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FLUID COOLER INSTALLATION AND METHOD FOR TURBOFAN ENGINE

Abstract

A fluid cooler for installation in a bypass duct of a turbofan gas turbine engine and associated methods are provided. The fluid cooler includes an inlet duct, a heat exchanger and an outlet duct. The inlet duct includes an inlet protruding into the bypass duct to receive a portion of the bypass air into the inlet duct. The heat exchanger is in fluid communication with the inlet duct. The heat exchanger facilitates heat transfer between a fluid and the portion of bypass air received into the inlet duct. The heat exchanger defines a general flow direction for the portion of bypass air that is different from the main flow direction of bypass air inside the bypass duct. The outlet duct conveys the portion of bypass air from the heat exchanger back to the bypass duct.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a division of U.S. patent application Ser. No. 17/176,643 filed on Feb. 16, 2021, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD
[0002] The disclosure relates generally to gas turbine engines, and more particularly to fluid coolers in gas turbine engines.
BACKGROUND
[0003] Bypass air flowing in a bypass duct of a turbofan gas turbine engine can be a heat sink for other systems of the engine. However, installing a heat exchanger inside a bypass duct of a turbofan engine can negatively affect performance. For example, the presence of a heat exchanger in the bypass duct can disrupt the flow of bypass air and result in energy losses and a penalty in the specific fuel consumption of the engine. Improvement is desirable.
SUMMARY
[0004] In one aspect, the disclosure describes a turbofan gas turbine engine comprising: [0005] a bypass duct at least partially surrounding a core engine, the bypass duct defining a first general flow direction for bypass air flowing inside the bypass duct; [0006] a fan delivering the bypass air to the bypass duct and core air to the core engine; and [0007] a fluid cooler including: [0008] an inlet duct having an inlet protruding into the bypass duct and receiving a portion of the bypass air into the inlet duct; [0009] a heat exchanger in fluid communication with the inlet duct, the heat exchanger facilitating heat transfer between a fluid and the portion of bypass air received into the inlet duct, the heat exchanger defining a second general flow direction for the portion of bypass air through the heat exchanger, the second general flow direction being different from the first general flow direction defined by the bypass duct; and [0010] an outlet duct conveying the portion of bypass air from the heat exchanger to the bypass duct.
[0011] In another aspect, the disclosure describes a fluid cooler for installation in an opening formed in a shroud of a bypass duct of a turbofan gas turbine engine. The fluid cooler comprises: [0012] a mounting interface for attachment of the fluid cooler to the shroud of the bypass duct; [0013] an inlet duct having a ram air inlet disposed above the mounting interface for protruding into the bypass duct during use and receive a portion of the bypass air into the inlet duct; [0014] a heat exchanger in fluid communication with the inlet duct for facilitating heat transfer between a fluid and the portion of bypass air received into the inlet duct, at least a portion of the heat exchanger being disposed below the mounting interface to be disposed outside of the bypass duct during use; and [0015] an outlet duct for conveying the portion of bypass air from the heat exchanger to the bypass duct.
[0016] In a further aspect, the disclosure describes a method for cooling a fluid using bypass air flowing along a first flow direction inside a bypass duct of a turbofan gas turbine engine. The method comprises: [0017] receiving a portion of the bypass air flowing along the first flow direction; [0018] directing the portion of bypass air from the first flow direction toward a second flow direction different from the first flow direction; [0019] conveying the portion of bypass air through a heat exchanger along the second flow direction to facilitate heat transfer between the portion of bypass air and the fluid; and [0020] conveying the portion of bypass air from the heat exchanger to the bypass duct.

[0021] In a further aspect, the disclosure describes a method of manufacturing a fluid cooler. The fluid cooler includes an inlet duct extending along a nonlinear trajectory to direct a cooling fluid flowing in a first direction toward a different second direction through a heat exchanger. The method comprises: [0022] constructing a first model of the inlet duct, the first model including a guide vane disposed inside the inlet duct; [0023] identifying a region of energy loss in a flow of test fluid flowing through the inlet duct of the first model; [0024] constructing a second model of the inlet duct, the second model being based on the first model and including a modification of the guide vane from the first model in response to the identification of the region of energy loss; [0025] manufacturing the inlet duct based on the second model; and [0026] assembling the inlet duct in fluid communication with the heat exchanger.
[0027] Further details of these and other aspects of the subject matter of this application will be apparent from the detailed description included below and the drawings.

