner.

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 and rapidly releasing said heated pressurized air in said tank through a Mach number 8 – 10 nozzle. 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 ceramiclined walls of the tank.

In another embodiment of the process of the invention, driver gas cold air or hot driver gas 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 is held constant during the test period. In yet another mode of the process of the invention, the cold air or hot gas is introduced prior to discharge of the hot air thereby increasing the pressure in the tank.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be further described with reference to the following figures wherein:

FIG. 1 is a schematic diagram of the high enthalpy air tank apparatus of the invention in horizontal arrangement;

FIG. 2 is a schematic diagram of the high enthalpy air tank apparatus of the invention in vertical arrangement;

FIG. 3 is a schematic sectional view of an alternate design of the high enthalpy air tank apparatus of the invention including a traveling separator member between the cold air and hot air.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, FIGS. 1 and 2 show an arrangement of components of a Mach number 9 facility capable of duplicating flight conditions in the air breathing corridor at this Mach number. FIG. 1 shows the arrangement where the tank is horizontal and FIG. 2 where the tank is vertical. This facility is sized for a 10 megawatt arc heater and should furnish a test duration of 5 to 20 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 FIGS. 1 and 2, 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 305 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 in 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**. In FIG. 1 the outlet **21** is located at the end of tank **5** while in FIG. 2 the outlet **21** is on the side of tank **5**. 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 BTU's/lb.; Total pressure = 150 – 200 ATM; Total temperature = 5,760°R; Mass flow rate = 35 lb./sec. sec.

If desired, a high pressure cold air storage tank or hot driver gas supply **27** 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**.

In operation of the facility, the tank **5** is first evacuated and the downstream gate valve **25** is closed. Valve **15** is opened and air 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 **25** is opened and the hot air exhausts through hypersonic nozzle **23** to the test section (not shown).

For another mode of operation, valve **24** is opened at the same instant as valve **25**; and cold air is injected into the tank at the same rate that hot air is being exhausted. This holds the stagnation pressure constant and the test duration is then determined by the time for the interface between the cold air or driver gas and the hot air to travel the length of the tank. This interface will not be a distinct boundary but if, for example, there were enough hot air in the tank for a 20 second test, then a 5 to 10 second test duration is more than likely obtained. This test period is more than adequate for many types of testing including propulsion research. Introducing the cold air or driver gas at the bottom of a vertical tank appears to be the simpler and more desirable arrangement if free convection heat loss considerations to the walls of the tank permit a vertical arrangement.

Alternately, after pressurizing the tank with the archeated air, the opening of valve **25** is delayed as valve **24** is opened to introduce cold air into the tank **5**. This increases the pressure in the tank above that obtainable with the arc heater. As in the case where the valve **24** is opened simultaneously with valve **25** there exists the problem of how distorted and diffused the interface will be between the hot and cold air. However, assuming that the cold air is introduced at a rate that minimizes the mixing, then the result is to compress the hot air before valve **25** is opened. After compressing the air in this manner, valve **25** is opened and the hot air is exhausted through the nozzle **23**. This mode of operation will decrease the test duration for a given tank size but will permit attainment of much higher pressures than with the arc heater alone. In addition, if for example, the tank pressure is increased from 100 atm. to 200 atm. by this method, then there will be about a 20 percent increase in temperature of the hot air due to adiabatic compression.

The apparatus shown in FIG. 3 is considered as a solution to the problem presented by the uncertainty in predicting the amount of diffusion and distortion of the interface between the hot and cold air or driver gas. The apparatus of FIG. 3 is similar to the horizontal apparatus of FIG. 1 but modified in the following aspects: Arc heater **9** is placed along the side of tank **5** rather than at its end and a traveling separator **31** is positioned within the tank and is free to move down the tank as the cold air is introduced. During the arc heater pressurization period, the separator **31** is pressed against the upstream end by the pressure in the tank and is cooled by its contact with the upstream end. During the injection of the cold air the traveling separator **31** moves down the tank on special water-cooled rails (not shown) built into the tank. Since the tank is lined with ceramic tile, such as for example, zirconium oxide, the rail will protrude slightly through the ceramic lining. Because the separator **31** moves freely and has such a large area, only minute pressure difference across the separator is required to move it. The clearance between the rim of the separator and the tank is adequate to allow for ordinary fabrication inaccuracies in the tank of this type and even with clearances of one-sixteenth to one-fourth inch the spillage of the cold air around the sides of the separator will not strongly dilute the hot air since the pressure difference required to move the separator is so small. The cold air cools the separator during its period of travel down the tank **5**.

A number of analyses have been made of the heat losses during the pressurization period but these have necessarily been of an approximate nature. The estimation of losses by radiation was conservative in that it did not account for self-absorption and the results indicated a temperature decrease of 5 to 10 percent during a 2 minute pressurization period. If clean, dry air is used, radiation losses are not expected to be unduly severe. However, an uncertainty exists in this effect because of the possible existance of contamination from the arc heater. The contamination might be in the form of a minute amount of metallic vapor or of 1 to 3 percent nitric oxide.

An approximate analysis which considered the losses due to conduction of stagnant air to the walls was made and although this analysis was not considered especially applicable to this problem, it pointed out the need for a tank with a reasonably large diameter. The air conduction losses are inversely proportional to the square of the tank radius and with too small a radius, the losses become intolerable. However, for the 4-foot size shown in FIG. **1**, the temperature decrease was less than 1 percent for a 2 minute pressurization period. Another analysis, more applicable then the stagnant air conduction analysis, has in a very approximate manner accounted for the natural convection losses as well as air conduction losses and this analysis predicts the largest losses. This analysis predicted a temperature decrease of about 50 percent of the difference between the inlet air temperature from the arc heater and the wall temperature. This seems severe but is not intolerable. For example, if the wall temperature is permitted to reach 4,000°R and the inlet air temperature is 7,400°R, then this still permits the attainment of a 5,700°R average air temperature which is adequate for $M = 9$ simulation, (even without the mode of operation wherein valve **24** is opened to introduce cold air into the tank **5** before valve **25** is opened) which would significantly raise the temperature.

The high wall temperature of the ceramic liner in the tank will be attained by a pre-heating cycle. The liner must be sized to attain this wall temperature with a reasonable amount of power input. There is no danger of overheating the thick steel walls of the tank to an unsafe condition because the high specific heat and mass of the steel cannot be raised by more than 100°F to 200°F even if all the energy from the arc-heated air went into the tank walls.

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.

2. The apparatus of claim **1** wherein the electric arc heater means is a high mass flow, high powered 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** including means for supplying cold air near said inlet for driving said heated air.

6. The apparatus of claim **1** including means for supplying additional hot driver gas near said inlet for driving said heated air.

7. 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.

8. The apparatus of claim **6** including means for supplying cold air into the end of said tank opposite said outlet.

9. The apparatus of claim **7** including a separator element positioned within said tank transverse to the longitudinal axis thereof said separator element having peripheral edges nearly in contact with the internal walls of said tank.

10. 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 atms. 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 and rapidly releasing said heated pressurized air in said tank through a Mach number 8 – 10 nozzle.

11. The method of claim **9** wherein the pressurizing period of about 2 to 4 minutes and the discharge period is about 5 to 20 seconds.

12. The method of claim **9** wherein cold air under pressure 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.

13. The method of claim **9** wherein hot driver gas under pressure 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.

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

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