METHOD OF MANUFACTURING A UNITARY VENTURI

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A method for fabricating a unitary venturi is disclosed, the method comprising the steps of determining three-dimensional information of the unitary venturi having an annular venturi wall and a swirler having a plurality of vanes arranged circumferentially around a swirler axis, converting the three-dimensional information into a plurality of slices that each define a cross-sectional layer of the unitary venturi, and successively forming each layer of the unitary venturi by fusing a metallic powder using laser energy. Exemplary embodiments are disclosed, showing a unitary venturi comprising an annular venturi wall having a swirler axis and a heat shield located at an end wherein unitary venturi is made by using a rapid manufacturing process. In one aspect of the invention, the rapid manufacturing process is a laser sintering process.
DETERMINE THREE-DIMENSIONAL INFORMATION OF UNITARY VENTURI 500

CONVERT THE THREE-DIMENSIONAL INFORMATION INTO A PLURALITY OF SLICES THAT EACH DEFINE A CROSS-SECTIONAL LAYER OF UNITARY VENTURI 500

SUCCESSIVELY FORM EACH LAYER BY FUSING A METALLIC POWDER USING LASER ENERGY TO FABRICATE UNITARY VENTURI 500
METHOD OF MANUFACTURING A UNITARY VENTURI

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This Application claims priority to U.S. Provisional Application Ser. No. 61/044,116, filed Apr. 11, 2008, which is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] This invention relates generally to venturis, and more specifically to unitary venturis having swirlers for promoting mixing of fuel and air and a heat shield for protection from combustion heat in fuel nozzles used in gas turbine engines.

[0003] Turbine engines typically include a plurality of fuel nozzles for supplying fuel to the combustor in the engine. The fuel is introduced at the front end of a burner in a highly atomized spray from a fuel nozzle. Compressed air flows around the fuel nozzle and mixes with the fuel to form a fuel-air mixture, which is ignited by the burner. Because of limited fuel pressure availability and a wide range of required fuel flow, many fuel injectors include pilot and main nozzles, with only the pilot nozzles being used during start-up, and both nozzles being used during higher power operation. The flow to the main nozzles is reduced or stopped during start-up and lower power operation. Such injectors can be more efficient and cleaner-burning than single nozzle fuel injectors, as the fuel flow can be more accurately controlled and the fuel spray more accurately directed for the particular combustor requirement. The pilot and main nozzles can be contained within the same nozzle assembly or can be supported in separate nozzle assemblies. These dual nozzle fuel injectors can also be constructed to allow further control of the fuel for dual combustors, providing even greater fuel efficiency and reduction of harmful emissions. The temperature of the ignited fuel-air mixture can reach an excess of 3500°F (1920°C). It is therefore important that the fuel supply conduits, flow passages and distribution systems are substantially leak free and are protected from the flames and heat.

[0004] Various governmental regulatory bodies have established emission limits for acceptable levels of unburned hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx), which have been identified as the primary contributors to the generation of undesirable atmospheric conditions. Therefore, different combustor designs have been developed to meet those criteria. For example, one way in which the problem of minimizing the emission of undesirable gas turbine engine combustion products has been attacked is the provision of staged combustion. In that arrangement, a combustor is provided in which a first stage burner is utilized for low speed and low power conditions to more closely control the character of the combustion products. A combination of first stage and second stage burners is provided for higher power outlet conditions while attempting to maintain the combustion products within the emissions limits. It will be appreciated that balancing the operation of the first and second stage burners to allow efficient thermal operation of the engine, while simultaneously minimizing the production of undesirable combustion products, is difficult to achieve. In that regard, operating at low combustion temperatures to lower the emissions of NOx, can also result in incomplete or partially incomplete combustion, which can lead to the production of excessive amounts of HC and CO, in addition to producing lower power output and lower thermal efficiency. High combustion temperature, on the other hand, although improving thermal efficiency and lowering the amount of HC and CO, often results in a higher output of NOx. In the art, one of the ways in which production of undesirable combustion product components in gas turbine engine combustors is minimized over the engine operating regime is by using a staged combustion system using primary and secondary fuel injection ports.

