US 20250257955A1

(19) United States
(12) Patent Application Publication
Xia et al.
(10) Pub. No.: US 2025/0257955 A1
(43) Pub. Date: Aug. 14, 2025

(54) FIN HAVING ELLIPTICAL COLLAR BASES AND AIRFOILS AND RELATED FIN-AND-TUBE HEAT EXCHANGER

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(21) Appl. No.: **19/049,525**

(22) Filed: **Feb. 10, 2025**

(30) **Foreign Application Priority Data**

Feb. 9, 2024 (CN) 202410178526.2

Publication Classification

(51) **Int. Cl.**
F28F 3/02 (2006.01)
F28F 1/30 (2006.01)

(52) **U.S. Cl.**
CPC ***F28F 3/025*** (2013.01); ***F28F 1/30*** (2013.01)

(57) **ABSTRACT**

A fin-and-tube heat exchanger and a fin are disclosed. The fin includes a corrugated plate having a first side and a second side opposing the first side, the corrugated plate having a plurality of alternative peaks and valleys relative to the first side of the corrugated plate; one of a plurality of elliptical collar bases protruding from the first side of the corrugated plate; and a first airfoil and a second airfoil extending between a major axis and a minor axis of, and curving around, the one of the plurality of elliptical collar bases. The first airfoil is disposed in a first quadrant for the one of the plurality of elliptical collar bases. The second airfoil is disposed in a second quadrant for the one of the plurality of elliptical collar bases, the second quadrant is adjacent to the first quadrant at the major axis.

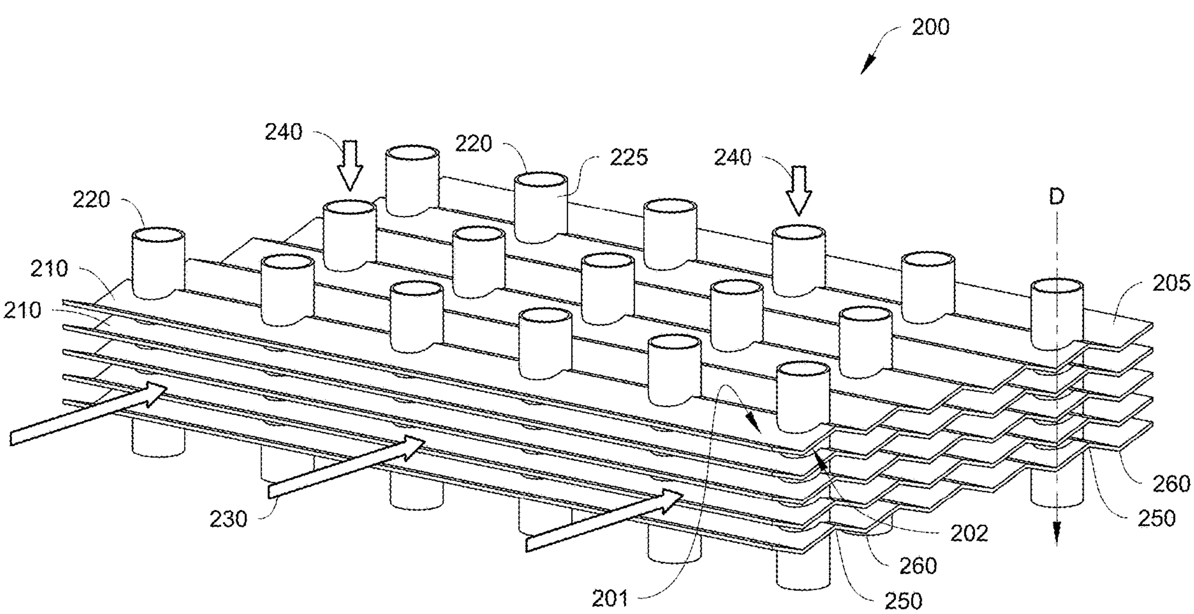
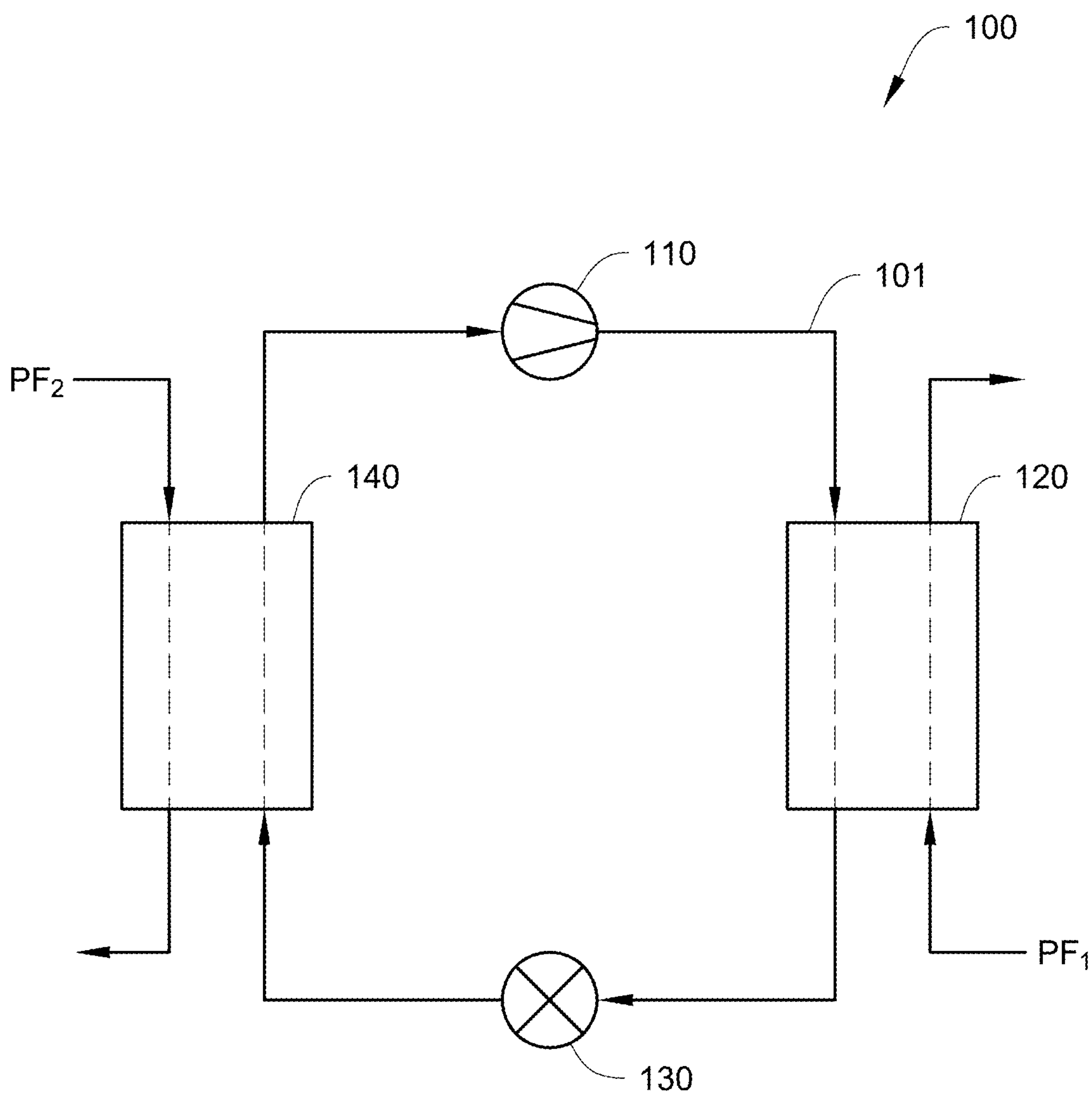


