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Additively manufactured turbomachinery components with designed atmosphere of an inner voided core for heat transfer control

Abstract

An additively manufactured component includes an outer shell, the outer shell enclosing a space therein. An inner lattice structure is in the space of the outer shell. Interspaces are formed in the inner lattice structure. A method of forming an additively manufactured component includes evacuating a chamber in which the additively manufactured component will be formed, and forming in the chamber layer by layer an outer shell enclosing a core. The core includes a lattice structure with interspaces formed in the lattice structure.

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Background/Summary

BACKGROUND
(1) The present disclosure relates to additively manufactured components, and in particular, to additively manufactured turbomachinery components.
(2) Turbomachinery components of environmental control systems often utilize two or more rotors within the same casing. Each of the rotors can have different flow streams which have different temperatures. Heat transfer between these rotors degrades unit performance. Therefore, cost effective techniques are desired to minimize parasitic heat fluxes between the rotors. Alternatively, the heat exchanger of the environment control system is desired to have high heat fluxes while decreasing weight and vibrational transfer. Therefore, cost effective techniques are desired to maximize thermal heat fluxes while minimizing vibrational transfer characteristics.
SUMMARY
(3) In one embodiment, an additively manufactured component includes an outer shell, the outer shell enclosing a space therein. An inner lattice structure is in the space of the outer shell. Interspaces are formed in the inner lattice structure.
(4) In another embodiment, a method of forming an additively manufactured component includes evacuating a chamber in which the additively manufactured component will be formed. and forming in the chamber layer by layer an outer shell enclosing a core. The core includes a lattice structure with interspaces formed in the lattice structure.
(5) In another embodiment, an air cycle machine includes a first component which includes an outer shell and a core enclosed by the outer shell. The core includes a lattice structure with interspaces.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a perspective view of an exemplary embodiment of an additively manufactured component with a portion of an outer shell removed to show a core of the additively manufactured component.
(2) FIG. **2**A is a cross sectional view of a rhombus shaped inner lattice where a plurality of interspaces are separated from each other.
(3) FIG. **2**B is a cross sectional view of the rhombus shaped inner lattice where some of the plurality of interspaces are interconnected.
(4) FIG. **3**A is a cross-sectional view of an air cycle machine.
(5) FIG. **3**B is a cross-sectional view of an insulating seal plate positioned in the air cycle machine.
(6) FIG. **3**C is a side view of a dual-rotor component with an insulating lattice structure.
(7) FIG. **4**A is cross-sectional view of a cabin air compressor.
(8) FIG. **4**B is a cross-sectional view of a rotor of the cabin air compressor with pressure equilibrium holes.
(9) While the above-identified drawing figures set forth one or more embodiments, other embodiments are also contemplated. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit

of the principles of the claims. The figures may not be drawn to scale, and applications and embodiments may include features and components not specifically shown in the drawings.

DETAILED DESCRIPTION

(10) This disclosure relates to an additively manufactured (AM) component where within the manufactured component there is a lattice structure which has interspaces formed therein. The interspaces can be filled with a selected gas at a selected pressure. By filling the interspaces with the selected gas at the selected pressure the heat and vibrational transfer characteristics can be altered. The AM component will be discussed below with reference to FIGS. **1-5**.

(11) FIG. **1** is a perspective view of an exemplary embodiment of additively manufactured component **10**. Additively manufactured component **10** includes outer shell **12**, inner lattice **14**, and interspaces **16**. A portion of outer shell **12** is removed in FIG. **1** to show inner lattice **14**.

(12) As shown in FIG. **1**, inner lattice **14** is a foam metal core enclosed by outer shell **12**. Outer shell **12** is also metal and can be formed from the same metal as inner lattice **14** or a different metal. Outer shell **12** of FIG. **1** can be connected to a larger assembly outside of additively manufactured component **10** through welding, brazing, or any other suitable attachment mechanism known to those of skill in the art. In the embodiment of FIG. **1**, additively manufactured component **10** is an elongated rectangular rod, however additively manufactured component **10** can be cylindrically shaped, frustoconically shaped, shaped as a rod with a square cross section, shaped as turbomachinery components, or any other suitable shape which has outer shell **12** with inner lattice **14** therein. While additively manufactured component **10** in FIG. **1** is made of metal, additively manufactured component **10** can be formed by direct metal laser sintering, electron beam freeform fabrication, electron-beam melting, selective laser melting, or selective laser sintering in an additive fashion. The powder used to make outer shell **12** and inner lattice **14** can be made of a material selected from the group comprising stainless steel, corrosion-resistant steel, nickel-chromium alloy, titanium, aluminum, synthetic fiber, fiberglass, composites, and combinations thereof. Other suitable materials known to those of skill in the art to be able to be formed in an additive fashion can be used. Inside of outer shell **12** of additively manufactured component **10** is inner lattice **14**. Inner lattice **14** has plurality of interspaces **16** therein. Inner lattice **14** is formed by direct metal laser sintering, electron beam freeform fabrication, electron-beam melting, selective laser melting, or selective laser sintering the powder in an additive fashion.

(13) Additively manufactured component **10** can be utilized in any application in which a lighter part is desired and/or in any application in which changes to the heat and vibration transfer characteristics is desired. Such application includes, but is not limited to, seal plates of air cycle machines, rotors of air cycle machines, and rotors of cabin air compressors. Other potential applications include components on aircraft, boats, automobiles, or spacecraft.

