Systems and methods for transporting and assembling segmented wind turbine blades are disclosed. A system in accordance with a particular embodiment includes multiple transport devices that are each moveable as a unit from a blade fabrication site to a blade assembly site, and that have corresponding carriers positioned to carry corresponding spanwise segments of a wind turbine blade. The system can still further include a guide structure carried by at least one of the transport devices and coupled to a corresponding one of the carriers, with a motion path aligned with a corresponding blade axis. The guide structure can be positioned to guide the corresponding carrier along the motion path toward the other transport devices, e.g., to facilitate assembly of the blade segments.
SYSTEMS AND METHODS FOR TRANSPORTING AND ASSEMBLING SEGMENTED WIND TURBINE BLADES

CROSS-REFERENCE TO RELATED APPLICATIONS


TECHNICAL FIELD

[0002] The present disclosure is directed generally to systems and methods for transporting and assembling segmented wind turbine blades, including wind turbine blades having multiple segments aligned along a spanwise axis.

BACKGROUND

[0003] As fossil fuels become scarcer and more expensive to extract and process, energy producers and users are becoming increasingly interested in other forms of energy. One such energy form that has recently seen a resurgence is wind energy. Wind energy is typically harvested by placing a multitude of wind turbines in geographical areas that tend to experience steady, moderate winds. Modern wind turbines typically include an electric generator connected to one or more wind-driven turbine blades, which rotate about a vertical axis or a horizontal axis.

[0004] In general, larger (e.g., longer) wind turbine blades produce energy more efficiently than do short blades. Accordingly, there is a desire in the wind turbine blade industry to make blades as long as possible. However, long blades create several challenges. Such blades are heavy and therefore have a significant amount of inertia, which can reduce the efficiency with which the blades produce energy, particularly at low wind conditions. In addition, long blades are difficult to manufacture and in many cases are also difficult to transport. Accordingly, there remains a need for large, efficient, lightweight wind turbine blades, and suitable methods for transporting and assembling such blades.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a partially schematic, isometric illustration of a wind turbine system having blades configured in accordance with an embodiment of the disclosure.

[0006] FIG. 2 is a partially schematic, elevation view of a wind turbine blade having a segmented structure in accordance with an embodiment of the disclosure.

[0007] FIG. 3 is a partially schematic, side elevation view of an arrangement of transport platforms for assembling segmented wind turbine blades in accordance with an embodiment of the disclosure.

[0008] FIG. 4 is a partially schematic, end isometric view of a guide structure having a support carrying a wind turbine blade segment for alignment and attachment in accordance with an embodiment of the disclosure.

[0009] FIG. 5 is an enlarged, partially schematic illustration of a portion of the support shown in FIG. 4.

[0010] FIG. 6A is an enlarged, partially schematic illustration of another portion of the support shown in FIG. 4.

[0011] FIG. 6B is an enlarged, partially schematic illustration of a portion of the support shown in FIG. 4 having a guide roller arrangement configured in accordance with another embodiment of the disclosure.

[0012] FIG. 7A is a partially schematic, isometric illustration of a guide structure having a motion device configured in accordance of an embodiment of the disclosure.

[0013] FIG. 7B is a partially schematic, isometric illustration of the guide structure shown in FIG. 7A with the carrier removed in accordance of an embodiment of the disclosure.

[0014] FIG. 8 is a partially schematic, side elevation view of the guide structure shown in FIG. 7A.

[0015] FIG. 9 is a partially schematic, isometric illustration of a support carrying a portion of a wind turbine blade segment in accordance with an embodiment of the disclosure.

[0016] FIG. 10A is a partially schematic, isometric illustration of a platform alignment system configured in accordance with an embodiment of the disclosure.

[0017] FIGS. 10B and 10C are partially schematic illustrations of transport platforms positioned in preparation for joining wind turbine blade segments in accordance with a particular embodiment of the disclosure.

[0018] FIG. 10D is a partially schematic, side elevation view of two opposing end portions of wind turbine blade segments positioned on adjacent transport platforms prior to assembly in accordance with an embodiment of the disclosure.

[0019] FIG. 11A is a partially schematic, side elevation view of a wind turbine blade spar having multiple portions, each with layers that terminate at staggered locations to form a non-monotonically varying bond line.

[0020] FIG. 11B is an illustration of an embodiment of the structure shown in FIG. 11A with clamps positioned to prevent or limit delamination in accordance with an embodiment of the disclosure.

[0021] FIG. 11C is an enlarged illustration of a portion of the spar shown in FIG. 6B.

[0022] FIG. 11D is a partially schematic, isometric view of two opposing end portions of a wind turbine blade spar prior to joining.

[0023] FIG. 11E is a partially schematic, isometric view of the two opposing spar end portions of FIG. 11D after joining, in accordance with an embodiment of the disclosure.

[0024] FIG. 12 is a partially schematic, isometric view of two opposing end portions of wind turbine blade segments prior to joining in accordance with an embodiment of the disclosure.

[0025] FIG. 13 illustrates an apparatus for applying heat and/or pressure to a bonded wind turbine blade spar joint in accordance with an embodiment of the disclosure.

[0026] FIGS. 14A-14F illustrate systems and methods for assembling and transporting wind turbine blades in accordance with further embodiments of the disclosure.

DETAILED DESCRIPTION

[0027] The present disclosure is directed generally to systems and methods for efficiently transporting and assembling wind turbine blade sections. Several details describing structures or processes that are well-known and often associated with such systems and methods, but that may unnecessarily obscure some significant aspects of the disclosure, are not set forth in the following description for purposes of brevity.
Moreover, although the following disclosure sets forth several embodiments, several other embodiments can have different configurations or different components than those described herein. In particular, other embodiments may have additional elements or may lack one or more of the elements described below with reference to FIGS. 1-14:

[0028] FIG. 1 is a partially schematic, isometric illustration of an assembled wind turbine system 100 that includes a wind turbine 103 having blades 110 configured in accordance with an embodiment of the disclosure. The wind turbine 103 includes a tower 101 (a portion of which is shown in FIG. 1), a housing or nacelle 102 carried at the top of the tower 101, and a generator 104 positioned within the housing 102. The generator 104 is connected to a shaft having a hub 105 that projects outside the housing 102. The blades 110 each include a hub attachment portion 112 at which the blades 110 are connected to the hub 105, and a tip 111 positioned radially or longitudinally outwardly from the hub 105. In an embodiment shown in FIG. 1, the wind turbine 103 includes three blades 110 connected to a horizontally-oriented shaft. Accordingly, each blade 110 is subjected to cyclically varying loads as it rotates between the 12:00, 3:00, 6:00 and 9:00 positions, because the effect of gravity is different at each position. In other embodiments, the wind turbine 103 can include other numbers of blades connected to a horizontally-oriented shaft, or the wind turbine 103 can have a shaft with a vertical or other orientation. In any of these embodiments, the blades 110 can have structures configured in accordance with the arrangements described in further detail below with reference to FIG. 2.

[0029] FIG. 2 is a partially schematic, partially cut-away illustration of one of the blades 110 shown in FIG. 1. The blade 110 extends outwardly in a radial direction from an inner region 113 that includes the hub attachment portion 112, to an outer region 114 that includes the tip 111. In particular embodiments, the internal structure of the blade 110 can be different at the inner region 113 than at the outer region 114. For example, the inner region 113 can include a truss structure 140 formed from a plurality of longitudinally extending beams or spars 170, chordwise extending ribs 142, and truss members 143 connected between the spars 170 and the ribs 142. The truss structure 140 can be surrounded by a skin 115 (most of which is removed in FIG. 2) that presents a smooth, aerodynamic surface to the wind during operation. The outer region 114 can include a non-truss structure. As used herein, the term “truss structure” refers generally to a load-bearing structure that includes generally straight, slender members forming closed shapes or units (e.g., triangular units). The term “non-truss structure” refers generally to a load-bearing structure having an arrangement that does not rely on, or does not primarily rely on, straight slender members forming closed-shape units for strength.

