Title: PRECOOLED AIR BREATHING ENGINE

FIG. 1

Abstract: There is provided a hypersonic air-breathing engine having an air passage with an inlet, an outlet, and an air flow, and a turbojet between the inlet and the outlet. There is an air bypass around the turbojet, an afterburner downstream of the turbojet and air bypass, and valves selectively restrict air flow through the turbojet and air bypass. The turbojet valve and air bypass valve are controlled to define a first mode where air flow through the air bypass is restricted and air flow through the turbojet is unrestricted, a second mode where air flow through the air bypass is increased relative to the first mode and the air flow through turbojet is reduced relative to the first mode, and a third mode where air flow through the air bypass is increased relative to the second mode and air flow through the turbojet is reduced relative to the second mode. Nanoparticles may be used to enhance the rate of heat transfer of the pre-cooler and contribute to heat release through combustion.
PRECOOLED AIR BREATHING ENGINE

TECHNICAL FIELD

[0001] This relates to a combustion system for a high-speed air-breathing propulsion system using a precooled turbojet, afterburner, and bypass ramjet cycle that may employ nanoparticles to assist with heat exchange.

BACKGROUND

[0002] Air-breathing engines require cooling of the air that is taken in by the engine prior to combustion in order to reduce the material demands and prevent damage to the interior components when operating at high flight speeds. Cooling the air prior to compression can alleviate mechanical compression requirements and improve the overall efficiency in the engine.

SUMMARY

[0003] According to an aspect, there is provided a hypersonic air-breathing engine comprising an air passage comprising an inlet, an outlet, and an air flow, a turbojet disposed in the air passage between the inlet and the outlet, an air bypass around the turbojet, an afterburner downstream of the turbojet and the air bypass, a turbojet valve that selectively restricts the air flow through the turbojet, and an air bypass valve that selectively restricts the air flow through the air bypass, wherein the turbojet valve and the air bypass valve are controlled to define a first mode wherein air flow through the air bypass is restricted and air flow through the turbojet is unrestricted, a second mode wherein air flow through the air bypass is increased relative to the first mode and the air flow through turbojet is reduced relative to the first mode, and a third mode wherein air flow through the air bypass is increased relative to the second mode and air flow through the turbojet is reduced relative to the second mode.

[0004] According to another aspect, the hypersonic air-breathing engine may further comprise a heat exchanger in thermal communication with the air passage upstream of the turbojet.

[0005] According to another aspect, the hypersonic air-breathing engine may further
comprise an intake cone disposed in the inlet of the air passage, and the heat exchanger may
be connected to the intake cone.

[0006] According to another aspect, the intake cone may be movable between an extended and retracted position relative to the air passage, and moving the intake cone between an extended and retracted position may control the amount of flow blockage through the heat exchanger.

[0007] According to another aspect, the air flow through the turbojet may be reduced by increasing the flow restriction through the heat exchanger.

[0008] According to another aspect, the heat exchanger may be in thermal communication with the intake cone.

[0009] According to another aspect, the turbojet may be fuelled by a hydrocarbon fuel.

[0010] According to another aspect, the heat exchanger may use hydrogen as a coolant.

[0011] According to another aspect, the hydrogen may be used as a fuel source for the afterburner after travelling through the heat exchanger.

[0012] According to another aspect, the turbojet may comprise an air inlet, a compressor, a combustion chamber having fuel injectors disposed in the combustion chamber, a turbine, and an outlet nozzle.

[0013] According to another aspect, in the first mode the air bypass valve may close to prevent air flow through the air bypass.

[0014] According to another aspect, the inlet of the air passage may comprise a valve that controls the air flow into the air passage.
According to another aspect, the outlet of the air passage may contract and expand to control the air flow exiting the air passage.

According to another aspect, in the second mode nanoparticles may be injected into the air passage adjacent to the inlet.