[0005] Another way that has been proposed to minimize the production of those undesirable combustion product components is to provide for more effective intermixing of the injected fuel and the combustion air. In that regard, numerous swirlers, mixer designs and venturi designs have been proposed over the years to improve the mixing of the fuel and air. In this way, burning occurs uniformly over the entire mixture and reduces the level of HC and CO that result from incomplete combustion. However, there is still a need to minimize the production of undesirable combustion products over a wide range of engine operation conditions. Better mixing of fuel and air in fuel nozzles using swirlers in a venturi designed to promote such mixing will be useful in reducing undesirable combustion emissions.

[0006] Over time, continued exposure to high temperatures during turbine engine operations may induce thermal stresses in the conduits and fuel nozzles which may damage the conduits or fuel nozzle and may adversely affect their operation. For example, thermal stresses may cause fuel flow reductions in the conduits and may lead to excessive fuel maldistribution within the turbine engine. Exposure of fuel flowing through the conduits and orifices in a fuel nozzle to high temperatures may lead to coking of the fuel and lead to blockages and non-uniform flow. To provide low emissions, modern fuel nozzles require numerous, complicated internal air and fuel circuits to create multiple, separate flame zones. Fuel circuits may require heat shields from the internal air to prevent coking, and certain tip areas may have to be cooled and shielded from combustion gases. Additional features may have to be provided in the heat shields to promote heat transfer and cooling. Furthermore, over time, continued operation with damaged fuel nozzles may result in decreased turbine efficiency, turbine component distress, and/or reduced engine exhaust gas temperature margin.

[0007] Improving the life cycle of fuel nozzles installed within the turbine engine may extend the longevity of the turbine engine. Known fuel nozzles include a delivery system, a mixing system, and a support system. The delivery system comprising conduits for transporting fluids delivers fuel to the turbine engine and is supported, and is shielded within the turbine engine, by the support system. More specifically, known support systems surround the delivery system, and as such are subjected to higher temperatures and have higher operating temperatures than delivery systems which are cooled by fluid flowing through the fuel nozzle. It may be possible to reduce the thermal stresses in the conduits and fuel nozzles by configuring their external and internal contours and thicknesses.

[0008] Air-fuel mixers have swirler assemblies that swirl the air passing through them to promote mixing of air with fuel prior to combustion. The swirler assemblies used in the combustors may be complex structures having axial, radial or conical swirlers or a combination of them. In the past, conventional manufacturing methods have been used to fabricate
mixers having separate venturi and swirler components that are assembled or joined together using known methods to form assemblies. For example, in some mixers with complex vanes, individual vanes are first machined and then brazed into an assembly. Investment casting methods have been used in the past in producing some combustor swirlers. Other swirlers and venturis have been machined from raw stock. Electro-discharge machining (EDM) has been used as a means of machining the vanes in conventional fuel nozzle components.

Conventional gas turbine engine components such as, for example, fuel nozzles and their associated swirlers, conduits, distribution systems, venturis and mixing systems are generally expensive to fabricate and/or repair because the conventional fuel nozzle designs have complex swirlers, conduits and distribution circuits and venturis for transporting, distributing and mixing fuel with air include a complex assembly and joining of more than thirty components. More specifically, the use of braze joints can increase the time needed to fabricate such components and can also complicate the fabrication process for any of several reasons, including: the need for an adequate region to allow for braze alloy placement; the need for minimizing unwanted braze alloy flow; the need for an acceptable inspection technique to verify braze quality; and, the necessity of having several braze alloys available in order to prevent the re-melting of previous braze joints. Moreover, numerous braze joints may result in several braze runs, which may weaken the parent material of the component. The presence of numerous braze joints can undesirably increase the weight and manufacturing cost of the component.

Accordingly, it would be desirable to have a venturi having complex geometries for mixing fuel and air in fuel nozzles while protecting the structures from heat for reducing undesirable effects from thermal exposure described earlier. It is desirable to have venturis have integral heat shields having features that promote heat exchange and cooling of structures. It is desirable to have a venturi having complex geometries with a unitary construction to reduce the cost and for ease of assembly as well as providing protection from adverse thermal environments. It is desirable to have a method of manufacturing to provide a unitary construction for a venturi having complex three-dimensional geometries, such as, for example, a venturi with swirler and heat shield systems for use in fuel nozzles.

