[0006] In the electric aircraft propulsion system disclosed herein, ducted fan blades are integrated into an electric machine. Generally speaking, rotating fan blades form part of the rotor assembly of the electric machine. By removing the requirement for a driven motor shaft, electric propulsion systems disclosed herein allow primary air flow through the electric machine. This may provide increased propulsion efficiency.

[0007] Also, the topology of electric propulsion systems disclosed in may allow the electric machine to have a relatively high aspect ratio between its diameter and axial length. This may allow the electric machine to accommodate a set of polyphase multi-polar stator windings. Additionally, or alternatively, the high aspect ratio may enable the electric machine to be scalable to provide higher output power without reaching magnetic saturation in the yoke or in the teeth of the stator. Additionally, or alternatively, the high aspect ratio may reduce the weight and/or rotary inertia of the rotor assembly.

[0008] In systems disclosed herein, propulsion fan blades are secured to both an inner hub and an outer shroud, with the hub, fan blades, and shroud forming part of a rotor and fan assembly for the electric machine. In order to compensate for at least a portion of expected centrifugal forces and/or hoop stresses during high speed operation, at least some components of the rotor and fan assembly are preferably pre-loaded (e.g. in a radial direction) during their manufacture and/or assembly, such that at least some components are under compression when the rotor and fan assembly is at rest. For example, rotor magnets positioned on an outer surface of the shroud, the shroud, and/or the fan blades may be pre-loaded in compression. By pre-loading components of the rotor and fan assembly, a portion of the centrifugal forces generated during rotation of the rotor and fan assembly may be effectively ‘offset’ by relieving the pre-compressive stress, resulting in less net tensile stress on the rotor and fan assembly during high-speed operation.

[0009] In accordance with one broad aspect of this disclosure, there is provided an electric propulsion system for an aircraft, the system including: a nacelle of the aircraft defining a primary air flow path from an inlet end of the nacelle to an outlet end of the nacelle; and an electric machine including: a stator positioned in the nacelle and including one or more stator windings; and a rotor and fan assembly positioned in the primary flow path, the rotor and fan assembly including: a cylindrical fan shroud having a first end, a second end, an inner surface, and an outer surface; a plurality of rotor magnets directly positioned on the outer surface of the fan shroud and concentric with the one or more stator windings; a fan hub positioned concentrically interior of the fan shroud, the fan hub having a first end, a second end, an inner surface, an outer surface, and a fan axis of rotation, the fan hub being mounted on a central support shaft via one or more bearings; and a

plurality of fan blades extending between the inner surface of the fan shroud and the outer surface of the fan hub, wherein the plurality of fan blades are pre-stressed in a radial direction when the rotor and fan assembly is at rest.

[0010] In some embodiments, the plurality of rotor magnets are pre-stressed in a radial direction when the rotor and fan assembly is at rest.

[0011] In some embodiments, the rotor and fan assembly further comprises a sleeve for securing the plurality of rotor magnets to the cylindrical fan shroud.

[0012] In some embodiments, the sleeve is a compression sleeve that applies a compressive load to the plurality of rotor magnets.

[0013] In some embodiments, an outer end of each fan blade is secured directly to the inner surface of the fan shroud.

[0014] In some embodiments, the outer end of each fan blade is secured to the inner surface of the fan shroud via a dovetail joint.

[0015] In some embodiments, the plurality of fan blades are loaded in compression in a radial direction when the rotor and fan assembly is at rest.

[0016] In some embodiments, an inner end of each fan blade has a fan blade base, and further comprising at least one nut positioned between each fan blade base and the fan hub, wherein the at least one nut applies a compressive load in the radial direction to that fan blade.

[0017] In some embodiments, each fan blade base has a projecting feature on one side of the fan blade base and a complementary recess on an opposite side of the fan blade base for receiving the projecting feature of an adjacent fan blade base.

[0018] In some embodiments, the plurality of rotor magnets are positioned in a Halbach configuration.

[0019] In some embodiments, the one or more stator windings comprise polyphase fault tolerant windings.

[0020] In some embodiments, the polyphase windings comprise at least three phases.

[0021] In some embodiments, the system further comprises a plurality of guide vanes positioned in the primary air flow path downstream of the electric machine to promote redirection of circumferential air flow resulting from rotation of the rotor and fan assembly relative to the nacelle towards axial air flow.

[0022] In some embodiments, the plurality of guide vanes provide structural support for the central support shaft.

[0023] In some embodiments, the stator has an inner stator diameter and an axial stator length, and wherein the inner stator diameter is at least 4 times, at least 20 times greater, or at least 20 times greater than the axial stator length.

[0024] In some embodiments, the stator has an inner diameter, and further comprising a stator enclosure for housing the stator, the stator enclosure comprising: an annular casing positioned concentrically around the stator, the annular casing having a first end, a second end, an inner surface, and an outer surface, a casing diameter; a front stator face plate coupled to the first end of the annular casing, the front stator face plate having an inner diameter generally aligned with the inner diameter of the stator; and a rear stator face plate coupled to the second end of the annular casing, the rear stator face plate having an inner diameter generally aligned with the inner diameter of the stator.