(14) FIGS. **2**A-**2**B disclose examples of inner lattice **14** and will be discussed together. FIG. **2**A is a cross sectional view of rhombus shaped inner lattice **14** where each interspace **16** of inner lattice **14** is fluidically isolated and separated from each other. FIG. **2**B is a cross sectional view of rhombus shaped inner lattice **14** where some of plurality of interspaces **16** are interconnected. Inner lattice **14** is composed of plurality of interspaces **16**. Each interspace **16** can be filled with heat transfer medium **18**, as shown in FIG. **2**A, and can optionally be coated with thermal radiation reflective coating **20**. As shown in FIG. **2**B, each of plurality of interspaces **16** can be connected to each other through plurality of lattice interconnections **22**. Lattice interconnections **22** are passages that fluidically connect interspaces **16** with each other. Plurality of interspaces **16** can be connected to an ambient atmosphere through plurality of pressure equilibrium holes **24**. Pressure equilibrium holes **24** in FIG. **2**B extend through outer shell **12** to connect plurality of interspaces **16** and plurality of lattice interconnections **22** to ambient atmosphere.

(15) Inner lattice **14** can be rhombus shaped as shown in the embodiments of FIGS. **2**A and **2**B. Alternatively inner lattice **14** can be triangular, quadrangular, hexagonal, spherical, non-symmetrical, or any other shape known to those of skill in the art to be able to form plurality of

interspaces **16** in inner lattice **14**. Inner lattice **14** can be formed at the same time as forming outer shell **12** and can be integral with outer shell **12**. As such, inner lattice **14** can be formed of the same materials as outer shell **12** as discussed above with respect to FIG. **1**.

(16) Each of interspaces **16** can be filled with heat transfer medium **18**. Heat transfer medium **18** can be a selected fluid at a selected pressure. The selected fluid can be a gas which can comprises at least one of krypton, argon, xenon, nitrogen, oxygen, and combinations thereof. The selected gas can further comprise any gas known to those of skill in the art as being insertable into interspaces **16**. The selected fluid can also be a liquid. The selected liquid can comprise at least one of water, oil, heat-transfer fluid, coolant, and combinations thereof. The selected liquid can further comprise any liquid known to those of skill in the art as being insertable into interspaces **16**. The selected pressure can be less than 0.3 atmosphere (ATM), which is approximately the pressure experienced by aerospace components at a cruising altitude of a plane. Alternatively, the selected pressure can be less than 0.03 ATM, which is considered a low vacuum. Alternatively, the selected pressure could be less than 0.003 ATM which is considered a medium vacuum. When heat transfer medium **18** is inserted at pressures which are considered low vacuum, medium vacuum, or at even lower pressures, additively manufactured component **10** can conduct heat through the component at significantly slower rates and vibrational transfer through additively manufactured component **10** can be significantly reduced.

(17) Heat transfer medium **18** can be inserted into inner lattice **14** either during or after formation of interspaces **16**. Insertion of heat transfer medium **18** during formation of interspaces **16** comprises at least evacuating a chamber of the additive manufacturing machine used to form additively manufactured component **10**. The chamber is then filled with the selected fluid at the selected pressure. While the chamber is filled with the selected fluid at the selected pressure, the additive manufacturing machine forms additively manufactured component **10** in the chamber, thus trapping the selected fluid at the selected pressure within interspaces **16** of additively manufactured component **10**. Alternatively, heat transfer medium **18** can be inserted into interspaces **16** after formation of additively manufactured component **10**. If additively manufactured component **10** has plurality of lattice interconnections **22** and pressure equilibrium holes **24**, the selected fluid can be inserted into interspaces **16** at the selected pressure through pressure equilibrium holes **24** and into deeper interspaces **16** of additively manufactured component **10** through lattice interconnections **22**. After insertion of heat transfer medium **18**, pressure equilibrium holes **24** can be sealed, sealing in heat transfer medium **18**.

(18) Thermal radiation reflective coating **20** can be coated on the insides of each of interspaces **16**. Thermal radiation reflective coating **20** is shown coated on the inside of a top rhombus interspace **16** and a right rhombus interspace **16** in FIGS. **2**A and **2**B. Thermal radiation reflective coating **20** can be coated on any number of interspaces **16** ranging from zero to n, where n is the number of interspaces **16**. When coated on zero interspaces, none of interspaces **16** are coated with thermal radiation reflective coating **20** and when coated on n interspaces, all of interspaces **16** are coated with thermal radiation reflective coating **20**. Thermal radiation reflective coating **20** reflects the thermal radiation that radiates from the object due to its increased temperature. Thermal radiation reflective coating **20** reduces the internal heat transfer of additively manufacture component **10**. Thermal radiation reflective coating **20** can be applied to interspaces **16** via a chemical or physical layer deposition. Thermal radiation reflective coating **20** can be formed directly into the side walls of interspaces **16** when additively manufacturing additively manufactured component **10**.

(19) Interspaces **16** can be sectioned-off to form multiple sections of interspaces **16** within additively manufactured component **10** where each section of interspaces **16** is fluidically isolated from the other sections of interspaces **16**. In the example shown in FIG. **2**B, inner lattice **14** includes two sections of interspaces **16**. A single lattice interconnection **22** connects the top rhombi interspace **16** and the left rhombi interspace **16** to form a first section of connected interspaces **16** that share the same heat transfer medium **18**. The left rhombi interspace **16** and the bottom rhombi

interspace **16** are connected by a single lattice interconnection **22** to form a second section of connected interspaces **16** that share the same heat transfer medium **18** and that is fluidically isolated from the first section of connected interspaces **12** if pressure equilibrium holes **24** are sealed.

(20) Pressure equilibrium holes **24** extend through outer shell **12** into at least one or more of interspaces **16**. Pressure equilibrium holes **24** fluidically connect the at least one or more interspaces **16** to an outside ambient atmosphere with an ambient pressure. Pressure equilibrium holes **24** allow for an internal pressure within interspaces **16** of additively manufactured component **10** to be substantially the same as the ambient pressure. Interspaces **16** connected by lattice interconnections **22** to interspaces **16** with equilibrium holes **24** can also equilibrate to the ambient pressure. Maintaining interspaces **16** at the ambient pressure can reduce deflection, expansion or contraction of the part compared to maintaining interspaces **16** at a specific pressure if the pressure outside the part changes substantially.