[0030] In a particular aspect of an embodiment shown in FIG. 2, the blade 110 includes three segments 116, shown as a first segment 116a, a second segment 116b, and a third segment 116c. The first and second segments 116a, 116b can each have the truss structure 140 described above, and the third segment 116c can have a non-truss structure. Accordingly, the blade 110 can have a truss structure for the inner two-thirds of its span, and a non-truss structure for the outer one-third of its span. In other embodiments, these values can be different, depending, for example, on the size, shape and/or other characteristics of the blade 110. In still further embodiments, the blade 110 can have other numbers and/or arrangements of segments. For example, the blade 110 can have a non-truss structure for the majority of the length of each segment 116, and a truss structure at the joints between neighboring sections. Further details of such an arrangement are described in co-pending U.S. Application No. _____, titled “Segmented Wind Turbine Blades with Truss Connection Regions, and Associated Systems and Methods,” filed concurrently herewith and incorporated herein by reference. The segments 116 can be manufactured individually at one or more sites, and then connected to each other at a manufacturing facility, or at an end user installation site. For example, the segments 116 can each be sized to be carried by a 53-foot or other suitably sized container, trailer, or other transport device for shipment, as will be described in further detail later. In other embodiments, one or more of the segments (e.g., the first segment 116a and the second segment 116b) can be built entirely at the installation site.

[0031] In any of the foregoing embodiments, individual segments 116 can include ribs 142, truss members 143, and portions of the spars 170 that extend for the length of the segment 116. The segments 116 can be joined to each other by joining adjacent spar portions, e.g., as discussed later with reference to FIGS. 11A-13, and connecting truss members 143 between the segments 116. In any of these embodiments, the skin 115 can be laid up on the truss structure 140 with or without forming a joint at the interface between adjacent segments 116. For example, the spar portions can be joined at a location between two neighboring ribs 142, and a relatively small panel of skin 115 can be laid over the spar joint and the two neighboring ribs 142. The neighboring ribs 142 can be spaced apart by about one meter in one embodiment, and by other values in other embodiments. Larger panels of the skin 115 can be laid inboard and outboard of the small panel. In another embodiment, the skin 115 can have joints not aligned with spar joints, or no spanwise joints, and can be laid up as a continuous element. In any of these embodiments, the skin 115 can be attached to the blade 110 (e.g., via ultrasound or otherwise) to the ribs 142 alone, or to the ribs 142 and the spars 170. In many of these embodiments, the truss structure 140 can serve as primary structure for carrying shear and bending loads in the blade 110. Further details of several embodiments of the blade 110 are described in co-pending PCT Application No. US09/660,757, filed Dec. 4, 2000, and incorporated herein by reference.

[0032] FIG. 3 is a partially schematic, side elevation view of an arrangement for transporting, aligning, and assembling the blade segments described above with reference to FIG. 2. In one aspect of this embodiment, the arrangement can include multiple transport platforms or devices 121. For example, the arrangement can include three such platforms, shown in FIG. 3 as a first transport platform 121a, a second transport platform 121b, and a third transport platform 121c. The transport platforms 121 can include truck-driven highway-compatible trailers, as shown in a particular embodiment illustrated in FIG. 3. In other embodiments, the transport platforms 121 can include other devices (e.g., railroad cars, containers, dollies, trolleys, carts, or barges). In any of these embodiments, each of the transport platforms 121 can carry corresponding blade segments 116, two of which (the first and third segments 116a, 116c) are shown in FIG. 3. The blade segments 116 can be assembled blade segments, e.g., at least partially assembled blade segments. Accordingly, the blade segments are approximately full length, though they may undergo additional assembly steps after arriving at a final
assembly site. One or more of the transport platforms 121 can carry a guide structure 122 (or portions of the guide structure 122) which is used to align the corresponding blade segments 116 with each other and move the corresponding blade segments 116 into position for joining. In a particular embodiment shown in FIG. 3, the guide structure 122 can include multiple supports 123 carried by one or more of the transport platforms 121. For example, each transport platform 121 can include two supports 123, one positioned at each end of a corresponding one of the blade segments 116. In general (e.g., except for the support 123 located at the hub attachment portion 112 of the first blade segment 116a), the supports 123 can be axially offset from the ends of the blade segments to which they are attached. Accordingly, neighboring blade segments can be moved toward each other for attachment. Each transport platform 121a, 121b, 121c can carry supports 123 that move corresponding blade segments along a corresponding axial motion path A1, A2, A3, respectively. Further details of this arrangement are described below with reference to FIGS. 4-10C and 14A-14F.

[0033] FIG. 4 is a partially schematic end view of the first blade segment 116a shown in FIG. 3, carried by two supports 123. Many of the following features are common to both supports 123, but are shown and described in the context of the near support 123 shown in FIG. 4. The support 123 can include a base 124 having one or more axial guides 152 (two are shown in FIG. 4). The support 123 can further include a first portion 126 carried by the base 124, and a second portion 127 carried by the first portion 126. The first portion 126 can be movable relative to the base 124 along a restricted axial guide path A1, and the second portion 127 can be movable relative to the first portion 126 along a restricted lateral guide path L1. Accordingly, the first portion 126 can include one or more lateral guides 128 (two are shown in FIG. 4) that facilitate the motion of the second portion 127 along the lateral guidance path L1. The second portion 127 in turn supports a carrier 180 that is releasably engaged with the first blade segment 116a. In a particular aspect of this embodiment, the carrier 180 includes two engagement portions 181, each of which is engaged with a flange 117 at the hub attachment portion 112 of the first blade segment 116a. The engagement portions 181 can be attached to the flange 117 with bolts, pins, or other suitable, releasable attachment devices. In any of these embodiments, the support 123 can facilitate both lateral and axial motion of the blade segment 116a, allowing it to be aligned with and then attached to a mating blade segment.

[0034] In a particular embodiment shown in FIG. 4, both of the supports 123 move along the same axial guidance path A1. In other embodiments, the supports 123 may be laterally offset from each other, and may accordingly move along different axial guide paths. In such cases, the two axial guide paths associated with a single blade segment may be parallel to prevent binding, and/or the associated supports may have a rotational degree of freedom. Such an embodiment may be used for blade segments such as the third blade segment 116c shown in FIG. 3 that have a significant amount of lateral or chordwise offset from one end of the segment to the other.

[0035] FIG. 5 is an enlarged isometric illustration of part of the support 123 shown in FIG. 4. As shown in FIG. 5, the second portion 127 of the support 123 includes multiple roller assemblies 150 (one of which is visible in FIG. 5) that facilitate the lateral motion of the second portion 127 along the lateral guides 128 carried by the first portion 126. The first portion 126 includes multiple roller assemblies 150 that facilitate axial motion of the first portion 126 along the axial guides 125 carried by the base 124. Each of the roller assemblies 150 can include a bracket 151 carrying one or more rollers, including a load roller 152. The load rollers 152 bear the weight (or a majority of the weight) of the structure to which they are attached, and transmit loads to the corresponding guide below. The roller assemblies 150 can also include guide rollers 153 described further below with reference to FIGS. 6A-6B.