**BRIEF DESCRIPTION OF THE INVENTION**

The above-mentioned need or needs may be met by exemplary embodiments which provide a method for fabricating a unitary venturi, the method comprising the steps of determining three-dimensional information of the unitary venturi having an annular venturi wall and a swirler having a plurality of vanes arranged circumferentially around a swirler axis, converting the three-dimensional information into a plurality of slices that each define a cross-sectional layer of the unitary venturi, and successively forming each layer of the unitary venturi by fusing a metallic powder using laser energy. Exemplary embodiments are disclosed, showing a unitary venturi comprising an annular venturi wall having a swirler axis and a heat shield located at an end wherein unitary venturi is made by using a rapid manufacturing process. In one aspect of the invention, the rapid manufacturing process is a laser sintering process.

**DETAILED DESCRIPTION OF THE INVENTION**

The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the concluding part of the specification. The invention, however, may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

**FIG. 1** is a diagrammatic view of a high bypass turbofan gas turbine engine comprising an exemplary fuel nozzle having a venturi according to an exemplary embodiment of the present invention.

**FIG. 2** is an isometric view of an exemplary fuel nozzle having a venturi according to an exemplary embodiment of the present invention.

**FIG. 3** is an axial cross-sectional view of an exemplary nozzle tip assembly of the exemplary fuel nozzle shown in **FIG. 2**.

**FIG. 4** is an isometric view of a venturi according to an exemplary embodiment of the present invention.

**FIG. 5** is an axial cross sectional view of the exemplary venturi shown in **FIG. 4**.

**FIG. 6** is another isometric view of the exemplary venturi shown in **FIG. 4**, with a portion of the venturi sectioned away.

**FIG. 7** is a top plan view of a venturi shown in **FIG. 6** with a portion of the venturi sectioned away.

**FIG. 8** is an isometric view of a venturi according to an alternative exemplary embodiment of the present invention with a portion sectioned away.

**FIG. 9** is a flow chart showing an exemplary embodiment of a method for fabricating a unitary venturi.
turbines 28 and 32, the combustion products leave core engine 14 through an exhaust nozzle 36 to provide at least a portion of the jet propulsive thrust of the engine 10.

Fan section 16 includes a rotatable, axial-flow fan rotor 38 that is surrounded by an annular fan casing 40. It will be appreciated that fan casing 40 is supported from core engine 14 by a plurality of substantially radially-extending, circumferentially-spaced outlet guide vanes 42. In this way, fan casing 40 encloses fan rotor 38 and fan rotor blades 44. Downstream section 46 of fan casing 40 extends over an outer portion of core engine 14 to define a secondary, or bypass, airflow conduit 48 that provides additional jet propulsive thrust.

From a flow standpoint, it will be appreciated that an initial airflow, represented by arrow 50, enters gas turbine engine 10 through an inlet 52 to fan casing 40. Airflow 50 passes through fan blades 44 and splits into a first compressed air flow (represented by arrow 54) that moves through conduit 48 and a second compressed air flow (represented by arrow 56) which enters booster 22.

The pressure of second compressed air flow 56 is increased and enters high pressure compressor 24, as represented by arrow 58. After mixing with fuel and being combusted in combustor 26, combustion products 60 exit combustor 26 and flow through first turbine 28. Combustion products 60 then flow through second turbine 32 and exit exhaust nozzle 36 to provide at least a portion of the thrust for gas turbine engine 10.

The combustor 26 includes an annular combustion chamber 62 that is coaxial with longitudinal axis 12, as well as an inlet 64 and an outlet 66. As noted above, combustor 26 receives an annular stream of pressurized air from a high pressure compressor discharge outlet 69. A portion of this compressor discharge air ("CDP" air) identified by the numeral 190 in the figures herein, flows into a mixer (not shown). Fuel is injected from a fuel nozzle tip assembly to mix with the air and form a fuel-air mixture that is provided to combustion chamber 62 for combustion. Ignition of the fuel-air mixture is accomplished by a suitable igniter, and the resulting combustion gases 60 flow in an axial direction toward and into an annular, first stage turbine nozzle 72. Nozzle 72 is defined by an annular flow channel that includes a plurality of radially-extending, circumferentially-spaced nozzle vanes 74 that turn the gases so that they flow angularly and impinge upon the first stage turbine blades of first turbine 28. As shown in FIG. 1, first turbine 28 preferably rotates high pressure compressor 24 via first drive shaft 30. Low pressure turbine 32 preferably drives booster 24 and fan rotor 38 via second drive shaft 34.