Fig. 1



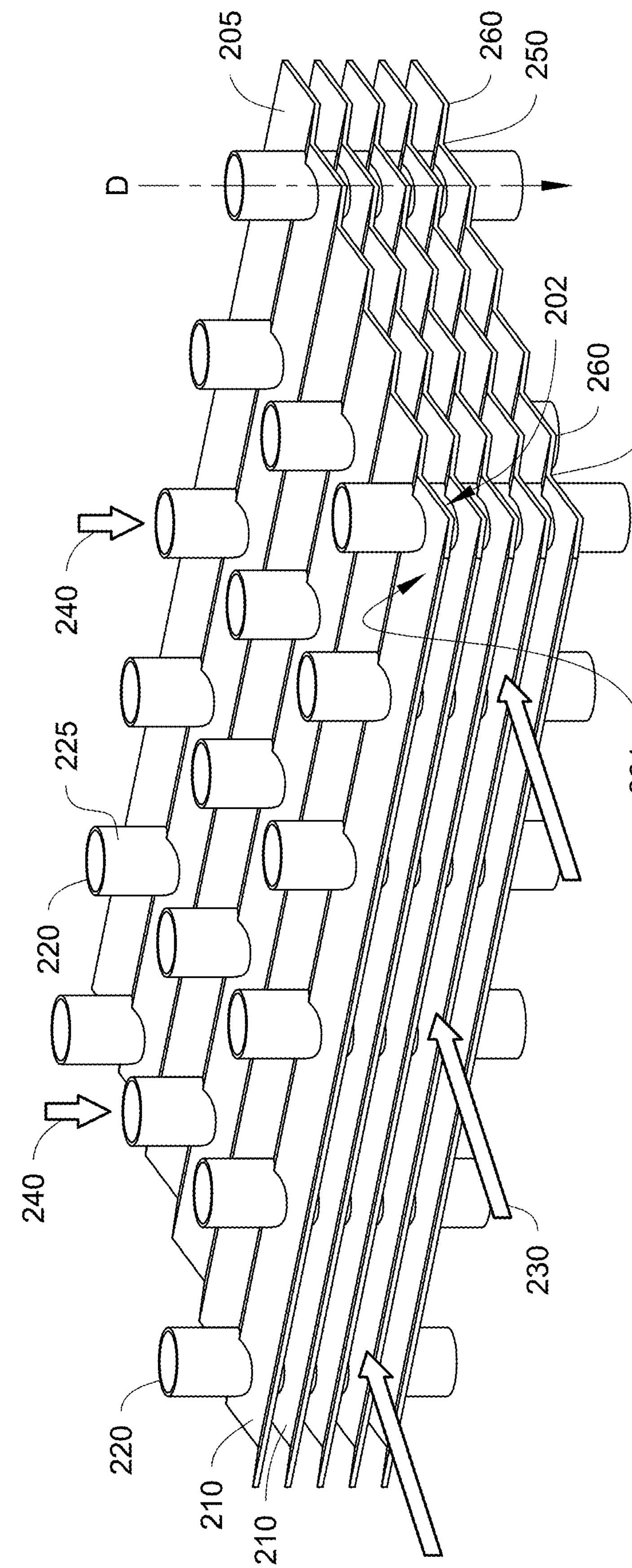
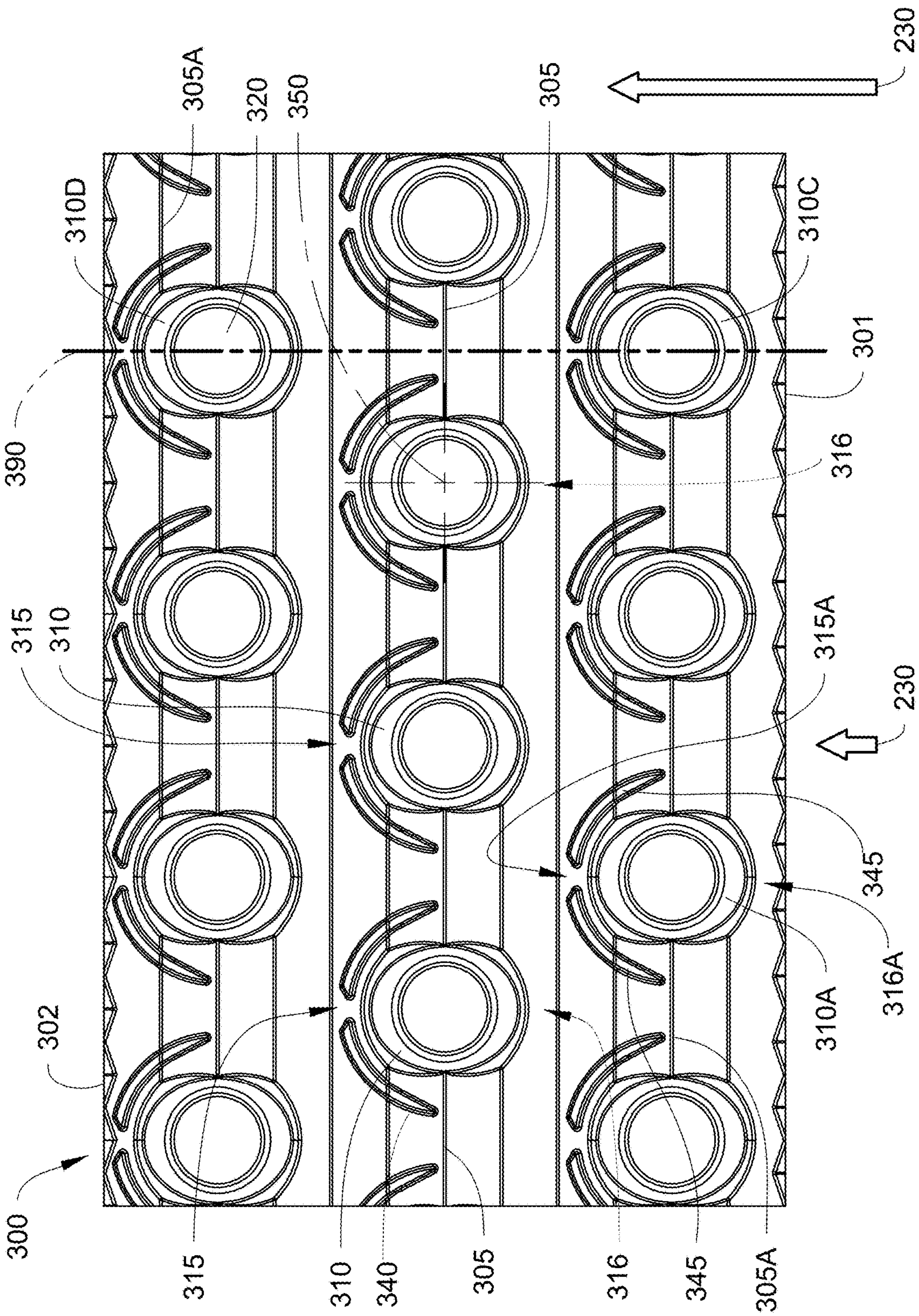
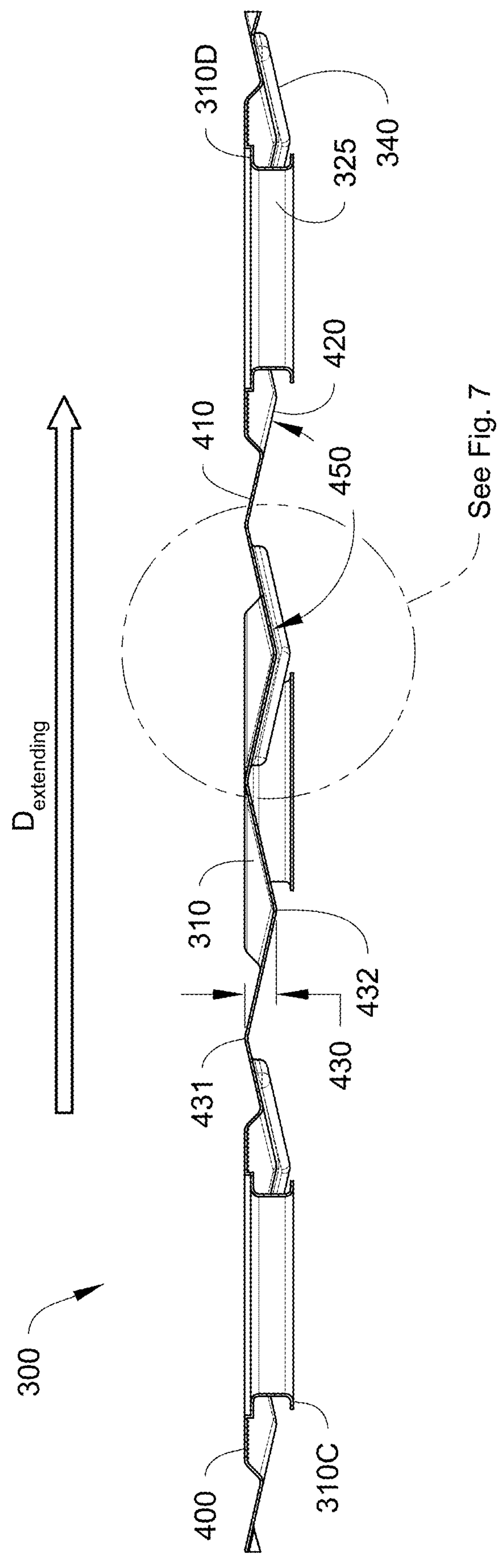


Fig. 2



305A
320
350
305
230
310D
310C
301
390
316
315
310
315A
230
345
316A
310A
302
300
315
310
340
305
316
345
305A

Fig. 3



310D
340
325
420
410
450
See Fig. 7
$D_{extending}$
310
432
430
431
300
310C
400

Fig. 4

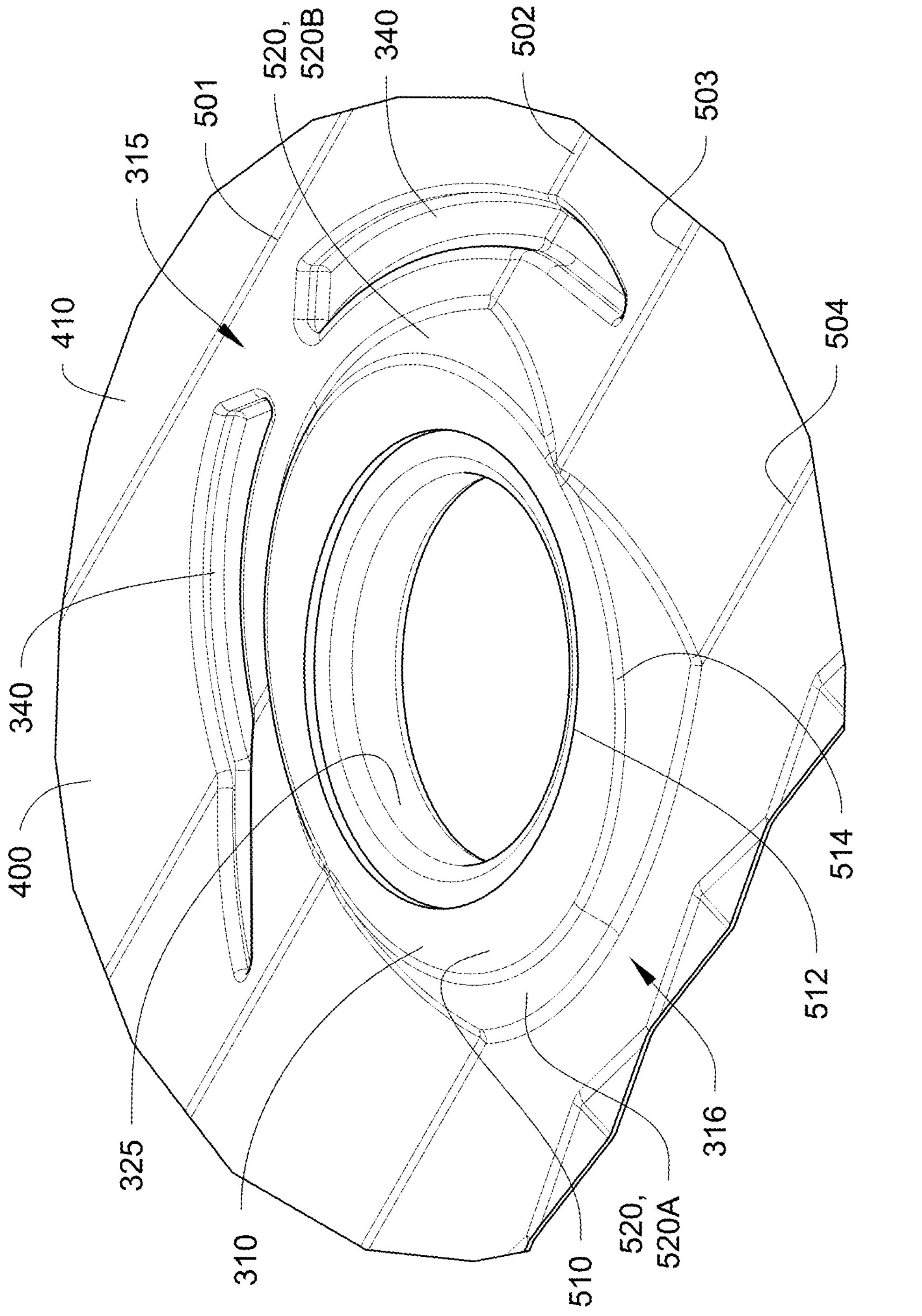
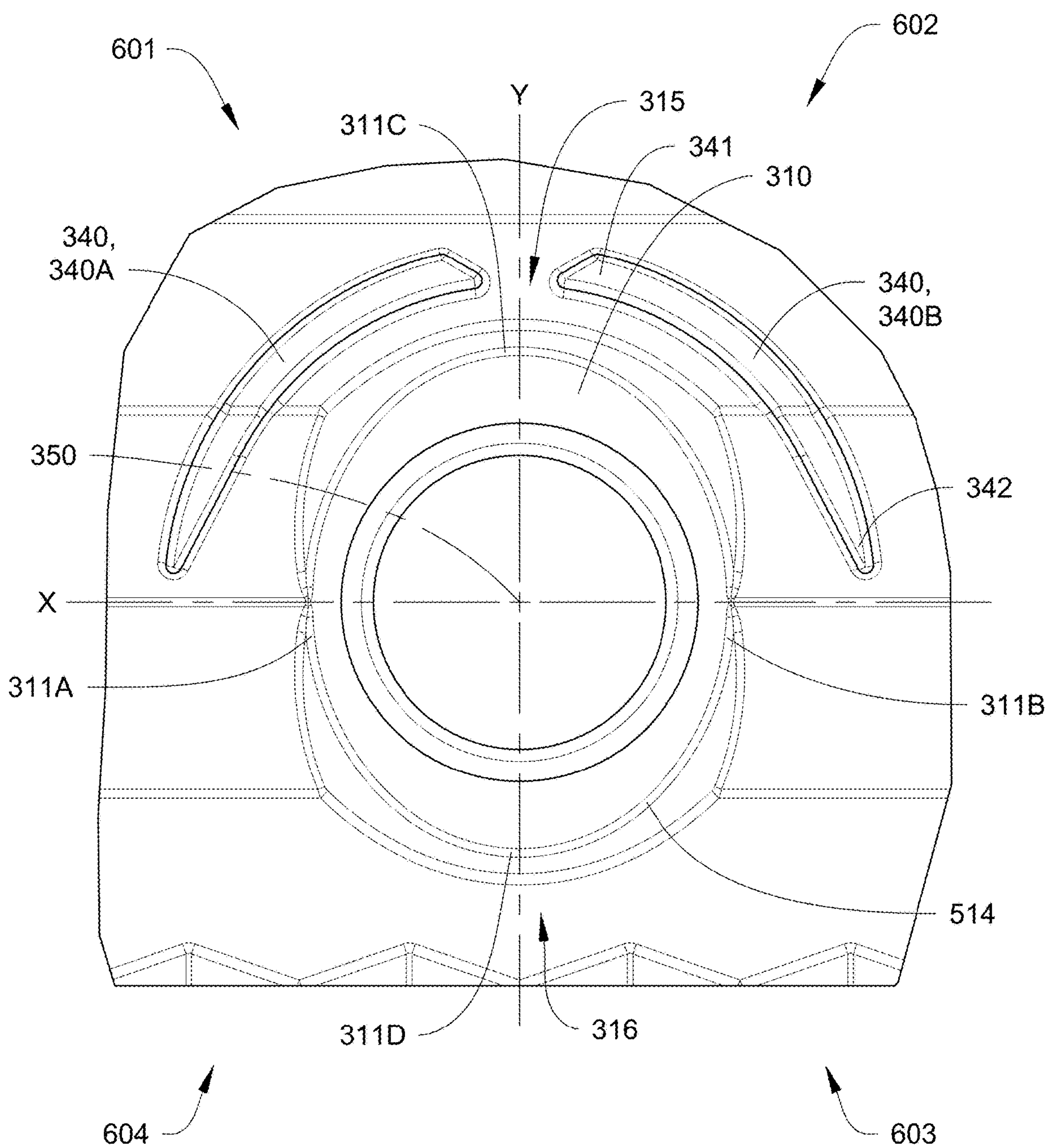