[0036] Referring now to FIG. 6A, the roller assembly 150 can include multiple guide rollers 153 that engage with the corresponding guide along which the roller assembly 150 moves (e.g., the axial guide 125). In a particular aspect of this embodiment, the axial guide 125 can include a C-channel or I-beam, and the guide rollers 153 can engage an inner surface of the upwardly facing flanges of the axial guide 125. In other embodiments, other arrangements can be used to guide the motion of the first portion 126 relative to the base 124. For example, as shown in FIG. 6B, the guide rollers 153 can be positioned at the upper surfaces of the upwardly facing flanges of the axial guide 125. In any of these embodiments, the guide 125, 128 and the associated roller assemblies 150 are positioned to permit motion that is restricted or limited to be along only the axial guide path A1 and the lateral guide path L1, respectively.

[0037] FIG. 7A is a partially schematic, isometric illustration of an embodiment of the support 123 illustrating selected features in addition to those described above with reference to FIGS. 4-6B. In one aspect of this embodiment, the support 123 can include a carrier 780 having vertically upstanding members carrying engagement portions 781 positioned to engage laterally outwardly facing surfaces of a corresponding blade segment, as will be described further below with reference to FIG. 9. The support 123 can also include a motion device 160 that facilitates relative motion between the components of the support 123.

[0038] In an embodiment shown in FIG. 7A, the motion device 160 can facilitate motion of the components along three orthogonal axes. For example, the motion device 160 can include a base height adjuster 161 that moves the base 124 in a generally vertical direction relative to the transport platform 121, an axial motion actuator 162 that moves the first portion 126 relative to the base 124 along the axial guidance path A1, and a lateral motion actuator 163 that moves the second portion 127 relative to the first portion 126 along the lateral guidance path L1. The motion provided by the motion device 160 can be fully manual, fully powered, or a combination of the two. For example, the base height adjuster 161 can include multiple threaded studs 166 located around the base 124, which are manually rotated to adjust the height of the base 124 and/or adjust the planarity of the base 124. The axial motion actuator 162 can include a motor or other powered device carried by the base 124 and operated to couple the first portion 126 to drive the first portion 126 along the axial guides 125. The lateral motion actuator 163 can include a motor or other powered device carried by the first portion 126 and operatively coupled to the second portion 127 to drive it along the lateral guides 128. Accordingly, the motion device 160 can be used to move the carrier 780 to a position and orientation suitable for connecting the blade segment (not shown in FIG. 7A) with a neighboring blade segment.
[0039] In a particular embodiment, once the carrier 780 has the desired position, the resistance provided by the threads of the studs 166 can prevent the carrier 780 from changing its elevation. Optionally, the studs 166 can be further secured, e.g., with locknuts. Similarly, the resistance provided by the windings and/or internal gearing of the axial motion actuator 162 and the lateral motion actuator 163 can prevent the carrier 780 from moving out of the desired position in the lateral directions, respectively. In other embodiments, separate locking devices can be used for this purpose.

[0040] In any of the foregoing embodiments, the motion device 160 can also be automated. For example, the motion device 160 can include a processor (e.g., a computer-based controller), and an input device. An operator can input a desired location and/or orientation for the carrier 780, and the motion device 160 can automatically drive the carrier 780 to the desired location and/or orientation using one or more sensors (e.g., position sensors) in a closed loop arrangement. In still further embodiments, the actuators 162, 163 can be removable, so that they can be moved from one portion of a support 123 to another, or from one support 123 to another, thereby reducing the number of actuators required to position the blade segments.

[0041] As shown in FIG. 7B, the support 123 can be deliberately configured to allow particular elements to be rapidly assembled and disassembled during normal use. For example, the carrier 780 can be removed from rest of the support 123 during transit. In particular, the carrier 780 can be lifted away from second portion 127 (including the roller assemblies 150 engaged with the lateral guides 125), the first portion 126, and the base 124. The carrier 780 can then be placed on a transport platform without the roller assemblies 150 potentially allowing the carrier 780 to move. When the carrier 780 is to be moved relative to the transport platform prior to assembling the associated blade segments, the first portion 126, second portion 127 and base 124 can be slid under the carrier 780 as a unit to allow the carrier 780 to move.

[0042] FIG. 8 is a partially schematic, side elevation view of a portion of the support 123 shown in FIGS. 7A-7B, illustrating further details of a particular embodiment of the motion device 160. As shown in FIG. 8, the axial motion actuator 162 can be coupled to the first portion 126 with a drive link 164 that allows for motion in two opposing directions along the axial guides 125. In a particular aspect of this embodiment, the axial motion actuator 162 includes a rotary motor having a shaft connected to a drive sprocket 165a which drives a chain connected at one end to one side of the first portion 126. The opposite end of the chain is wrapped around a guide sprocket 165b and connected to the opposite end of the first portion 126. In other embodiments, the drive link 164 can include other devices, for example, a direct drive device. The lateral motion actuator 163 can be coupled to the second portion 127 with a similar drive link.

[0043] FIG. 9 is a partially schematic, isometric illustration of the support 123 releasably attached to the third blade segment 116c described above with reference to FIG. 2. In one aspect of this embodiment, the engagement portions 781 are attached directly to a corresponding rib 142 of the blade segment 116c. In another embodiment, the engagement portions 781 are attached to a structure carried by the rib 142, e.g., one of the truss attachment members described in co-pending PCT Application US09/66875, previously incorporated herein by reference. In any of these embodiments, the engagement portions 781 can be releasably attached to the third blade segment 116c with threaded fasteners or other suitable structures. Accordingly, a portion of the skin 115 overlying this portion of the blade segment 116c can be removed or omitted while the blade segment 116c is carried by the support 123. After the support 123 has been disconnected from the blade segment 116c during an assembly and installation process, the missing skin portion can be attached in place over the rib 142. Alternatively, the skin 115 can be removed over the rib 142, but can have one or more holes that receive the threaded fasteners. These holes can be filled after the support 123 has been disconnected.

[0044] As is also shown in FIG. 9, the supports 123 can be attached to the third blade segment 116c before the blade segment 116c is placed on a corresponding transport platform 121f. For example, the supports 123 can be placed on the transport platform 121f without the blade segment 116c. Thus, the supports 123 can be filled using forklift, overhead crane or other suitable device and then placed on the transport platform 121f while attached to the third blade segment 116c. In another embodiment, the supports 123 can first be placed on the transport platform 121f, and the third blade segment 116c can then be attached to the supports 123. Either of the foregoing arrangements can be used for any of the blade segments 116a-116c.

[0045] In a particular embodiment, the carrier 780 is detached from the second portion 127, the first portion 126 and the base 124 before the blade segment 116c is placed on the transport platform, as described above with reference to FIG. 7B. Accordingly, the carrier 780 can rest directly on the transport platform while the blade segment 116c is transported to the assembly site, without any motion along the axial motion path A3 or the lateral motion path L. When the transport platform reaches the final assembly site, the carrier 780 can be lifted while the rest of the support 123 is re-inserted below the carrier 780. The support 123 is then ready for positioning and alignment. In other embodiments, other arrangements can be used to restrict the carrier 780 from moving. For example, the roller assemblies 150 (FIG. 7B) can be locked or retracted during transit. An advantage of embodiments in which the base 124, first portion 126 and second portion 127 are removed as a unit is that this part of the support 123 can be modularized, and can be moved from one support 123 to another, thus reducing the number of such modular units required to position a set of blade segments.