Combustion chamber 62 is housed within engine outer casing 18. Fuel is supplied to the combustion chamber by fuel nozzles 100, such as for example shown in FIGS. 2 and 3. Liquid fuel is transported through conduits within a stem 103, such as, for example, shown in FIG. 3, to the fuel nozzle tip assembly 68. Conduits that have a unitary construction may be used for transporting the liquid fuel into the fuel nozzle tip assembly 68 of the fuel nozzles 100. The fuel supply conduits, may be located within the stem 103 and coupled to a fuel distributor tip 180. Pilot fuel and main fuel are sprayed into the combustor 26 by fuel nozzle tip assemblies 68, such as for example, shown in FIGS. 2 and 3. During operation of the turbine engine, initially, pilot fuel is supplied through a pilot fuel flow passage, such as, for example, shown as items 102, 104 in FIG. 3, during predetermined engine operation conditions, such as during startup and idle operations. The pilot fuel is discharged from fuel distributor tip 180 through the pilot fuel outlet 162. When additional power is demanded, main fuel is supplied through main fuel passageways 105 (see FIG. 3) and the main fuel is sprayed using the main fuel outlets 165.

FIGS. 3-7 show an exemplary embodiment of the present invention of a unitary venturi 500. FIGS. 2 and 3 show an exemplary embodiment of a fuel nozzle 100 and fuel nozzle tip 68 having the exemplary unitary venturi 500. FIG. 8 shows an alternative exemplary embodiment of a unitary venturi 600. The term "unitary" is used in this application to denote that the associated component, such as the venturi 500, 600 described herein, is made as a single piece during manufacturing. Thus, a unitary component has a monolithic construction for the component. FIG. 4 shows an isometric view of a unitary venturi 500 according to an exemplary embodiment of the present invention. The exemplary venturis 500, 600 shown in FIGS. 3-8 include a circumferential array of vanes 508 that impart a swirling motion to the air passing therethrough to enhance fuel-air mixing within the fuel nozzle. The exemplary venturis 500, 600 shown in FIGS. 3-8 may have a unitary construction made using methods described subsequently herein.

Referring to FIGS. 2 and 3, fuel distributor tip 180 extends from the stem 103 such that main fuel passageways 105 and the pilot fuel passageways 102, 104 in the unitary distributor ring 171 are coupled in flow communication corresponding fuel supply conduits contained within the stem 103. Main fuel passageways 105 are coupled in flow communication to main fuel circuits defined within unitary distributor ring 171. Primary pilot passage 103 and secondary pilot passage 104 are coupled in flow communication with corresponding pilot injectors positioned radially inward within a fuel nozzle (see FIG. 3). It will be apparent to those skilled in the art that although the distributor ring 171 has been described herein above as a unitary conduit (i.e., having a unitary construction), it is possible to use a distributor ring 171 having other suitable manufacturing constructs using methods known in the art. The unitary distributor ring 171 is attached to the stem 103 using conventional attachment means such as brazing. Alternatively, the unitary distributor ring 171 and the stem 103 may be made by rapid manufacturing methods such as for example, direct laser metal sintering, described herein.

FIG. 3 shows an axial cross section of an exemplary fuel nozzle tip 68 having an exemplary embodiment of the present invention of a unitary venturi 500. The exemplary fuel nozzle tip 68 shown in FIG. 3 has two pilot fuel flow passages, referred to herein as a primary pilot flow passage 102 and a secondary pilot flow passage 104. Referring to FIG. 3, the fuel from the primary pilot flow passage 102 exits the fuel nozzle through a primary pilot fuel injector 163 and the fuel from the secondary pilot flow passage 104 exits the fuel nozzle through a secondary pilot fuel injector 167. The primary pilot flow passage 102 in the distributor ring 171 is in flow communication with a corresponding pilot primary passage in the supply conduit contained within the stem 103 (see FIG. 2). Similarly, the secondary pilot flow passage 104 in the distributor ring 171 is in flow communication with a corresponding pilot secondary passage in the supply conduit contained within the stem 103.