[0025] In some embodiments, power electronics for the one or more stator windings are coupled to the annular casing.

[0026] In some embodiments, the annular casing and at least one of the front stator face plate and the rear stator face plate are integrally formed.

[0027] In some embodiments, a plurality of cooling fins are provided on a front surface of the front stator face plate.

[0028] In some embodiments, the system further comprises a plurality of condensers positioned around the stator enclosure.

[0029] In some embodiments, the system further comprises a plurality of air flow ducts, each of the air flow ducts positioned to direct air into an upstream end of one of the plurality of condensers.

[0030] In some embodiments, the system further comprises heat pipes in thermal communication with the plurality of condensers and with at least one of the one or more stator windings.

[0031] In some embodiments, the rotor and fan assembly further comprises a rotor cooling system.

[0032] In some embodiments, the rotor cooling system comprises at least one rotor heat pipe in thermal communication with each of the plurality of rotor magnets, each rotor heat pipe

being configured to promote oscillatory motion of fluid within that rotor heat pipe in response to a temperature difference between that rotor magnet and ambient air.

[0033] In some embodiments, wherein the cylindrical fan shroud has an axial shroud length, the plurality of fan blades has an axial blade length, and wherein the axial shroud length no more than 105% of the axial blade length.

[0034] In some embodiments, the rotor and fan assembly further comprises a nose cone coupled to the first end of the fan hub.

[0035] In some embodiments, the system further comprises a hub fairing positioned downstream of the rotor and fan assembly.

[0036] In some embodiments, the system further comprises a linear actuator coupled to the hub fairing, wherein the hub fairing may be selectively moved between an extended position in which at least a portion of the hub fairing is positioned in an exit nozzle of the nacelle, and a retracted position in which the hub fairing is proximate the fan hub.

[0037] In accordance with another broad aspect of this disclosure, there is provided an aircraft including a nacelle defining a primary air flow path from an inlet end of the nacelle to an outlet end of the nacelle; and an electric machine including: a stator positioned in the nacelle and including one or more stator windings; and a rotor and fan assembly positioned in the primary flow path, the rotor and fan assembly including: a cylindrical fan shroud having a first end, a second end, an inner surface, and an outer surface; a plurality of rotor magnets directly positioned on the outer surface of the fan shroud and concentric with the one or more stator windings; a fan hub positioned concentrically interior of the fan shroud, the fan hub having a first end, a second end, an inner surface, an outer surface, and a fan axis of rotation, the fan hub being mounted on a central support shaft via one or more bearings; and a plurality of fan blades extending between the fan shroud and the fan hub, wherein the plurality of fan blades are pre-stressed in a radial direction when the rotor and fan assembly is at rest.

[0038] It will be appreciated by a person skilled in the art that a method or apparatus disclosed herein may embody any one or more of the features contained herein and that the features may be used in any particular combination or sub-combination.

[0039] These and other aspects and features of various embodiments will be described in greater detail below.

CLAIMS:

1. An electric propulsion system for an aircraft, the system comprising:

a nacelle of the aircraft defining a primary air flow path from an inlet end of the nacelle to an outlet end of the nacelle; and

an electric machine comprising:

a stator positioned in the nacelle and comprising one or more stator windings; and

a rotor and fan assembly positioned in the primary flow path, the rotor and fan assembly comprising:

a cylindrical fan shroud having a first end, a second end, an inner surface, and an outer surface;

a plurality of rotor magnets directly positioned on the outer surface of the fan shroud and concentric with the one or more stator windings;

a fan hub positioned concentrically interior of the fan shroud, the fan hub having a first end, a second end, an inner surface, an outer surface, and a fan axis of rotation, the fan hub being mounted on a central support shaft via one or more bearings; and

a plurality of fan blades extending between the fan shroud and the fan hub, wherein the plurality of fan blades are pre-stressed in a radial direction when the rotor and fan assembly is at rest.

2. The system of claim 1, wherein the plurality of rotor magnets are loaded in compression in a radial direction when the rotor and fan assembly is at rest.

3. The system of claim 2, wherein the rotor and fan assembly further comprises a sleeve for securing the plurality of rotor magnets to the cylindrical fan shroud.

4. The system of claim 3, wherein the sleeve is a compression sleeve that applies a compressive load to the plurality of rotor magnets.

5. The system of claim 1, wherein an outer end of each fan blade is secured directly to the inner surface of the fan shroud.

~~6. The system of claim 5, wherein the outer end of each fan blade is secured to the inner surface of the fan shroud via a dovetail joint.~~

~~7. The system of claim 1, wherein the plurality of fan blades are pre-stressed in a radial direction when the rotor and fan assembly is at rest.~~

~~8~~6. The system of claim ~~7~~1, wherein an inner end of each fan blade has a fan blade base, and further comprising at least one nut positioned between each fan blade base and the fan hub, wherein the at least one nut applies a compressive load in the radial direction to that fan blade.