Description

DESCRIPTION OF THE DRAWINGS
[0028] Reference is now made to the accompanying drawings, in which:
[0029] FIG. **1** shows a schematic axial cross-section view of a turbofan gas turbine engine including a fluid cooler as described herein;
[0030] FIG. **2** is a perspective view of an exemplary fluid cooler installed in a bypass duct of the engine of FIG. **1** and showing an inlet of the fluid cooler;
[0031] FIG. **3** is another perspective view of a housing of the fluid cooler of FIG. **2** installed in the bypass duct of the engine of FIG. **1** and showing an outlet of the fluid cooler;
[0032] FIG. **4** is a schematic perspective view of an exemplary heat exchanger of the fluid cooler of FIG. **2**;
[0033] FIG. **5** is a schematic cross-sectional view of the fluid cooler of FIG. **2** taken along line **5-5** in FIG. **2**;
[0034] FIG. **6** is an enlarged cross-sectional view of an exemplary inlet of the fluid cooler of FIG. **2**;
[0035] FIG. **7** is an enlarged cross-sectional view of an exemplary guide vane of the fluid cooler of FIG. **2**;
[0036] FIG. **8** is a flowchart illustrating a method for cooling a fluid using bypass air from a bypass duct of a turbofan gas turbine engine;
[0037] FIG. **9** is a flowchart illustrating a method of manufacturing a fluid cooler;
[0038] FIG. **10** is a tridimensional stream line plot illustrating the flow of cooling air through a baseline design of the fluid cooler of FIG. **2**; and
[0039] FIGS. **11**A-**11**D are fluid velocity maps illustrating Mach number contours associated with different design iterations of the fluid cooler of FIG. **2**.
DETAILED DESCRIPTION
[0040] The following disclosure describes fluid cooler installations and associated methods for turbofan gas turbine engines. In some embodiments, the fluid cooler installations and methods described herein may reduce energy losses in the flow of bypass air in bypass ducts of turbofan gas turbine engines compared to existing fluid cooler installations. For example, the fluid coolers described herein may permit heat exchangers to be oriented non-perpendicular (e.g., obliquely) to the main bypass air flow direction so that heat exchangers having more cooling capacity for a given frontal area (and associated drag penalty) may be used. In some embodiments, the configurations of fluid coolers described herein may also allow the cooling air to be routed from the main flow of bypass air to the heat exchanger and then returned to the main flow of bypass air in a relatively efficient manner to promote reduced energy losses.

[0041] The terms “attached” or “connected” may include both direct attachment/connection (in which two elements contact each other) and indirect attachment/connection (in which at least one additional element is located between the two elements).
[0042] The term “substantially” as used herein may be applied to modify any quantitative representation which could permissibly vary without resulting in a change in the basic function to which it is related.
[0043] Aspects of various embodiments are described through reference to the drawings.
[0044] FIG. **1** illustrates a gas turbine engine **10** of a type preferably provided for use in subsonic flight, generally comprising in serial flow communication a fan **12** through which ambient air is propelled, a multistage compressor **14** for pressurizing the air, a combustor **16** in which the compressed air is mixed with fuel and ignited for generating an annular stream of hot combustion gases, and a turbine section **18** for extracting energy from the combustion gases. Engine **10** may be suitable for use in aircraft applications. For example, engine **10** may be a turbofan gas turbine engine. Engine **10** may include core engine **20** and bypass duct **22** at least partially surrounding core engine **20**. Core engine **20** may include compressor **14**, combustor **16** and turbine section **18**. Core engine **20** may define a core gas path in which core airflow C is received and conveyed. Bypass duct **22** may define a substantially annular passage around core engine **20** in which bypass airflow B is received and conveyed. Fan **12** may be disposed within an air inlet of engine **10** and deliver bypass airflow B to bypass duct **22** and may also deliver core airflow C to core engine **20**. Engine **10** may have central axis CA, which may correspond to a rotation axis of fan **12** and/or of other (e.g., low-pressure and/or high-pressure) shaft(s) of engine **10**. Central axis CA may also correspond to a central axis of annular bypass duct **22**.
[0045] Engine **10** may include fluid cooler **24** using a portion of bypass airflow B, referenced herein as cooling airflow b, as a heat sink for cooling another fluid. In some embodiments, fluid cooler **24** may include an air-to-air heat exchanger where cooling airflow b is used to cool pressurized air (i.e., bleed air) extracted from compressor **14** before such pressurized air is used for another purpose such as in an environmental control system (ECS) of an aircraft to which engine **10** is mounted for example. In some embodiments, fluid cooler **24** may include an air-to-liquid heat exchanger where cooling airflow b is used to cool oil from a lubricating system of engine **10**, or fuel. Cooling airflow b may be captured (e.g., as ram air) from the main bypass airflow B and conveyed through a heat exchanger of fluid cooler **24** where heat is transferred from the other fluid to cooling airflow b. After passing though the heat exchanger, cooling airflow b may be returned to the main bypass airflow B inside of bypass duct **22**. The addition of heat to cooling airflow b may provide a performance benefit by adding energy to bypass airflow B and may compensate for some energy loss associated with directing cooling airflow b through fluid cooler **24**. In some embodiments, a relatively small positive net thrust may be achieved in some situations where the heat load is elevated enough and at high enough flight altitudes with low air density.
[0046] FORWARD and AFT directions are indicated in FIG. **1** where the FORWARD direction corresponds generally to a direction of motion of the illustrated turbofan engine **10** during flight when mounted to an aircraft.
[0047] FIG. **2** is a perspective view of an exemplary fluid cooler **24** installed in bypass duct **22** of engine **10**. Fluid cooler **24** may be installed in opening **26** formed in shroud **28** of bypass duct **22**. Shroud **28** may be a radially-outer or a radially-inner shroud of bypass duct **22**. Accordingly, shroud **28** may define a radially-outer or a radially-inner boundary of bypass duct **22**. In various embodiments, a portion of fluid cooler **24** may be disposed (i.e., submerged, protrude) inside of bypass duct **22** and another portion of fluid cooler **24** may be disposed outside of bypass duct **22**. The portion of fluid cooler **24** shown in FIG. **2** may be disposed (i.e., submerged, protrude) inside of bypass duct **22**.
[0048] Fluid cooler **24** may include housing **30** in which at least part of a heat exchanger may be disposed. Submerged portion **30**A of housing **30** disposed (i.e., submerged) inside of bypass duct