520,
520B
340
502
503
501
315
410
504
340
400
514
512
316
325
310
510
520,
520A

Fig. 5

Fig. 6


601
602
Y
315
311C
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340,
340B
350
342
X
311A
311B
514
311D
316
604
603

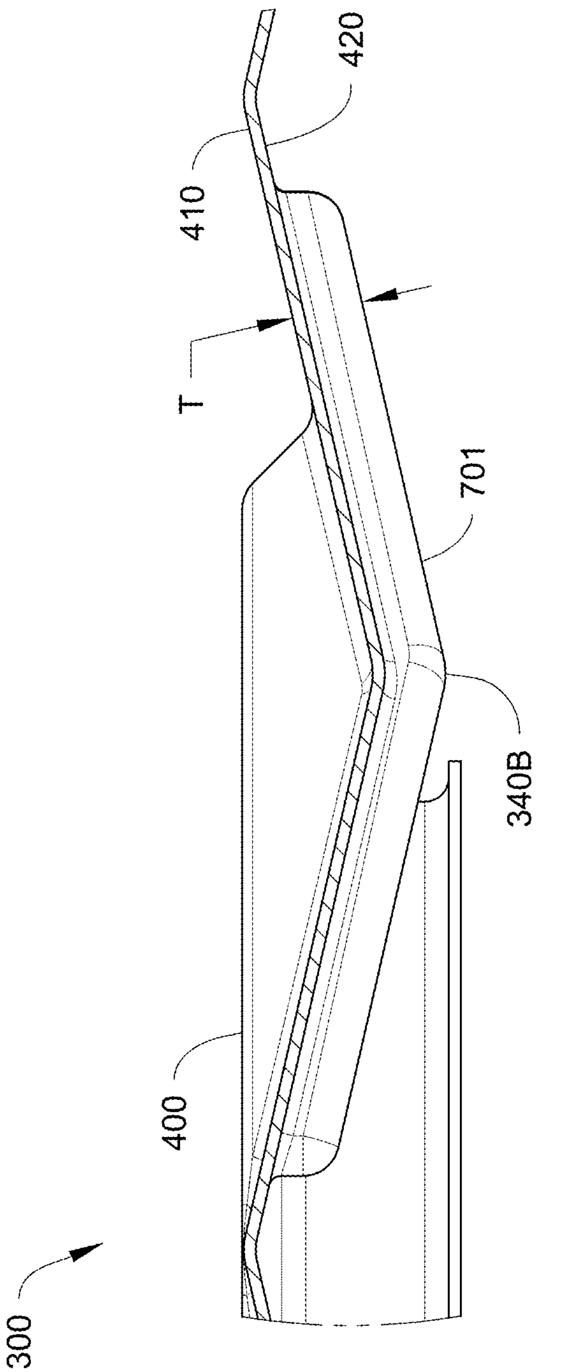
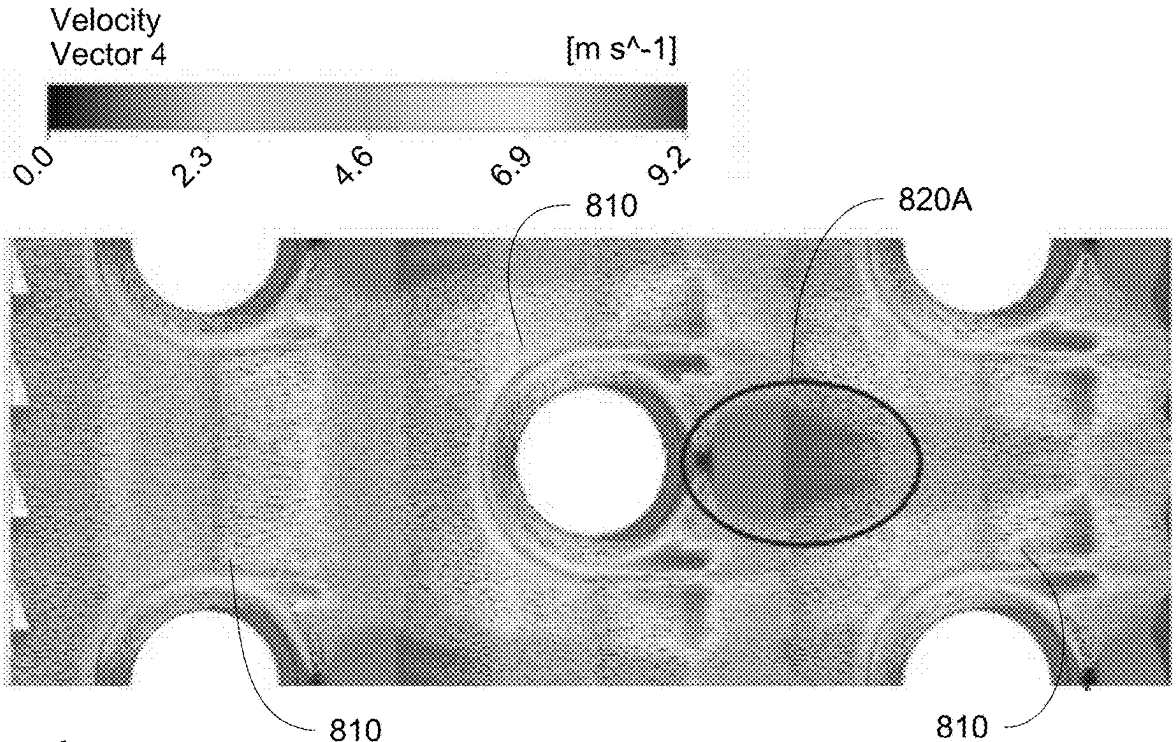


Fig. 7

Fig. 8A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Vector 4
[m s^-1]
0.0
2.3
4.6
6.9
9.2
810
820A
810
810

