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Goossen et al.

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- (54) **TRANSFORMING UNMANNED AERIAL-TO-GROUND VEHICLE**
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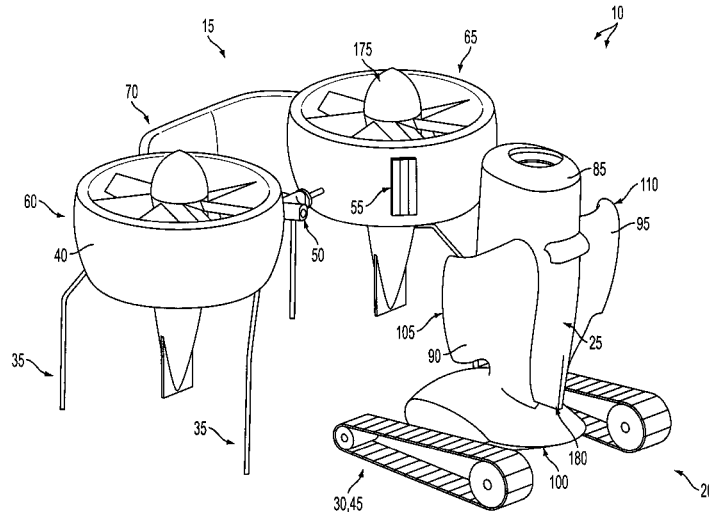
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- (57) **ABSTRACT**

A transforming unmanned aerial-to-ground vehicle assembly comprising: an aerodynamic flying assembly comprising an unmanned aerial vehicle integrated with an unmanned ground vehicle, a power unit shared by the unmanned aerial vehicle and the unmanned ground vehicle, vehicle controls shared by the unmanned aerial vehicle and the unmanned ground vehicle, a disengagement mechanism to separate the unmanned ground vehicle from the unmanned aerial vehicle, one or more manipulator arms located on either the unmanned aerial vehicle or the unmanned ground vehicle, and landing gear.

20 Claims, 6 Drawing Sheets



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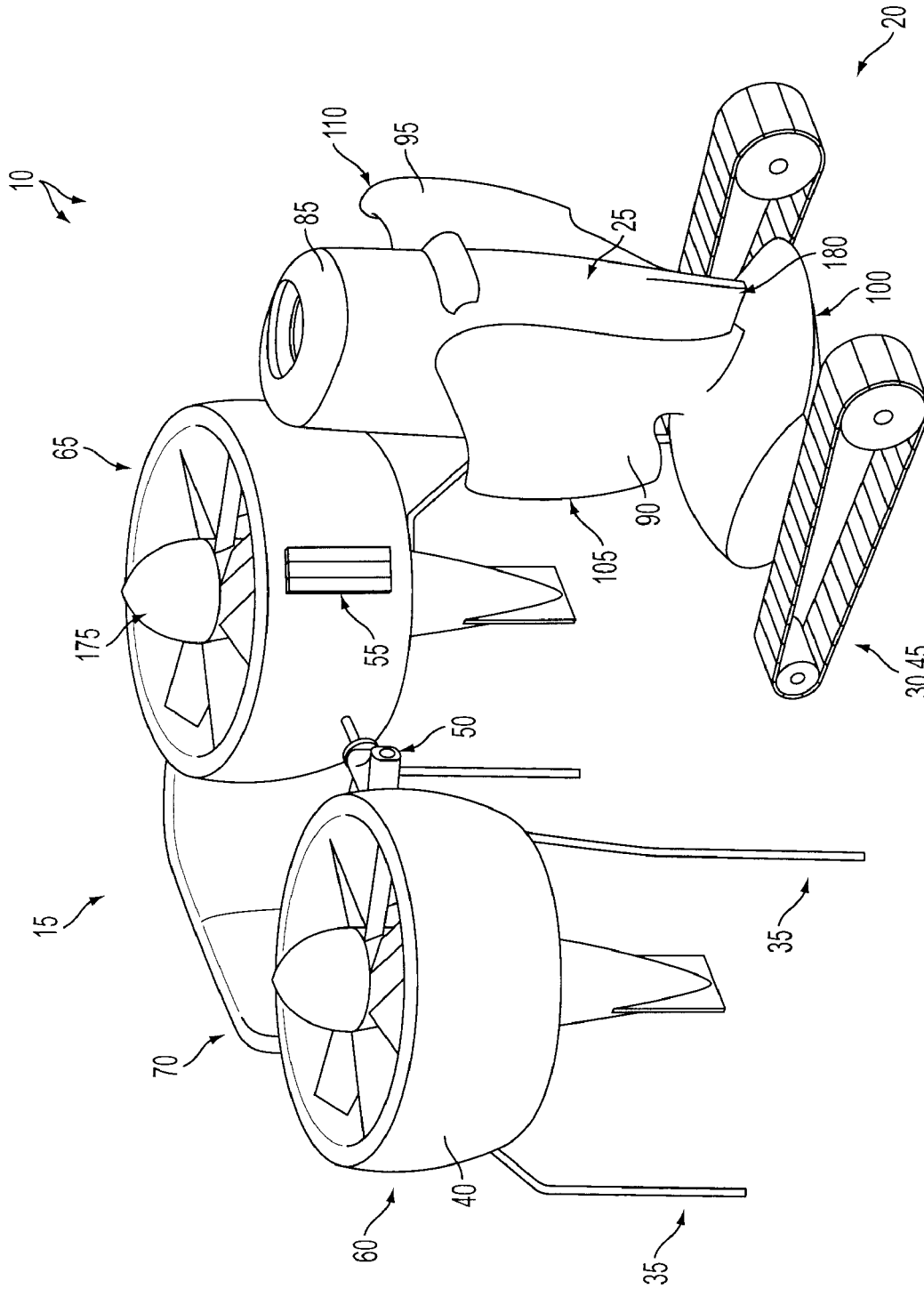