22 may include an aerodynamic fairing that is intended for reduced drag created in bypass airflow B by way of housing **30** protruding into bypass duct **22**. Fluid cooler **24** may include inlet **32** disposed on a forward side of housing **30** and permitting cooling airflow b (i.e., a portion of bypass airflow B) to be received into inlet **32** as ram air and used by the heat exchanger to cool another fluid. Housing **30** may also define inlet lip **38** at least partially surrounding inlet **32**. Fluid cooler **24** may include outlet **34** disposed on an aft side of housing **30** and permitting cooling airflow b to be released from fluid cooler **24** after picking up heat from the other fluid via the heat exchanger, and discharged back into bypass duct **22**. In some embodiments, the size (e.g., cross-sectional area) of inlet **32** may be selected to be smaller than outlet **34** due to the increase in temperature of cooling air b that happens in fluid cooler **24**. The relative sizing of inlet **32** and outlet **34** may facilitate the profiling of housing **30** to hinder flow detachment around housing **30**.

[0049] Fluid cooler **24** may include mounting interface **36** for direct or indirect attachment of fluid cooler **24** to shroud **28** of bypass duct **22**. In some embodiments, mounting interface **36** may be attached to a portion of shroud **28** that is recessed relative to a main portion of shroud **28**. Various types of mounting interfaces **36** may suitable. As shown in FIG. **2** as an example, mounting interface **36** may include one or more flanges that are attached to or integrally formed with housing **30** and that extend outwardly from housing **30**. The flange(s) may overlap and be engaged with a portion of shroud **28** surrounding opening **26** to define a lap joint therebetween. The flange(s) may extend completely or partially around fluid cooler **24** and may facilitate the establishment of a sealed connection (e.g., via a suitable gasket) between housing **30** and shroud **28**. The flange(s) may also permit fluid cooler **24** to be releasably attached to shroud **28** via one or more fasteners such as bolts as shown in FIGS. **5** and **6**. Mounting interface **36** may substantially conform to a (e.g., flat, single-curvature, double-curvature) shape of a counterpart portion of shroud **28**. Alternatively or in addition, mounting interface **36** may include a shoulder surface formed in housing **30** for engagement with a portion of shroud **28** around opening **26**.

[0050] Part(s) of fluid cooler **24** that are disposed above mounting interface **36** in relation to FIG. **2** may protrude into bypass duct **22**. For example, inlet **32**, outlet **34** and part of submerged portion **30**A of housing **30** may protrude into bypass duct **22**. Part(s) of fluid cooler **24** that are disposed below mounting interface **36** may be disposed outside of bypass duct **22** and may not contribute to the overall frontal area of fluid cooler **24** perpendicular to bypass airflow B. Having part(s) of fluid cooler **24** disposed outside of bypass duct **22** may also facilitate the connection of servicing lines for cooled fluid F with the heat exchanger.

[0051] FIG. **3** is a perspective view of housing **30** of fluid cooler **24** installed in bypass duct **22**. FIG. **3** shows an aft side of housing **30** with outlet **34** formed therein. Housing **30** may include aperture **39** allowing a heat exchanger as described further below to be inserted into housing **30**. Housing **30** is shown in FIG. **3** with the heat exchanger removed therefrom. Housing **30** may include submerged (e.g., upper) housing portion **30**A that is disposed above mounting interface **36**, protrudes into bypass duct **22** and is thereby submerged into bypass airflow B. Housing **30** may also include concealed (e.g., lower) housing portion **30**B that is disposed below mounting interface **36** and outside of bypass duct **22**.

[0052] FIG. **4** is a schematic perspective view of an exemplary heat exchanger **40** of fluid cooler **24**. It is understood that various types of (e.g., air-to-air, air-to-liquid) heat exchangers may be suitable for use in fluid cooler **24**. Heat exchanger **40** may include an automotive type radiator. Heat exchanger **40** may include a plate-fin heat exchanger for example. Heat exchanger **40** may include header (e.g., manifold) tanks **42**A, **42**B that are fluidly connected together via core **44** defining a plurality of narrow passageways to provide a relatively high surface area for heat transfer between the two fluids relative to volume.