[0046] FIG. 10A is a partially schematic, isometric illustration of a platform alignment system 190 used to align the three transport platforms 121a, 121b, 121c described above with reference to FIG. 3. For purposes of illustration, the guide structures 122 and blade segments 116 described above are not shown in FIG. 10A. In a particular aspect of the illustrated embodiment, the platform alignment system 190 can include one or more platform height adjustors 191. For example, the platform height adjustors 191 can include hydraulic cylinders, pneumatic cylinders, jack screws, or other devices positioned at one or more locations of each of the transport platforms 121 to adjust the height of the platforms, as well as the tilt of the platforms 121. The platform height adjustors 191 can be adjusted manually or automatically in response to an indication that the corresponding transport platforms 121 are not at an appropriate height or tilt orientation. To provide this input, the platform alignment system 190 can include an emitter 192 that emits radiation received by one or more receivers 193 located at the transport platforms 121. For example, the emitter 192 can include a laser that emits a laser beam and rotates to produce a laser
plane 194. The receiver 193 can include multiple receiver elements 195 carried by each of the transport platforms 121. In a particular embodiment, each transport platform 121 can include a receiver element 195 located at each corner of the transport platform 121. Accordingly, when the emitter 192 is activated, and produces the radiation plane 194 at a desired height and orientation (e.g., horizontal), the operator can adjust the platform 121, depending upon the desired orientation, to position the radiation plane 194 over multiple adjacent elements 195 of the receiver 193. In still further embodiments, the alignment system can include components that do not rely on emitting or receiving radiation for suitable operation.

[0048] As described above, the platform alignment system 190 can be used to align each of the transport platforms 121 relative to the others in a generally horizontal or other desired plane. In addition, each of the transport platforms 121 can be aligned axially. For example, each of the transport platforms 121a-121c can include a corresponding axial guide path A1-A3 along which the corresponding blade segment 116 is moved. In a particular embodiment, each of the axial guide paths A1-A3 is aligned along a common axis. In other embodiments, however, the guide paths may be angularly offset from each other depending upon the desired orientation of the plane at the interface between the neighboring blade segments. Also, as discussed above with reference to FIG. 4, the individual supports carried by each of the transport platforms 121 may move along different (though typically parallel) guide paths, depending upon the shape of the blade segment carried by the supports. In any of the foregoing embodiments, the platform 121a-121c may also be configured to align each of the axes A1-A3 relative to each other. In other embodiments, however, an operator can adequately align the axes A1-A3 visually. The blade segments carried by the platforms may be more finely aligned using the lateral motion actuators 163 described above.

[0049] FIGS. 103 and 10C illustrate the transport platform 121a-1c aligned to attach the corresponding blade segments 116a-116c. For purposes of illustration, the first and second blade segments 116a, 116b are shown in FIGS. 103 and 10C without the skins attached. The skins can be attached either before or after the blades are shipped to an assembly site via the transport platforms 121. As shown in FIGS. 103-10C, the first and second axial guide paths A1 and A2 are co-linear, and the third guide path A3 is offset due to the curvature of the blade 110. Once the transport platforms 121 are properly aligned with each other, the corresponding blade segments carried by the transport platforms 121 may be attached. In a particular embodiment in which more than two transport platforms 121 are used to carry the requisite number of blade segments, two blade segments may be connected to each other before adding additional segments. For example, the first and second segments 116a, 116b carried by the first and second transport platforms 121a, 121b, respectively can be connected to each other before connecting the third blade segment 116c carried by the third transport platform 121c to the assembled first and second segments. In such cases, all three transport platforms 121a-121c can be initially aligned with each other, and the connection between neighboring segments can be completed sequentially. In another embodiment, the first two transport platforms 121a-121b can be aligned with each other and the associated segments 116a, 116b connected, and then the third transport platform 121c can be aligned with the first two transport platforms 121a-121b while the third segment 116c connected to the assembled first and second segments. In such cases, the transport platforms 121 may be aligned in other manners, and/or the blade segments may be connected in other sequences.

[0050] FIG. 10D is a side elevation view of a portion of the first blade segment 116a and the second blade segment 116b positioned on corresponding first and second transport platforms 121a, 121b. As this view illustrates, each blade segment 116a, 116b includes multiple spars 170, e.g., a first spar 170a, a second spar 170b and a third spar 170c. Each spar 170 has a first end portion 171a at the first segment 116a and a second end portion 171b at the second segment 116b. The first end portions 171a of the first blade segment 116a are aligned with the corresponding second end portions 171b of the second blade segment 116b. In the configuration, the first and second blade segments 116a, 116b are ready to be joined together as described below with reference to FIGS. 11A-13.

[0051] FIG. 11A is a partially schematic, side elevation view of a joint between the first and second end portions 171a, 171b of a representative spar 170. The joint can be formed along a non-monotonically varying (e.g., zig-zagging) bond line 176. Such a bond line 176 is expected to produce a stronger bond between the first and second portions 171a, 171b than is a straight or diagonal bond line.

[0052] The first portion 171a can include multiple, stacked, laminated first layers 172a, and the second portion 171b can include multiple, stacked, laminated second layers 172b. In another embodiment, the layers 172a, 172b can be made in one piece without gluing. In a particular embodiment, the layers 172a, 172b can be formed from a unidirectional fiber material (e.g., fiberglass or a carbon fiber) and a corresponding resin. Each of the layers 172a, 172b can be formed from a single ply or multiple plies (e.g., six plies). The layers 172a, 172b can be prepared layers, hand lay-ups, preimpregnated, or can be formed using other techniques, e.g., vacuum-assisted transfer molding techniques. The first layers 172a terminate at first terminations 173a, and the second layers 172b terminate at second terminations 173b. Neighboring terminations 173a, 173b located at different positions along a thickness axis T can be staggered relative to each other along a span axis S to create the zig-zag bond line 176. This arrangement produces projections 174 and corresponding recesses 175 into which the projections 174 fit. In a particular aspect of this embodiment, each layer has a termination that is staggered relative to its neighbor, except where the bond line 176 changes direction. At such points, two adjacent layers can be terminated at the same location and bonded to each other, to prevent a single layer from being subjected to increased stress levels. The zig-zag bond line 176 can be symmetric, as shown in FIG. 11A, or asymmetric in other embodiments. In still further embodiments, the bond line 176 can be scarfed or can have a zig-zag shape in a direction transverse to the plane of FIG. 11A, as described further in PCT Application US09/66875, previously incorporated herein by reference.

[0053] During a representative manufacturing process, each of the first layers 172a are stacked, bonded and cured, as are each of the second layers 172b; while the two portions
171a, 171b are positioned apart from each other. The layers 172, 172a can be pre-cut before stacking so that when stacked, they form the recesses 175 and projections 174. After the two portions 171a, 171b have been cured, the recesses 175 and/or projections 174 can be coated and/or filled with an adhesive. The two portions 171a, 171b are then brought toward each other so that projections 174 of each portion are received in the corresponding recesses 175 of the other. The joint region can then be bonded and cured.

[0054] FIG. 11B is an illustration of a spar 170 having a bond line 176 generally similar to that described above with reference to FIG. 11A. As is also shown in FIG. 11B, the spar 170 can include one or more clamps or straps 177 that are positioned at or near the bond line 176. The clamps 177 can be positioned to prevent or halt delamination that might result between any of the layers in the composite spar 170. For example, as shown in FIG. 11C, if a potential delamination 178 begins between two layers 172a, the compressive force provided by the clamp 177 can prevent the delamination 178 from spreading further in a span-wise direction. The clamp 177 can be positioned where it is expected that the potential risk of delamination is high, e.g., at or near the termination 173 of the outermost layers 172a. 172b as shown in FIG. 11B. In other embodiments, the function provided by the clamps 177 can be provided by other structures, e.g., the truss attachment members described further in PCT Application WO09/66875, previously incorporated herein by reference.