FIG. 1

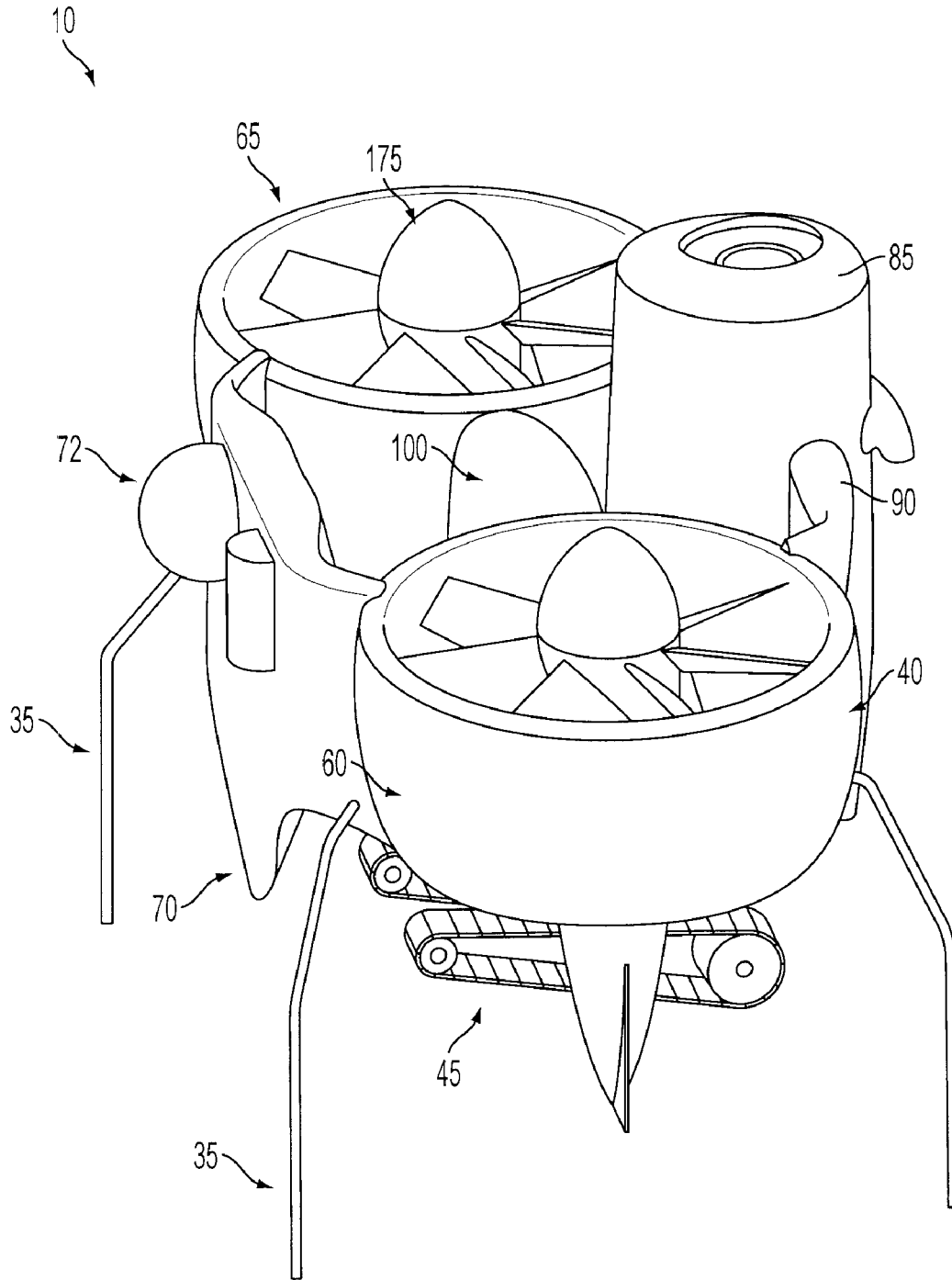


FIG. 2

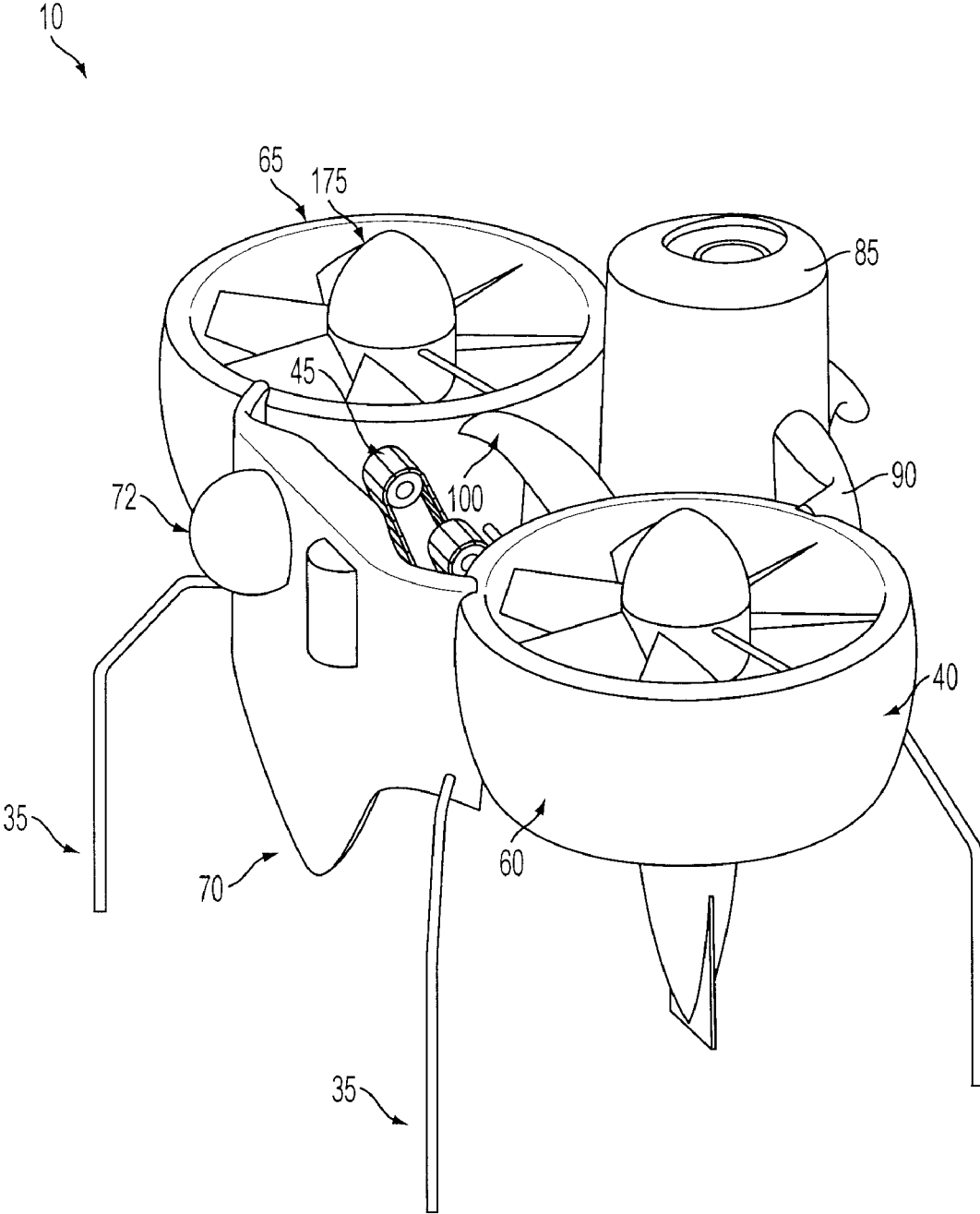


FIG. 3

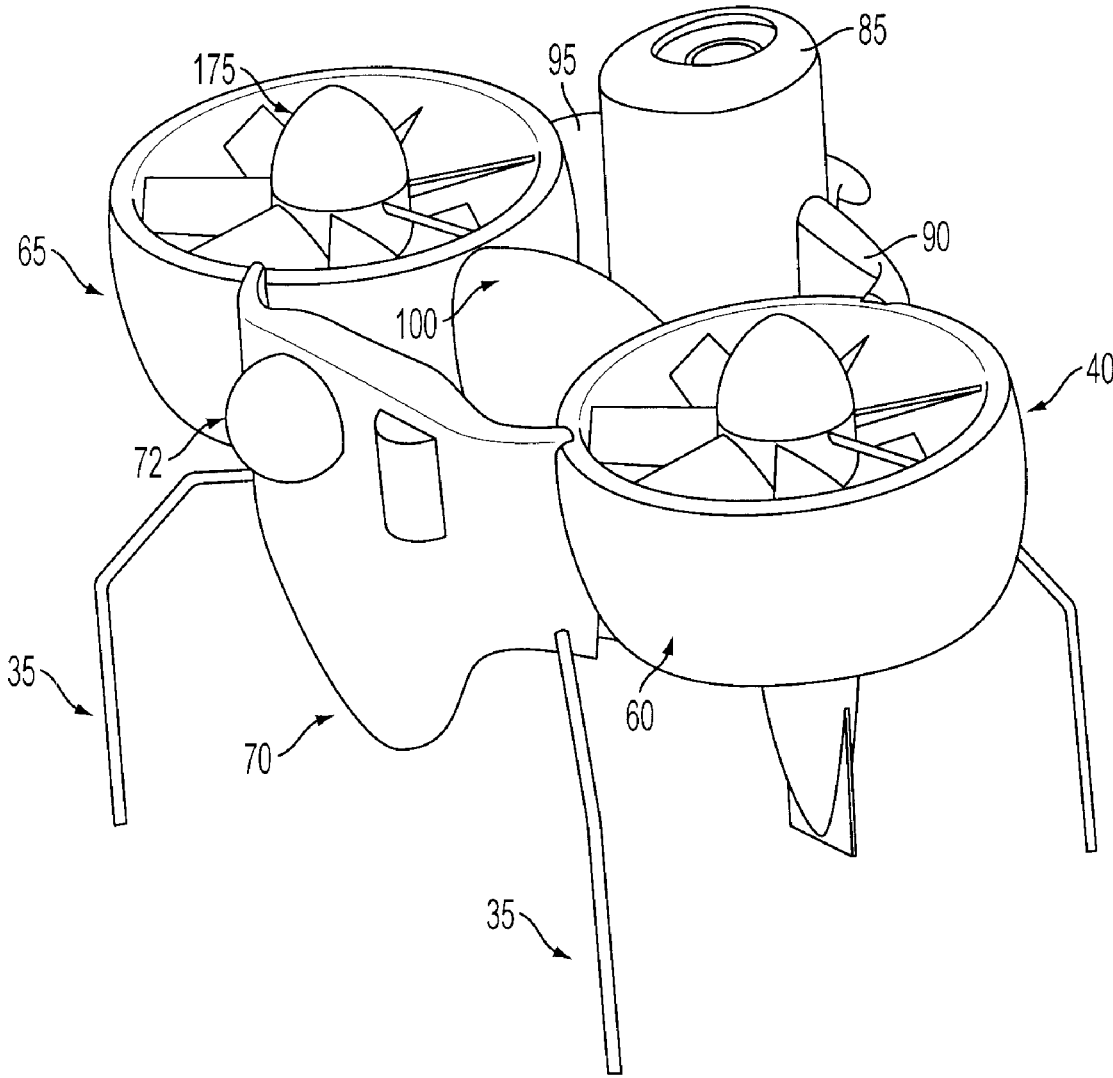


FIG. 4

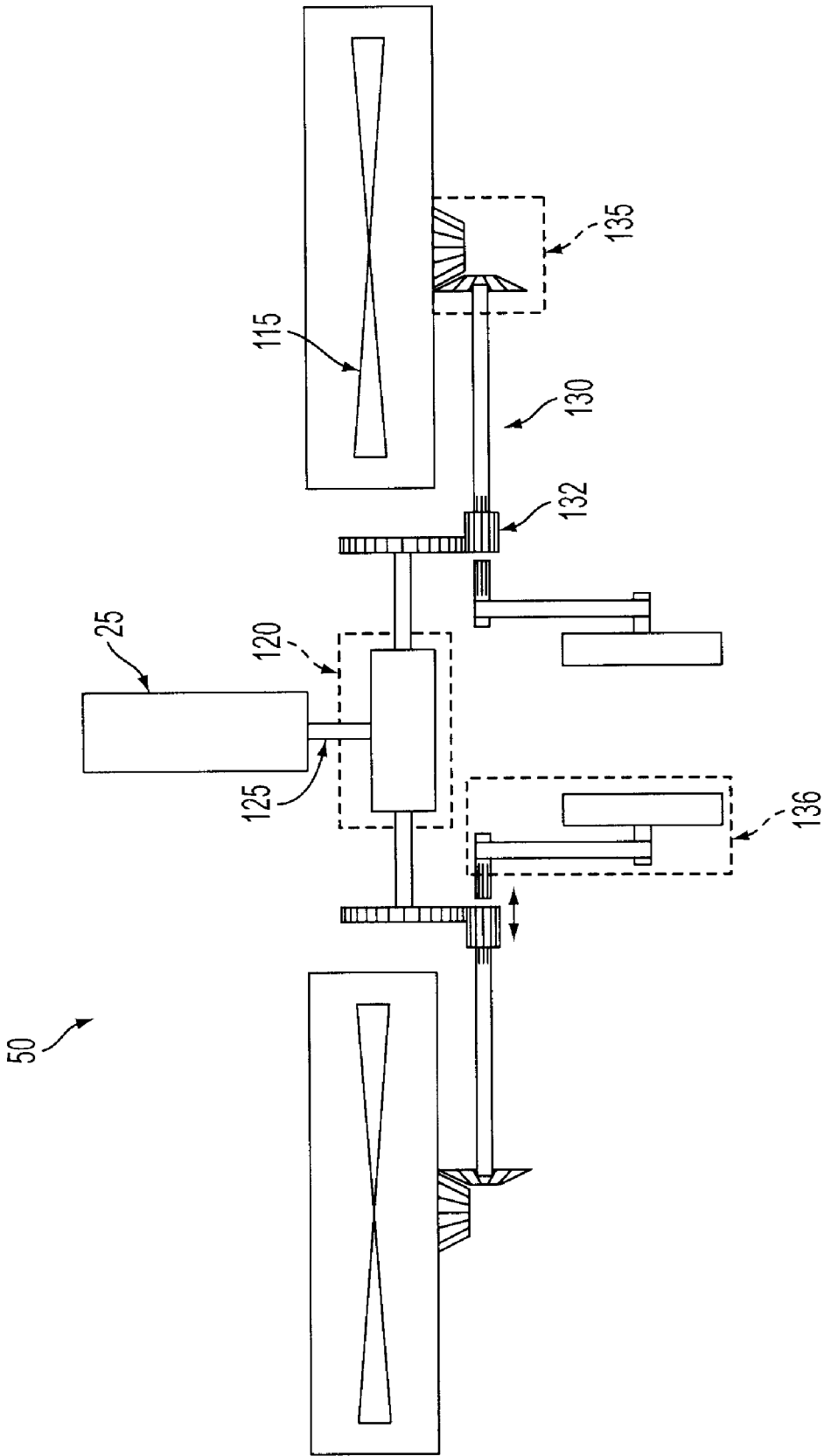


FIG. 5

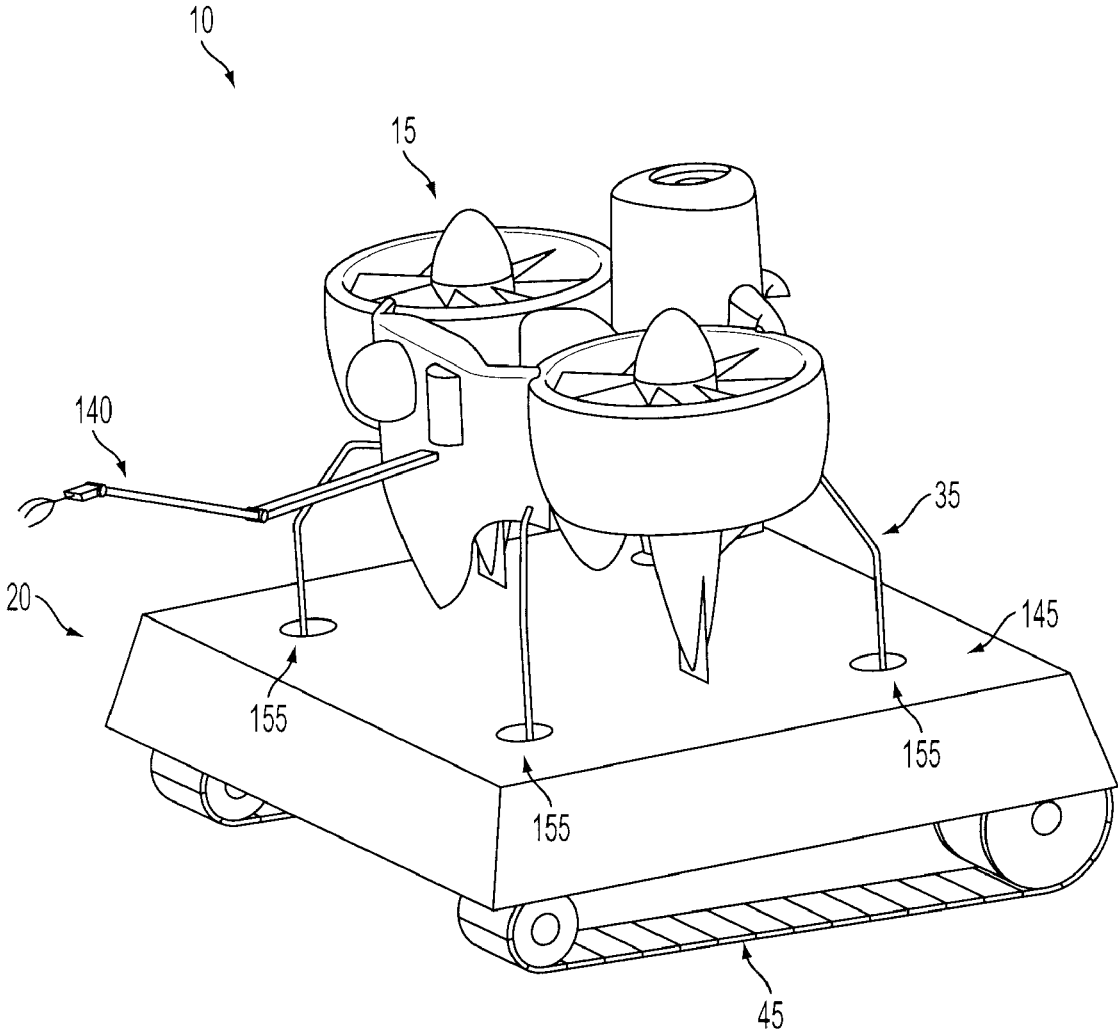


FIG. 6

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TRANSFORMING UNMANNED AERIAL-TO-GROUND VEHICLE

BACKGROUND OF THE INVENTION

An unmanned aerial vehicle (UAV) is an unpiloted aircraft. UAVs can be remote controlled or fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems. UAVs are currently used in a number of military roles, including reconnaissance and attack. They are also used in a small but growing number of civil applications such as firefighting when a human observer would be at risk, police observation of civil disturbances and crime scenes, and reconnaissance support in natural disasters. UAVs are often preferred for missions that are too dull, dirty, or dangerous for manned aircraft. There is a wide variety of UAV shapes, sizes, configurations, and characteristics, but generally, a UAV is capable of controlled, sustained, level flight and is powered by a jet, reciprocating or turbine engine.