[0053] An inset in FIG. **4** shows an exploded perspective view of an exemplary construction of core **44** having a plate-fin configuration. Core **44** may include substantially parallel parting plates **46** separated by finned chamber **48** to transfer heat between fluids. Heat transfer fin **50** may be disposed between parting plates **46** and define a plurality of passages **52** for one of the fluids. Sides of finned chamber **48** may be sealed by side bars/walls that are not shown in the inset. Layers of parting plates **46** and heat transfer fin **50** stacked together may define a plurality of finned chambers **48** that each convey the first or the second fluid in an alternating arrangement. Heat transfer fin **50** in adjacent finned chambers **48** may be oriented at orientations providing passages **52** that allow for crossflow, counterflow, cross-counterflow or parallel flow configurations.

[0054] Core **44** may define cooling air entrance **54** for cooling air b and cooling air exit **56** for cooling air b. Cooling air entrance **54** and cooling air exit **56** may be substantially planar and parallel in some embodiments. Cooling air b may be conveyed from cooling air entrance **54** to cooling air exit **56** substantially along cooling airflow direction D2 defined by passages **52** which may be substantially parallel. Header tanks **42**A, **42**B may define cooled fluid entrance **58** and cooled fluid exit **60** for cooled fluid F (e.g., air, oil, fuel) that is cooled by cooling air b. Cooled fluid F may be conveyed between header tanks **42**A, **42**B across core **44** substantially along cooled fluid flow direction D3 defined by parting plates **46** of heat exchanger **40** which may be substantially parallel. Cooling airflow direction D2 and cooled fluid flow direction D3 may be substantially perpendicular to each other.

[0055] FIG. **5** is a schematic cross-sectional view of fluid cooler **24** of FIG. **2** taken along line **5-5** in FIG. **2**. Bypass duct **22** may define a general bypass flow direction D1 for bypass airflow B flowing inside bypass duct **22**. Bypass flow direction D1 may correspond to the main (i.e., primary) fluid motion inside of bypass duct **22**. In some embodiments and/or locations within bypass duct **22**, bypass flow direction D1 may be substantially parallel (e.g., axial relative to) to central axis CA of engine **10**.

[0056] Fluid cooler **24** may include inlet duct **62** having inlet **32** disposed above mounting interface **36** and protruding into bypass duct **22** to receive a portion of bypass airflow B into inlet duct **62**. Inlet **32** may be configured (e.g., as a scoop) for receiving ram air into inlet duct **62**. Heat exchanger **40** may be in fluid communication with inlet duct **62** for facilitating heat transfer between cooled fluid F and cooling fluid b received into inlet duct **62**. Fluid cooler **24** may include outlet duct **64** having outlet **34** for conveying cooling air b from heat exchanger **40** back to bypass duct **22** after cooling air b has picked up heat from cooled fluid F. Outlet **34** may also be disposed above mounting interface **36** and protrude into bypass duct **22**.

[0057] Inlet duct **62** and outlet duct **64** may both direct cooling air b along a nonlinear trajectory to accommodate the oblique or other orientation of heat exchanger **40** relative to bypass airflow direction D1 and/or relative to central axis CA. For example, cooling airflow direction D2 defined by heat exchanger **40** may be oriented at angle β relative to bypass airflow direction D1 and/or to central axis CA. In some embodiments, angle β may be between 70° and 76°. Cooling fluid flow direction D3 defined by heat exchanger **40** may be oriented at a relatively shallow angle α relative to bypass airflow direction D1 and/or to central axis CA. In some embodiments, angle α may be between 14° and 20° for example. In some embodiments, angle α may be between 0° and 20° for example. In some embodiments, core **44** may have a generally cuboid (i.e., box-shaped) configuration as illustrated in FIG. **4** and directions D2 and D3 may be used to define an orientation of core **44** relative to another frame of reference. It is understood that other orientations of core **44** may be suitable.

[0058] The oblique orientation of core **44** relative to bypass airflow B may allow for a reduced frontal area of heat exchanger **40** as seen by bypass airflow B for a given cooling capacity compared to having core **44** oriented perpendicular to bypass airflow B. In some embodiments, this may facilitate the use of a core **44** having cooling air entrance **54** and cooling air exit **56** of greater areas (e.g., wider and/or taller) to provide greater cooling capacity compared to other installations. In some embodiments, this may also facilitate the use of a core **44** having a smaller thickness (i.e., the distance between cooling air entrance **54** and cooling air exit **56**) to provide a shorter path for cooling airflow b across core **44**, and consequently reduce the flow resistance and associated energy loss across core **44** compared to other installations. In some embodiments, the configuration of fluid cooler **24** may allow for scaling up cooling capacity with reduced increase in frontal area of fluid cooler **24**.

[0059] Fluid cooler **24** may also be configured so that at least a portion heat exchanger **40** is disposed below mounting interface **36** and outside of the bypass duct **22** during use. Accordingly, the portion of heater exchanger **40** disposed outside of bypass duct **22** may not contribute to the effective frontal area of fluid cooler **24** inside of bypass duct **22**. In some embodiments, a portion of heat exchanger **40** may protrude inside of bypass duct **22** (e.g., above mounting interface **36**) and another portion of heat exchanger **40** may be disposed outside of bypass duct **22** (e.g., below mounting interface **36**).