[0055] FIG. 11D is an enlarged isometric view illustrating a third end portion 171c, and an opposing fourth end portion 171d of the second spar 170b (also shown in FIG. 10D) prior to being joined together. As described above with reference to FIG. 11A, the second spar 170b can be formed from a plurality of layers 172 (e.g., first layers 172a and second layers 172b). In the illustrated embodiment, the first layers 172a produce first projections 174a and corresponding first recesses 175a. Similarly, the second layers 172b produce second projections 174b and corresponding second recesses 175b. The corresponding projections 174 and recesses 175 form a staggered, zig-zag bond line between the opposing spar end portions 171c and 171d when they are subsequently joined together as illustrated in FIG. 11E.

[0056] FIG. 12 is an enlarged, partially schematic view illustrating a method of joining the first blade segment 116a to the second blade segment 116b in accordance with an embodiment of the disclosure. As this view illustrates, the opposing end portions 171 of the corresponding spars 170 are initially separated from each other but are axially aligned. Referring first to the second spar 170b, a first truss attachment member 150a on the first blade segment 116a can include a first lug or truss attachment portion 154a having a first aperture 120a. Similarly, the opposite second truss attachment member 150b on the second blade segment 116b can include a corresponding second truss attachment portion 154b having a second aperture 120b. Third and fourth truss attachment members 150c, 150d on the first spar 170a, and fifth and sixth truss attachment members 150e, 150f on the third spar 170c, can also include similar truss attachment portions having corresponding apertures.

[0057] To join the first blade segment 116a to the second blade segment 116b, a push/pull device 1210 (e.g., a manual or automatic spreader bar, come-along, hydraulic device, etc. that can pull objects together or push objects apart at a controlled rate and with sufficient force) is temporarily installed between the corresponding truss attachment portions 154a and 154b. More specifically, in the illustrated embodiment the push/pull device 1210 includes a first clevis 1212a on one end and a second clevis 1212b on the opposite end. The clevises 1212 are attached to the body of the push/pull device 1210 by threaded rods 1216 that can be drawn into the body of the push/pull device 1210 or extended out of the body of the push/pull device 1210 by appropriate operation of a manual actuator 1214 (e.g., a ratchet handle). Each of the clevises 1212 can be releasably attached to the corresponding truss attachment portion 154 by a temporary fastener 1218 (e.g., a bolt) that extends through the clevis 1212 and the corresponding aperture 1202. After the push/pull device 1210 has been coupled to the opposing truss attachment portions 154, the actuator 1214 can be moved up and down in the appropriate direction to ratchet the spar end portions 171c and 171d together and/or apart as desired.

[0058] To join the first blade segment 116a to the second blade segment 116b in accordance with one embodiment of the disclosure, a second push/pull device (not shown) is operably coupled between the third and fourth truss attachment members 150c, 150d on the first spar 170a, and a third push/pull device (also not shown) is operably coupled between the fifth and sixth truss attachment members 150e, 150f on the third spar 170c, as described above with reference to the second spar 170b. The spars 170 are then simultaneously pulled together by operation of the three push/pull devices 1210 to “dry fit” the end portions 171 and confirm that they are properly aligned. After this has been done, the push/pull devices 1210 are operated to separate the spar end portions 171 so that the end portions 171 can be suitably prepared for bonding as described in detail below.

[0059] Once the end portions 171 of the spars 170 have been fit checked as described above, the overlapping surfaces of the projections/recesses 174/175 (FIG. 10A) of the end portions 171 can be prepared for bonding. In a particular embodiment, the mating surfaces can be prepared for bonding by first sanding with an appropriate grade sandpaper, followed by a cleaning with acetone and/or a wipe with a lint-free cloth, followed by a wipe with isopropyl alcohol. A suitable adhesive (e.g., epoxy, polyurethane, methyl methacrylate, and/or other adhesive) can then be mixed and applied to the mating surfaces of the end portions 171. Enough adhesive is applied to the mating surfaces to adequately cover the zig-zag bond line. A localized or linear spacer made of suitable material can be laid on a surface of each spar 170 horizontal to the length of the spar. The end portions 171 of the spars 170 are then pulled together simultaneously by individual actuation of the, e.g., three, push/pull devices 1210. As the end portions 171 move together, adhesive that squeezes out of the joint can be wiped away. In another arrangement, the blade assembler can first draw these end portions 171 together, and then inject adhesive between overlapping projections and recesses, as is described further in pending U.S. patent application Ser. No. _____. titled “Segmented Wind Turbine Blades with Truss Connection Regions, and Associated Systems and Methods,” filed concurrently herewith and previously incorporated by reference. The overlapping end portions 171 can then be clamped together with a pressure enclosure tool as described in more detail below. After the end portions of the blade segments 116 have been suitably joined, the truss struts (e.g., truss struts 143) can be installed in the bay between the ribs 142 using, e.g., the apertures 1202 in the attachment members 150. After the diagonal truss struts have been attached to the blade
segments, the push/pull device(s) 1210 can be removed. The blade segments 116 can then be prepared for installation on the ribs 142.

[0060] FIG. 13 is a partially exploded, schematic isometric view of the joint between the first blade segment 116a and the second blade segment 116b illustrating an apparatus and method for clamping and curing the joint end portions 171 of the spars 170 in accordance with an embodiment of the disclosure. In FIG. 13, the push/pull device(s) 1210 have been removed for purposes of clarity, but those of ordinary skill in the art will understand that the push/pull device(s) 1210 can be left in place during the clamping and curing of the spar joints if desirable.

[0061] In the illustrated embodiment, a clamping assembly 1330 can include a clamping tool 1320 that includes at least two opposing plate portions 1321a, 1321b that clamp inwardly on the joint between the engaged spar end portions 171a, 171b. The clamping tool 1320 applies adequate pressure to the joint during the adhesive curing process. The clamping tool 1320 can include manually operable clamping devices (e.g., such as C-clamps) and/or automatic clamping devices, such as hydraulic clamps. In addition, a vacuum blanket or bag 1322 can be wrapped around the joint and evacuated to remove any air pockets from the adhesive bond line. Moreover, in one particular aspect of this embodiment, a heating element 1324 (e.g., an electro-thermal heating element) can also be positioned locally around the joint to ensure proper curing of the adhesive at a suitable temperature for a suitable period of time (e.g., 24 hours). In the other embodiments, the heating element 1324, the vacuum bag 1322, and/or the clamping tool 1320 can be omitted, and the bonded joint can be positioned in an autoclave or other suitable apparatus for elevating the temperature and/or pressure of the joint to ensure suitable curing of the adhesive. Although only a single clamping assembly 1330 is illustrated in FIG. 13 for purposes of clarity, it will be understood that similar or equivalent pressure enclosure tools can also be used to simultaneously cure the joints formed between the other end portions 171a, 171b, 171c, 171d associated with the first spar 170a and the third spar 170c. The methods and system described above for joining turbine blade spars together can also be used at the other blade segment joints.

[0062] In other embodiments the spar 170 can be joined using techniques other than those described above with reference to FIGS. 11A-11E, for example, those disclosed in PCT Application US09/66875, previously incorporated herein by reference. Still further techniques include, but are not limited to the use of fasteners, bolts arranged in multiple directions, shear connecting tension bolts, scarf joints, butt joints and laminated overlays.