UAVs may have remote sensing functions that include electromagnetic spectrum sensors, biological sensors, and chemical sensors. UAVs can transport goods using various means based on the configuration of the UAV itself. Most payloads are stored in an internal pod somewhere in the airframe or duct. UAVs may further be used for search and rescue in inclement weather or reconnaissance missions in enemy territory.

Similarly, unmanned ground vehicles (UGV) are robotic platforms that are used as an extension of human capability. This type of robot is generally capable of operating outdoors and over a wide variety of terrain, functioning in place of humans. There are two general classes of UGVs: autonomous and teleoperated. Autonomous UGVs are essentially an autonomous robot, whereas teleoperated UGVs are vehicles that are controlled by a human operator at a remote location via a communications link. All cognitive processes are provided by the operator based upon sensory feedback from either line-of-sight visual observation or remote sensory input such as video cameras. The operator controls the vehicle via a wired or wireless connection while the user provides all control based upon observed performance of the vehicle. There are a wide variety of teleoperated UGVs in use today. Examples are explosives and bomb disabling vehicles.

UGVs have the ability to gain information about the surrounding environment and detect objects of interest such as people and vehicles. UGVs can also work for extended durations without human intervention or travel from point A to point B without human navigation assistance, while avoiding situations that are harmful to people or itself. If a UGV is harmed, it may have the ability to repair itself without outside assistance.

A disadvantage associated with current UGVs is slow deployment to a threat due to their ground ambulation mechanism, for example, wheels or continuous tracks, as well as an inability to maneuver through irregularities in terrain, such as fast moving rivers or steep trenches. A disadvantage associated with UAVs is that they are more likely to be detected en route to a mission in the open air.

SUMMARY OF THE INVENTION

Outlined herein is a transforming unmanned aerial-to-ground vehicle. The present invention has the beneficial effects of rapid deployment of an unmanned ground vehicle and/or obstacle avoidance through integration with an unmanned aerial vehicle.

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In one aspect, the present invention provides a transforming unmanned aerial-to-ground vehicle assembly comprising: (a) an unmanned aerial vehicle integrated with an unmanned ground vehicle, (b) a power unit shared by the unmanned aerial vehicle and the unmanned ground vehicle, (c) vehicle controls shared by the unmanned aerial vehicle and the unmanned ground vehicle, (d) a disengagement mechanism to separate the unmanned ground vehicle from the unmanned aerial vehicle, (e) one or more manipulator arms located on either the unmanned aerial vehicle or the unmanned ground vehicle, and (f) landing gear.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a transforming unmanned aerial-to-ground vehicle assembly in which the unmanned ground vehicle is disengaged from the unmanned aerial vehicle and in which the unmanned ground vehicle is in the active position.

FIG. 2 is a perspective view of a transforming unmanned aerial-to-ground vehicle assembly in which the unmanned ground vehicle is integrated and engaged with the unmanned aerial vehicle and in which the base and ambulation mechanism are transitioning from an active position to a stowed position.

FIG. 3 is a perspective view of a transforming unmanned aerial-to-ground vehicle assembly in which the unmanned ground vehicle is integrated and engaged with the unmanned aerial vehicle and in which the ambulation mechanism is folding into the base.

FIG. 4 is a perspective view of a transforming unmanned aerial-to-ground vehicle assembly in which the unmanned ground vehicle is integrated and engaged with the unmanned aerial vehicle and in which the unmanned ground vehicle is in the stowed position.

FIG. 5 is a side view of a power transmission system between an unmanned ground vehicle and an unmanned aerial vehicle.

FIG. 6 is a perspective view of a transforming unmanned aerial-to-ground vehicle assembly in which the unmanned ground vehicle is integrated and engaged with the unmanned aerial vehicle.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In one aspect, as shown in FIGS. 1-4 and 6, the present invention provides a transforming unmanned aerial-to-ground vehicle assembly 10 comprising: (a) an unmanned aerial vehicle 15 integrated with an unmanned ground vehicle 20, (b) a power unit 25 shared by the unmanned aerial vehicle 15 and the unmanned ground vehicle 20, (c) vehicle controls shared by the unmanned aerial vehicle 15 and the unmanned ground vehicle 20, (d) a disengagement mechanism 30 to separate the unmanned ground vehicle 20 from the unmanned aerial vehicle 15, (e) one or more manipulator arms 140 located on either the unmanned aerial vehicle 15 or the unmanned ground vehicle 20, and (f) landing gear 35.

As used herein, an unmanned aerial vehicle (UAV) 15 may comprise single ducted fan (Not Shown), double ducted fan (FIGS. 1-4), or multi-ducted fan assemblies, one or more helicopter assemblies, or any other vertical takeoff and landing vehicle known in the art. In a dual ducted fan embodiment, the fans counter rotate to compensate for the torque generated by each individual fan. Each embodiment may employ electric motors in place of a mechanical drive system. These various embodiments are detailed below. Preferably, the

ducted fan assemblies **15** each include a duct **40**, a spinner, a tail cone, a nose cone, a fan, a stator fan mount, and a drive gear **135**. In a tri-ducted fan embodiment, the third ducted fan may have a right angle shaft from one of the duct drive gears **135** to transfer power to it. Alternatively, in a quad-ducted fan embodiment, the mechanical drive system could have two engines each of which drives two of the four ducts using drive gears **135**. Preferably, the helicopter assemblies each include a housing, a rotor, rotor blades, and a drive gear.

As used herein, an unmanned ground vehicle (UGV) **20** may comprise any autonomous or remotely controlled vehicle with any ground ambulation mechanism **45** known in the art, for example, wheels or continuous tracks. More specific embodiments are detailed below.

As used herein, an engine shared by the UAV **15** and UGV **20** may be primarily located on either the UAV **15** or UGV **20**. The power unit **25** may comprise a reciprocating engine or a turbine engine of a type known in the art. Preferably, a turbine engine **25** has a starter generator with a power density sufficient to drive up to four ducted fans or helicopter rotors. Energy transfer from the engine **25** to the one or more fans or helicopter rotors is through an energy transfer device **50** such as a differential spline system, a belt system, or a chain system. Alternatively, there may be no mechanical connections to the fans or rotors and instead the shared power unit **25** may comprise an electric generator that couples to electric motors under each of the UAV's ducted fans (or helicopter rotors) and to an electric motor on the UGV's ambulation mechanism **45**.