(21) FIGS. **3**A-**3**C will be discussed together since they show air cycle machine **110** and two applications of AM turbomachinery component **10** in air cycle machine **110**. FIG. **3**A is a cross-sectional view of air cycle machine **110**. FIG. **3**B is a cross-sectional view of insulating seal plate **124** positioned in air cycle machine **110**. FIG. **3**C is a side view of dual-rotor component **178** with insulating lattice structure **180** therebetween with a portion of an outer shell removed to show insulating lattice structure **180**.

(22) FIG. **3**A is a cross-sectional view of air cycle machine **110**, which includes fan section **112**, compressor section **114**, first turbine section **116**, second turbine section **118**, tie rod **120**, fan and compressor housing **122**, seal plate **124**, first turbine housing **126**, and second turbine housing **128**. Fan section **112** includes fan inlet **130**, fan duct **132**, fan outlet **134**, and fan rotor **136**. Compressor section **114** includes compressor inlet **140**, compressor duct **142**, compressor outlet **144**, compressor rotor **146**, diffuser **148**, and compressor rotor shroud **149**. First turbine section **116** includes first turbine inlet **150**, first turbine duct **152**, first turbine outlet **154**, first turbine rotor **156**, and first turbine rotor shroud **158**. Second turbine section **118** includes second turbine inlet **160**, second turbine duct **162**, second turbine outlet **164**, and second turbine rotor **166**. Air cycle machine **110** further includes first journal bearing **170**, first rotating shaft **172**, second journal bearing **174**, and second rotating shaft **176**. Also shown in FIG. **1** is axis Z.

(23) Fan section **112**, compressor section **114**, first turbine section **116**, and second turbine section **118** are all mounted on tie rod **120**. Tie rod **120** rotates about axis Z. Fan and compressor housing **122** is connected to seal plate **124** and first turbine housing **126** with fasteners. Seal plate **124** separates flow paths in fan and compressor housing **122** from flow paths in first turbine housing **126**. First turbine housing **126** is connected to second turbine housing **128** with fasteners. Fan and compressor housing **122**, first turbine housing **126**, and second turbine housing **128** together form an overall housing for air cycle machine **110**. Fan and compressor housing **122** houses fan section **112** and compressor section **114**, first turbine housing **126** houses first turbine section **116**, and second turbine housing **128** houses second turbine section **118**.

(24) Fan section **112** includes fan inlet **130**, fan duct **132**, fan outlet **134**, and fan rotor **136**. Fan section **112** typically draws in ram air from a ram air scoop or alternatively from an associated gas turbine or other aircraft component. Air is drawn into fan inlet **130** and is ducted through fan duct **132** to fan outlet **134**. Fan rotor **136** is positioned in fan duct **132** adjacent to fan outlet **134** and is mounted to and rotates with tie rod **120**. Fan rotor **136** draws air into fan section **112** to be routed through air cycle machine **110**.

(25) Compressor section **114** includes compressor inlet **140**, compressor duct **142**, compressor outlet **144**, compressor rotor **146**, and diffuser **148**. Air is routed into compressor inlet **140** and is ducted through compressor duct **142** to compressor outlet **144**. Compressor rotor **146** and diffuser **148** are positioned in compressor duct **142**. Compressor rotor **146** is mounted to and rotates with tie rod **120** to compress the air flowing through compressor duct **142**. Diffuser **148** is a static structure

through which the compressor air can flow after the air has been compressed with compressor rotor **146**. Air exiting diffuser **148** can then exit compressor duct **142** through compressor outlet **144**. Compressor rotor shroud **149** is positioned radially outward from and surrounds compressor rotor **146**.

(26) First turbine section **116** includes first turbine inlet **150**, first turbine duct **152**, first turbine outlet **154**, first turbine rotor **156**, and first turbine rotor shroud **158**. Air is routed into first turbine inlet **150** and is ducted through first turbine duct **152** to first turbine outlet **154**. First turbine rotor **156** is positioned in first turbine duct **152** and is mounted to and rotates with tie rod **120**. First turbine rotor **156** will extract energy from the air passing through first turbine section **116** to drive rotation of tie rod **120**. First turbine rotor shroud **158** is positioned radially outward from and surrounds first turbine rotor **56**.

(27) Second turbine section **118** includes second turbine inlet **160**, second turbine duct **162**, second turbine outlet **164**, and second turbine rotor **166**. Air is routed into second turbine inlet **160** and is ducted through second turbine duct **162** to second turbine outlet **164**. Second turbine rotor **166** is positioned in second turbine duct **162** and is mounted to and rotates with tie rod **120**. Second turbine rotor **166** will extract energy from the air passing through second turbine section **118** to drive rotation of tie rod **120**.

(28) FIG. **3**B is a cross-sectional view of seal plate **124** positioned in air cycle machine **110**. FIG. **3**B shows fan and compressor housing **122**, seal plate **124**, first turbine housing **126**, compressor duct **142**, compressor rotor **146**, diffuser **148**, compressor rotor shroud **149**, first turbine duct **152**, first turbine rotor **156**, first turbine rotor shroud **158**. Seal plate **124** includes body **200** and bore **202**. Body **200** includes first side **210**, second side **212**, radially inner end **214**, radially outer end **216**, hub **218**, first disk portion **220**, second disk portion **222**, third disk portion **224**, fourth disk portion **226**, first plurality of holes **228**, second plurality of holes **230**, third plurality of holes **232**, and groove **234**. As shown in FIG. **4**, body **200** further includes outer shell **12** and inner lattice structure **14**.