[0060] The locations of header tanks **42**A, **42**B relative to core **44** in the orientation of heat exchanger **40** shown in FIG. **5** may also promote a smaller overall frontal area of fluid cooler **24** inside of bypass duct **22**. For example, header tanks **42**A, **42**B may be respectively disposed forward and aft of core **44** where cooled fluid flow direction D3 has a greater vector component that is along bypass airflow direction D1 as opposed to transverse thereto. Compared to having header tanks **42**A, **42**B disposed on opposite lateral sides of core **44** and directly contributing to the overall width of fluid cooler **24** across bypass airflow B, the forward-aft locations of header tanks **42**A, **42**B may benefit from the oblique orientation of heat exchanger **40** to promote a smaller frontal area. In some embodiments, forward header tank **42**A may be disposed above mounting interface **36** and protrude in bypass duct **22**. In some embodiments, aft header tank **42**B may be disposed below mounting interface **36** and outside of bypass duct **22**.

[0061] A forward portion of housing **30** may define inlet lip **38** associated with inlet **32**. Inlet lip **38** may be exposed to the incoming bypass airflow B. Housing **30** may define a hollow internal cavity **66** behind inlet lip **38**. In other words, an inner side of a wall of housing **30** defining inlet lip **38** may face internal cavity **66**. Forward header tank **42**A may be disposed inside cavity **66** and be in thermal communication with the wall of housing **30** defining inlet lip **38**. Some of the heat from cooled fluid F supplied to forward header tank **42**A may be released inside of cavity **66** and transferred to the wall of housing **30** defining inlet lip **38** to provide icing protection (e.g., anti-icing, de-icing) of inlet lip **38** in some embodiments.

[0062] Inlet duct **62** may extend along a nonlinear (e.g., curved) trajectory to direct cooling airflow b received at inlet **32** generally along bypass airflow direction D1 toward cooling airflow direction D2 through heat exchanger **40**. In some embodiments, inlet duct **62** may have a S-shaped trajectory. In some embodiments, inlet duct **62** may include one or more guide vanes **68** disposed therein to interact with cooling airflow b and assist with the directing of cooling airflow b toward cooling airflow direction D2 through core **44**. Guide vane **68** may extend laterally relative to central axis CA. For example, leading edge **68**A of guide vane **68** may extend transversely to central axis CA and also transversely to a radial direction relative to central axis CA. In other words, leading edge **68**A may extend substantially perpendicular to the page in FIG. **5**.

[0063] Outlet duct **64** may extend along a nonlinear (e.g., curved) trajectory to direct cooling airflow b discharged from cooling air exit **56** of heat exchanger **40** along cooling airflow direction D2 toward bypass airflow direction D1. Outlet **34** may also protrude into bypass duct **22** and facilitate a return of cooling airflow b to bypass airflow B with reduced flow disruptions to bypass airflow B.

[0064] FIG. **6** is an enlarged axial cross-sectional view of inlet **32** of fluid cooler **24** as shown in FIG. **5** in a plane parallel to and containing central axis CA shown in FIG. **5**. FIG. **6** also shows an axial cross-sectional profile of inlet lip **38** associated with inlet **32**. In some embodiments, inlet lip **38** may have a rounded (i.e., blunt, non-sharp) axial cross-sectional profile. In some embodiments, the rounded shape of inlet lip **38** may allow for a stagnation point to remain attached to inlet lip **38** at various positions on inlet lip **38** and for a range of flow conditions. In some embodiments, this may allow the aerodynamic continuity to be maintained throughout a range of flow conditions on a