According to an aspect, there is provided a method of operating an air-breathing engine, the air-breathing engine comprising a turbojet disposed in an air passage between an inlet and an outlet of the air passage, an air bypass around the turbojet, and an afterburner downstream of the turbojet and the air bypass, the method comprising the steps of operating the air-breathing engine in a first mode by restricting air flow through the air bypass and allowing air flow through the turbojet, operating the air-breathing engine in a second mode by increasing the air flow through the air bypass relative to the first mode and decreasing the air flow through the turbojet relative to the first mode, and operating the air-breathing engine in a third mode by decreasing air flow through the turbojet relative to the second mode and increasing the air flow through the air bypass relative to the second mode.

According to another aspect, the hypersonic air-breathing engine may further comprise a heat exchanger in thermal communication with the air passage upstream of the turbojet.

According to another aspect, the hypersonic air-breathing engine may further comprise an intake cone disposed in the inlet of the air passage, and the heat exchanger is connected to the intake cone.

According to another aspect, the intake cone may be movable between an extended and retracted position relative to the air passage, and moving the intake cone between an extended and retracted position may expand and compress the heat exchanger.

According to another aspect, the air flow through the turbojet may be reduced by the controlling the flow restriction through the heat exchanger.
[0022] According to another aspect, the heat exchanger may be in thermal communication with the intake cone.

[0023] According to another aspect, the turbojet may be fuelled by a hydrocarbon fuel.

[0024] According to another aspect, the heat exchanger may use hydrogen as a coolant.

[0025] According to another aspect, the hydrogen may be used as a fuel source for the afterburner after travelling through the heat exchanger.

[0026] According to another aspect, the turbojet may comprise an air inlet, a compressor, a combustion chamber having fuel injectors disposed in the combustion chamber, a turbine, and an outlet.

[0027] According to another aspect, in the first mode the air bypass valve may close to prevent air flow through the air bypass.

[0028] According to another aspect, the inlet of the air passage may comprise a valve that controls the air flow into the air passage.

[0029] According to another aspect, the outlet of the air passage may contract and expand to control the air flow exiting the air passage.

[0030] According to another aspect, the second mode nanoparticles may be injected into the air passage adjacent to the inlet.

[0031] According to an aspect, there is provided a hypersonic air-breathing engine comprising an air passage comprising an inlet and an outlet, a combustion chamber disposed in the air passage between the inlet and the outlet, a heat exchanger in thermal communication with the air passage upstream of the combustion chamber, the heat exchanger comprising a
source of nanoparticles and a nozzle connected to eject a flow of nanoparticles from the source of nanoparticles into the air passage to cool air flowing through the air passage.

[0032] According to another aspect, the nozzle may comprise multiple nozzles spaced within the air passage.

[0033] According to another aspect, the hypersonic air-breathing engine may further comprise an intake cone disposed in the inlet of the air passage, and the heat exchanger may be connected to the intake cone.

[0034] According to another aspect, the heat exchanger may be in thermal communication with the intake cone.

[0035] According to another aspect, the heat exchanger may comprise a coolant.

[0036] According to another aspect, the coolant of the heat exchanger may act as a carrier for the nanoparticles.

[0037] According to another aspect, the coolant may comprise hydrogen.

[0038] According to another aspect, the source of nanoparticles may be a nanoparticle chamber disposed within the intake cone, and the intake cone may comprise the nozzle connected to eject the flow of nanoparticles.

[0039] According to another aspect, the heat exchanger may comprise a coolant, and at least a portion of the coolant may exchange thermal energy with the intake cone prior to entering the nanoparticle chamber and propelling the nanoparticles through the nozzle.

[0040] According to another aspect, the coolant may comprise hydrogen.

[0041] According to another aspect, the nanoparticles may comprise boron or boron
Based nanoparticles.

[0042] According to another aspect, the nanoparticles may comprise aluminium nanoparticles.

[0043] According to another aspect, the nanoparticles may be combusted in the combustion chamber after being ejected into the air passage.