(29) Air cycle machine **110** has a similar structure to the structure and design of additively manufactured component **10** as described above in reference to FIG. **3**A. Seal plate **124** includes body **200** with bore **202** extending through a center of body **200**. Body **200** has a plate shape and includes first side **210** and second side **212** opposite of first side **210**. Body **200** also has radially inner end **214** and radially outer end **216** opposite of radially inner end **214**. Radially inner end **214** of body **200** defines bore **202** extending through body **200** of seal plate **124**.

(30) Body **200** includes hub **218** extending from radially inner end **214** and positioned adjacent to bore **202**. Hub **218** is a center portion of body **200**. First disk portion **220** of body **200** extends radially outward from hub **218**. Second disk portion **222** of body **200** extends radially outward from first disk portion **220**. Third disk portion **224** of body **200** extends radially outward from second disk portion **222**. Fourth disk portion **226** of body **200** extends radially outward from third disk portion **224** to radially outer end **216**. First plurality of holes **228** are positioned around and extend through second disk portion **222** of body **200**. Second plurality of holes **230** are positioned around and extend through third disk portion **224** of body **200**. Third plurality of holes **232** are positioned around and extend through fourth disk portion **226** of body **200**. Groove **234** is positioned on fourth disk portion **226** of body **200** and extends into body **200** from second side **212** of body **200**. Groove **234** is configured to receive an o-ring to seal against other components of air cycle machine **110**.

(31) Outer shell **12** completely surrounds inner lattice structure **14** in an interior of body **200** and forms an exterior of seal plate **124**. Outer shell **12** is a solid, continuous surface. Inner lattice structure **14** is a lattice structure. Inner lattice structure **14** can take any shape as discussed above with respect to FIGS. **1-2**B. Inner lattice structure **14** includes members arranged in a **3**D crisscrossing pattern with interspaces **16** between the members. Inner lattice structure **14** can vary in density as shown in FIG. **3**B.

(32) Seal plate **124** can be additively manufactured. Any suitable additive manufacturing process (also known as a **3**D printing process) can be used to manufacture seal plate **124**, including, any process discussed above with respect to FIGS. **1-2**B. Seal plate **124** can be made from any material that can be used in an additive manufacturing process as discussed above with respect to FIGS. **1-2**B.

(33) Traditional seal plates for rotary machines have solid cross-sections and can be manufactured by subtractive manufacturing processes, such as hogout, or compression molding. Additively manufacturing seal plate **124** allows inner lattice structure **14** to be used in seal plate **124**. Using inner lattice structure **14** in seal plate **124** allows seal plate **124** to have a reduced weight compared to traditional seal plates, as there are hollow interspaces **16** within inner lattice structure **14**. Seal plate **124** has an equivalent strength as traditional seal plates due to the increased strength provided by inner lattice structure **14**.

(34) Inner lattice structure **14** in seal plate **124** can also improve the thermal resistance of seal plate **124**. Seal plate **124** is used as a heat transfer barrier between compressor section **114** and first turbine section **116**. Manufacturing seal plate **124** with inner lattice structure **14** improves the thermal resistance of seal plate **124**, as there are interspaces **16** in inner lattice structure **14** that reduce the thermal conductivity of seal plate **124** while improving the insulating abilities of seal plate **124**. As discussed above with respect to FIGS. **1-2**B, interspaces **16** can be filled with heat transfer medium **18** to further impede heat transfer from first side **210** to second side **212**. As discussed above with respect to FIGS. **1-2**B, the pressure of the heat transfer medium **18** can be substantially near a vacuum, thus significantly reducing the heat transfer through seal plate **124**. As discussed above with respect to FIGS. **1-2**B, interspaces **16** can be coated with thermal radiation reflective coating **20** which further impedes heat transfer from first side **210** to second side **212**. These improvements further improve the ability of seal plate **124** to reduce parasitic heat fluxes which would otherwise reduce the efficiency of air cycle machine **110**. These parasitic heat fluxes originate from the fact that second side **212** is at an increased temperature compared to first side **210**. Heat transfer across seal plate **124** is energy lost to entropy, thus the energy lost to heat transfer cannot do useful work.

(35) Inner lattice structure **14** in seal plate **124** can also improve the vibrational transfer characteristics of seal plate **124**. As discussed above with respect to FIGS. **1-2**B, interspaces **16** can be filled with heat transfer medium **18** at a selected pressure. The lower the pressure in interspaces **16**, the less noise that propagates through seal plate **124**. As such, seal plate **124** will transfer significantly less noise from one section of air cycle machine **110** to the other sections.

(36) Hub **218** of seal plate **124** abuts a seal that interfaces with rotating components, including compressor rotor **146** and first turbine rotor **156** of air cycle machine **110**. A first side of first disk portion **220** of seal plate **124** is positioned adjacent first turbine rotor **156**, and a second side of first disk portion **220** of seal plate **124** is positioned adjacent compressor rotor **146**. A first side of second disk portion **222** of seal plate **124** abuts first turbine rotor shroud **158**. Bolts extend through first plurality of holes **228** in second disk portion **222** to bolt seal plate **124** to first turbine rotor shroud **158**. A second side of second disk portion **222** of seal plate **124** is positioned adjacent to a radially outer end of compressor rotor **146**. A first side of third disk portion **224** of seal plate **124** abuts a flange of first turbine housing **126**, and a second side of third disk portion **224** of seal plate **124** abuts diffuser **148**. Bolts extend through second plurality of holes **230** to bolt seal plate **124** between diffuser **148** and first turbine housing **126**. Fourth disk portion **226** of seal plate **124** is positioned between and fan and compressor housing **122** and first turbine housing **126**. Bolts extends through third plurality of holes **232** to bolt seal plate **124** between fan and compressor housing **122** and first turbine housing **126**.