~~9~~7. The system of claim ~~8~~6, wherein each fan blade base has a projecting feature on one side of the fan blade base and a complementary recess on an opposite side of the fan blade base for receiving the projecting feature of an adjacent fan blade base.

~~10~~8. The system of claim 1, wherein the plurality of rotor magnets are positioned in a Halbach configuration.

~~11~~9. The system of claim 1, wherein the one or more stator windings comprise polyphase fault tolerant windings.

~~12~~10. The system of claim ~~11~~9, wherein the polyphase windings comprise at least three phases.

~~13~~11. The system of claim 1, further comprising a plurality of guide vanes positioned in the primary air flow path downstream of the electric machine to promote redirection of circumferential air flow resulting from rotation of the rotor and fan assembly relative to the nacelle towards axial air flow.

~~14~~12. The system of claim ~~13~~11, wherein the plurality of guide vanes provide structural support for the central support shaft.

~~15~~13. The system of claim 1, wherein the stator has an inner stator diameter and an axial stator length, and wherein the inner stator diameter is at least 4 times greater than the axial stator length.

~~16~~14. The system of claim ~~15~~13, wherein the inner stator diameter is at least 10 times greater than the axial stator length or at least 20 times greater than the axial stator length.

~~17~~15. The system of claim 1, wherein the stator has an inner diameter, and further comprising a stator enclosure for housing the stator, the stator enclosure comprising:

an annular casing positioned concentrically around the stator, the annular casing having a first end, a second end, an inner surface, and an outer surface, a casing diameter;

a front stator face plate coupled to the first end of the annular casing, the front stator face plate having an inner diameter generally aligned with the inner diameter of the stator; and

a rear stator face plate coupled to the second end of the annular casing, the rear stator face plate having an inner diameter generally aligned with the inner diameter of the stator.

~~18~~16. The system of claim ~~17~~15, wherein power electronics for the one or more stator windings are coupled to the annular casing.

~~19~~17. The system of claim ~~17~~15, wherein the annular casing and at least one of the front stator face plate and the rear stator face plate are integrally formed.

~~20~~18. The system of claim ~~17~~15, wherein a plurality of cooling fins are provided on a front surface of the front stator face plate.

~~21~~19. The system of claim ~~17~~15, further comprising a plurality of condensers positioned around the stator enclosure.

~~22~~20. The system of claim ~~21~~19, further comprising a plurality of air flow ducts, each of the air flow ducts positioned to direct air into an upstream end of one of the plurality of condensers.

~~23~~21. The system of claim ~~21~~19 or ~~22~~20, further comprising heat pipes in thermal communication with the plurality of condensers and with at least one of the one or more stator windings.

~~24~~22. The system of claim 1, wherein the rotor and fan assembly further comprises a rotor cooling system.

~~25~~23. The system of claim ~~24~~22, wherein the rotor cooling system comprises at least one rotor heat pipe in thermal communication with each of the plurality of rotor magnets, each rotor heat pipe being configured to promote oscillatory motion of fluid within that rotor heat pipe in response to a temperature difference between that rotor magnet and ambient air.

~~26~~24. The system of claim 1, wherein the rotor and fan assembly further comprises a nose cone coupled to the first end of the fan hub.

~~27~~25. The system of claim 1, further comprising a hub fairing positioned downstream of the rotor and fan assembly.

~~28~~26. The system of claim ~~27~~25, further comprising a linear actuator coupled to the hub fairing, wherein the hub fairing may be selectively moved between an extended position in which at least a portion of the hub fairing is positioned in an exit nozzle of the nacelle, and a retracted position in which the hub fairing is proximate the fan hub.

~~29~~27. An aircraft, comprising:

a nacelle defining a primary air flow path from an inlet end of the nacelle to an outlet end of the nacelle; and

an electric machine comprising:

a stator positioned in the nacelle and comprising one or more stator windings; and

a rotor and fan assembly positioned in the primary flow path, the rotor and fan assembly comprising:

a cylindrical fan shroud having a first end, a second end, an inner surface, and an outer surface;

a plurality of rotor magnets directly positioned on the outer surface of the fan shroud and concentric with the one or more stator windings;

a fan hub positioned concentrically interior of the fan shroud, the fan hub having a first end, a second end, an inner surface, an outer surface, and a fan axis of rotation, the fan hub being mounted on a central support shaft via one or more bearings; and

a plurality of fan blades extending between the fan shroud and the fan hub, wherein the plurality of fan blades are pre-stressed in a radial direction when the rotor and fan assembly is at rest.

~~30~~28. The system of claim ~~17~~15, wherein the nacelle when in operation substantially restricts air from the primary air flow path from contacting the stator.