Fig. 8B

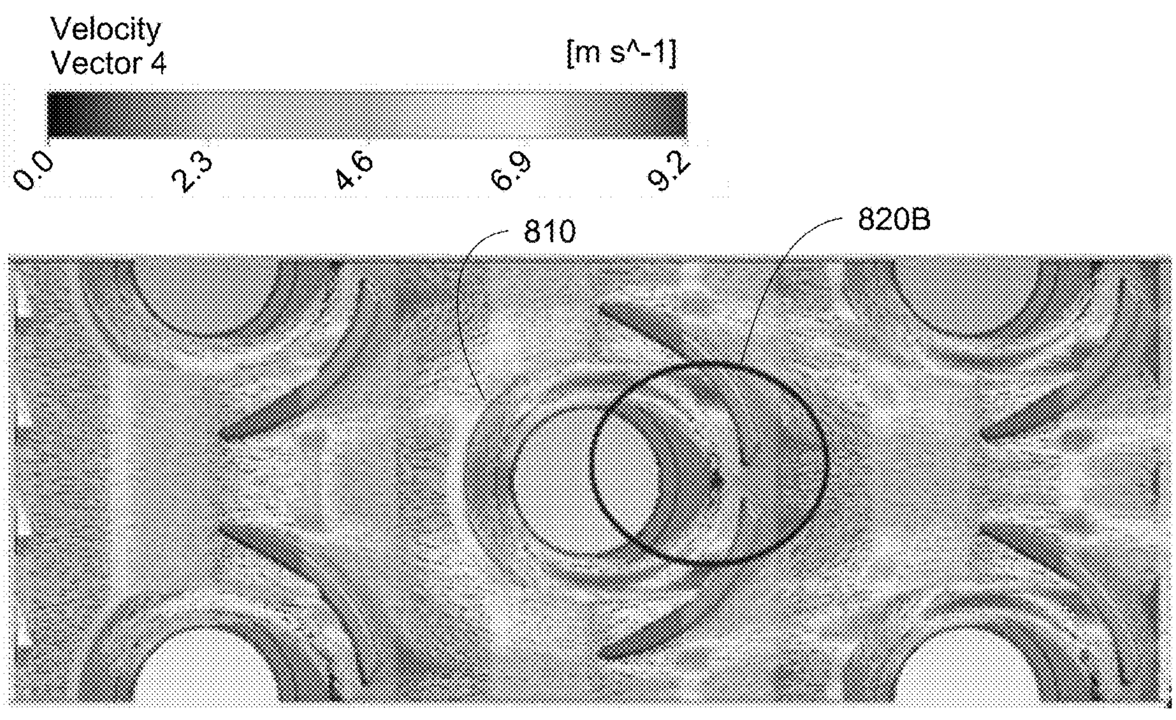

Velocity
Vector 4
[m s^-1]
0.0
2.3
4.6
6.9
9.2
810
820B

Fig. 8C

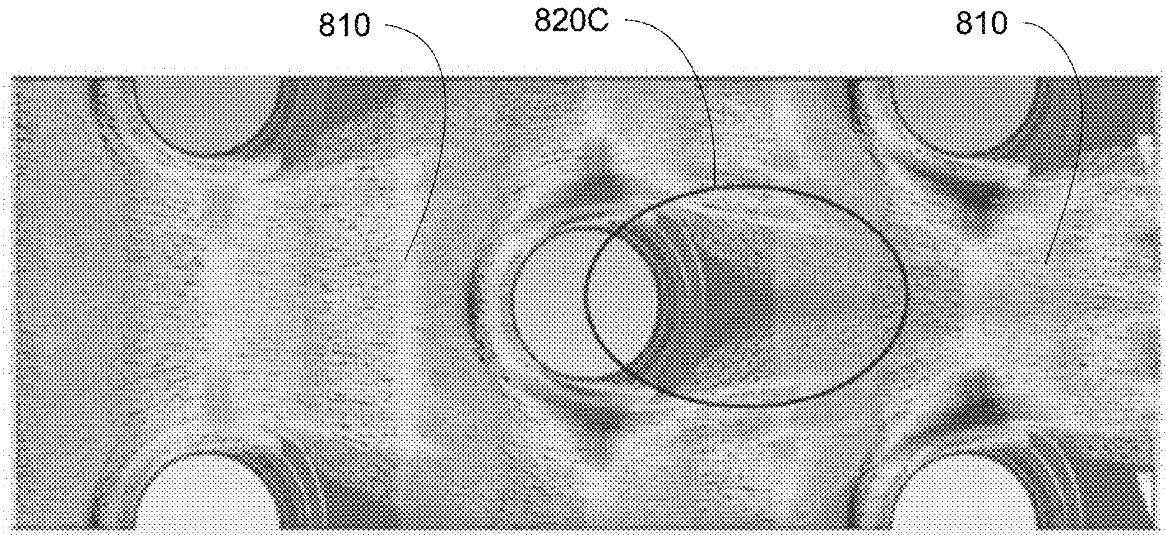


Fig. 8D

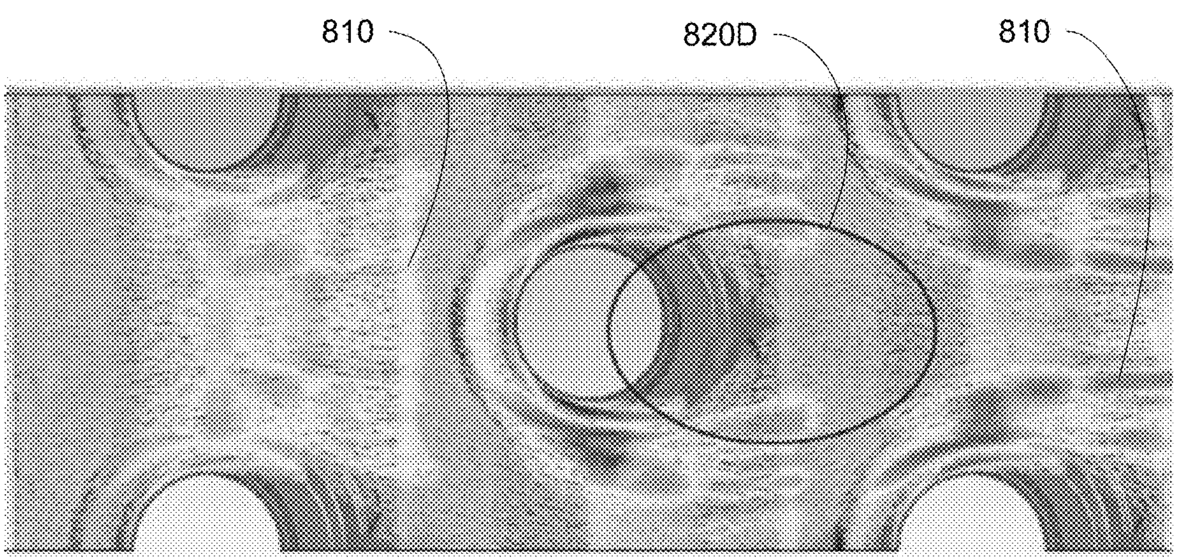


Fig. 9A

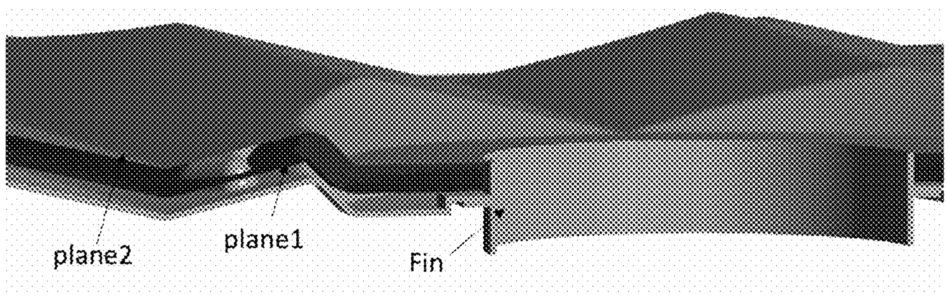


Fig. 9B

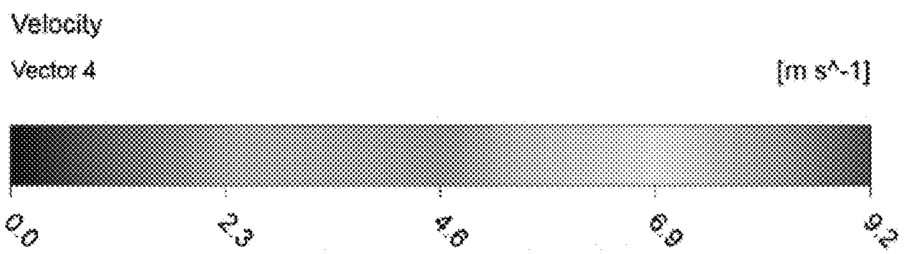


Fig. 9C

Fig. 9D

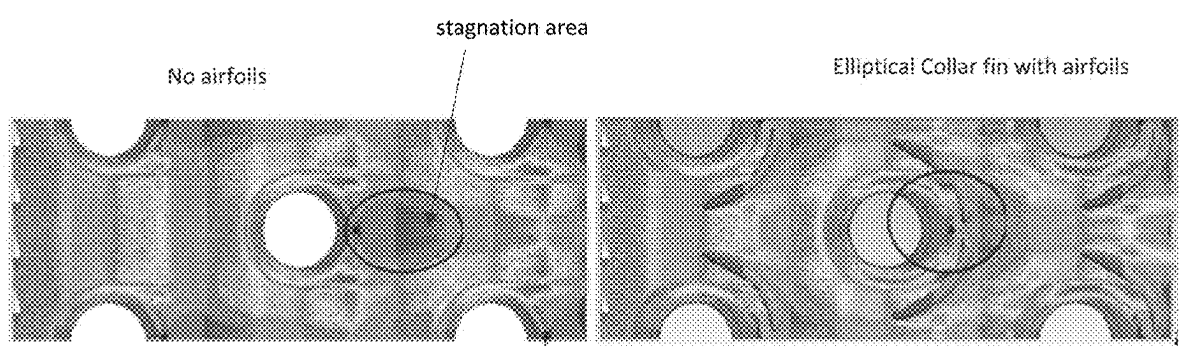
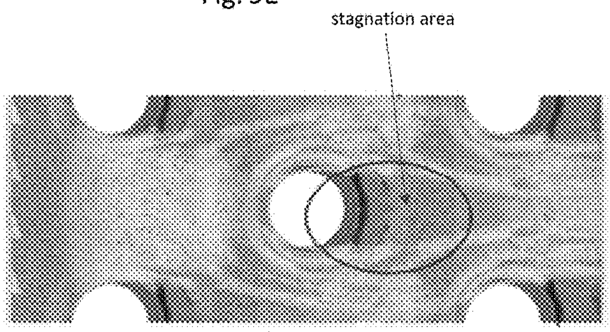
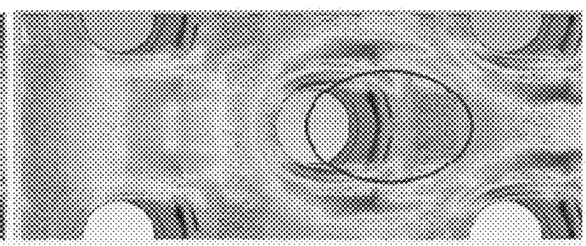


Fig. 9E



No airfoils

Fig. 9F



Eliptical Collar fin with airfoils

Fig. 10A

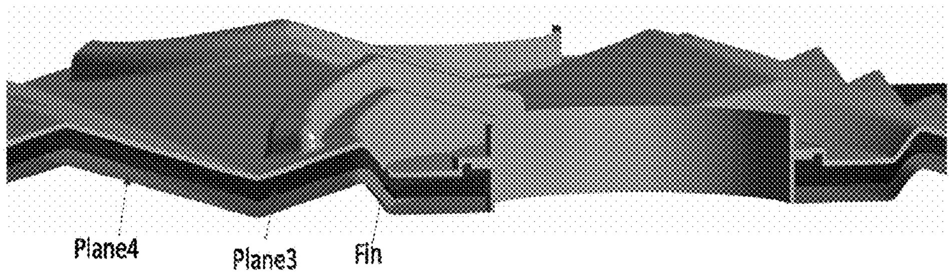


Fig. 10B

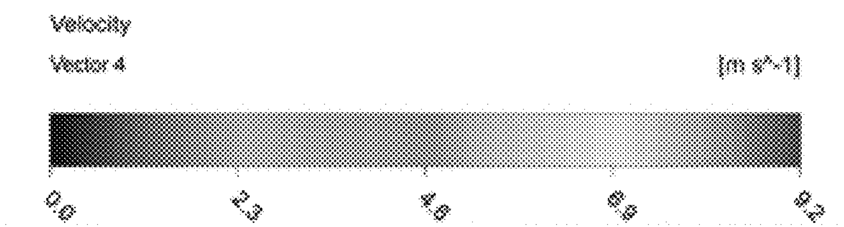


Fig. 10C

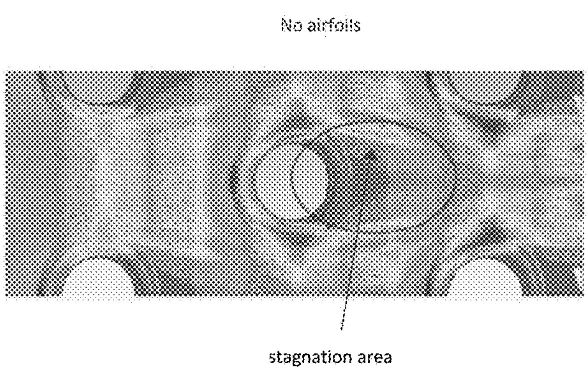


Fig. 10D

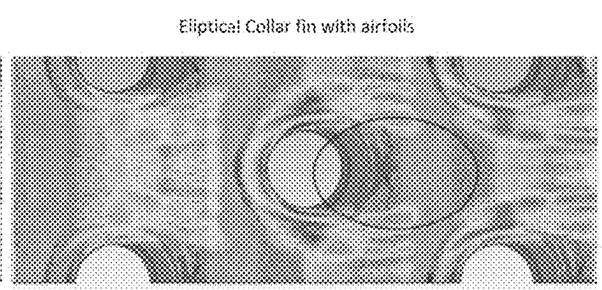
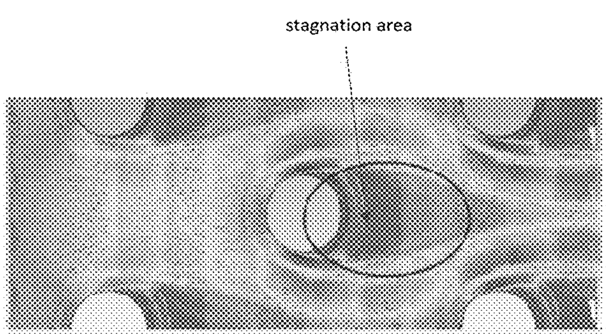
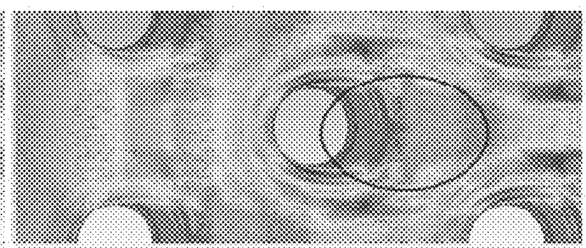


Fig. 10E



No airfoils

Fig. 10F



Eliptical Collar fin with airfoils

FIN HAVING ELLIPTICAL COLLAR BASES AND AIRFOILS AND RELATED FIN-AND-TUBE HEAT EXCHANGER

FIELD

[0001] This disclosure relates to fins of a heat exchanger for refrigerant circuits for a heating, ventilation, air conditioning, and refrigeration ("HVACR") system. More particularly, this disclosure relates to fins having elliptical collar bases and airfoils for, when a fluid crossflows the heat transfer tubes at the elliptical collar bases, reducing an area of fluid stagnation due to wake detachment in the trailing area behind of the heat transfer tubes that extend through the fins.

BACKGROUND

[0002] Heating, ventilation, air conditioning, and refrigeration ("HVACR") systems are generally used to heat, cool, and/or ventilate an enclosed space (e.g., an interior space of a commercial building or a residential building, an interior space of a refrigerated transport unit, or the like). An HVACR system may include a refrigerant circuit for providing cooled or heated air to the area. The refrigerant circuit utilizes a working fluid containing refrigerant to cool or heat a process fluid (e.g., air) directly or indirectly. A heat exchanger can be used to facilitate the heat exchange between the working fluid and the process fluid. The heat exchanger can have a plurality of fins. The process fluid can flow between the fins to exchange thermal energy with the working fluid via the fins and the heat transfer tubes.

SUMMARY

[0003] This disclosure relates to fins of a heat exchanger for refrigerant circuits for a heating, ventilation, air conditioning, and refrigeration ("HVACR") system. More particularly, this disclosure relates to fins having elliptical collar bases and airfoils for, when a fluid crossflows the heat transfer tubes at the elliptical collar bases, reducing an area of fluid stagnation due to wake detachment in the trailing area behind of the heat transfer tubes that extend through the fins.

[0004] In an embodiment, a fin includes a corrugated plate having a first side and a second side opposing the first side, the corrugated plate having a plurality of folds that are alternative peaks and valleys relative to the first side of the corrugated plate; one of a plurality of elliptical collar bases protruding from the first side of the corrugated plate; and a first airfoil and a second airfoil extending between a major axis and a minor axis of, and curving around, the one of the plurality of elliptical collar bases. The first airfoil is disposed in a first quadrant for the one of the plurality of elliptical collar bases, and the second airfoil is disposed in a second quadrant for the one of the plurality of elliptical collar bases, the second quadrant is adjacent to the first quadrant at the major axis.

[0005] In an embodiment, the one of the plurality of elliptical collar bases embosses into the second side and protrudes from the first side over one of the peaks.

[0006] In an embodiment, the one of the plurality of elliptical collar bases extends across three adjacent folds on the corrugated plate and within five adjacent folds on the corrugated plate.

[0007] In an embodiment, a transitioning side connects the one of the plurality of elliptical collar bases to the corrugated plate.

[0008] In an embodiment, the transitioning side wedges outwardly from the one of the plurality of elliptical collar bases to the first side of the corrugated plate.