(37) There are gaps between compressor rotor **146** and surrounding components, such as compressor rotor shroud **149**, and between first turbine rotor **156** and surrounding components, such as first turbine rotor shroud **158**, to prevent contact between compressor rotor **146** and first

turbine rotor **156** and surrounding components. Contact between compressor rotor **146** and first turbine rotor **156** and surrounding components can damage the components. The gaps between compressor rotor **146** and first turbine rotor **156** and surrounding components have to account for deflections that compressor rotor **146** and first turbine rotor **156** and surrounding components, such as seal plate **124**, can be subjected to during operation of compressor rotor **146** and first turbine rotor **156** as well as deflections induced by pressure changes. Thus, the more deformation that compressor rotor **146**, first turbine rotor **156**, and seal plate **124** are subjected to during operation of compressor rotor **146** and first turbine rotor **156**, the larger the gaps need to be to ensure component safety. However, air can leak from air cycle machine **110** through the gaps, which leads to inefficiencies in air cycle machine **110**. Thus, minimizing the gaps between compressor rotor **146** and first turbine rotor **156** and surrounding components is desired. If seal plate **124** has pressure equilibrium holes **24** in outer shell **12**, seal plate **124** would not deflect as much due to pressure induced changes, thus reducing the minimum sizes required for the gaps.

(38) Seal plate **124** is one example of a seal plate in which inner lattice structure **14** can be used. In alternate embodiments, inner lattice structure **14** can be used in any suitable seal plate having any geometry. Further, air cycle machine **110** is one example of a turbomachinery or rotary machine in which seal plate **124** or any other seal plate with inner lattice structure **14** can be used. In alternate embodiments, seal plate **124** or any other seal plate with inner lattice structure **14** can be used in any other rotary machine having a seal plate.

(39) FIG. **3**C is a side view of dual-rotor component **178** with dual rotor interconnection plate **180** therebetween. Dual rotor component **178** includes compressor rotor **146** and first turbine rotor **156**. Between and connecting compressor rotor **146** and first turbine rotor **156** is dual rotor interconnection plate **180** which includes outer shell **12** and inner lattice structure **14**.

(40) Dual rotor component **178** is an alternative embodiment to those discussed above in reference to FIGS. **3**A and **3**B. Dual rotor component combines compressor rotor **146** and first turbine rotor **156** of FIGS. **3**A and **3**B into a single component. As such, first disk portion **220** of seal plate **124** can be removed. Further the gap between first turbine rotor **156** and first side **210** of seal plate **124** as well as the gap between compressor rotor **146** and second side **212** of seal plate **124** can be removed. Removing these gaps increases the efficiency of air cycle machine **110**. However, parasitic heat fluxes from a hot side on compressor rotor **146** to a cold side on first turbine rotor **156** can affect efficiency. These parasitic heat fluxes can be reduced significantly by dual rotor interconnection plate **180**.

(41) Dual rotor interconnection plate **180** includes outer shell **12** and inner lattice structure **14**. Inner lattice structure **14** can have interspaces **16** therein. As discussed above with respect to FIGS. **1**-**2**B interspaces **16** of inner lattice structure **14** of dual rotor interconnection **180** can be filled with heat transfer medium **18**. Heat transfer medium **18** can alter the heat flux dynamics of dual rotor **178**, reducing the parasitic heat fluxes thus negating the primary reason not to combine compressor rotor **146** and first turbine rotor **156** into a single component. Further, as discussed above with respect to FIGS. **1**-**2**B, interspaces **16** of inner lattice structure **14** can be coated with thermal radiation reflective coating **20**, further reducing the parasitic heat fluxes through the component.

(42) Alternatively, interspaces **16** of inner lattice structure **14** of dual rotor interconnection **180** can be connected to an ambient atmosphere through pressure equilibrium holes **24** (not shown in FIG. **3**C). By connecting interspaces **16** to the ambient atmosphere, if the pressure changes drastically, the part will not expand or contract as a result of the pressure change. As such, the gaps between compressor rotor **146** and compressor rotor shroud **149** as well as the gaps between first compressor rotor **156** and first rotor shroud **158** can be further reduced, increasing the efficiency of air cycle machine **110**. Increasing the efficiency of air cycle machine **110** is important as increased efficiency enables a reduction in the size and weight of air cycle machine to achieve the same results and thus decreases fuel burn rate on an aircraft.

(43) FIGS. **4**A and **4**B will be discussed together since they show cabin air compressor **310** and an

application of AM turbomachinery component **10** in cabin air compressor **310**. FIG. **4**A is cross-sectional view of cabin air compressor **310**. FIG. **4**B is a cross-sectional view of rotor **326** with pressure equilibrium holes **24** positioned in cabin air compressor **310**.

(44) FIG. **4**A is a cross-sectional view of cabin air compressor **310**. Cabin air compressor **310** includes compressor section **312**, motor section **314**, tie rod **316**, compressor inlet housing **318**, compressor outlet housing **320**, motor housing **322**, variable diffuser **324**, rotor **326**, and rotor shroud **328**. Compressor inlet housing **318** includes inlet **330** and inlet duct **332**. Compressor outlet housing **320** includes outlet duct **334** and outlet **336**. Variable diffuser **316** includes backing plate **340**, inboard plate **342**, diffuser vanes **344**, drive ring **346**, drive ring bearing **348**, backup ring **350**, pinion **352**, and variable diffuser actuator **354**. Motor section **314** includes motor rotor **360** and motor stator **362**. Cabin air compressor **310** further includes first journal bearing **370**, first rotating shaft **372**, second journal bearing **374**, and second rotating shaft **376**. FIG. **4**A also shows axis A.

(45) Cabin air compressor **310** includes compressor section **312** and motor section **314** mounted on tie rod **316**. Tie rod **316** is configured to rotate about axis A. Compressor section **312** includes compressor inlet housing **318** and compressor outlet housing **320** that are connected to one another. Motor section **314** includes motor housing **322**, which is connected to compressor outlet housing **320**. Variable diffuser **324** is positioned between compressor inlet housing **318** and compressor outlet housing **320**. Rotor **326** is positioned between compressor inlet housing **318** and compressor outlet housing **320**. Rotor **326** is mounted on tie rod **316**, which rotatably connects rotor **326** and motor section **314**. Rotor shroud **328** is positioned radially outward from and partially surrounds compressor rotor **326**.