[0044] According to an aspect, there is provided a method of cooling air in an air-breathing engine, the air-breathing engine comprising a combustion chamber disposed in an air passage, and a heat exchanger in thermal communication with the air passage upstream of the combustion chamber, the method comprising the steps of operating the heat exchanger to cool air flowing through the air passage by injecting a flow of nanoparticles from a source of nanoparticles into the air passage.

[0045] According to another aspect, the nanoparticles may be injected by a nozzle.

[0046] According to another aspect, the nozzle may comprise multiple nozzles spaced within the air passage.

[0047] According to another aspect, wherein the air-breathing engine may further comprise an intake cone disposed in the inlet of the air passage, and the heat exchanger may be connected to the cone.

[0048] According to another aspect, the heat exchanger may be in thermal communication with the intake cone.

[0049] According to another aspect, the heat exchanger may comprise a coolant.

[0050] According to another aspect, the coolant of the heat exchanger may act as a carrier for the nanoparticles.
According to another aspect, the coolant may comprise hydrogen.

According to another aspect, the source of nanoparticles may be a nanoparticle chamber disposed within the intake cone, and the intake cone may comprise the nozzle connected to eject the flow of nanoparticles.

According to another aspect, the heat exchanger may comprise a coolant, and at least a portion of the coolant may exchange thermal energy with the cone prior to entering the nanoparticle chamber and propelling the nanoparticles through the nozzle.

According to another aspect, the coolant may comprise hydrogen.

According to another aspect, the nanoparticles may comprise boron or boron based nanoparticles.

According to another aspect, wherein the nanoparticles may comprise aluminium nanoparticles.

According to another aspect, the nanoparticles may be combusted in the combustion chamber after being ejected into the air passage.

According to another aspect, the nanoparticles may be combusted in afterburner after being ejected into the air passage.

According to another aspect, the nanoparticles may be combusted in the bypass after being ejected into the air passage.

In other aspects, the features described above may be combined together in any reasonable combination as will be recognized by those skilled in the art.
BRIEF DESCRIPTION OF THE DRAWINGS

[0061] These and other features will become more apparent from the following description in which reference is made to the appended drawings, the drawings are for the purpose of illustration only and are not intended to be in any way limiting, wherein:

FIG. 1 is a schematic a precooled turbojet/ramjet cycle using nanoparticles to assist heat exchange in a subsonic mode.

FIG. 2 is a schematic a precooled turbojet/ramjet cycle using nanoparticles to assist heat exchange in a supersonic mode.

FIG. 3 is a schematic a precooled turbojet/ramjet cycle using nanoparticles to assist heat exchange in a hypersonic mode.

FIG. 4 is a schematic of a nanoparticle intake.

FIG. 5 is a graph showing expected gains in stagnation pressure as a result of nanoparticle injection.

DETAILED DESCRIPTION

[0062] A precooled air-breathing engine, generally indicated by reference number 100, will now be described with reference to FIG. 1 through 5.

[0063] Referring to FIG. 1 - 3, the engine described herein is a hypersonic air-breathing engine that provides thrust from rest to hypersonic speeds, which is generally understood to be speeds above Mach 5. The engine combines a conventional turbojet 7 and afterburner 6 with a movable intake cone 1a and a core heat exchanger 1b. The core heat exchanger 1b is connected to the intake cone and movement of the intake cone 1a affects the level of blockage to the inlet 2 of the turbojet 7. When the intake cone 1a is extended upstream away from the turbojet 7 as shown in FIG. 1, the spacing between the tubes 1c of the heat exchanger 1b is increased, decreasing blockage. When the intake cone 1a is retracted as shown in FIG. 2 and 3, the spacing between the heat exchanger tubes 1c is decreased, which increases the level of blockage. Referring to FIG. 2, a bypass 14 around the turbojet 7 is controlled through valves 8 near the entrance and exit of the turbojet, depicted as physical shoulders that engages the inner surface of engine 100. Other designs to control the flow through bypass 14 may also be used. Downstream of the turbojet 7, the exit area of the nozzle 10 is controlled through...
movable nozzle vanes 9.