As used herein, vehicle controls include vehicle control avionics and vehicle control system sensors of a type known in the art. More specifically, these controls include UAV and UGV surface and fan controls as well as drive systems for the ambulation mechanism **45** and manipulator arms **140**. The control system is also responsible for navigating the UGV **20** into the proper engagement position and for activating the disengage and engage mechanisms.

As used herein, a disengagement mechanism **30** to separate the UGV **20** from the UAV **15** may include, for example, the UGV's ambulation mechanism **45**, the UAV **15** itself, and one or more manipulator arms **140**. Engagement and locking mechanisms may also include a solenoid driven clamping system, engagement rods, locking dovetails, screw jacks, or other known clamping and locking mechanisms. For example, the UGV's ambulation mechanism **45** may be capable of raising and lowering the UGV **20** or moving the UGV **20** forward and rearward such that the UGV **20** enters into and out of engagement with a latching mechanism **55** on the UAV **15**. In another embodiment, the UAV **15** may simply lift off in flight, removing landing gear **35** from latches **55** on the UGV **20**. In a further embodiment, the one or more manipulator arms **140** may be capable of raising and lowering the UGV **20** or moving the UGV **20** forward and rearward such that the UGV **20** enters into and out of engagement with a latching mechanism **55** on the UAV **15**. In addition, the engagement mechanism may include a guidance control system, such as a cone to receive connectors or landing legs as illustrated in FIG. 6, a basic wedge connection, electromagnetics, or an optical system employing surveillance cameras and optical processing.

As used herein, one or more manipulator arms **140** contained on either the UAV **15** or the UGV **20** comprise a robotic arm with an end effector, such as a sensor, clamp, grapple, or claw, for gathering data or maneuvering past obstacles. Preferably, the one or more manipulator arms **140** have multiple degrees of freedom. The one or more manipulator arms **140** are preferably stowed during flight.

As used herein, the landing gear **35** may be retractable or fixed and may be attached to either the UGV **20** or the UAV **15**. Preferably, the landing gear **35** comprises a plurality of shaped rods that are attached in a manner that prevents them from rotating during landing for example via a solenoid driven positioning system. The shape of the landing gear rods **35** may vary, but where the landing gear **35** is retractable, the rods **35** preferably conform to the shape of the exterior of the duct **40** so that upon rotating ninety degrees, the landing gear **35** rests substantially flush against the duct **40**. Alternatively, the landing gear **35** may comprise jointed rods.

In one embodiment, shown in FIGS. 1-4, the UAV **15** comprises a first ducted fan assembly **60**, a second ducted fan assembly **65**, and a forward payload pod **70** affixed on a first end **75** to the first ducted fan assembly **60** and affixed on a second end **80** to the second ducted fan assembly **65**, wherein the UGV **20** comprises a power unit **25** contained in a power unit housing **85**, a first rearward payload pod **90** connected to the power unit housing **85**, a second rearward payload pod **95** connected to the power unit housing **85**, a base **100** moveably connected to the power unit housing **85**, and an ambulation mechanism **45** moveably connected to the base **100**, and wherein a free end **105** of the first rearward payload pod **90** is capable of being connected to the first ducted fan assembly **60** and a free end **110** of the second rearward payload pod **95** is capable of being connected to the second ducted fan assembly **65**. As used herein, the UAV **15** is used to quickly deploy the UGV **20** to a mission site.

As used herein, the first ducted fan assembly **60** and second ducted fan assembly **65** are substantially identical in dimension. As such, the system is balanced from side-to-side and adjustments are made in the design and placement of the forward payload pod **70**, the rearward payload pods, **90**, **95** and the UGV **20** to maintain a functional center of gravity. In embodiments that employ more than two ducted fan assemblies **15**, the additional ducts **15** are joined together by additional fixed or removable payload pods.

As used herein, the forward payload pod **70** may contain sensors and/or various payloads, including a fuel tank or bladder. These sensors are of a type known in the art and may include visual imaging **72** or other surveillance payloads common to both the UGV **20** and the UAV **15**. These surveillance payloads are preferably primarily located on the UGV **20**, but when the UAV **15** and UGV **20** are engaged the surveillance payloads operate to provide visibility to the desired sensing field of view. Preferably, the forward payload pod **70** may have sensor visibility that is one hundred eighty degrees or greater in forward flight. The forward payload pod **70** may be permanently affixed between the first and second ducted fan assemblies **60**, **65** or may be alternatively affixed via latching mechanisms **55** to allow a change in payload or sensors or a quick refuel. The forward payload pod **70** preferably has an aerodynamic cross-section and, in a front view, is substantially "V" shaped with the longest chord essentially midway between the two ducted fan assemblies **60**, **65** to generate more lift. The center of gravity relative to the leading edge lip of each duct **40** is maintained by the location of the attachment points **75**, **80** between the forward payload pod **70** and the ducted fan assemblies **60**, **65** and also by the weight capacity of the forward payload pod **70**. The center of gravity and the locations of the forward payload pod's attachment points **75**, **80** are also contingent on the location of the attachment point between the UGV's rearward payload pods **90**, **95** and the ducted fan assemblies **60**, **65**, as discussed in more detail below.

As used herein, the power unit **25** may be a turbine or reciprocating engine, an electric generator, or any other

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power source known in the art. Where the power unit **25** is a turbine engine or a reciprocating engine, for example, the drive gear is counter-rotating such that the fans **115** are counter-rotating. As shown in detail in FIG. **5**, power is provided into a differential **120**, for example, from the engine **25** through a retractable splined coupling **132** extending from the power unit housing **85**. The differential **120** transfers this power to the ducted fan assemblies **60**, **65** through two splined shafts **130** that are each connected to a right angle gear **135** under each prop. The relative speeds of the output shafts **130** are controlled through individually applying braking forces to the splined shafts **130** by speed brakes or via a shaft loading system. Speed brakes can be either frictional or electric generators with variable load controls. The splined coupling **125** can be retracted into the power unit housing **85** for disengagement from the UAV **15** and extended for re-engagement with the UAV **15** and is preferably tapered to easily mate with the differential **120**. FIG. **5** shows the splined shafts **130** engaged with the ducted fan assemblies **60**, **65** to drive the fans. The UGV **20** disengages from the UAV fans and engages the UGV drive mechanism **136** by sliding the splined coupling **132** inward toward the center of the UGV **20**. For embodiments with more than two ducted fan assemblies **60**, **65**, the differential is configured to drive an equivalent number of splined shafts. Where the power unit **25** is an electric generator, power is supplied through electrical couplings between the UGV's rearward payload pods **90**, **95** and the UAV's ducts **40** and the electric motors drive the fans with an electronic speed control.