(46) Compressor inlet housing **318** includes inlet **330** and inlet duct **332**. Inlet **330** is positioned at a first end of compressor inlet housing **318**. Inlet duct **332** extends from inlet **330** through compressor inlet housing **318** to rotor **326**. Compressor outlet housing **320** includes outlet duct **334** and outlet **336**. Outlet duct **334** extends through compressor outlet housing **320** from rotor **326** to outlet **336**.

(47) Variable diffuser **316** includes backing plate **340**, inboard plate **342**, diffuser vanes **344**, drive ring **346**, drive ring bearing **348**, pinion **350**, backup ring **352**, and variable diffuser actuator **354**. Backing plate **340** abuts compressor outlet housing **320** on a first side and inboard plate **342** on a second side. Inboard plate **342** abuts backing plate **340** on a first side and diffuser vanes **344** on a second side. Diffuser vanes **344** abut inboard plate **342** on a first side and rotor shroud **328** on a second side. Diffuser vanes **344** are configured to direct the compressed air from rotor **326** into outlet duct **334**. Drive ring **346** is positioned radially outward from rotor shroud **328**, and drive ring bearing **348** is positioned between driver ring **346** and rotor shroud **328**. Drive ring **346** abuts rotor shroud **328** on a first side and backup ring **350** on a second side. Backup ring **350** is positioned radially outward of rotor shroud **328**. Pinion **352** is connected to variable diffuser actuator **354** and is coupled to drive ring **346**. Pinion **352** permits control of variable diffuser **316**. Drive ring **346** is coupled to diffuser vanes **344** with pins, and as drive ring **346** is rotated drive ring **346** will drag diffuser vanes **344** and cause them to rotate.

(48) Motor section **314** includes motor housing **322**, motor rotor **360**, and motor stator **362**. Motor housing **322** surrounds motor rotor **360** and motor stator **362**. Motor rotor **360** is disposed within motor stator **362** and is configured to rotate about axis A. Motor rotor **360** is mounted to tie rod **316** to drive rotation of tie rod **316**.

(49) Motor rotor **360** of motor section **314** drives rotation of shafts in cabin air compressor **310**, which rotates rotor **326**. The rotation of rotor **326** draws air into inlet **330** of compressor inlet housing **318**. The air flows through inlet duct **332** to rotor **326** and will be compressed by rotor **326**. The compressed air is then routed through variable diffuser **316** and into outlet duct **334** of compressor outlet housing **320**. The air then exits cabin air compressor **310** through outlet **336** of compressor outlet housing **320** and can be routed to another component of an environmental control system, such as an air cycle machine.

(50) Cabin air compressor **310** further includes first journal bearing **370**, first rotating shaft **372**, second journal bearing **374**, and second rotating shaft **376**. First journal bearing **370** is positioned in compressor section **312** and is supported by compressor outlet housing **320**. First rotating shaft **372** extends between and rotates with rotor **326** and motor rotor **360**. Motor rotor **360** drives rotation of rotor **326** with first rotating shaft **372**. A radially outer surface of first rotating shaft **372** abuts a radially inner surface of first journal bearing **370**. Second journal bearing **374** is positioned in motor section **314** and is supported by motor housing **322**. Second rotating shaft **376** extends from and rotates with motor rotor **360**. A radially outer surface of second rotating shaft **376** abuts a radially inner surface of second journal bearing **374**.

(51) FIG. **4**B is a cross-sectional view of rotor **326** from FIG. **4**A positioned in cabin air compressor **310**. FIG. **4**B shows tie rod **316**, compressor outlet housing **320**, rotor **326**, rotor shroud **328**, first journal bearing **370**, and first rotating shaft **372** of cabin air compressor **310**. Rotor **326** includes hub **400**, blades **402**, and bore **404**. Hub **400** includes first side **410**, second side **412**, radially inner end **414**, radially outer end **416**, shaft portion **418**, disk portion **420**, first flange **422**, second flange **424**, and third flange **426**. As shown in FIG. **4**B, rotor **326** further includes outer shell **12**, inner lattice structure **14**, and pressure equilibrium holes **24**.

(52) Rotor shroud **328** is positioned radially outward from rotor **326** and partially surrounds rotor **326**. Rotor **326** includes hub **400** and blades **402** attached to and extending outward from hub **400**. Bore **404** extends through a center of hub **400** and a tie rod of a rotary machine can extend through bore **404**. Hub **400** has first side **410** and second side **412** opposite of first side **410**. Hub **400** also has radially inner end **414** and radially outer end **416** opposite of radially inner end **414**. Radially inner end **414** defines bore **404** extending through hub **400** of rotor **326**.

(53) Hub **400** has shaft portion **418** that extends axially from first side **410** to second side **412** of hub **400** along axis A. When in operation, rotor **326** increases the pressure in a flow path which is on second side **412**, while the pressure on a backside of rotor **326** outside of the flow path, which is on first side **410** would stay at an ambient pressure. Disk portion **420** extends radially outwards from shaft portion **418** toward radially outer end **416** of hub **400** near first end **410** of hub **400**. Hub **400** further includes first flange **422**, second flange **424**, and third flange **426**. First flange **422** is positioned on disk portion **420** near radially outer end **416** of hub **400** and extends axially outward from first side **410** of hub **400**. First flange **422** of hub **400** of rotor **326** forms a labyrinth seal that seals against compressor outlet housing **320**. As rotor **326** rotates with tie rod **316**, the labyrinth seal on first flange **422** will rotate against compressor outlet housing **320**, which is a stationary component of cabin air compressor **310**. Second flange **424** is positioned on shaft portion **418** at first side **410** of hub **410** and extends axially outward from first side **410** of hub **400**. Second flange **424** of hub **400** of rotor **326** abuts and rotates with first rotating shaft **372**. Third flange **426** is positioned on shaft portion **418** near second side **412** of hub **400** and extends radially inward from shaft portion **418** of hub **400**. Blades **402** are positioned on hub **400** and extend radially and axially outward from hub **400**. Third flange **426** of hub **400** of rotor **326** abuts and rotates with tie rod **316**. Third flange **426** of hub **400** mounts rotor **326** to tie rod **316**.