[0064] At low flight speeds (M0<1), the engine 100 relies solely on the onboard turbojet 7 that is fueled by a conventional hydrocarbon-based fuel, and will generally be in the configuration shown in FIG. 1. The engine 100 takes in ambient air 11. The intake cone 1a is extended upstream away from the turbojet 7, minimizing the level of flow obstruction through the core heat exchanger 1b, which is not active. As a result, minimum pressure losses occur prior to compression in the turbojet 7. During this mode, the bypass 14 is closed and all air is processed through the inlet 2 into the core turbojet 7. The nozzle 10 at the exhaust end of the engine 100 is configured in the subsonic mode and is contracted to create a small exit area. The turbojet 7 has a compressor 3, combustion chamber 3a, turbine 4, hydrocarbon fuel injectors 3b, and an exhaust 5.

[0065] Referring to FIG. 2, as the engine 100 accelerates the vehicle to supersonic velocities, a coolant is flowed through the core heat exchanger to cool the air intake, and may flow into the intake cone 1a as shown in FIG. 4. Preferably, the coolant is cold hydrogen fuel that is also circulated to afterburner 6. Other coolants may also be used, provided that they are able to provide sufficient cooling to the inlet air. One example of another suitable coolant is helium. FIG. 4 shows a schematic of how the nanoparticle injection mechanism operates. Nanoparticles stored in the intake cone 1a are mixed and cooled by the pressurized gas, such as hydrogen fuel as shown. Only a small amount of nanoparticles are required to provide significant gains in the engine. Note that some, or all, of the hydrogen fuel, when employed for this purpose, used to cool and mix with the nanoparticles might bypass the core heat exchanger in order to reach the target cold temperatures. The nanoparticles, which may be boron, aluminium, compounds based on these materials, or other suitable materials as may be determined to be suitable through ordinary testing, are mixed with a carrier gas at a high mass loading ratio. Referring to FIG. 4, the carrier gas may be the same as the coolant that circulates through heat exchanger 1b, where a portion is diverted to be mixed with the nanoparticles. Alternatively, a separate source of pressurized gas may be used to mix with the nanoparticles, depending on the preferences of the user, and the design that is determined to be most efficient in the circumstances. The mixture is pressurized and injected through ports
12 on the intake cone 1a into the supersonic air. Mixing and heat transfer between the nanoparticles and the supersonic air occur prior to complete deceleration of the main air stream. In addition to air cooling through direct contact with the nanoparticles, cooling of the intake cone surface 1a adds to the overall air heat transfer rate. As the supersonic air cools during deceleration, the stagnation pressure increases, resulting in a gain in engine performance. Figure 5 shows an example of the expected stagnation pressure gains for 500 nm diameter boron particles injected at 100K into a decelerating Mach 2.5 air flow initially at 270K. Clearly, only small amounts of nanoparticles are required to produce a large gain in stagnation pressure. Gains in stagnation pressure through nanoparticle injection may reduce the requirements of, or negate the need for mechanical compression in the turbojet. The amount of hydrogen injected into the air stream from the intake cone is limited by local flammability limits. High nanoparticle mass loadings in the hydrogen carrier gas will allow for overall low concentrations of hydrogen in the intake.

[0066] In addition to extracting heat from the supersonic air near the intake cone, the nanoparticles also become seeded into the flow and enhance convective heat transfer in the core heat exchanger where the flow is subsonic. The nanoparticles transport heat throughout the flow, increasing the effective rate of convective heat transfer between the air and the tubes of the heat exchanger. After providing the heat transfer role, the nanoparticles bum in the combustion chamber and contribute to the thrust of the vehicle. Strategic selection of the nanoparticle results in large amounts of heat release in the combustion chamber. The rate of heat transfer in the core heat exchanger is also enhanced though the retraction of the intake, which reduces the gaps between the heat exchanger tubes. The role of the core heat exchanger is to further decrease the gas temperature prior to compression in the turbojet. Reduced temperature prior to compression allows combustion temperatures to remain below levels that would otherwise damage the turbine blades in the turbojet.