As described previously, fuel nozzles, such as those used in gas turbine engines, are subject to high temperatures.
Such exposure to high temperatures may, in some cases, result in fuel coking and blockage in the fuel passages, such as for example, the exit passage 164. One way to mitigate the fuel coking and/or blockage in the distributor ring 171 is by using heat shields to protect the passages (such as items 102, 104, 105 shown in FIG. 3) from the adverse thermal environment. In the exemplary embodiment shown in FIG. 3, the fuel conduits 102, 104, 105 are protected by gaps 116 and heat shields that at least partially surround these conduits. The gap 116 provides protection to the fuel passages by providing insulation from adverse thermal environment. In the exemplary embodiment shown, the insulation gaps 116 have widths between about 0.015 inches and 0.025 inches. The heat shields, such as those described herein, can be made from any suitable material with ability to withstand high temperature, such as, for example, cobalt based alloys and nickel based alloys commonly used in gas turbine engines. In exemplary embodiment shown in FIG. 3, the distributor ring 171 has a unitary construction wherein the distributor ring 171, the flow passages 102, 104, 105, the fuel outlets 165, the heat shields and the gaps 116 are formed such that they have a monolithic construction.

FIG. 4 shows an isometric view of a swirler 500 according to an exemplary embodiment of the present invention and FIG. 5 shows an axial cross sectional view of the exemplary swirler shown in FIG. 4. Referring to FIG. 5, the exemplary swirler comprises an annular swirler wall 502 around the swirler axis 11 that forms a mixing cavity 550 wherein a portion of air and fuel are mixed. The annular swirler wall may have any suitable shape in the axial and circumferential directions. A conical shape, such as shown for example in FIG. 5, that allows for an expansion of the air/fuel mixture in the axially forward direction is preferred. The exemplary swirler 500 shown in FIG. 5 has an axially forward portion 509 having an axially forward end 501, and an axially aft portion 511 having an axially aft end 519. The axially forward portion 509 has a generally cylindrical shape (see FIG. 6) wherein the annular swirler wall 502 is generally cylindrical around the swirler axis 11. The venturi wall 502 has at least one groove 504 located on its radially exterior side capable of receiving a brazing material during assembly of a nozzle tip assembly 68. In the exemplary embodiment shown in FIGS. 5 and 6, two annular grooves 504 are shown, one groove 504 near the axially forward end 501 and another groove 504 near an intermediate location between the axially forward end 501 and the axially aft end 519. The grooves 504 may be formed using conventional machining methods. Alternatively, the grooves 504 may be formed integrally when the venturi wall 502 is formed, such as, for example, using the methods of manufacturing a unitary venturi 500 as described subsequently herein. In another aspect of the present invention, the venturi 500 comprises a lip 518 (alternatively referred to herein as a drip-lip 518) located at the axially aft end 519 of the venturi wall 502. The drip-lip 518 has a geometry (see FIG. 5) such that liquid fuel particles that flow along the inner surface 503 of the wall 502 separate from the wall 502 and continue to flow axially aft. The drip-lip 518 thus serves to prevent the fuel from flowing radially outwards along the venturi walls at exit.

As shown in FIG. 5, the exemplary embodiment of the venturi 500 comprises an annular splitter 530 having an annular splitter wall 532 located radially inward from the annular swirler wall 502 and coaxially located with it around the swirler axis 11. The radially outer surface 533 of the splitter 530 and the radially inner surface 503 of the venturi wall 502 form an annular swirled-air passage 534. The forward portion of the splitter wall 532 has a recess 535 that facilitates interfacing the venturi 500 with an adjacent component, such as for example, shown as item 208 in FIG. 2, during assembly of a fuel nozzle tip assembly 68. The splitter 530 has a splitter cavity 560 wherein a portion of the air 190 mixes with the fuel ejected from the pilot outlets 162, 164 (see FIG. 2).

The exemplary embodiment of the venturi 500 shown in FIGS. 5 and 6 comprises a swirl 510. Although the swirler 510 is shown in FIG. 5 as being located at the axially forward portion 509 of the venturi 500, in other alternative embodiments of the present invention, it may be located at other axial locations within the venturi 500. The swirler 510 comprises a plurality of vanes 508 that extend radially inward between the venturi wall 502 and the annular splitter 530. The plurality of vanes 508 are arranged in the circumferential direction around the swirler axis 11.