(54) Hub **400** and blades **402** further include outer shell **12** that surrounds inner lattice structure **14** in an interior of hub **400** and blades **402**. Outer shell **12** is a solid, continuous surface. Inner lattice structure **14** has interspaces **16** therein. Inter spaces **16** can hold heat transfer medium **18** therein. Interspaces **16** can be interconnected through lattice interconnections **22** (not shown in FIG. **4**B) and can further be connected to an ambient atmosphere through pressure equilibrium holes **24** which extend through outer shell **12** and connect interspaces **16** to the ambient atmosphere. As shown in FIG. **4**B, pressure equilibrium holes **24** are substantially larger than interspaces **16**. Alternatively, pressure equilibrium holes can be substantially smaller than interspaces **16**. In the embodiment shown in FIG. **4**B, there are only 2 pressure equilibrium holes **24**. In alternative embodiments, there can be a single pressure equilibrium hole. In another alternative embodiment, there can be a plurality of pressure equilibrium holes **24**.

(55) There is a gap between blades **402** of rotor **326** and rotor shroud **328** to prevent contact between blades **402** of rotor **326** and rotor shroud **328**. Contact between blades **402** and rotor shroud **328** can damage both components. The gap between blades **402** and rotor shroud **328** has to account for deflection that hub **400** and blades **402** of rotor **326** can be subjected to during operation of rotor **326**. Thus, the more deformation that hub **400** and blades **402** are subjected to during operation of rotor **326**, the larger the gap needs to be to ensure component safety. However, air can leak from cabin air compressor **310** through the gap, which leads to inefficiencies in cabin air compressor **310**. Thus, minimizing the gap between blades **402** of rotor **326** and rotor shroud **328** is desired. Pressure equilibrium holes **24** can reduce the gap required as rotor **326** would deflect less due to changes in pressure. The expansion can be further reduced if interspaces **16** are interconnected with lattice interconnections **22**. Thus interspaces **16** connected together through lattice interconnections **22** to pressure equilibrium holes **24** would be at a pressure experienced at first side **410**. Thus, more of the interspaces would be connected to an ambient pressure. Pressure equilibrium holes **24** are placed on first side **410** to avoid the increased pressure created by blades **402** of rotor **326** when in operation. In alternative embodiments, pressure equilibrium holes **24** can be placed on second side **412**, thus interspaces **16** connected together through lattice interconnections **22** to pressure equilibrium holes **24** would be at a pressure experienced at the second side.
(56) As discussed above with respect to FIGS. **1-2**B, any suitable additive manufacturing process (also known as a **3**D printing process) can be used to manufacture rotor **326**, including, for example, direct metal laser sintering, electron beam freeform fabrication, electron-beam melting, selective laser melting, or selective laser sintering. As discussed above with respect to FIGS. **1-2**B, additively manufacture component **10**, such as rotor **326**, can be made out of any material that can be used in an additive manufacturing process, including any of stainless steel, corrosion-resistant steel, nickel-chromium alloy, titanium, aluminum, synthetic fiber, fiberglass, composites, and combinations thereof.
(57) Traditional compressor rotors for rotary machines have solid cross-sections and are manufactured by forging and/or subtractive manufacturing processes, such as hogout. Additively manufacturing rotor **326** allows inner lattice structure **14** to be used in rotor **326**. Using inner lattice structure **14** in rotor **326** allows rotor **326** to have a reduced weight compared to traditional rotors, as there are interspaces **16** between lattice structure **14**. Rotor **326** also has an equivalent strength as traditional rotors due to the increased strength of inner lattice structure **14**.
(58) Reducing the weight while maintaining the strength of rotor **326** allows for the gap between blades **402** of rotor **326** and rotor shroud **328** to be reduced. Reducing the gap between blades **402** of rotor **326** and rotor shroud **28** increases the compression efficiency of cabin air compressor **310** as more air is forced through rotor **326** and into variable diffuser **324**.
(59) Rotor **326** is one example of a rotor in which inner lattice structure **14** can be used. In alternate embodiments, inner lattice structure **14** can be used in any suitable rotor, for example a turbine rotor, having any geometry. Further, cabin air compressor **310** is one example of a turbomachinery or rotary machine in which rotor **326** or any other rotor with inner lattice structure **14** can be used. In alternate embodiments, rotor **326** or any other rotor with inner lattice structure **14** can be used in an air cycle machine or any other rotary machine
Discussion of Possible Embodiments
(60) The following are non-exclusive descriptions of possible embodiments of the present invention.
(61) An additively manufactured component comprising an outer shell, the outer shell enclosing a space therein, an inner lattice structure in the space of the outer shell, and interspaces formed in the inner lattice structure.
(62) The additively manufactured component of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or