[0063] The foregoing process can be used to connect the first and second blade segments, and then to connect the second and third blade segments. The order in which the process steps are completed can be changed in other embodiments. For example, the second and third segments can be attached to each other first, and then the first segment can be attached to the second segment. Once the spars 170 of adjacent blade segments are connected, a section of skin 115 (FIG. 2) is laid up or otherwise positioned on the joint to form a smooth continuous skin from one blade segment to the next. The completed blade may then be attached to a crane or other suitable structure for lifting the blade, and each of the now-attached segments can be decoupled from the corresponding supports 123 shown in FIG. 10D. If necessary, the blade skin can be patched or otherwise treated to seal any temporary holes or openings necessitated by the temporary connection to the supports 123. Once the blade is finished, it can be lifted from the platforms and attached to the hub 105 shown in FIG. 1. In another embodiment, the completed blade can be removed from the assembly site to the wind turbine via one of the transport devices described above, or via a different transport device, as described further below with reference to FIGS. 14A-14F.

[0064] FIGS. 14A-14F illustrate systems and methods for moving and assembling wind turbine blade segments in accordance with further embodiments of the disclosure. Referring first to FIG. 14A, multiple blade segments may be carried by a single transport device. For example, FIG. 14A illustrates a first transport device 1421a (rig generally similar to those described above) having a first carrier 1480a that simultaneously supports multiple blade segments. In a particular embodiment shown in FIG. 14A, the multiple blade segments include one second blade segment 116b, and two third blade segments 116c. The first carrier 1480a can include two fixture elements 1481 that hold the blade segments in a fixed position relative to the first transport device 1421a.

[0065] FIG. 14A also illustrates another first carrier 1480a that supports two second blade segments 116b and one third blade segment 116c, in position for transport by a first transport device 1421a. FIG. 14A still further illustrates additional first carriers 1480a, each of which supports one first blade segment 116a. In a particular embodiment, the first blade segments 116a are too large to allow multiple blade segments to be carried on the same first transport device 1421a. Accordingly, each first blade segment 116a is transported individually. The first carriers 1480a positioned to carry the first blade segments 116a can include a corresponding fixture element 1481 and an adjustment element 1482. The adjustment element 1482 allows the first blade segment 116a to be rotated off-axis, as shown in FIG. 14A, so that it will fit under highway overpasses. The fixture element 1481 holds the blade in this rotated configuration. Using the arrangement above, five first transport devices 1421a can be used to transport all nine blade segments used for a three-blade turbine.

[0066] In FIG. 14B, the first blade segment 116a has been removed from the first transport device 1421a. An operator has rotated the first blade segment 116a (as indicated by arrow R) under the guidance and control of the adjustment element 1482, so that the blade now has a vertical position. A new fixture element 1481 is then positioned beneath the first blade segment 116a to support it in this new orientation.

[0067] Referring next to FIG. 14C, the second blade segment 116b has been removed from the first transport device 1421a (FIG. 14A) and placed on the second transport device 1421b. The second transport device 1421b can include a chassis 1422 carrying a positioning unit 1423. The positioning unit 1423 can include multiple wheels 1424 (e.g., four castor-type wheels are shown in FIG. 14C) outfitted with large, all-terrain tires 1425. Accordingly, the second transport device 1421b can be rolled along the ground at an assembly site that has unpaved, unimproved or only rudimentarily improved surfaces. The second transport device 1421b can further include a second carrier 1480b that supports the second blade segment 116b. The second carrier 1480b can include multiple upwardly projecting support members 1483, each of which carries an engagement member 1484. In a particular embodiment, the individual engagement members
1484 include straps or other flexible tension elements having attachment features 1485 (e.g., clips, hooks, buckles, or other suitable arrangements) that are releasably attached to the second blade segment 116b. The engagement members 1484 are attached to the corresponding support members 1483 with an adjustable arrangement, e.g., a releasable ratchet device.

[0068] In operation, an operator can adjust the axial position, lateral position, and yaw angle of the second blade segment 116b by rolling the second transport device 1480b appropriately. The operator can adjust the vertical position of the second blade segment 116b by adjusting each of the engagement members 1484 (e.g., by the same amount). The operator can adjust a rotation angle R1 (e.g., a roll angle) of the second blade segment 116b relative to a first axis A1 by adjusting the engagement members 1484 on one side of the first axis A1 by a different amount than the engagement members 1484 on the other side of the first axis A1. The operator can adjust a transverse rotation angle R2 (e.g., a pitch angle) of the second blade segment 116b relative to a second (transverse) axis A2 by adjusting fore and aft engagement members 1484 by different amounts. When the second blade segment 116b has the proper position relative to the first blade segment 116a, the operator can roll the second transport device 1421b toward the first blade segment 116a as indicated by arrow T1 to align the ends of the spars 170b-170c carried by each of the first and second blade segment 116a, 116b. The foregoing operations can be completed manually, or via powered drivers (e.g., motors) or other devices.

[0069] In FIG. 14D, the second transport device 1421b has been removed, and the second blade segment 116b is now supported by fixtures 1481 that carry the second blade segment 116b in the proper position at the assembly site. The second blade segment 116b has been attached to the first blade segment 116a by connecting the ends of the corresponding spars 170b-170c; adding a rib 142, and adding truss members 143 at the connection location. Further details of an arrangement for carrying out this process are disclosed in pending U.S. application Ser. No. ____, titled “Segmented Wind Turbine Blades with Truss Connection Regions, and Associated Systems and Methods,” and previously incorporated herein by reference.

[0070] In FIG. 14E, a process generally similar to that described above with reference to FIGS. 14C and 14D is conducted to attach the third blade segment 116c to the second blade segment 116b. As discussed above, the overall blade 110 may be curved so that the axes along which the second and third blade segments 116b, 116c are attached may be different than the axes along which the first and second blade segments 116a, 116b are attached. Because the second transport device 1480b is easily movable, the operator can use the same or a generally similar second transport device 1480b to move the third blade segment 116c toward the second blade segment 116b. Accordingly, the operator can adjust the vertical position of the third blade segment 116c, as well as a rotation angle R3 relative to a third (longitudinal) axis A3, and a rotation angle R4 relative to a fourth (transverse) axis A4. The operator can then move the third blade segment 116c via the second transport device 1480b toward the second blade segment 116b, as indicated by arrow T3, and connect the two segments 116b, 116c using any of the techniques described above.

[0071] FIG. 14F illustrates the assembled blade 110, with a tip section 116d attached to the third blade segment 116c. In a particular embodiment, the assembled blade 110 can now be repositioned on the first transport device 1421a with a significant portion of the blade 110 overlapping the first transport device 1421a. While this arrangement would not be suitable for transporting the blade over typical highways, it can be used to transport the blade 110 from an assembly site (e.g., located at a wind farm) to a particular wind turbine (also located at the wind farm). Accordingly, the first transport device 1421a can be driven at very low speed over improved or unimproved roads (e.g., at the wind farm) having gradual curvatures, without damaging the wind turbine blade 110 or structures along the way. Typically, the transport distances and speeds associated with moving the assembled blade from the assembly site to the wind turbine will be less (e.g., significantly less) than the distances and speeds associated with transporting the individual blade segments to the assembly site.

[0072] One feature of an embodiment described above with reference to FIGS. 14A-14F is that the blade segments 116 can be assembled at an unimproved assembly site (which may be typical at a wind farm) without impacting the accuracy which with the blade segments 116 are attached. This process can be conducted economically by using fewer first transport devices 1480a to transport the blade segments 116 to the site, and/or by using a single second transport device 1480b to sequentially assemble multiple blade segments. Still another feature of at least some of the foregoing embodiments is that the assembled blade can be transported from the assembly site to the wind turbine using a standard first transport device 1480a (e.g., an over-the-highway tractor-trailer rig), even though the assembled blade 110 is over-length (by 50%, 60%, 70%, or another significant amount), and even though the road between the assembly site and the wind turbine may not be up to the standards of a typical highway.