As used herein, the power unit housing **85** preferably has a smooth aerodynamic shape and surface, as well as other aerodynamic properties. For example, the power unit housing **85** may have a tail cone for engine exhaust exit **180**. Further, the power unit housing **85** may house engine controls.

As used herein, the rearward payload pods **90**, **95** preferably have an aerodynamic cross-section. The first and second rearward payload pods **90**, **95** may be permanently affixed to the UGV's power unit housing **85** or alternatively affixed via latching mechanisms **55** to allow a change in payload or sensors. The rearward payload pods **90**, **95** are preferably attached closer to the rearward side of the UGV's power unit housing **85** than to the forward side in order to concentrate the UGV's weight closer to the center of the transforming unmanned aerial-to-ground vehicle assembly **10** to maintain a functional center of gravity. The free ends of the first and second rearward payload pods **105**, **110** are affixed via latching mechanisms **55** to the first and second ducted fan assemblies **60**, **65**, respectively, to allow the UGV **20** to disengage and re-engage with the UAV **15**. To maintain the center of gravity, the location of the attachment points of the rearward payload pods **90**, **95** to the ducted fan assemblies **60**, **65** are conditioned upon the weight capacities of the rearward payload pods **90**, **95**, the weight of the UGV **20**, and the location and weight of the forward payload pod **70**. Further, first and second rearward payload pods **105**, **110** may house one or more manipulator arms **140**.

In addition, the rearward payload pods **90**, **95** may contain the shared vehicle controls. If the rearward payload pods **90**, **95** contain the vehicle controls instead of the power unit housing **85**, the rearward payload pods **90**, **95** must remain attached to the UGV **20** upon disengagement from the UAV **15**, otherwise the UGV **20** would be rendered inoperable. If the power unit housing **85** contains the vehicle controls, then the rearward payload pods **90**, **95** may remain attached to the UAV **15** when the UGV **20** disengages from the UAV **15**. Alternatively, in an embodiment employing wireless communication, portions of the vehicle controls may be contained on

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either the UGV **20** or the UAV **15** and the vehicle controls may include re-engagement command signals to rejoin the UGV **20** to the UAV **15**.

As used herein, the base is moveably connected to the power unit housing **85** via at least one rigid member that may travel in a slot beginning at a point on the forward side of the power unit housing **85** that runs substantially vertically downward to the bottom side of the power unit housing **85**. This slot allows the base **100** to travel from an essentially horizontal position parallel to the ground to an essentially vertical position. An electric motor coupled to the vehicle controls operates in forward and reverse modes to drive the rigid member and base **100** in the appropriate direction along the slot. In order to prevent contaminants, such as dirt and water, from entering the power unit housing **85**, the slot may be lined with, for example, rubber flaps, stiff groups of bristles, or a continuous movable track attached at both ends to the rigid member.

As used herein, the ambulation mechanism **45** may comprise wheels, continuous tracks, or any other type of ambulation mechanism **45** known in the art, that are moveably connected to the base **100** by a suspension system of a type known in the art. Terrain capabilities are determined by the UGV's center of gravity and tipping angles. By spreading the distance between the continuous tracks or wheels, for example, a larger base is created that can accommodate larger tipping angles. The ambulation mechanism **45** is powered by the power unit **25** in a manner described above. For instance, where the power unit **25** is an electric generator, the electric generator **25** transfers power to an electric motor that in turn drives the ambulation mechanism **45** using systems known in the art. Similarly, where the power unit **25** is an engine, the engine **25** transfers power to a differential which in turn transfers power to splined shafts connected to the ambulation mechanism **45**.

The ambulation mechanism **45** is also moveably connected to the base **100** in another respect. The ambulation mechanism **45** moves relative to the base **100** by transitioning into or underneath the base when the UGV **20** is engaged or integrated with the UAV **15**, as detailed below.

In one embodiment, the UGV **20** is capable of transitioning between a stowed position for flight and an active position for ground ambulation. As used herein, a stowed position means that the UGV **20** and UAV **15** are integrated or engaged and the ambulation mechanism **45** is moved out of contact with the ground and stowed in an aerodynamic fashion. This can be accomplished by simply lifting the ambulation mechanism **45** off the ground such that the base **100** is sheltered beneath the power unit housing **85**. Alternatively, as shown in FIGS. **3-4**, the UGV **20** is affixed to the UAV **15** via the first and second rearward payload pods **90**, **95**, and the base **100** is rotated to a substantially vertical position such that the bottom of the base **100** faces the forward payload pod **70**, the top of the base **100** faces the power unit housing **85**, and each side of the base **100** faces one of the ducted fan assemblies **60**, **65**. In the stowed position, the base **100** is preferably locked to the first and second ducted fan assemblies **60**, **65** via solenoid driven release latches **55**, for example, coupled to the vehicle controls.

As used herein, the active position means that the base **100** is rotated to a substantially horizontal position and the UGV **20** and UAV **15** are disengaged or prepared to disengage and the ambulation mechanism **45** is capable of contacting the ground. When the UGV **20** transitions into an active position prior to separating from the UAV **15**, the ambulation mechanism **45** is fully extended or unfolded from the base **100** and operable. When the UGV **20** and UAV **15** are coupled at the

latching mechanism **55** the splined coupling **132** slides to engage the UAV drive shaft **130** and disengage from the ambulation drive **136**. The ambulation tracks **30, 45** are then rotated up into a stowed position within the base **100**. The base **100** provides an aerodynamic enclosure for the ambulation tracks **30, 45** while in flight. The ambulation mechanism **45** is folded into the base **100** via a mechanical system that first lifts the ambulation tracks off the ground, slides them into the base **100**, and then the base **100** containing the ambulation tracks **30, 45** is rotated and lifted in between the two UAV duct fan assemblies **60, 65**.

In one embodiment, the base is aerodynamically shaped. As used herein, when the base **100** is in the stowed position and is substantially vertical, as shown in FIG. 2, the aerodynamic cross-section is facing in the appropriate direction for flight. Similarly, when the base **100** is in the active position and is substantially horizontal, as shown in FIG. 1, the aerodynamic cross-section is facing the appropriate direction for forward motion along the ground.