Referring to FIGS. 5 and 6, in the exemplary embodiment of the swirler 510 shown therein, each vane 508 has a root portion 520 located radially near the splitter 530 and a tip portion 521 that is located radially near the venturi wall 502. Each vane 508 has a leading edge 512 and a trailing edge 514 that extend between the root portion 520 and the tip portion 521. The vanes 508 have a suitable shape, such as, for example, an airfoil shape, between the leading edge 512 and the trailing edge 514. Circumferentially adjacent vanes 508 form a flow passage for passing air, such as the CDP air shown as item 190 in FIG. 2, that enters the swirler 510. The vanes 208 can be inclined both radially and axially relative to the swirler axis 11 to impart a rotational component of motion to the incoming air 190 that enters the swirler 510. These inclined vanes 508 cause the air 190 to swirl in a generally helical manner within venturi 500. In one aspect of the present invention, the vane 508 has a fillet 526 that extends between the root portion 520 of the vane 508 and the split wall 532. In addition to facilitating reduction of stress concentrations in the root portion 510, the fillet 526 also facilitates a smooth flow of air within the swirler and in the swirled air passage 534. The fillet 526 has a smooth contour shape 527 that is designed to promote the smooth flow of air in the swirler. The contour shapes and orientations for a particular vane 508 are designed using known methods of fluid flow analysis. Fillets similar to fillets 526 having suitable fillet contours may also be used between the tip portion 521 of the vane 508 and the venturi wall 502.

The venturi 500 comprises a heat shield 540 for protecting venturi and other components in the fuel nozzle tip assembly 68 (see FIG. 3) from the flames and heat from ignition of the fuel/air mixture in a fuel nozzle 100. The exemplary heat shield 540 shown in FIGS. 5-7 has an annular shape around the swirler axis 11 and is located axially aft from the swirler 510, near the axially aft end 519 of the venturi 500. The heat shield 540 has an annular wall 542 that
extends in a radially outward direction from the swirler axis 11. The annular wall 542 protects venturi 500 and other components in the fuel nozzle tip assembly 68 from the flames and heat from ignition of the fuel/air mixture, having temperatures in the range of 2500 Deg. F. to 4000 Deg. F. The heat shield 540 is made from a suitable material that can withstand high temperatures. Materials such as, for example, CoCr, HS188, N2 and N5 may be used. In the exemplary embodiments shown herein, the heat shield 540 is made from CoCr material, and has a thickness between 0.030 inches and 0.060 inches. It is possible, in other embodiments of the present invention, that the heat shield 540 may be manufactured from a material that is different from the other portions of the venturi, such as the venturi wall 502 or the swirler 510.

[0037] The exemplary venturi 500 shown in FIGS. 5-7 has certain design features that enhance the cooling of the heat shield 540 to reduce its operating temperatures. The exemplary venturi 500 comprises at least one slot 544 extending between the venturi wall 502 and the heat shield 540. The preferred exemplary embodiment of the venturi 500, shown in FIG. 6, comprises a plurality of slots 544 extending between the venturi wall 502 and the heat shield 540 wherein the slots 544 are arranged circumferentially around the swirler axis 11. The slots 544 provide an exit passage for cooling air that flows through the cavity between the fuel conduit and the venturi wall 502 (See FIG. 3). The cooling air entering the axially oriented portion of each slot 544 (See FIGS. 3, 5) is redirected in the radially oriented portion of the slot 544 (See FIG. 3, 5) to exit from the slots 544 in a generally radial direction onto the side of the annular wall 542 of the heat shield. In another aspect of the present invention, the exemplary venturi 500 comprises a plurality of bumps 546 located on the heat shield 540 and arranged circumferentially on the axially forward side of the heat shield wall 542 around the swirler axis 11. These bumps 546 provide additional heat transfer area and increase the heat transfer from the heat shield 540 to the cooling air directed towards, thereby reducing the operating temperatures of the heat shield 540. In the exemplary embodiment shown in FIG. 6, the bumps 546 are arranged in four circumferential rows, with each row having between 100 and 120 bumps.