[0073] Another feature of several of the foregoing embodiments is that the blade segments can be easily transported from one or more manufacturing facilities to an installation site using conventional transport systems e.g., highway trucks, trains, or barges. Because the blade is segmented, it is easier to transport than it would be if it were completely assembled at the manufacturing site. In addition, the transport platforms can include guide structures that accurately align each of the blade segments relative to neighboring segments to facilitate accurate and repeatable assembly techniques. This in turn can produce more uniform blades, despite the fact that the blades are segmented. As a result, the blades can operate more efficiently when installed on corresponding wind turbines, and can reduce maintenance costs over the life-time of the blades.

[0074] From the foregoing, it will be appreciated that specific embodiments have been described herein for purposes of illustration, but that various modifications may be made without deviating from the present disclosure. For example, the guide structures described above may have arrangements other than nested portions that are each movable along a single axis. The guide structures may include features other than rollers to control the motion of the supports relative to each other. In another embodiment, the guide structure can be configured to facilitate restricted rotational motion, in addition to restricted linear motion. The supports can have other arrangements, including arrangements in which the supports extend above the blade and straddle the blade, with the blade supported (e.g., suspended) from above. In still further embodiments, not all the transport platforms 121 provide axial motion for the corresponding blade segment. For
example, the second blade segment 116b can have a fixed axial position relative to the second transport platform 121b, and the first and third segments 116a, 116c can move toward opposing ends of the centrally located second segment 116b. While FIG. 3 illustrates two supports 123 for each blade segment, in other embodiments, the guide structure 122 can include other arrangements, including a single support 123 at each transport platform 121, or more than two supports 123 at each transport platform 121. The wind turbine blades can have structures other than those expressly disclosed herein, but can still be transported, aligned and/or assembled using the systems and methods described above. For example, in other embodiments these methods and systems can be used to join turbine blades that extend in opposing directions. In still further embodiments, these methods and systems can be used to join leading or trailing edge members together, or to join portions of a segmented root together.

Certain aspects of the disclosure described above in the context of particular embodiments may be combined or eliminated in other embodiments. For example, the motorized or otherwise powered actuators described in the context of providing lateral and axial motion may be applied to vertical motion in particular embodiments. The carriers and guide structures described in the context of the first transport devices 121. 1421a may be combined with the second transport device 1421b in particular embodiments. Further, while advantages associated with certain embodiments have been described in the context of those embodiments, other embodiments may also exhibit such advantages. Not all advantages need necessarily exhibit such advantages to follow within the scope of the present disclosure. Accordingly, the disclosure and associated technology can encompass other embodiments not expressly shown or described herein.

I/we claim:

1. A system for assembling spanwise segments of a wind turbine blade, comprising:
   a first transport device being moveable as a unit from a blade fabrication site to a blade assembly site, the first transport device having a first carrier positioned to carry a first spanwise segment of a wind turbine blade with the first segment aligned along a first blade axis;
   a second transport device being moveable as a unit from a blade fabrication site to the blade assembly site, the second transport device having a second carrier positioned to carry a second spanwise segment of a wind turbine blade with the second segment aligned along a second blade axis; and
   a guide structure carried by at least one of the first and second transport devices, the guide structure being comprised between the at least one transport device and a corresponding one of the carriers, the guide structure having a motion path aligned with a corresponding one of the first and second blade axes, the guide structure being positioned to guide the corresponding carrier along the motion path toward the other of the first and second transport devices.

2. The system of claim 1 wherein the guide structure is positioned to guide the corresponding carrier in a linear manner.

3. The system of claim 1 wherein the first and second transport devices are wheeled.

4. The system of claim 3 wherein the first and second transport devices include corresponding highway truck trailers.

5. The system of claim 1, further comprising a drive mechanism carried by at least one of the first and second transport devices, the drive mechanism being positioned to drive at least one of the first and second carriers relative to the other along the guide path.

6. The system of claim 1 wherein the guide structure includes a base portion carried by the first transport device, a first portion carried by the base portion and movable relative to the base portion along a restricted first motion path, and a second portion carried by the first portion and movable relative to the first portion along a restricted second motion path, transverse to the first motion path.

7. The system of claim 6 wherein the first portion includes a roller assembly that is moveable relative to the first portion and that is releasably engaged with the first carrier.

8. The system of claim 6 wherein the first portion includes a first roller assembly that is engaged with the base and rollable relative to the base along the first motion path, and wherein the second portion includes a second roller assembly that is engaged with the first portion and rollable relative to the first portion along the second motion path.

9. The system of claim 6, further comprising:
   a first driver operatively coupled between the base and the first portion to move the first portion relative to the base; and
   a second driver operatively coupled between the first portion and the second portion to move the second portion relative to the first portion.

10. The system of claim 6 wherein the base includes an axial guide, and wherein the first portion includes a roller assembly, and wherein the roller assembly includes a first, load-bearing roller positioned to rotate about a generally horizontal axis, and a second, guide roller positioned to rotate about a non-horizontal axis.

11. The system of claim 6 wherein the guide structure is a first guide structure positioned between the first transport device and the first carrier, the first carrier being moveable along the first blade axis, and wherein the system further comprises a second guide structure positioned between the second transport device and the second carrier, the second carrier being moveable along the second blade axis.

12. The system of claim 1, further comprising:
   a driver device operatively coupled to the guide structure to move the corresponding carrier along the motion path; a sensor positioned to sense a location of the carrier; and a controller operatively coupled to the driver device and the sensor, the controller being programmed with instructions that, when executed, automatically activate the driver to move the carrier in response to a signal received from the sensor.

13. A system for assembling spanwise segments of a wind turbine blade, comprising:
   a transport device;
   an all-terrain positioning unit depending from the transport device and activatable to move the transport device along a first axis;
   a carrier supported by the transport device, the carrier being positioned to support a spanwise-extending wind turbine blade segment; and
   multiple engagement members depending from the carrier, with individual engagement members releasably connectable to the blade segment, and movable relative to the carrier to adjust a vertical position of the blade segment, a first rotation angle of the blade segment relative
to the first axis, and a second rotation angle of the blade relative to a second axis transverse to the first axis.

14. The system of claim 13 wherein the positioning unit includes four all-terrain tires.

15. The system of claim 13 wherein the multiple engagement members include four engagement members, and wherein individual engagement members include a flexible tension member.

16. The system of claim 13 wherein the carrier includes multiple upright support members, and wherein the multiple engagement members include four engagement members, and wherein each engagement member includes a flexible strap having an adjustable length portion between the carrier and the blade segment.

17. A method for assembling spanwise segments of a wind turbine blade, comprising:
transporting a first assembled spanwise segment of a wind turbine blade as a unit from a blade fabrication site to a blade assembly site while the first blade segment is carried by a first transport device;
transporting a second assembled spanwise segment of a wind turbine blade as a unit from a blade fabrication site to the blade assembly site while the second blade segment is carried by a second transport device;
at the blade assembly site, moving at least one of the first and second blade segments relative to the other along a restricted guide path, while the first blade segment is carried by the first transport device and the second blade segment is carried by the second transport device;
connecting the first and second blade segments to each other while the first blade segment is carried by the first transport device and the segment blade section is carried by the second transport device;
separating the connected first and second blade segments from the first and second transport devices; and
mounting the first and second blade segments as a unit to a wind turbine.