portion of the wall of housing **30** defining inlet lip **38** and extending toward inlet duct **62** and away from inlet duct **62**. In some non-limiting embodiments, inlet lip **38** may have radius R selected so that inlet lip **38** may define a (e.g., non-sharp) bullnose edge.
[0065] FIG. **7** is an enlarged cross-sectional view of part of inlet duct **62** including guide vane **68**. In some embodiments, guide vane **68** may be disposed closer to heat exchanger **40** than to inlet **32**. Guide vane **68** may have chord line CH extending between leading edge **68**A and trailing edge **68**B of guide vane **68**. In some embodiments, mid point MP of chord line CH may be disposed closer to cooling air entrance **54** of heat exchanger **40** than to inlet **32** of inlet duct **62**.
[0066] FIG. **8** is a flowchart illustrating method **1000** for cooling cooled fluid F using bypass air from bypass duct **22** of engine **10**. Method **1000** may be conducted using fluid cooler **24** described herein or using another fluid cooler. Aspects of fluid cooler **24** may be included in method **1000**. Aspects of method **1000** may also be combined with aspects of other methods described herein. Method **1000** may include: [0067] receiving a portion of bypass air (e.g., cooling airflow b) flowing along a first flow direction (e.g., bypass flow direction D1) (see block **1002**); [0068] directing the portion of bypass air from the first flow direction toward a second flow direction (e.g., cooling airflow direction D2) different from the first flow direction (see block **1004**); [0069] conveying the portion of bypass air through heat exchanger **40** along the second flow direction to facilitate heat transfer between the portion of bypass air and the cooled fluid F (see block **1006**); and [0070] conveying the portion of bypass air from heat exchanger **40** to bypass duct **22** (see block **1008**).
[0071] In some embodiments, conveying cooling airflow b from heat exchanger **40** to bypass duct **22** may include directing cooling airflow b from cooling airflow direction D2 back toward bypass airflow direction D1.
[0072] In some embodiments, cooling airflow b may be received into inlet **32** defined by inlet lip **38** and icing protection for inlet lip **38** may be provided using heat from cooled fluid F (e.g., via forward header tank **42**A).
[0073] FIG. **9** is a flowchart illustrating method **2000** of manufacturing a fluid cooler. Method **2000** may be used for manufacturing fluid cooler **24** described herein and aspects of fluid cooler **24** may be included in method **2000**. Aspects of method **2000** may also be combined with aspects of other methods described herein. For example, the manufactured fluid cooler **24** may include inlet duct **32** extending along a nonlinear trajectory to direct a fluid flowing in a first direction toward a second direction through heat exchanger **40** where the second direction is different from the first direction. Aspects of method **2000** are described in reference to FIGS. **10** and **11**A-**11**D. Method **2000** may include: [0074] constructing first model **124** (shown in FIG. **11**A) including inlet duct **162**, first model **124** including guide vane **168** or **170** disposed inside inlet duct **162** (see block **2002**); [0075] identifying region(s) **172**A-**172**D of energy loss in a flow of test fluid (e.g., air) flowing through inlet duct **162** (see block **2004**); [0076] constructing second model **224**, **324** or **424** (shown in FIGS. **11**B-**11**D) including inlet duct **262**, **362** or **462**, second model **224**, **324** or **424** being based on first model **124** and including a modification of guide vane **168** or **170** from first model **124** in response to the identification of region(s) **172**A-**172**D of energy loss (see block **2006**); [0077] manufacturing inlet duct **62** based on inlet duct **262**, **362** or **462** of second model **224**, **324** or **424** (see block **2008**); and [0078] assembling inlet duct **62** in fluid communication with heat exchanger **40** (see block **2010**).
[0079] FIG. **10** is a tridimensional stream line plot illustrating the flow of cooling airflow b through a baseline model **024** of fluid cooler **24** of FIG. **2** that does not include guide vane **68**. Baseline model **024** may include inlet **032** and outlet **034**. Bypass airflow B may be received in inlet **032**, flow through baseline model **024** and exit outlet **034**. Bypass airflow B and cooling airflow b are illustrated by way of stream lines that may be determined based on the expected flow (e.g., boundary) conditions and the geometry of the passage(s) provided inside of model **024**. The stream lines may be a family of curves that are instantaneously tangent to the velocity vector of the flow.

The stream lines show the direction in which a massless fluid element will travel at different moments in time. The stream lines may be determined by modelling and simulation using computational fluid dynamics (CFD) and model **024** in digital form (e.g., a data structure). Accordingly, methods disclosed herein (or part(s) thereof) could be performed using one or more computers using suitable CFD software. Alternatively or in addition, the stream lines may be determined empirically using model **024** in physical form and wind tunnel testing for example.

[0080] FIGS. **11**A-**11**D are fluid velocity maps illustrating Mach number contours associated with different design iterations (i.e., models **124**, **224**, **324** and **424**) of fluid cooler **24**. The fluid velocity maps are taken as axial cross-sections of the type shown in FIG. **5**. Reference numerals used in FIG. **11**A used to represent elements previously described are incremented by 100. Reference numerals used in FIGS. **11**B-**11**D used to represent elements shown in FIG. **11**A are progressively incremented by 100 with each of FIGS. **11**B-**11**D. In reference to FIG. **11**A, regions **172**A-**172**D of relatively low Mach number may be represent secondary flows developed as a result of static pressure differentials. For example, regions **172**A-**172**D may include recirculation zones. Regions **172**A-**172**D may be indicative of energy loss in cooling airflow b. The fluid velocity maps of FIGS. **11**A-**11**D may be determined by modelling and simulation using CFD and models **124**, **224**, **324** and **424** in digital form. Alternatively, fluid velocity maps may be determined empirically using models **124**, **224**, **324** and **424** in physical form and wind tunnel testing for example.