[0038] An alternative exemplary embodiment of the present invention of a venturi is shown in FIG. 8. FIG. 8 is an isometric view of the alternative exemplary venturi 600 with a portion sectioned away. Referring to FIGS. 3 and 6, it is apparent to those skilled in the art that the airflow entering the swirler 510 of the venturi 500, in some cases, may not be uniform in the circumferential direction when it enters passages between the vanes 508. This non-uniformity is further enhanced by the presence of other features, such as, for example, the wall 260 (See FIG. 3). In conventional venturis, such non-uniformity of the flow may cause non-uniformities in the mixing of fuel and air in the venturi and lead to non-uniform combustion temperatures. In one aspect of the present invention of a venturi 600 (See FIG. 8), the adverse effects of circumferentially non-uniform flow entry can be minimized by having a swirler 610 comprising swirler vanes 609 with geometries that are different from those of circumferentially adjacent vanes 608. Customized swirler vane 608, 609 geometries can be selected for each circumferential location based on known fluid flow analytical techniques. In the alternative exemplary embodiment of the present invention shown in FIG. 8, the vane 609 has an axial recess 635 for suitably receiving an airflow that has been altered locally, such as, for example, due to the presence of a wall 260 in an adjacent component in a fuel nozzle assembly tip 68 (see FIG. 3). The alternative embodiment of the venturi 600 further comprises a heat shield 640, splitter 630, venturi wall 602, and other features as described previously herein for the exemplary venturi 500. A venturi 600 having swirlers with different geometries for the vanes 608, 609 located at different circumferential locations can have a unitary construction and made using the methods of manufacture described herein.

[0039] The exemplary embodiments of the unitary venturi 500 shown in FIGS. 5-7, and the alternative embodiments of the unitary venturi 600 shown in FIG. 8, can be made using rapid manufacturing processes such as Direct Metal Laser Sintering (DMLS), Laser Net Shape Manufacturing (LNSM), electron beam sintering and other known processes in the manufacturing. DMLS is a preferred method of manufacturing unitary venturis 500, 600 described herein.

[0040] FIG. 9 is a flow chart illustrating an exemplary embodiment of a method 700 for fabricating unitary venturis, such as items 500 and 600 described herein, and shown in FIGS. 3-8. Although the method of fabrication 700 is described below using unitary venturi 500 as an example, the same methods, steps, procedures, etc. apply for the alternative exemplary embodiment of the venturi 600 shown in FIG. 8. Method 700 includes fabricating unitary venturi 500 (Shown in FIGS. 3-7) using Direct Metal Laser Sintering (DMLS). DMLS is a known manufacturing process that fabricates metal components using three-dimensional information, for example a three-dimensional computer model, of the component. The three-dimensional information is converted into a plurality of slices, each slice defining a cross section of the component for a predetermined height of the slice. The component is then “built-up” slice by slice, or layer by layer, until finished. Each layer of the component is formed by fusing a metallic powder using a laser.

[0041] Accordingly, method 700 includes the step 705 of determining three-dimensional information of a unitary venturi 500 and the step 710 of converting the three-dimensional information into a plurality of slices that each define a cross-sectional layer of the unitary venturi 500. The unitary venturi 500 is then fabricated using DMLS, or more specifically each layer is successively formed in step 715 by fusing a metallic powder using laser energy. Each layer has a size between about 0.0005 inches and about 0.001 inches. Unitary venturi 500 may be fabricated using any suitable laser sintering machine. Examples of suitable laser sintering machines include, but are not limited to, an EOSINT® M 270 DMLS machine, a PHENIX PM250 machine, and/or an EOSINT® M 250 Xtended DMLS machine, available from EOS of North America, Inc. of Novi, Mich. The metallic powder used to fabricate unitary venturi 500 is preferably a powder including cobalt chromium, but may be any other suitable metallic powder, such as, but not limited to, HS188 and INCO625. The metallic powder can have a particle size of between about 10 microns and 74 microns, preferably between about 15 microns and about 30 microns.

[0042] Although the methods of manufacturing unitary venturi 500 have been described herein using DMLS as the preferred method, those skilled in the art of manufacturing will recognize that any other suitable rapid manufacturing methods using layer-by-layer construction or additive fabrication can also be used. These alternative rapid manufacturing methods include, but not limited to, Selective Laser Sintering (SLS), 3D printing, such as by inkjets and laserjets,
Sterolithography (SLS), Direct Selective Laser Sintering (DSLS), Electron Beam Sintering (EBS), Electron Beam Melting (EBM), Laser Engineered Net Shaping (LENS), Laser Net Shape Manufacturing (LNSM) and Direct Metal Deposition (DMD).

The unitary venturi 500 for a fuel nozzle 100 in a turbine engine (see FIGS. 1-3) comprises fewer components and joints than known venturis, swirlers and fuel nozzles. Specifically, the above described unitary venturi 500 requires fewer components because of the use of a one-piece unitary venturi 500 comprising a swirler 510 having a plurality of vanes 508, a venturi wall 502 and a heat shield 540. As a result, the described unitary venturi 500 provides a lighter, less costly alternative to known venturis. Moreover, the described unitary construction for the unitary venturi 500 provides fewer opportunities for leakage or failure and is more easily repairable compared to known venturis.