[0009] In an embodiment, the one of the plurality of elliptical collar bases is centered over one of the peaks.

[0010] In an embodiment, the one of the plurality of elliptical collar bases is flush with the one of the peaks.

[0011] In an embodiment, the one of the airfoils extends across one of the valleys in a trailing area of the one of the plurality of elliptical collar bases.

[0012] In an embodiment, the one of the airfoils has a trailing end extended toward the major axis of the one of the plurality of elliptical collar bases, and a leading end extended toward the minor axis of the one of the plurality of elliptical collar bases.

[0013] In an embodiment, a leading end of the one of the airfoils is disposed further away from the one of the plurality of elliptical collar bases (e.g., relative to an outer edge of the one of the plurality of elliptical collars) than a trailing end of the first airfoil.

[0014] In an embodiment, the one of the airfoils is extended within three adjacent folds of the corrugated plate.

[0015] In an embodiment, the one of the airfoils embosses into the first side and protrudes from the second side of the corrugated plate.

[0016] In an embodiment, the fin includes a rippled edge.

[0017] In an embodiment, a plurality of heat transfer tubes extends through a plurality of fins. One of the plurality of fins includes a corrugated plate having a first side and a second side opposing the first side. The corrugated plate has a plurality of alternative peaks and valleys relative to the first side of the corrugated plate. One of a plurality of elliptical collar bases protrudes from the first side of the corrugated plate. A first airfoil and a second airfoil extend between a major axis and a minor axis of, and curving around, the one of the plurality of elliptical collar bases. The first airfoil is disposed in a first quadrant for the one of the plurality of elliptical collar bases, and the second airfoil is disposed in a second quadrant for the one of the plurality of elliptical collar bases. The second quadrant is adjacent to the first quadrant at the major axis.

[0018] In an embodiment, the one of the plurality of elliptical collar bases embosses into the second side and protrudes from the first side over one of the peaks, and the one of the airfoils embosses into the first side and protrudes from the second side of the corrugated plate.

[0019] In an embodiment, the one of the plurality of fins includes a fin collar connected to the one of the plurality of elliptical collar bases, and an external surface of one of the heat transfer tubes is contacted with the fin collar.

[0020] In an embodiment, the one of the airfoils extends across one of the valleys in a trailing area of the one of the plurality of elliptical collar bases, and a leading end of the one of the airfoils is disposed further away from the one of the plurality of elliptical collar bases than a trailing end of the first airfoil.

[0021] In an embodiment, a transitioning side connects the one of the plurality of elliptical collar bases to the corrugated plate, and the transitioning side wedges outwardly from the one of the plurality of elliptical collar bases to the first side of the corrugated plate.

[0022] In an embodiment, the one of the plurality of elliptical collar bases is centered over one of the peaks, and the one of the plurality of elliptical collar bases is flush with the one of the peaks.

[0023] In an embodiment, the one of the plurality of fins has a leading edge and a trailing edge, and a rippled edge is disposed on one or both of the leading edge and the trailing edge.

[0024] By including the elliptical collar bases and airfoils on the fins according to the embodiments of the present application, the fluid-side heat transfer coefficient (e.g., the air-side heat transfer coefficient, or the like) of a fin can be improved (e.g., compared to comparative fins having the same tube diameter, face pitch, row pitch, and/or the like) by more than 5%, while increasing the pressure drop across the fin by a small percentage, which is generally overweighed by the gain in the heat transfer coefficient. It is appreciated that, pressure drop can be the pressure drop of a fluid (e.g., air) when the fluid flows through a fin-and-tube heat exchanger and exchanges heat with the refrigerant inside the tube. It is appreciated that, in an embodiment, the fluid-side heat transfer coefficient can be air-side heat transfer coefficient of a fin of a heat exchanger, and the heat exchanger can be a fin-and-tube heat exchanger.

[0025] The improvements to the fluid-side heat transfer coefficient of a fin (e.g., to the air-side heat transfer coefficient or the like) according the present disclosure can be at least partially attributed to reduce boundary layer thickness and increase turbulence in the fluid flowing between the fins and/or the heat transfer tubes of a fin-and-tube heat exchanger. In some embodiments, when the fluid flows through the heat exchanger, the fluid flows across heat transfer tubes and separates at a location forming wake detachment in the trailing area that is behind the respective tubes relative to the flow direction of the fluid (e.g., the air flowing across the heat transfer tubes and/or between the fins). In the area of wake detachment, the fluid stagnates and limits the capacity of heat transfer. The fins of the present disclosure reduce the stagnation zone in the trailing areas, thereby improving the heat transfer for the fins.

[0026] Rippled edges on the fins, and/or the shape and size of the elliptical collar bases, can improve the stiffness of the fin according to the embodiments of the present disclosure (e.g., by optimizing elliptical collar base dimension, an angle between the collar base and the corrugated plate of the fins, and/or the like). For example, a fin having a face pitch (e.g., 22 mm) and row pitch (e.g., 19.05 mm) for receiving 7 mm heat transfer tubes, and three rows of fin collars for receiving heat transfer tubes and large elliptical collar base dimension may have a maximum deformation of at or about 5.2 millimeter (mm) and a maximum stress of at or about 28.5 mega-Pascal (MPa) under condition A and a maximum deformation of at or about 254.7 mm and a maximum stress of at or about 222.5 MPa under condition B. By including the elliptical collar base (which may have a predetermined dimension) with three rows of opening for receiving the heat transfer tubes, the maximum deformation could reduce to at or about 4.9 mm and the maximum stress could reduce to at or about 27.5 MPa under condition A and a maximum deformation of at or about 176.1 mm and a maximum stress of at or about 139.2 MPa under condition B. It is appreciated that "condition A" can be a stress test condition in which an at or about 1200 mm length fin is clamped at both ends, and "condition B" can be the same fin stress tested that is supported in the middle.

BRIEF DESCRIPTION OF DRAWINGS

[0027] FIG. **1** is a schematic diagram of an embodiment of a refrigerant circuit in a heating, ventilation, air conditioning, and refrigeration (HVACR) system.

[0028] FIG. **2** shows an internal schematic view of a fin-and-tube heat exchanger according to an embodiment.

[0029] FIG. **3** is a top view of a fin according to an embodiment.

[0030] FIG. **4** is a cross-sectional view of the fin as in the embodiment of FIG. **3**.

[0031] FIG. **5** is a perspective detailed view showing one of the elliptical collar bases and one pair of the airfoils as in the embodiment of FIG. **3**.

[0032] FIG. **6** is a detailed top view of one of the elliptical collar bases according to an embodiment.

[0033] FIG. **7** is an enlarged side view of the airfoil according to an embodiment.

[0034] FIG. **8**A shows a computational fluid dynamics (CFD) of fluid flow on the second side of the fin according to a comparative design.

[0035] FIG. **8**B shows the CFD of fluid flow on the second side of a fin according to an embodiment.

[0036] FIG. **8**C shows the CFD of fluid flow on the first side of a fin according to the comparative design of FIG. **8**A.

[0037] FIG. **8**D shows the CFD of fluid flow on the first side of a fin according to an embodiment.

[0038] FIG. **9**A shows locations of planes **1** and **2** over a fin on which the CFDs are computed.

[0039] FIG. **9**B is a legend for showing colors corresponding to the velocities of fluid flows shown in the CFDs of FIGS. **9**C-**9**F.

[0040] FIG. **9**C shows the CFD of fluid flow on plane **1** of a fin according to a comparative design.

[0041] FIG. **9**D shows the CFD of fluid flow on plane **1** of a fin according to an embodiment.

[0042] FIG. **9**E shows the CFD of fluid flow on plane **2** of the fin of the comparative design of FIG. **9**C.

[0043] FIG. **9**F shows the CFD of fluid flow on plane **2** of the fin according to an embodiment.

[0044] FIG. **10**A shows locations of planes **3** and **4** over a fin on which the CFDs are computed.

[0045] FIG. **10**B is a legend for showing colors corresponding to the velocities of fluid flows shown in FIGS. **10**C-**10**F.

[0046] FIG. **10**C shows the CFD of fluid flow on plane **3** of a fin according to the comparative design of FIG. **9**C.

[0047] FIG. **10**D shows the CFD of fluid flow on plane **3** of a fin according to an embodiment.

[0048] FIG. **10**E shows the CFD of fluid flow on plane **4** of the fin of the comparative design of FIG. **9**C.

[0049] FIG. **10**F shows the CFD of fluid flow on plane **4** of the fin according to an embodiment.

[0050] Like numbers represent like features.

DETAILED DESCRIPTION

[0051] This disclosure relates to fins of a heat exchanger for refrigerant circuits for a heating, ventilation, air conditioning, and refrigeration ("HVACR") system. More particularly, this disclosure relates to fins having elliptical collar bases and airfoils for, when a fluid crossflows the heat transfer tubes at the elliptical collar bases, reducing an area of fluid stagnation due to wake detachment in the trailing area behind of the heat transfer tubes that extend through the fins.

[0052] FIG. **1** is a schematic diagram of an embodiment of a refrigerant circuit **101** in a heating, ventilation, air conditioning, and refrigeration (HVACR) system **100**. The HVACR system **100** may be an industrial, commercial, or residential HVACR system **100** configured to condition the inside of a building (e.g., office space, residential house, or the like). In an embodiment, the HVACR system **100** may be a transport climate control system for heating or cooling the inside of a transport unit (e.g., a shipping container, a transport/trucking container, a reefer, or the like) and/or a passenger vehicle (e.g., a bus, a plane, or the like).

[0053] In an embodiment, the refrigerant circuit **101** includes a compressor **110**, a condenser **120**, an expander **130**, and an evaporator **140**. In an embodiment, the refrigerant circuit **101** can be modified to include additional components. For example, the refrigerant circuit **101** in an embodiment can include an economizer heat exchanger, one or more flow control devices, a receiver tank, a dryer, a suction-liquid heat exchanger, or the like. The components of the refrigerant circuit **101** are fluidly connected. Dotted lines and dotted dashed lines are provided in FIG. **1** to indicate fluid flows through the components (e.g., condenser **120**, evaporator **140**) for clarity, and should be understood as not specifying a specific route within each component.

[0054] In an embodiment, the refrigerant circuit **101** applies known principles of gas compression and heat transfer. The refrigerant circuit can be configured to heat or cool a process fluid (e.g., water, air, chiller fluid, or the like). In an embodiment, the refrigerant circuit **101** may represent in a chiller that cools a process fluid such as water or the like. In an embodiment, the refrigerant circuit **101** may represent an air conditioner and/or a heat pump that cools and/or heats a process fluid such as air, water, or the like.

[0055] During the operation of the refrigerant circuit **101**, a working fluid (e.g., a refrigerant, a refrigerant mixture, or the like) flows into the compressor **110** from the evaporator **140** in a gaseous state at a relatively lower pressure. The compressor **110** compresses the gaseous state working fluid into a high pressure state, which also heats the gas. After being compressed, the relatively higher pressure and higher temperature gaseous state working fluid flows from the compressor **110** to the condenser **120**. In addition to the working fluid flowing through the condenser **120**, a first process fluid PF_1 (e.g., external air, external water, cooling/heater water, or the like) also separately flows through the condenser **120**. The first process fluid absorbs heat from the working fluid as the first process fluid PF_1 flows through the condenser **120**, which cools the working fluid as it flows through the condenser. The working fluid condenses to liquid and then flows into the expander **130**. The expander **130** allows the working fluid to expand, which converts the working fluid to a mixed vapor and liquid state. An "expander" as described herein may also be referred to as an expansion device. In an embodiment, the expander may be an expansion device such as an expansion valve, expansion plate, expansion vessel, orifice, or the like, or other such types of expansion mechanisms. It should be appreciated that the expander may be any type of expander used in the field for expanding a working fluid to cause the working fluid to decrease in pressure and temperature. For example, the expander can be configured for throttling the working fluid from liquid state with high pressure and high temperature state to two-phase (e.g., a mixture of liquid and vapor) having low pressure and low temperature.

[0056] The relatively lower temperature, the two-phase working fluid then flows into the evaporator **140**. A second process fluid PF_2 (e.g., air, chiller liquid, water, or the like) also flows through the evaporator **140**. The working fluid absorbs heat from the second process fluid PF_2 as it flows through the evaporator **140**, which cools the second process fluid PF_2 as it flows through the evaporator **140**. As the working fluid absorbs heat, the working fluid evaporates to vapor. The working fluid then returns to the compressor **110** from the evaporator **140**. The above-described process continues while the refrigerant circuit **101** is operated, for example, in a cooling mode.