[0081] In reference to FIG. **11**A, first model **124** may include bypass airflow B flowing in bypass duct **122** and cooling airflow b flowing in the fluid cooler. Model **124** may includes inlet **132**, inlet lip **138**, inlet duct **162**, heat exchanger core **144**, outlet duct **164** and outlet **134**. Inlet duct **162** may also includes one or more guide vanes **168**, **170**. Guide vanes **168**, **170** may each be relatively thin walls (e.g., fins) extending substantially the entire length of inlet duct **162**. As an initial design iteration, guide vanes **168**, **170** may be shaped to follow and extend along respective estimated/anticipated stream lines such as those shown in FIG. **10** for example. The lengths of guide vanes **168**, **170** of first model **124** may correspond to at least a majority of an entire length of the applicable respective stream lines along inlet duct **162**. Inlet lip **138** may be relatively sharp (i.e., zero or small radius of curvature). First model **124** may also include regions **172**A-**172**E of energy loss in cooling airflow b. Inlet duct **162** may include outer wall **174**.

[0082] As shown in FIGS. **11**A-**11**D, outlet duct **164** may be configured so that at least some cooling airflow b exiting outlet **134** closely matches the velocity and flow direction of bypass airflow B when cooling airflow b is recombined with bypass airflow B.

[0083] FIGS. **11**B-**11**D respectively show three design iterations in order and subsequent to first model **124**. It is understood that fewer or additional design iterations may be performed to achieve the desired level of optimization. Single or multiple design changes may be made with each iteration so that some iterations may be added or combined together so that fewer iterations and models are required. The different design iterations represented by models **124**, **224**, **324** and **424** may be considered examples of embodiments with varying degree of optimization but suitable for use in fluid cooler **24** in some situations.

[0084] FIG. **11**B shows second model **224** which may represent a design iteration subsequent to first model **124**. Second model **224** may be based on first model **124** and may include one or more design modifications that improve (e.g., reduce energy loss in) the flow conditions of cooling airflow b relative to first model **124**. Second model **224** may include bypass airflow B flowing in bypass duct **222** and cooling airflow b flowing in the fluid cooler. Second model **224** may includes inlet **232**, inlet lip **238**, inlet duct **262**, heat exchanger core **244**, outlet duct **264**, outlet **234** and guide vanes **268**, **270**. Inlet duct **262** may include outer wall **274**. Second model **224** may also include regions **272**A-**272**C of energy loss in cooling airflow b.

[0085] Second model **224** may include a modification of guide vane **168** and/or **170** from first model **124** in response to the identification of regions **172**A-**172**E of energy loss in first model **124**. For example, the shape and/or position of guide vanes **168**, **170** may be modified. As an example, region **172**A of energy loss identified in first model **124** may be adjacent guide vane **170**, and a modification of guide vane **170** may include a positional shift of part of guide vane **170** toward region **172**A of energy loss to produce guide vane **270**. As another example, a modification of guide vane **168** may include a positional shift of part of guide vane **168** toward region **172**C of energy loss to produce guide vane **268**. For example, one or both guide vanes **168**, **170** may be adjusted to at least partially fill-in regions **172**C and/or **272**A, and to substantially follow (e.g., be tangent to) the desired natural stream lines within 0° to 5° divergence from the natural stream lines.

[0086] Second model **224** may include modifications to various parts of first model **124**. As another example, the shape and/or position of outer wall **174** of inlet duct **162** may be altered. Region **172**E of energy loss identified in first model **124** may be adjacent outer wall **174** of inlet duct **162**. Second model **224** may include a positional shift of outer wall **174** toward region **172**E of energy loss to produce outer wall **274**. For example, outer wall **174** may be adjusted to at least partially fill-in region **172**E, and to substantially follow (e.g., be tangent to) the desired natural stream lines within 0° to 5° divergence from the natural stream lines.

[0087] FIG. **11**C shows third model **324** which may represent a design iteration subsequent to first model **124** and/or second model **224**. Third model **324** may include one or more design modifications that further improve (e.g., reduce energy loss in) the flow conditions of cooling airflow b. Third model **324** may include bypass airflow B flowing in bypass duct **322** and cooling airflow b flowing in the fluid cooler. Third model **324** may includes inlet **332**, inlet lip **338**, inlet duct **362**, heat exchanger core **344**, outlet duct **364**, outlet **334**, guide vanes **368**, **370**. Inlet duct **362** may include outer wall **374**. Third model **324** may also include regions **272**A-**272**E of energy loss in cooling airflow b.

[0088] Third model **324** may include a modification of guide vanes **268** and/or **270** from second model **224** in response to the identification of regions **272**A-**272**C of energy loss in second model **224**. For example, the thickness of one or both guide vanes **268**, **270** may be increased to produce guide vanes **368**, **370**. For example, guide vanes **268**, **270** may be thickened to at least partially fill-in regions **272**C and **272**A respectively, tangent to the desired stream lines within 0° to 5° of divergence.

[0089] FIG. **11**D shows fourth model **424** which may represent a design iteration subsequent to first model **124**, second model **224** or third model **324**. Fourth model **424** may include one or more design modifications that further improve (e.g., reduce energy loss in) the flow conditions of cooling airflow b. Fourth model **424** may include bypass airflow B flowing in bypass duct **422** and cooling airflow b flowing in the fluid cooler. Fourth model **424** may includes inlet **432**, inlet lip **438**, inlet duct **462**, heat exchanger core **444**, outlet duct **464**, outlet **434**, guide vanes **468**, **470**. Inlet duct **462** may include outer wall **474**. Fourth model **424** may also include regions **472**A-**472**C of energy loss in cooling airflow b.