[0067] At intermediate Mach numbers, air bypass is required. Since the turbojet operates lean, there is excess air available for combustion with the hydrogen fuel. Note that the magnitude of heat transfer is coupled to the amount of hydrogen available for combustion in the afterburner 6. All of the combustion products are then expanded through a supersonic
nozzle 10, where the area of the nozzle 10 is expanded as the Mach number increases. The level of bypass changes throughout the flight regime to optimize thrust or fuel consumption.

[0068] At higher Mach numbers, referring to FIG. 3, the engine is designed to operate in pure Ramjet mode with 100% bypass. The actual speed at which this occurs will depend on the preferences of the user and the specific details of the engine. At this condition, the heat exchanger 1b completely blocks air access into the turbojet. The turbojet does not operate at this condition. There is no flow of hydrocarbon fuel into the turbojet. In the pure Ramjet mode, the engine gains performance through supersonic cooling increase in stagnation pressure in the intake. The terminal flight speed is limited to that of a pre-cooled hydrogen fueled ramjet.

[0069] In this patent document, the word "comprising" is used in its non-limiting sense to mean that items following the word are included, but items not specifically mentioned are not excluded. A reference to an element by the indefinite article "a" does not exclude the possibility that more than one of the elements is present, unless the context clearly requires that there be one and only one of the elements.

[0070] The scope of the following claims should not be limited by the preferred embodiments set forth in the examples above and in the drawings, but should be given the broadest interpretation consistent with the description as a whole.
What is Claimed is:

1. A hypersonic air-breathing engine comprising:
   - an air passage comprising an inlet, an outlet, and an air flow;
   - a turbojet disposed in the air passage between the inlet and the outlet;
   - an air bypass around the turbojet;
   - an afterburner downstream of the turbojet and the air bypass;
   - a turbojet valve that selectively restricts the air flow through the turbojet; and
   - an air bypass valve that selectively restricts the air flow through the air bypass;

   wherein the turbojet valve and the air bypass valve are controlled to define:
   - a first mode wherein air flow through the air bypass is restricted and air flow through the turbojet is unrestricted;
   - a second mode wherein air flow through the air bypass is increased relative to the first mode and the air flow through turbojet is reduced relative to the first mode;

2. The hypersonic air-breathing engine of claim 1, wherein the hypersonic air-breathing engine further comprises a heat exchanger in thermal communication with the air passage upstream of the turbojet.

3. The hypersonic air-breathing engine of claim 2, wherein the hypersonic air-breathing engine further comprises an intake cone disposed in the inlet of the air passage, and the heat exchanger is connected to the cone.

4. The hypersonic air-breathing engine of claim 3, wherein the intake cone is movable between an extended and retracted position relative to the air passage, and wherein moving the intake cone between an extended and retracted position expands and compresses the heat exchanger to restrict air flow through the heat exchanger.
5. The hypersonic air-breathing engine of claim 4, wherein the air flow through the turbojet is reduced by the compression of the heat exchanger.

6. The hypersonic air-breathing engine of claim 3, 4 or 5, wherein the heat exchanger is in thermal communication with the intake cone.

7. The hypersonic air-breathing engine of any of claims 1 through 6, wherein the turbojet is fuelled by a hydrocarbon fuel.

8. The hypersonic air-breathing engine of any of claims 2 through 6, wherein the heat exchanger uses hydrogen as a coolant.

9. The hypersonic air-breathing engine of claim 8, wherein the hydrogen is used as a fuel source for the afterburner after travelling through the heat exchanger.

10. The hypersonic air-breathing engine of any of claims 1 through 9, wherein the turbojet comprises an air inlet, a compressor, a combustion chamber having fuel injectors disposed in the combustion chamber, a turbine, and an outlet.