additional components:
(63) A further embodiment of the additively manufactured component, wherein the interspaces of the inner lattice structure are interconnected.
(64) A further embodiment of the additively manufactured component, wherein the outer shell is sealed to an outside environment.
(65) A further embodiment of the additively manufactured component, wherein a heat transfer medium is in the interspaces of the inner lattice structure.
(66) A further embodiment of the additively manufactured component, wherein the heat transfer medium is a gas.
(67) A further embodiment of the additively manufactured component, wherein the heat transfer medium is a liquid.
(68) A further embodiment of the additively manufactured component, wherein the outer shell comprises a pressure equilibration hole extending through the outer shell to an outside environment.
(69) A further embodiment of the additively manufactured component, wherein an inner surface of the interspaces is coated with a thermal radiation reflective coating.
(70) A method of forming an additively manufactured component comprising evacuating a chamber in which the additively manufactured component will be formed and forming in the chamber layer by layer an outer shell enclosing a core, wherein the core comprises a lattice structure with interspaces formed in the lattice structure.
(71) The method forming an additively manufactured component of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:
(72) A further embodiment of the method of forming an additively manufactured component, further comprising flooding the chamber with a selected gas at a selected pressure before forming the outer shell and the core.
(73) A further embodiment of the method of forming an additively manufactured component, wherein the selected gas comprises at least one of krypton, argon, xenon, nitrogen, oxygen, and combinations thereof.
(74) A further embodiment of the method of forming an additively manufactured component, wherein the selected pressure is less than 0.3 ATM.
(75) A further embodiment of the method of forming an additively manufactured component, wherein the selected pressure is less than 0.03 ATM.
(76) A further embodiment of the method of forming an additively manufactured component, further comprising forming a pressure equilibration hole in the outer shell and applying a thermal radiation reflective coating to the lattice structure.
(77) A further embodiment of the method of forming an additively manufactured component,
(78) An environmental control system comprising a first component comprising an outer shell and a core enclosed by the outer shell, wherein the core comprises a lattice structure with interspaces.
(79) The environmental control system of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:
(80) A further embodiment of the environmental control system, wherein the interspaces are interconnected.
(81) A further embodiment of the environmental control system, wherein the interspaces are connected to an ambient atmosphere by a pressure equilibration hole extending through the outer shell.
(82) A further embodiment of the environmental control system, the environmental control system further comprising an air cycle machine comprising a hot section with a first impeller and a cold section with a second impeller wherein the first component is a plate axially between the first

impeller and the second impeller.
(83) A further embodiment of the environmental control system, wherein the first component is an impeller, and the outer shell of the impeller comprises a flow path surface with at least one blade and a back surface located outside of a flow path of the impeller and a pressure equilibration hole extending through the back surface of the outer shell.
(84) While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. An additively manufactured component comprising: an outer shell, the outer shell enclosing a space therein, the outer shell having a first side and a second side; an inner lattice structure in the space of the outer shell; and interspaces formed in the inner lattice structure, wherein the inner lattice structure comprises: a first plurality of interconnected interspaces between the first side of the outer shell and a second plurality of interconnected interspaces; the second plurality of interconnected interspaces between the first plurality of interconnected interspaces and the second side of the outer shell, wherein the first plurality of interconnected interspaces is fluidically isolated from the second plurality of interconnected interspaces, wherein the first plurality of interconnected interspaces encloses a heat transfer medium comprising atmospheric air at ambient pressure, and the second plurality of interconnected interspaces encloses a heat transfer medium comprising at least one of krypton, argon, and xenon at a pressure less than 0.3 ATM; and a pressure equilibration hole extending through the outer shell to an outside environment, wherein the pressure equilibration hole is smaller than the interspaces of the inner lattice structure and the pressure equilibration hole is connected to the first plurality of interconnected interspaces and fluidically isolated from the second plurality of interconnected interspaces, wherein a pressure at the first side of the outer shell is lower than a pressure at the second side of the outer shell, and further wherein the pressure equilibrium hole is located on the first side of the outer shell.
2. The additively manufactured component of claim 1, wherein the outer shell is sealed to an outside environment.
3. The additively manufactured component of claim 1, wherein an inner surface of at least one of the first and second plurality of interconnected interspaces is coated with a thermal radiation reflective coating.
4. An additively manufactured component comprising: an outer shell, the outer shell enclosing a space therein, the outer shell having a first side and a second side; an inner lattice structure in the space of the outer shell; and interspaces formed in the inner lattice structure, wherein the inner lattice structure comprises: a first plurality of interconnected interspaces between the first side of the outer shell and a second plurality of interconnected interspaces; the second plurality of interconnected interspaces between the first plurality of interconnected interspaces and the second side of the outer shell, wherein the first plurality of interconnected interspaces is fluidically isolated from the second plurality of interconnected interspaces, wherein the first plurality of interconnected interspaces encloses a heat transfer medium comprising at least one of krypton, argon, and xenon at a first pressure less than 0.3 ATM and the second plurality of interconnected interspaces encloses a heat transfer medium comprising at least one of krypton, argon, and xenon at a second pressure less than 0.3 ATM, wherein the first pressure and the second pressure are different.
5. An additively manufactured component comprising: an outer shell, the outer shell enclosing a

space therein, the outer shell having a first side and a second side; an inner lattice structure in the space of the outer shell; and interspaces formed in the inner lattice structure, wherein the inner lattice structure comprises: a first plurality of interconnected interspaces between the first side of the outer shell and a second plurality of interconnected interspaces; the second plurality of interconnected interspaces between the first plurality of interconnected interspaces and the second side of the outer shell, wherein the first plurality of interconnected interspaces is fluidically isolated from the second plurality of interconnected interspaces, wherein the first plurality of interconnected interspaces encloses a heat transfer medium comprising ambient air at ambient pressure, and the second plurality of interconnected interspaces encloses a heat transfer medium comprising a liquid comprising at least one of water, oil, heat-transfer fluid, and coolant; and a pressure equilibration hole extending through the outer shell to an outside environment, wherein the pressure equilibration hole is smaller than the interspaces of the inner lattice structure and the pressure equilibration hole is connected to the first plurality of interconnected interspaces and fluidically isolated from the second plurality of interconnected interspaces, wherein a pressure at the first side of the outer shell is lower than a pressure at the second side of the outer shell, and further wherein the pressure equilibrium hole is located on the first side of the outer shell.