[0090] Fourth model **424** may include a removal of guide vane **370** relative to third model **324**. Fourth model **424** may include a reduction in length of guide vane **368** and a rounding of the leading edge of guide vane **368** to produce guide vane **468**. The single guide vane **468** may provide two separate flow paths P1 and P2 to heat exchanger core **444**. In some embodiments, one or both paths P1, P2 may have an expanding cross-sectional area toward core **444** so that some diffusion of cooling airflow b may be provided immediately upstream of core **444**. Such diffusion of cooling airflow b may be beneficial in creating a pressure and promoting spreading of cooling airflow b across cooling air entrance **454** of core **444**.

[0091] Fourth model **424** may include a rounding of inlet lip **438**. For example, cross-sectional radius R of inlet lip **438** may be increased to be greater than in one or more previous design iterations. Regions **472**C of energy loss at inlet lip **438** may represent a stagnation point that is attached to inlet lip **438** at the operating conditions represented in fourth model **424**.

[0092] In reference to FIGS. **2**, **3** and **3**, inlet duct **62**, outlet duct **64** and any other parts of housing **30** shown in FIGS. **2**, **3** and **3** may be manufactured according to any one of models **124**, **224**, **324**,

424 or any combinations thereof. Housing **30** may be manufactured out of metallic and/or fiber reinforced polymeric material for example. In some embodiments, housing **30** may be made of sheet metal (e.g., aluminum alloy, titanium alloy or steel) using suitable metal forming techniques including die forming. In some embodiments, multiple pieces of sheet metal may be formed and subsequently assembled (e.g., fastened and/or welded) together. In some embodiments, part(s) of housing **30** may be made from a metallic material using additive manufacturing.
[0093] In some embodiments, part(s) of housing **30** may be made from a suitable fiber-reinforced composite material. Part(s) of housing **30** may, for example, be made by injection molding using a polymeric material reinforced with relatively short and randomly oriented carbon fibers. Part(s) of housing **30** may, for example, be made by **3**D printing using a polymeric material reinforced with relatively short and randomly oriented carbon fibers.
[0094] In some embodiments, heat exchanger **40** may be assembled with housing **30** after the manufacturing of housing **30**. For example, heat exchanger **40** may be inserted into housing **30** via aperture **39** shown in FIGS. **3** and **5** so that core **44** becomes in fluid communication with inlet duct **62** and outlet duct **64**. In cases where housing **30** is made of multiple pieces, heat exchanger **40** and associated plumbing may be assembled with pieces of housing **30** as the pieces of housing **30** are assembled together.
[0095] The embodiments described in this document provide non-limiting examples of possible implementations of the present technology. Upon review of the present disclosure, a person of ordinary skill in the art will recognize that changes may be made to the embodiments described herein without departing from the scope of the present technology. Yet further modifications could be implemented by a person of ordinary skill in the art in view of the present disclosure, which modifications would be within the scope of the present technology.

Claims

1. A fluid cooler for installation in an opening formed in a shroud of a bypass duct of a turbofan gas turbine engine, the fluid cooler comprising: a mounting interface for attachment of the fluid cooler to the shroud of the bypass duct; an inlet duct having a ram air inlet disposed above the mounting interface for protruding into the bypass duct during use and receive a portion of bypass air into the inlet duct; a heat exchanger in fluid communication with the inlet duct for facilitating heat transfer between a fluid and the portion of bypass air received into the inlet duct, at least a portion of the heat exchanger being disposed below the mounting interface to be disposed outside of the bypass duct during use; and an outlet duct for conveying the portion of bypass air from the heat exchanger to the bypass duct.
2. The fluid cooler as defined in claim 1, comprising a guide vane disposed inside the inlet duct for interacting with the portion of bypass air received into the inlet duct.
3. The fluid cooler as defined in claim 2, wherein: the guide vane has a leading edge, a trailing edge and a chord line extending between the leading edge and the trailing edge; and a mid point of the chord line is disposed closer to an entrance of the heat exchanger for the portion of bypass air than to the ram air inlet of the inlet duct.
4. The fluid cooler as defined in claim 1, wherein: the inlet duct defines a nonlinear path to direct the portion of bypass air from a first flow direction toward a second flow direction through the heat exchanger; and the second flow direction is oriented 70° to 76° of the first flow direction.
5. The fluid cooler as defined in claim 1, wherein: the portion of the heat exchanger is a first portion of the heat exchanger; and a second portion of the heat exchanger is disposed above the mounting interface for protruding into the bypass duct during use.
6. The fluid cooler as defined in claim 1, wherein: the heat exchanger includes a first header tank and a second header tank fluidly connected via a core; the first header tank is disposed entirely

above the mounting interface; and the second header tank is disposed entirely below the mounting interface.