11. The hypersonic air-breathing engine of any of claims 1 through 10, wherein in the first mode the air bypass valve seals against the turbojet to prevent air flow through the air bypass.

12. The hypersonic air-breathing engine of any of claims 1 through 11, wherein the inlet of the air passage comprises a valve that controls the air flow into the air passage.

13. The hypersonic air-breathing engine of any of claims 1 through 12, wherein the outlet of the air passage contracts and expands to control the air flow exiting the air passage.

14. The hypersonic air-breathing engine of any of claims 1 through 13, wherein in the second mode nanoparticles are injected into the air passage adjacent to the inlet.
15. A method of operating an air-breathing engine, the air-breathing engine comprising a turbojet disposed in an air passage between an inlet and an outlet of the air passage, an air bypass around the turbojet, and an afterburner downstream of the turbojet and the air bypass, the method comprising the steps of:

operating the air-breathing engine in a first mode by restricting air flow through the air bypass and allowing air flow through the turbojet;

operating the air-breathing engine in a second mode by increasing the air flow through the air bypass relative to the first mode and decreasing the air flow through the turbojet relative to the first mode;

operating the air-breathing engine in a third mode by decreasing air flow through the turbojet relative to the second mode and increasing the air flow through the air bypass relative to the second mode.

16. The method of claim 15, wherein the hypersonic air-breathing engine further comprises a heat exchanger in thermal communication with the air passage upstream of the turbojet.

17. The method of claim 16, wherein the hypersonic air-breathing engine further comprises an intake cone disposed in the inlet of the air passage, and the heat exchanger is connected to the cone.

18. The method of claim 17, wherein the cone is movable between an extended and retracted position relative to the air passage, and wherein moving the intake cone between an extended and retracted position expands and compresses the heat exchanger.

19. The method of claim 18, wherein the air flow through the turbojet is reduced by the compression of the heat exchanger.

20. The method of claim 17, 18 or 19, wherein the heat exchanger is in thermal communication with the intake cone.
21. The method of claim any of claims 15 through 20, wherein the turbojet is fuelled by a hydrocarbon fuel.

22. The method of any of claims 16 through 20, wherein the heat exchanger uses hydrogen as a coolant.

23. The method of claim 22, wherein the hydrogen is used as a fuel source for the afterburner after travelling through the heat exchanger.

24. The method of any of claims 15 through 23, wherein the turbojet comprises an air inlet, a compressor, a combustion chamber having fuel injectors disposed in the combustion chamber, a turbine, and an outlet.

25. The method of any of claims 15 through 24, wherein in the first mode the air bypass valve seals against the turbojet to prevent air flow through the air bypass.

26. The method of any of claims 15 through 25, wherein the inlet of the air passage comprises a valve that controls the air flow into the air passage.

27. The method of any of claims 15 through 26, wherein the outlet of the air passage contracts and expands to control the air flow exiting the air passage.

28. The method of any of claims 15 through 27, wherein in the second mode nanoparticles are injected into the air passage adjacent to the inlet.

29. A hypersonic air-breathing engine comprising:
   - an air passage comprising an inlet and an outlet;
   - a combustion chamber disposed in the air passage between the inlet and the outlet;
   - a heat exchanger in thermal communication with the air passage upstream of
the combustion chamber, the heat exchanger comprising:

- a source of nanoparticles; and
- a nozzle connected to eject a flow of nanoparticles from the source of nanoparticles into the air passage to cool air flowing through the air passage.

30. The hypersonic air-breathing engine of claim 29, wherein the nozzle comprises multiple nozzles spaced within the air passage.

31. The hypersonic air-breathing engine of claim 29, wherein the hypersonic air-breathing engine further comprises a cone disposed in the inlet of the air passage, and the heat exchanger is connected to the intake cone.

32. The hypersonic air-breathing engine of claim 31, wherein the heat exchanger is in thermal communication with the intake cone.