[0057] The refrigerant circuit **101** can be configured as a cooling system (e.g., a chiller of an HVACR, an air conditioning system, a heat pump of an HVACR, or the like) that can be operated in a cooling mode, and/or the refrigerant circuit **101** can be configured to operate as a heat pump system that can run in a cooling mode and a heating mode. In an embodiment, the refrigerant circuit **101** is a chiller that cools the second process fluid PF_2 that is a chiller liquid (e.g., air, water, glycol and/or water mixture, or the like). In an embodiment, the refrigerant circuit **101** is a heat pump that cools and heat the second process fluid PF_2 (e.g., air, water, glycol and/or water mixture, or the like).

[0058] FIG. **2** shows an internal schematic view of a fin-and-tube heat exchanger **200** according to an embodiment. The view of FIG. **2** omits the housing (and/or a frame of the heat exchanger) for the heat exchanger **200** to illustrate the fins and tubes of the heat exchanger **200**. In an embodiment, the heat exchanger **200** can be the condenser **120** or the evaporator **140** as shown and described in FIG. **1**. As shown in FIG. **200**, the heat exchanger **200** includes a plurality of fins **210** stack on top of each other and a plurality of heat transfer tubes ("tubes") **220** that extend through the fins **210**.

[0059] In an embodiment, the fin **210** includes a corrugated plate **205** having a wavy shape with alternating folds **250** and **260**. For example, the corrugated plate **205** can have a zig-zag shape. The corrugated plate **205** has a first side **201** and a second side **202** opposite to the first side **201** of the corrugated plate **205**. In an embodiment, the folds **250** and **260** can be peaks **250** and valleys **260** that are located on the plurality of fins **210**, and the folds **250** and **260** are aligned in the direction D. In an embodiment, the folds **250** and **260** alternate, between being the peaks and valleys, in the direction of the fluid flow of the first fluid **230**. It is appreciated that the folds **250** and **260** can be characterized as peaks **250** and valleys **260** relative to the view of FIG. **2** and/or with respect to a first side **201** of the corrugated plate of the fin **210**. The first fluid **230** flows in a flow path between the fins **210** (e.g., including the fin collar bases) and the outer surface of the tubes **220**. It is appreciated that, in some embodiments, the tube **220** can be attached to the inside of the fin collar **325** (shown in FIG. **4**) that is connected to the elliptical fin collar bases. In some embodiments, the tube and the fin collar may be contacted by interference fit.

[0060] In an embodiment, a wave of the wavy shape of the fin **210** includes one downward fin plate from a peak **250** to a valley **260** and the next adjacent upward fin plate from the same valley **260** to the next adjacent peak **250**. The fin **210** may include an optimized fin wave number per row of heat transfer tube for the fin-and-tube heat exchanger. In an embodiment, an angle between the downward fin plate and the upward fin plate may be in a predetermined angle range.

[0061] At least one of the tubes **220** extends through at least one of the fins **210** and couples with the fins **210**. In an embodiment, the plurality of tubes **220** extend through the plurality of fins **210**. The tubes **220** can interference fit into the opening in the fin collar bases and/or the fin collar (shown in FIG. **5**), for example, by inserting and extending the tubes through the openings on the elliptical collar bases. The fin-and-tube heat exchanger facilitates heat transfer through the tubes **220** and fins **210** between first fluid **230** and the second fluid **240**.

[0062] The first fluid **230** is arranged to flow through the space between the fins **210** (e.g., above or below the fin with the tubes disposed therein and closely contacted). The second fluid **240** is arranged to flow through the space within the tubes **220**. The first fluid **230** can exchange thermal energy with the second fluid **240** through the fins **210** and the tubes **220**. The first fluid **230** can flow above, between, and below the fins **210**.

[0063] In an embodiment, the first fluid **230** can be air, e.g., return indoor air from a climate controlled space to be conditioned (e.g., heated, cooled, or the like) in the fin-and-tube heat exchanger **200**. In another embodiment, the first fluid **230** can be outside air to be conditioned by the second fluid **240** flowing in the tubes **220**. The second fluid **240** can be a refrigerant, a refrigerant mixture, or the like. The tubes **220** are arranged in parallel with each other and/or perpendicular with the fins **210**. The fins **210** may be arranged to be parallel with each other.

[0064] It is appreciated that, as shown in FIG. **2**, when viewing in the direction D of the flow of the second fluid **240**, the tubes **220** are arranged in a grid pattern (e.g., in-line, staggered, or the like). In an embodiment, the tubes **220** can be arranged in a staggered pattern as shown, e.g., in FIG. **3**.

[0065] FIG. **3** is a top view of a fin **300** according to an embodiment. In an embodiment, FIG. **3** can be a top view of the fin **210** viewing in the direction D of FIG. **2**. The fin **300** includes one or more elliptical collar bases **310** disposed on a corrugated plate having a plurality of folds **305**. The folds **305** can be the folds **250** and **260** as discussed above of FIG. **2**.

[0066] As shown in FIG. **3**, the fin **300** includes a plurality of elliptical collar bases **310** for guiding a flow pattern for the first fluid **230** flowing over and/or under the fin **300**. The first fluid **230** is guided to flow in the flow pattern around the heat transfer tubes (e.g., tubes **220** of FIG. **2**) and extending through the space above and/or below the fin **300**. In an embodiment, the first fluid **230** is guided to crossflow the tubes (e.g., **220** of FIG. **2**) to the trailing area of the tube, guided by the airfoils.

[0067] In an embodiment, the first fluid **230** flows in the space between two adjacent fins of a stack of the fins (e.g., as shown by the stack of fins **210** in FIG. **2**).

[0068] An opening **320** is disposed in a plurality, or all, of the elliptical collar bases **310**. The opening **320** is arranged to receive the tube (e.g., tube **220** as shown in FIG. **2**) that can extend through the fins **300** at the elliptical collar base **310** (e.g., at a location in the fin collar base **310**). The opening **320** can be a space defined by a fin collar **325** surrounding the opening **320**. The fin collar **325** can contact with an external surface of the tube (e.g., the surface **225** of the tube **220** as shown in FIG. **2**) to facilitate heat transfer through the tubes and the fins **300**. In an embodiment, the fin collar **325** can be a circular/round structure, or a tubular section of a flange, extended from the opening **320** of the collar base **310** configured to receiving a heat transfer tube (not shown). It is appreciated that, in some embodiments, the fin collar **325** may have a height that correlates with a fin pitch, or a wave height (e.g., a vertical distance between the peak and the valley of the corrugated plate of the fin **300**) of the fins **300**. In an embodiment, the opening **320** has a circular shape and a center **350** such that the openings **320** are centered on the folds **305** of the fin **300**. It is appreciated that, in an embodiment, an opening **320** is disposed in each and all of the elliptical collar bases **310**.

[0069] In an embodiment, the fin collars **325** are contacted with the external surface of the tubes (e.g., the surface **225** of the tube **220** as shown in FIG. **2**) and having an interference fit with the tubes to facilitate heat transfer through the tubes/fin collars and the fins **300**. It is appreciated that the fin collar **325** can have a circular wall.

[0070] One or more trailing areas **315** are in the flow path of the first fluid **230**, downstream of the elliptical collar bases **310**, the fin collars (shown in FIG. **4**), and/or the tubes (shown in FIG. **4**). For example, the trailing area **315**A is in the flow path downstream of the elliptical collar base **310**A (and/or the tube and fin collars associated with the elliptical collar base **310**A) relatively to the flow direction of the first fluid **230**.

[0071] It is appreciated that, when the first fluid flows across a heat transfer tube, a separation point presents in the area trailing/behind the heat transfer tube. After the separation point, vortex forms, causing wake detachment and stagnation zone behand the tube. It is appreciated that the trailing areas **315** are in the flow path above and below the fin **300** trailing the locations of the elliptical collar bases **310**, the fin collar (not shown), and/or tubes (not shown) relative to the flow direction of the fluid **230**.

[0072] One or more leading areas **316** are in the flow path of the first fluid **230**, upstream of the trailing areas **315**. For example, the leading area **316**A is in the flow path upstream of the trailing area **315**A (in some embodiments, including the tubes and/or fin collars therein) relatively to the flow direction of the first fluid **230**. In an embodiment, the trailing area **315** and the leading area **316** are adjacent to each other. In an embodiment, the leading area **316** is a region on the fin **300** upstream of a tube, a fin collar and/or the location, where the velocity vector or the local flow direction of the first fluid **230** is flowing in the overall flow direction **230**. It is appreciated that the flow path of the first fluid **230** may flow over, and/or between, the fins, the fin collars, and/or around the heat transfer tubes that extend through the fin **300**, as illustrated, e.g., in the computational fluid dynamics of FIGS. **8**B and **8**D.

[0073] A plurality pairs of airfoils **340** are located on the corrugated plate. As shown in FIG. **3**, one pair of the airfoils **345** of the plurality airfoils **340** is located around one of the elliptical collar bases **310**A. In an embodiment, one pair of airfoils **340** is located respectively around at least some, or all, of the elliptical collar bases **310** on the fin **300**. The pair of airfoils **340** are located on the fin **300** such that the airfoils **340** extend from the trailing areas **315** to the leading area **316** of the same elliptical collar base **310**, the tube (not shown), and/or the fin collar (not shown). It is appreciated that the airfoils **340** are configured for guiding the flow pattern of the first fluid **230** in the leading areas **316** to the trailing areas **315** around the elliptical collar bases **310**, the fin collars (not shown) and/or the tubes (not shown) that extend through the fins **300** at the elliptical collar base **310**. In an embodiment, each of the airfoils in the pairs of airfoils **340** extends from the trailing area **315** to the leading area **316** of the same elliptical collar base **310**, the tube (not shown), and/or the fin collar (not shown).

[0074] The fin **300** has one, two, or more edges at the ends of the fin **300**. For example, the edge **301** is disposed at a leading end of the fin **300** and the edge **302** is disposed at a trailing end of the fin **300**. The leading end may be located at an end of the fin **300** that is upstream (relative to the flow direction of the first fluid **230**) of the elliptical collar bases **310** and/or at a location where the first fluid **230** enters across the fins in a fin-and-tube heat exchanger. The trailing end may be the end of the fin **300** that is downstream of the elliptical collar bases **310** and/or at a location where the first fluid **230** exits the fin in a fin-and-tube heat exchanger. One or both of the edges **301** and **302** can be rippled edge(s) with folds/corrugations extend across, and/or orthogonal to, the flow direction of the first fluid **230**. It is appreciated that, by having rippled edge(s), the stiffness of the fin **300** may be improved over the same design of the fin without the corrugated edge(s). In an embodiment, the two edges of the fin **300** can be rippled edges.

[0075] FIG. **4** is a cross-sectional view of the fin **300** according to an embodiment. For example, FIG. **4** can be the cross-sectional view of the fin **300** at the line **390** as in FIG. **3**. The line **390** can be located through the centers of elliptical collar bases **310**C and **310**D as in FIG. **3**.

[0076] The fin **300** includes a corrugated plate **400**. The elliptical collar bases **310** and the airfoils **340** are disposed on the corrugated plate **400**. The corrugated plate **400** includes a first side **410** and a second side **420** opposing the first side **410**. In an embodiment, the first side **410** is the upper surface of the corrugated plate **400**, and the second side **420** is the lower surface of the corrugated plate **400**.

[0077] The corrugated plate **400** of the fin **300** has a wave height **430** and an angle **450** (e.g., v-waffle angle). The wave height **430** can be a vertical distance between a peak fold **431** and a valley fold **432** of the corrugated plate **400**. In an embodiment, the wave height **430** can be a vertical distance between the highest point on the first side **410** and the lowest point on the second side **420** of the corrugated plate **400** as in the cross-sectional view of FIG. **4**.

[0078] In an embodiment, the angle **450** can have a range of at or about 150° to at or about 160°. For example, the angle **450** can be at or about 150°, 156.3°, 160°, or the like. It is appreciated that the angle may be one of the fin design factors to optimize fin performance. The wave height **430** may depend on the v-waffle angle and correspond the dimension to related v-waffle angle, e.g., as at or about 1.2761 mm, at or about 1 mm, at or about 0.8398 mm, and/or the like.