As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural said elements or steps, unless such exclusion is explicitly recited. When introducing elements/components/steps/etc. of unitary venturi 500, 600 described and/or illustrated herein, the articles “a”, “an”, “the” and “said” are intended to mean that there are one or more of the element(s)/component(s)/etc. The terms “comprising”, “including” and “having” are intended to be inclusive and mean that there may be additional element(s)/component(s)/etc. other than the listed element(s)/component(s)/etc. Furthermore, references to “one embodiment” of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

Although the methods and articles such as unitary venturi 500, 600 described herein are described in the context of swirling of air for mixing liquid fuel with air in fuel nozzles in a turbine engine, it is understood that the unitary venturi 500, 600 and methods of their manufacture described herein are not limited to fuel nozzles or turbine engines. The unitary venturi 500, 600 illustrated in the figures included herein are not limited to the specific embodiments described herein, but rather, these can be utilized independently and separately from other components described herein.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to make and use the invention. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A method for fabricating a unitary venturi, said method comprising the steps of: determining three-dimensional information of the unitary venturi having an annular venturi wall and a swirler having a plurality of vanes arranged circumferentially around a swirler axis; converting the three-dimensional information into a plurality of slices that each define a cross-sectional layer of the unitary venturi; and successively forming each layer of the unitary venturi by fusing a metallic powder using laser energy.

2. A method in accordance with claim 1 wherein determining three-dimensional information of the unitary venturi further comprises determining a three-dimensional model of the unitary venturi.

3. A method in accordance with claim 1 wherein successively forming each layer of the unitary venturi by fusing a metallic powder using laser energy further comprises fusing a powder comprising at least one of cobalt chromium, HS188 and INCO 625.

4. A method in accordance with claim 1 wherein successively forming each layer of the unitary venturi by fusing a metallic powder using laser energy further comprises fusing a metallic powder that has a particle size between about 10 microns and about 75 microns.

5. A method in accordance with claim 4 wherein successively forming each layer of the unitary venturi by fusing a metallic powder using laser energy further comprises fusing a metallic powder that has a particle size between about 15 microns and about 30 microns.

6. A method in accordance with claim 1 wherein determining three-dimensional information of the unitary venturi further comprises determining a three-dimensional model of the unitary venturi having an annular splitter coaxially located around the swirler axis.

7. A method in accordance with claim 1 wherein determining three-dimensional information of the unitary venturi further comprises determining a three-dimensional model of the unitary venturi having at least one vane that has a geometry that is different from another vane.

8. A method in accordance with claim 1 wherein determining three-dimensional information of the unitary venturi further comprises determining a three-dimensional model of the unitary venturi having a heat shield located axially aft from the swirler.

9. A method in accordance with claim 8 wherein the unitary venturi has at least one slot extending between the venturi wall and the heat shield.

10. A method in accordance with claim 1 wherein the venturi wall has a groove capable of receiving a brazing material.

11. A unitary venturi comprising an annular venturi wall having a swirler axis and a heat shield located at an end wherein unitary venturi is made by using a rapid manufacturing process.

12. A unitary venturi according to claim 11 wherein the rapid manufacturing process is a laser sintering process.

13. A unitary venturi according to claim 11 wherein the rapid manufacturing process is DMLS.

14. A unitary venturi according to claim 11 further comprising a swirler having a plurality of vanes arranged circumferentially around the swirler axis.

15. A unitary venturi according to claim 14 wherein at least one vane has a geometry that is different from another vane.

16. A unitary venturi according to claim 11 further comprising an annular splitter coaxially located around the swirler axis.

17. A unitary venturi according to claim 11 wherein the heat shield is located at an axially aft end of the venturi.
18. A unitary venturi according to claim 11 further comprising a plurality of slots extending between the venturi wall and the heat shield, the slots being arranged circumferentially around the swirler axis.

19. A unitary venturi according to claim 18 further comprising a plurality of bumps located on the heat shield and arranged circumferentially around the swirler axis.

20. A unitary venturi according to claim 11 wherein the venturi wall has a groove capable of receiving a brazing material.

21. A venturi according to claim 11, further comprising a lip located at an axially aft end of the venturi wall.

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