33. The hypersonic air-breathing engine of any of claims 29 through 32, wherein the heat exchanger comprises a coolant.

34. The hypersonic air-breathing engine of claim 33, wherein the coolant of the heat exchanger acts as a carrier for the nanoparticles.

35. The hypersonic air-breathing engine of claim 33 or 34, wherein the coolant comprises hydrogen.

36. The hypersonic air-breathing engine of any of claims 31 through 35, wherein the source of nanoparticles is a nanoparticle chamber disposed within the intake cone, and the intake cone comprises the nozzle connected to eject the flow of nanoparticles.

37. The hypersonic air-breathing engine of claim 36, wherein the heat exchanger comprises a coolant, and at least a portion of the coolant exchanges thermal energy with the intake cone prior to entering the nanoparticle chamber.
38. The hypersonic air-breathing engine of claim 37, wherein the coolant comprises hydrogen.

39. The hypersonic air-breathing engine of any of claims 29 through 38, wherein the nanoparticles comprise boron or boron based nanoparticles.

40. The hypersonic air-breathing engine of any of claims 29 through 39, wherein the nanoparticles comprise aluminium nanoparticles.

41. The hypersonic air-breathing engine of any of claims 29 through 40, wherein the nanoparticles are combusted in the combustion chamber after being ejected into the air passage.

42. A method of cooling air in an air-breathing engine, the air-breathing engine comprising a combustion chamber disposed in an air passage, and a heat exchanger in thermal communication with the air passage upstream of the combustion chamber, the method comprising the steps of:
   operating the heat exchanger to cool air flowing through the air passage by injecting a flow of nanoparticles from a source of nanoparticles into the air passage.

43. The method of claim 42, wherein the nanoparticles are injected by a nozzle.

44. The method of claim 43, wherein the nozzle comprises multiple nozzles spaced within the air passage.

45. The method of claim 43 or 44, wherein the air-breathing engine further comprises an intake cone disposed in the inlet of the air passage, and the heat exchanger is connected to the intake cone.

46. The method of claim 45, wherein the heat exchanger is in thermal communication
with the intake cone.

47. The method of any of claims 42 through 46, wherein the heat exchanger comprises a coolant.

48. The method of claim 47, wherein the coolant of the heat exchanger acts as a carrier for the nanoparticles.

49. The method of claim 47 or 48, wherein the coolant comprises hydrogen.

50. The method of any of claims 45 through 49, wherein the source of nanoparticles is a nanoparticle chamber disposed within the intake cone, and the intake cone comprises the nozzle connected to eject the flow of nanoparticles.

51. The method of claim 50, wherein the heat exchanger comprises a coolant, and at least a portion of the coolant exchanges thermal energy with the cone prior to entering the nanoparticle chamber and propelling the nanoparticles through the nozzle.

52. The method of claim 51, wherein the coolant comprises hydrogen.

53. The method of any of claims 42 through 52, wherein the nanoparticles comprise boron or boron based nanoparticles.

54. The method of any of claims 42 through 53, wherein the nanoparticles comprise aluminium nanoparticles.

55. The method of any of claim 42 through 54, wherein the nanoparticles are combusted in the combustion chamber after being ejected into the air passage.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC: F02K 7/66 (2006.01), F02C 7/143 (2006.01), F02K 7/16 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (2006.01); F02K 7/00; F02C 7/143; F02K 7/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Databases: Canadian Patent Database (CPD); Questel™ Orbit™

Keywords: hypersonic, supersonic, bypass, turbojet, valve, nanoparticles, boron, heat exchanger, afterburner, rocket, ramjet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<th>Relevant to claim No.</th>
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<td>US 3 635 029 (MÉNIOUX, C. C. F.) 18 January 1972 (18-01-1972)</td>
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<td>* fig. 1-8; col. 1, lines 7-9; col. 4, lines 24-42 *</td>
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Form PCT/ISA/210 (second sheet) (January 2015)
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