[0079] FIG. **5** is a perspective detailed view showing one of the elliptical collar bases **310** and one pair of the airfoils **340** as shown in FIG. **3**. For example, FIG. **5** may be the elliptical collar base **310**A and its airfoils **345** as in FIG. **3**.

[0080] As shown in FIG. **5**, the elliptical collar base **310** extends from the corrugated plate **400** and protrudes from the first side **410**. The elliptical collar base **310** has a top surface **510**. The top surface **510** may be a flat surface. The corrugated plate **400** connects to the top surface **510** of the elliptical collar base **310** by a transitioning side **520** that is at least partially surrounding the top surface **510** of the elliptical collar base **310**. The transitioning side **520** can wedge outwardly from the elliptical collar base **310** to the corrugated plate **400**. The transitioning side **520** can have a predetermined transitional angle between the transitioning side **520** and the corrugated plate **400** (e.g., intersecting downward and upward fin plates on the first side **410** of the corrugated plate **400**).

[0081] The corrugated plate **400** includes the first side **410**, a second side (obstructed), and a plurality of folds **501-504**. The folds **501-504** are arranged to be alternative peaks and valleys with respect to the view of FIG. **5** such that the folds **501** and **503** may be peaks, and the folds **502** and **504** may be valleys, on the corrugated plate **400** with respect to the first side **410** of the corrugated plate **400**.

[0082] In an embodiment, the top surface **510** of the elliptical collar base **310** includes an inner edge **512** and an outer edge **514**. The inner edge **512** is circular for arranging around a cylindrical heat transfer tube. For example, the inner edge **512** can be circular for providing a circular opening at an end of the fin collar **325** in which the heat transfer tube (not shown) may be inserted through the opening of the elliptical collar base and the fin collar, and penetrated through the corrugated plate **400**.

[0083] The outer edge **514** can have an elliptical shape that has a major and a minor axis. In an embodiment, the elliptical shape's minor axis of the outer edge **514** is located on the same line for the peak fold **503**. The major axis of the outer edge **514** can be perpendicular to the line for the peak fold **503**. In an embodiment, the dimension of minor axis and major axis of the outer edge **514** can provide superior fin stiffness regarding the maximum deformation and maximum stress that can be sustained by the fin before plastic deformation and/or cracking occurring to the fin. For example, the fin may be subjected to stress concentration or localized material yielding by its own weight, resulting plastic deformation on the fin under certain conditions. It is appreciated that the elliptical shape may have a continuously curving outer edge line.

[0084] In an embodiment, the elliptical collar base **310** can be characterized to be centered over the fold **503** when the inner edge **512** and the outer edge **514** are co-centered on the fold **503**. In an embodiment, the top surface **510** of the can be parallel to the overall extending direction $D_{extending}$ (shown in FIG. **4**) of the corrugated plate **400**. In an embodiment, the top surface **510** of the elliptical collar base **310** is flush with the peak **503**.

[0085] In an embodiment, a plurality, or all, of the elliptical collar bases **310** (e.g., shown in FIG. **3**) protrude from the first side **410** of the corrugated plate **400** on, and/or over, the folds of the corrugated plate **400**. At least some, or all, of the elliptical collar bases **310** are centered on the peaks of the folds (e.g., folds **503**) of the corrugated plate **400** such that the peak fold **503** and the collar bases **310** protrude from the same side of the corrugated plate **400** and extend in the same direction. In an embodiment, the collar base **310** is arranged to span across three adjacent folds (e.g., **502**, **503**, **504**) on the corrugated plate **400**, and/or within five adjacent folds. For example, the top surface **510** of the elliptical collar base **310** includes an opening in the center for receiving a heat transfer tube. It is appreciated that the elliptical collar base may define a transition angle between a leading side **520**A and a downward corrugated fin plate section on one side of the elliptical collar base **310**, and define a transition angle between a trailing side **520**B and an upward corrugated fin plate section on the other side, relative to the one side of the elliptical collar base **310** on the corrugated plate **400**.

[0086] The transitioning side **520** can connect the top surface **510** of the elliptical collar base **310** to the first side **410** of the corrugated plate **400** and/or provides rigidity/stiffness, e.g., regarding the maximum deformation and maximum stress that can be sustained by the fin before plastic deformation or cracking. For example, the fin may be subjected to stress concentration or localized material yielding by its own weight, resulting plastic deformation on the fin under certain conditions. The transitioning side **520** wedges outwardly from the top surface **510** of the elliptical collar base **310** to the first side **410** of the corrugated plate **400**. In an embodiment, the side wall **520** includes a trailing side **520**B and a leading side **520**A. The trailing side **520**B is located in the trailing side of the fluid flow and extended from the fold **503** (peak), across fold **502** (valley), and toward fold **501** (peak). The leading side **520**A is located on the leading side of the fluid flow and extended from fold **503** (peak), across fold **504** (valley), and toward the next adjacent fold (peak) on the corrugated plate **400**.

[0087] The pair of airfoils **340** is disposed at least partially in the trailing area **315** of the corresponding elliptical collar base **310**. In an embodiment, the pair of airfoils **340** is disposed fully in the trailing area **315** of the corresponding elliptical collar base **310**.

[0088] In an embodiment, the elliptical collar base **310** protrudes from the first side **410** on a peak fold (e.g., fold **503**) and the airfoil **340** protrudes from the second side (e.g., second side **420** as shown in FIG. **4**) across a valley fold (e.g., fold **502**) such that the elliptical collar base **310** and the airfoils **340** protrudes from opposite sides of the corrugated plate **400**. In an embodiment, the airfoil **340** recesses into the first side **410** over a valley fold (e.g., fold **502**).

[0089] FIG. **6** is a detailed top view of one of the elliptical collar base according to an embodiment. For example, FIG. **6** can be the detailed top view of one of the elliptical collar bases **310** as shown in FIG. **3**. The surface of the elliptical collar base **310** has an elliptical shape that includes a first end **311**C, a second end **311**D, a first side **311**A and a second side **311**B. The elliptical shape has a major axis Y and a minor axis X through the center **350** of the elliptical shape. It is appreciated that the major axis Y extends along the wider dimension of the elliptical shape between the first end **331**C and the second end **311**D, and the minor axis X extends along the narrower dimension of the elliptical shape between the first side **311**A and the second side **311**B.

[0090] It is appreciated that the major axis Y and the minor axis X separate the area around the elliptical collar base **310** (and/or around the tube (not shown) disposed therein) into the first to the fourth quadrant **601-604**. The trailing area **315** of the elliptical collar base **310** may be disposed in the first and second quadrants **601** and **602** downstream of fluid flow passing the fin collar base **310**, the fin collar, and/or the tube (not shown) disposed through the fin collar.

[0091] The leading area **316** of the elliptical collar base **310** may be disposed in the third and fourth quadrants **603** and **604** upstream of fluid flow passing the fin collar base **310**, the fin collar, and/or the tube (not shown) disposed through the fin collar. In an embodiment, the first airfoil **340**A of the pair of airfoils **340** is disposed in the first quadrant **601**, and the second airfoil **340**B of the pair of airfoils **340** is disposed in the second quadrant **602**.

[0092] The airfoil **340** can have an eyebrow shape (e.g., an arc shape having wedged shaped end and a sharp end) around the elliptical collar base **310**. The eyebrow shape of the airfoils **340** can have a trailing end and a leading end. The trailing end of the airfoils **340** extends from the trailing area **315** to the leading end of the airfoils **340** in, or toward, the leading areas **316** of the elliptical collar bases **310**. It is appreciated that a heat transfer tube may be disposed through the elliptical collar bases **310** and the fin collar.

[0093] In an embodiment, the pair of airfoils **340** are disposed at a location of the corrugated fin plate spaced apart from an outer edge of the elliptical collar base. It is appreciated that the elliptical collar base may be located across a first wave (i.e., a portion of the corrugated plate between, sequentially, a peak, a valley, and a peak) and a second wave adjacent to the first wave. The first wave is upstream of the second wave. The pair of airfoil **340** is disposed in the second wave of the respective elliptical collar base, fin collar, and/or the heat transfer tube disposed through the elliptical collar base.

[0094] The airfoils **340** can each have a trailing end **341** and a leading end **342**. The trailing end **341** is disposed in the trailing area **315**, and the airfoil **340** extends toward the leading area **316** such that the trailing end **341** is closer to the elliptical collar base **310** than the leading end **342**. It is appreciated that the trailing end **341** of the airfoil can be disposed at a location closer to the outer edge **514** of the collar base **310** than the location for the leading end **342** of the airfoil, according to an embodiment. In the illustrated examples, the airfoils **340** are continuously extended between the leading end **342** and the trailing end **341**. It is appreciated that the airfoils **340** may be provided in two segments (e.g., a leading segment and a trailing segment that disjoin at the valley fold), in three segments, and/or in more segments.

[0095] The elliptical collar base **310** is disposed in the orientation such that the elliptical collar base is narrower across/perpendicular to the airflow direction and wider in the airflow direction. In such an orientation, a larger clearance can be provided between two adjacent elliptical collar bases **310** such that interference between two leading ends of the airfoils **340** for adjacent elliptical collar bases **310** may be avoided. It is appreciated that such orientation may provide superior heat transfer.

[0096] FIG. **7** is an enlarged side view of the airfoil according to an embodiment. For example, FIG. **7** can be a side view of the airfoil **340**B as shown in FIG. **6**. As shown in the illustrative example of FIG. **7**, the corrugated plate **400** has the first side **410** and the second side **420**. In the illustrative example of FIG. **7**, the airfoil **340**B can have a uniformed thickness T in the side view of the fin **300**. The thickness T of the airfoil **340**B can be defined as the distance, in an orthogonal direction the local section (i.e., the upper section or lower section of the corrugated plate between two adjacent folds) of the corrugated plate **400**, between the first side **410** of the corrugated plate **400** and the lower surface **701** of the airfoil **340**B. In an embodiment, the thickness is at or about 0.4 mm to at or about 0.6 mm.

[0097] FIGS. **8**A-D include computational fluid dynamics (CFD) simulations of the fin having an elliptical collar base with a pair of airfoils according to an embodiment, and the CFD of a comparative design. FIG. **8**A is the CFD of fluid flow on the second side of the fin according to a comparative design. FIG. **8**B is the CFD of fluid flow on the second side of a fin according to an embodiment. FIG. **8**C is the CFD of fluid flow on the first side of a fin according to the comparative design of FIG. **8**A. FIG. **8**D is the CFD of fluid flow on the first side of a fin according to an embodiment. For example, the fin shown in FIGS. **8**A and **8**C can be a fin without the airfoils of the embodiments of this disclosure. FIG. **8**B can be the fin **300** as shown, e.g., in FIG. **4**, viewing from the second side **420** of the fin **300**. FIG. **8**D can be the fin **300** as shown, e.g., in FIG. **4**, viewing from the first side **410** of the fin **300**. It is appreciated that, the tubes extending through the fin are omitted in FIGS. **8**A-**8**D.

[0098] FIG. **8**A shows the CFD in a layer of the flow path on the bottom of the fin as a comparative design. Area **810** is located in the flow path with white or light gray dashes showing the presence of fluid flows. Area **820**A indicates a portion of the trailing area (relative to the fluid flow direction) of the elliptical collar base, the fin collar, and/or the heat transfer tube may be disposed therein. With few white or light gray dashes covering the area **820**A, the features of the fin itself are clearly shown, indicating a stagnation of fluid flow in this area **820**A, due to wake detachment in the trailing area behind the heat transfer tube (and/or the fin collar and the collar base). It is appreciated that stagnated fluid can have a lower rate of heat transfer compared to area with fluid flow. Accordingly, by causing more fluid flow into the stagnated area, the fluid-side heat transfer coefficient of the fin (e.g., air-side heat transfer coefficient) may be improved.

[0099] FIG. **8**B shows the CFD in a layer of the flow path on the bottom of the fin having an elliptical collar base and a pair of airfoils according to an embodiment of the present disclosure that reduces stagnation of fluid flow. As shown in FIG. **8**B, a smaller portion of the area **820**B on the fin is more clearly shown compared to the area **820**A of FIG. **8**A. The area **820**B has a larger portion of the feature on the fin obstructed by white or light gray dashes that indicate the presence of fluid flow. Accordingly, a smaller portion in the area **820**B has stagnation of fluid flow thereby having a higher heat transfer comparing to the fin of FIG. **8**A.