18. The method of claim 17 wherein separating the first and second blade segments from the first and second transport devices includes:
disengaging the second blade segment from the second transport device while the connected first and second blade segments are carried by the first transport device;
carrying the connected first and second blade segments from the assembly site to the wind turbine with the first transport device; and
removing the connected first and second blade segments as a unit from the first transport device.

19. The method of claim 17 wherein transporting the first assembled spanwise segment of the wind turbine blade includes transporting the first segment via a first over-the-road truck-drawn trailer, and wherein transporting the second assembled spanwise segment of the wind turbine blade includes transporting the second segment via a second over-the-road truck-drawn trailer.

20. The method of claim 17, further comprising moving at least one of the first and second blade segments relative to the corresponding transport device and relative to the other blade segment at the assembly site prior to connecting the first and second blade segments.

21. The method of claim 20 wherein moving at least one of the first and second blade segments relative to the other includes moving the at least one blade segment along a linear axis while restricting or preventing motion of the at least one blade segment transverse to the linear axis.

22. The method of claim 20 wherein moving at least one of the first and second blade segments relative to the other includes moving the at least one blade segment along motion path that includes components in two orthogonal directions.

23. The method of claim 20 wherein moving at least one of the first and second blade segments relative to the other includes connecting a pulling device between the first and second blade segments and drawing the at least one blade segment toward the other with the pulling device.

24. The method of claim 17 wherein transporting the first assembled spanwise segment includes transporting the first assembled spanwise segment with a carrier while the carrier has a fixed position relative to the first transport device, and wherein the method further comprises removably positioning a guide structure between the carrier and the first transport device prior to moving the first blade segment, and wherein moving at least one of the first and second blade segments relative to the other along a restricted guide path includes moving the first blade segment along a restricted guide path established by the guide structure.

25. The method of claim 17 wherein carrying the first blade segment includes carrying multiple assembled blade segments with the first transport device.

26. The method of claim 17 wherein transporting a first assembled spanwise segment of a wind turbine blade includes transporting the first segment from a first fabrication site, and wherein transporting a second assembled spanwise segment of a wind turbine blade includes transporting the second segment from a second fabrication site.

27. A method for assembling spanwise segments of a wind turbine blade, comprising:
transporting a first assembled spanwise segment of a wind turbine blade as a unit on a surface road from a blade fabrication site to a blade assembly site while the first blade segment is supported by a first carrier that is in turn supported by a first truck-drawn trailer;
transporting a second assembled spanwise segment of a wind turbine blade as a unit on a surface road from a blade fabrication site to the blade assembly site while the second blade segment is supported by a second carrier that is in turn supported by a second truck-drawn trailer;
transporting a third assembled spanwise segment of a wind turbine blade as a unit on a surface road from a blade fabrication site to the blade assembly site while the third blade segment is supported by a third carrier that is in turn supported by a third truck-drawn trailer;
at the assembly site, aligning the first and second truck-drawn trailers relative to each other, while the first blade section is carried by the first truck-drawn trailer and the second blade section is carried by the second truck-drawn trailer;
at the assembly site, aligning the first and second carriers relative to each other, while the first blade section is carried by the first truck-drawn trailer and the second blade section is carried by the second truck-drawn trailer;
moving at least one of the first and second carriers relative to the other along a restricted motion path to position the first and second spanwise segments adjacent to each other;
connecting the first and second blade segments to each other while the first blade segment is carried by the first
truck-drawn trailer and the second blade segment is carried by the second truck-drawn trailer; moving at least one of the second and third carriers relative to the other along a restricted motion path to position the second and third spanwise segments adjacent to each other; connecting the second and third blade segments to each other while the second blade segment is carried by the second truck-drawn trailer and the third blade segment is carried by the third truck-drawn trailer; removing the first, second and third blade segments from the first, second and third truck-drawn trailers; and mounting the first, second and third blade segments as a unit to a wind turbine.

28. The method of claim 27 wherein connecting the first and second blade segments includes aligning a first spar end portion of the first blade segment with a second spar end portion of the second blade segment; aligning a third spar end portion of the first blade segment with a fourth spar end portion of the second blade segment; and moving the first spar end portion toward the second spar end portion and the third spar end portion toward the fourth spar end portion to connect the first spar end portion to the second spar end portion and connect the third spar end portion to the fourth spar end portion.

29. The method of claim 28 wherein the first and second end spar portions include staggered layers of material that form a non-monotonically varying bond line when the two end spar portions are connected.

30. The method of claim 28, further comprising temporarily coupling a compressive device between the first spanwise segment and the second spanwise segment, wherein moving the first spar end portion toward the second spar end portion and the third spar end portion toward the fourth spar end portion includes actuating the compressing device to draw the first spanwise segment and the second spanwise segment together.

31. A method for assembling spanwise segments of a wind turbine blade, comprising: transporting a first assembled spanwise segment of a wind turbine blade as a unit to a blade assembly site; transporting a second assembled spanwise segment of a wind turbine blade as a unit to the blade assembly site; at the assembly site, connecting the first and second segments to each other; carrying the first and second segments with a transport device; transporting the connected first and second segments as a unit from the assembly site to a wind turbine, with the transport device; removing the connected first and second segments, as a unit, from the transport device; and installing the connected first and second segments, as a unit, to the wind turbine.

32. The method of claim 31 wherein transporting a first segment includes transporting the first segment while the first segment is carried by a first transport device, and wherein transporting a second segment includes transporting the second segment while the second segment is carried by a second transport device, and wherein connecting the first and second segments includes connecting the first and second segments while the first segment is carried by the first transport device and the second segment is carried by the second transport device, and wherein transporting the connected first and second segments includes transporting the connected first and second segments with the first transport device and not the second transport device.

33. The method of claim 31 wherein transporting a first segment includes transporting the first segment over a first distance and at a first average rate, and wherein transporting the second segment includes transporting the second segment over a second distance and at a second average rate, and wherein transporting the connected first and second segments includes transporting the connected first and second segments over a third distance less than each of the first and second distances, and at a third average rate less than each of the first and second average rates.

34. The method of claim 31 wherein the connected first and second segments have a connected segment length, and wherein transporting the connected first and second segments as a unit includes transporting the connected first and second segments with at least 50% of the connected segment length cantilevered relative to the first transport device.

35. A method for assembling spanwise segments of a wind turbine blade, comprising: transporting a first assembled spanwise segment of a wind turbine blade as a unit to a blade assembly site; transporting a second assembled spanwise segment of the wind turbine blade as a unit to the blade assembly site; carrying at least the second segment with a transport device at the assembly site; rolling the transport device over rough terrain at the assembly site to position the second segment adjacent to the first segment; connecting the first and second segments to each other at the assembly site; installing the connected first and second segments, as a unit, on a wind turbine.

36. The method of claim 35, further comprising transporting the connected first and second segments as a unit from the assembly site to the wind turbine.

37. The method of claim 35 wherein carrying the second segment includes supporting the second segment at four different locations with four independently adjustable engagement members; wherein rolling the transport device includes rolling the transport device over unpaved terrain to adjust an axial position, lateral position, and yaw angle of the second segment; and wherein the method further comprises: adjusting the engagement members to adjust a height of the second segment; adjusting the engagement members to adjust a pitch angle of the second segment relative to the ground; and adjusting the engagement members to adjust a roll angle of the second segment relative to the ground.

38. The method of claim 35 wherein carrying the second blade segment includes suspending the second blade segment from four independently adjustable engagement members.