[0100] FIG. **8**C shows the CFD in a layer of the flow path on the top of the fin as a comparative design. Area **810** is in the flow path with white or light gray dashes showing fluid flows. Area **820**C shows the trailing area (relative to the fluid flow direction) of the fin collar, the fin collar base, and/or the heat transfer tube. With fewer white or light gray dashes covering a larger portion in this area **820**C, the features of the fin are more clearly shown in FIG. **8**C indicating a larger stagnation of fluid flow in this area **820**C.

[0101] FIG. **8**D shows the CFD in a layer of the flow path on the top of the fin having an elliptical collar base and a pair of airfoils according to an embodiment of the present disclosure. As shown in FIG. **8**D, a smaller portion of area **820**D on the fin is clearly shown within the area **820**D, compared to FIG. **8**C. Accordingly, a smaller portion in the area **820**D has stagnated fluid flow due to the reduction of stagnated fluid flow, for example, from the reduction of wake formed in the trailing area.

[0102] Comparing with the CFDs in FIGS. **8**A and **8**C (for a fin of a comparative design), the CFDs in FIGS. **8**B and **8**D (for a fin according to one or more embodiments) show a higher fluid-side heat transfer coefficient (when fluid flows over the fin). The improvement to the fluid-side heat transfer coefficient can be due to the reduction of stagnated fluid flow that at least partially caused by reducing wake detachment trailing the heat transfer tubes in the trailing area of the elliptical collar bases.

[0103] It is appreciated that, generally, a lower pressure drop across the fin can be more preferable for using less energy for moving fluids through the fin-and-tube heat exchanger. Also, a higher fluid-side heat transfer coefficient can be generally more preferable as the same heat transfer area on the fin can support a larger amount of heat transfer.

Aspects:

[0104] Any of Aspects 1-13 may be combined with any of Aspects 14-20.

[0105] Aspect 1. A fin comprising:

[0106] a corrugated plate having a first side and a second side opposing the first side, the corrugated plate having a plurality of folds that includes alternative peaks and valleys relative to the first side of the corrugated plate;

[0107] one of a plurality of elliptical collar bases protruding from the first side of the corrugated plate; and

[0108] a first airfoil and a second airfoil extending between a major axis and a minor axis of, and curving around, the one of the plurality of elliptical collar bases, wherein

[0109] the first airfoil is disposed in a first quadrant for the one of the plurality of elliptical collar bases, and

[0110] the second airfoil is disposed in a second quadrant for the one of the plurality of elliptical collar bases, the second quadrant being adjacent to the first quadrant at the major axis.

[0111] Aspect 2. The fin of aspect 1, wherein the one of the plurality of elliptical collar bases embosses into the second side and protrudes from the first side over one of the peaks.

[0112] Aspect 3. The fin of aspect 1 or 2, wherein the one of the plurality of elliptical collar bases extends across three adjacent folds on the corrugated plate and within five adjacent folds on the corrugated plate.

[0113] Aspect 4. The fin of any one of aspects 1-3, wherein

[0114] a transitioning side connects the one of the plurality of elliptical collar bases to the corrugated plate.

[0115] Aspect 5. The fin of aspect 4, wherein

[0116] the transitioning side wedges outwardly from the one of the plurality of elliptical collar bases to the first side of the corrugated plate.

[0117] Aspect 6. The fin of any one of aspects 1-5, wherein

[0118] the one of the plurality of elliptical collar bases is centered over one of the peaks.

[0119] Aspect 7. The fin of any one of aspects 1-6, wherein

[0120] the one of the plurality of elliptical collar bases is flush with the one of the peaks.

[0121] Aspect 8. The fin of any one of aspects 1-7, wherein

[0122] the first airfoil extends across one of the valleys in a trailing area of the one of the plurality of elliptical collar bases.

[0123] Aspect 9. The fin of any one of aspects 1-8, wherein

[0124] the first airfoil comprises

[0125] a trailing end extended toward the major axis of the one of the plurality of elliptical collar bases and

[0126] a leading end extended toward the minor axis of the one of the plurality of elliptical collar bases.

[0127] Aspect 10. The fin of any one of aspects 1-9, wherein

[0128] a leading end of the first airfoil is disposed further away from the one of the plurality of elliptical collar bases than a trailing end of the first airfoil.

[0129] Aspect 11. The fin of any one of aspects 1-10, wherein

[0130] the first airfoil is extended within three adjacent folds of the corrugated plate.

[0131] Aspect 12. The fin of any one of aspects 1-11, wherein

[0132] the first airfoil embosses into the first side and protrudes from the second side of the corrugated plate.

[0133] Aspect 13. The fin of any one of aspects 1-12, wherein the fin further includes a rippled edge.

[0134] Aspect 14. A fin-and-tube heat exchanger comprising:

[0135] a plurality of heat transfer tubes extending through a plurality of fins, wherein one of the plurality of fins comprise:

[0136] a corrugated plate having a first side and a second side opposing the first side, the corrugated plate having a plurality of folds that includes alternative peaks and valleys relative to the first side of the corrugated plate;

[0137] one of a plurality of elliptical collar bases protruding from the first side of the corrugated plate; and

[0138] a first airfoil and a second airfoil extending between a major axis and a minor axis of, and curving around, the one of the plurality of elliptical collar bases, wherein

[0139] the first airfoil is disposed in a first quadrant for the one of the plurality of elliptical collar bases, and

[0140] the second airfoil is disposed in a second quadrant for the one of the plurality of elliptical collar bases, the second quadrant being adjacent to the first quadrant at the major axis.

[0141] Aspect 15. The fin-and-tube heat exchanger of aspect 14, wherein

[0142] the one of the plurality of elliptical collar bases embosses into the second side and protrudes from the first side over one of the peaks, and

[0143] the first airfoil embosses into the first side and protrudes from the second side of the corrugated plate.

[0144] Aspect 16. The fin-and-tube heat exchanger of claim **14**, wherein

[0145] the one of the plurality of fins further comprises a fin collar connected to the one of the plurality of elliptical collar bases, and

[0146] an external surface of one of the heat transfer tubes is contacted with the fin collar.

[0147] Aspect 17. The fin-and-tube heat exchanger of claim **14**, wherein

[0148] the first airfoil extends across one of the valleys in a trailing area of the one of the plurality of elliptical collar bases, and

[0149] a leading end of the first airfoil is disposed further away from the one of the plurality of elliptical collar bases than a trailing end of the first airfoil.

[0150] Aspect 18. The fin-and-tube heat exchanger of claim **14**, wherein

[0151] a transitioning side connects the one of the plurality of elliptical collar bases to the corrugated plate, and

[0152] the transitioning side wedges outwardly from the one of the plurality of elliptical collar bases to the first side of the corrugated plate.

[0153] Aspect 19. The fin-and-tube heat exchanger of claim **14**, wherein

[0154] the one of the plurality of elliptical collar bases is centered over one of the peaks, and

[0155] the one of the plurality of elliptical collar bases is flush with the one of the peaks.

[0156] Aspect 20. The fin-and-tube heat exchanger of claim **14**, wherein

[0157] the one of the plurality of fins has a leading edge and a trailing edge, and a rippled edge is disposed on one or both of the leading edge and the trailing edge.

[0158] The terminology used herein is intended to describe particular embodiments and is not intended to be limiting. The terms "a," "an," and "the" include the plural forms as well, unless clearly indicated otherwise. The terms "comprises" and/or "comprising," when used in this Specification, specify the presence of the stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, and/or components.

[0159] With regard to the preceding description, it is to be understood that changes may be made in detail, especially in matters of the construction materials employed and the shape, size, and arrangement of parts without departing from the scope of the present disclosure. This Specification and the embodiments described are exemplary only, with the true scope and spirit of the disclosure being indicated by the claims that follow.

What is claimed is:

1. A fin comprising:

a corrugated plate having a first side and a second side opposing the first side, the corrugated plate having a plurality of folds that includes alternative peaks and valleys relative to the first side of the corrugated plate;

one of a plurality of elliptical collar bases protruding from the first side of the corrugated plate; and

a first airfoil and a second airfoil extending between a major axis and a minor axis of, and curving around, the one of the plurality of elliptical collar bases, wherein

the first airfoil is disposed in a first quadrant for the one of the plurality of elliptical collar bases, and the second airfoil is disposed in a second quadrant for the one of the plurality of elliptical collar bases, the second quadrant being adjacent to the first quadrant at the major axis.

2. The fin of claim **1**, wherein the one of the plurality of elliptical collar bases embosses into the second side and protrudes from the first side over one of the peaks.

3. The fin of claim **1**, wherein the one of the plurality of elliptical collar bases extends across three adjacent folds on the corrugated plate and within five adjacent folds on the corrugated plate.

4. The fin of claim **1**, wherein

a transitioning side connects the one of the plurality of elliptical collar bases to the corrugated plate.

5. The fin of claim **4**, wherein

the transitioning side wedges outwardly from the one of the plurality of elliptical collar bases to the first side of the corrugated plate.

6. The fin of claim **1**, wherein

the one of the plurality of elliptical collar bases is centered over one of the peaks.

7. The fin of claim **1**, wherein

the one of the plurality of elliptical collar bases is flush with the one of the peaks.

8. The fin of claim **1**, wherein

the first airfoil extends across one of the valleys in a trailing area of the one of the plurality of elliptical collar bases.

9. The fin of claim **1**, wherein

the first airfoil comprises

a trailing end extended toward the major axis of the one of the plurality of elliptical collar bases and

a leading end extended toward the minor axis of the one of the plurality of elliptical collar bases.

10. The fin of claim **1**, wherein

a leading end of the first airfoil is disposed further away from the one of the plurality of elliptical collar bases than a trailing end of the first airfoil.

11. The fin of claim **1**, wherein

the first airfoil is extended within three adjacent folds of the corrugated plate.

12. The fin of claim **1**, wherein

the first airfoil embosses into the first side and protrudes from the second side of the corrugated plate.

13. The fin of claim **1**, wherein the fin further includes a rippled edge.

14. A fin-and-tube heat exchanger comprising:

a plurality of heat transfer tubes extending through a plurality of fins, wherein one of the plurality of fins comprise:

a corrugated plate having a first side and a second side opposing the first side, the corrugated plate having a plurality of folds that includes alternative peaks and valleys relative to the first side of the corrugated plate;

one of a plurality of elliptical collar bases protruding from the first side of the corrugated plate; and

a first airfoil and a second airfoil extending between a major axis and a minor axis of, and curving around, the one of the plurality of elliptical collar bases, wherein

the first airfoil is disposed in a first quadrant for the one of the plurality of elliptical collar bases, and

the second airfoil is disposed in a second quadrant for the one of the plurality of elliptical collar bases, the second quadrant being adjacent to the first quadrant at the major axis.

15. The fin-and-tube heat exchanger of claim **14**, wherein

the one of the plurality of elliptical collar bases embosses into the second side and protrudes from the first side over one of the peaks, and

the first airfoil embosses into the first side and protrudes from the second side of the corrugated plate.

16. The fin-and-tube heat exchanger of claim **14**, wherein

the one of the plurality of fins further comprises a fin collar connected to the one of the plurality of elliptical collar bases, and

an external surface of one of the heat transfer tubes is contacted with the fin collar.

17. The fin-and-tube heat exchanger of claim **14**, wherein

the first airfoil extends across one of the valleys in a trailing area of the one of the plurality of elliptical collar bases, and

a leading end of the first airfoil is disposed further away from the one of the plurality of elliptical collar bases than a trailing end of the first airfoil.

18. The fin-and-tube heat exchanger of claim **14**, wherein

a transitioning side connects the one of the plurality of elliptical collar bases to the corrugated plate, and the transitioning side wedges outwardly from the one of the plurality of elliptical collar bases to the first side of the corrugated plate.

19. The fin-and-tube heat exchanger of claim **14**, wherein

the one of the plurality of elliptical collar bases is centered over one of the peaks, and

the one of the plurality of elliptical collar bases is flush with the one of the peaks.

20. The fin-and-tube heat exchanger of claim **14**, wherein

the one of the plurality of fins has a leading edge and a trailing edge, and

a rippled edge is disposed on one or both of the leading edge and the trailing edge.

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