In one embodiment, the UGV **20** is integrated with the UAV **15** via a latching mechanism **55**, and the latching mechanism **55** ensures proper alignment of electrical connector pins contained on both the UGV **20** and the UAV **15**. As used herein, the latching mechanism **55** may comprise solenoid driven latches or dovetail latches coupled to the vehicle controls. Although solenoid driven latches and dovetail latches are described, this disclosure is not meant to limit the attachment method. Any other well known method of attachment can be used. The free ends of the first and second rearward payload pods **105, 110** are each attached to a latching mechanism **55** and the ducted fan assemblies **60, 65** each are attached to a corresponding latching mechanism **55**. In addition, in an embodiment where the rearward payload pods **90, 95** are detachable from the UGV **20**, the rearward payload pods **90, 95** each are attached to an additional latching mechanism **55** and the UGV **20** is attached to corresponding latching mechanisms **55**. The female latching mechanisms **55**, which receive the male latching mechanisms **55**, preferably have wider openings that taper to help guide the rearward payload pods' latching mechanisms **55** into the corresponding latching mechanisms **55** on the ducted fan assemblies **15** and the UGV **20**.

In addition, the latching mechanisms **55** may be oriented substantially vertically or horizontally. The latching mechanisms **55** may also be angled. Where the latching mechanisms **55** are arranged vertically, the rearward payload pods' latching mechanisms **55** can engage and disengage from the UAV's latching mechanisms **55** by being raised or lowered into engagement by the ambulation mechanism **45**. In another embodiment, the UGV's latching mechanisms **55** can engage and disengage from the rearward payload pods' latching mechanisms **55** by being raised or lowered into engagement. Where the latching mechanisms **55** are arranged horizontally, the rearward payload pods' latching mechanisms **55** can engage and disengage from the UAV's latching mechanisms **55** by the UGV's ambulation mechanism **45** moving in forward or reverse. In another embodiment, the UGV's latching mechanisms **55** can engage and disengage from the rearward payload pods' latching mechanisms **55** by the UGV's ambulation mechanism **45** moving in forward or reverse.

Further, each latching mechanism **55** has a servo driven vertical adjustment to assist in alignment during re-engagement of the UGV **20** with the UAV **15**. Although, the primary adjustment may be in the horizontal direction with a major correction that may be accomplished by the ambulation mechanism's approach to the UAV **15**. Additional fine location adjustments may be accomplished by mechanical guides

or via short range vertical and horizontal servo latches. An alternative approach is to employ a rotating spiral latch that draws the UGV **20** into a firm locked position.

In one embodiment, the ambulation mechanism **45** is a dual set of continuous tracks. The continuous tracks **45** may comprise a flexible, treaded belt with the forward and rearward ends suspended around rollers. Alternatively, the continuous tracks **45** may comprise a number of rigid units that are joined to each other and suspended about rollers at the forward and rearward ends.

In one embodiment, the disengagement mechanism **30** comprises the dual set of continuous tracks, and disengages the UGV **20** from the UAV **15** by rotating the front ends of the tracks toward the ground until contact and continuing to push the front ends against the ground causing the UGV **20** to lift up and out of the latching mechanism **55**, and re-engages the UGV **20** with the UAV **15** by rotating the back ends of the tracks upward causing the UGV **20** to lift up and over the latching mechanism **55** and lowering the UGV **20** into the latching mechanism **55**.

In one embodiment, one of the one or more manipulator arms **140** is contained in the top of the power unit housing **85**. The manipulator arm **140** has at least three degrees of freedom that is extensible to a degree sufficient to reach the ground. The manipulator arm **140** may comprise servo driven azimuth controls, two servo driven elbows, a screw driven longitudinally driven extensible member, and a tool control at the end of the arm.

In one embodiment, the UAV **15** comprises a ducted fan assembly, which houses the shared power unit **25** and vehicle controls, and has permanently extended landing gear **35**, and wherein the UGV **20** comprises an all terrain vehicle that has a landing platform **145** formed on the top surface of the all terrain vehicle and one or more payload pods (not shown) integrated into a housing of the all terrain vehicle, and wherein the landing gear **35** of the UAV **15** is received by a plurality of landing gear receptacles **155** contained in the landing platform **145** of the UGV **20**. As used herein, the UGV **20** is used to deliver the UAV **15** to a location for the UAV **15** to carry out a mission. In addition, the UAV **15** is capable of lifting the UGV **20** to avoid obstacles on the ground, such as ravines or rivers.

As used herein, the UGV **20** preferably comprises a commercial-off-the-shelf, all terrain vehicle capable of extreme mobility and obstacle negotiation. Alternatively, the UGV **20** may comprise a tracked vehicle or a vehicle that is both tracked and wheeled. The payload pods integrated into the housing of the unmanned aerial vehicle may contain sensors, additional fuel, or any other mission appropriate cargo.

When the UGV **20** and UAV **15** are integrated and prepared for ground mobility, the UAV's landing gear **35** is locked into position via solenoid latches **55** in the landing gear receptacles on the UGV's landing platform **145**. These solenoid latches **55** are activated by the vehicle controls. In an embodiment with multiple single duct UAVs **15**, the landing platform **145** is configured to contain landing gear receptacles **155** for each UAV **15**. Each UAV **15** in turn contains vehicle controls for both the UAV **15** and UGV **20** this ensures that if one or more UAVs **15** are lost during a mission the remaining UAV **15** can still re-engage with the UGV **20** and control its operation.

As used herein, the power unit **25** may be a turbine or reciprocating engine, an electric generator, or any other power source known in the art. Where the power unit **25** is a turbine engine or a reciprocating engine, for example, the engine transfers power to a differential **120** contained in the UGV **20**, for example, via a retractable splined coupling **125**

extending from the power unit housing **85** through an opening (not shown) in the landing platform **145**. The splined coupling **125** can be refracted into the power unit housing **85** for disengagement from the UAV **15** and extended for re-engagement with the UAV **15** and is preferably tapered for easy engagement with the differential **120**. The opening in the landing platform **145** may have a spring loaded covering that slides aside upon the application of pressure from the extending splined coupling **125** and returns into place upon removal of the splined coupling **125**. The differential **120** transfers power from the splined coupling **125** to splined shafts **130** integrated in the UGV's transmission system. For embodiments with more than two ducted fan assemblies, there is a corresponding differential configured to drive a segment of the transmission system. Where the power unit **25** is an electric generator, power is supplied through electrical couplings contained in the UGV's landing gear receptacles **155** and the UAV's landing gear **35** and an electric motors drive the UGV **20** and the UAV's fans with an electronic speed control.

In one embodiment, the landing gear **35** comprises a plurality of substantially rigid legs, wherein the plurality of landing gear receptacles **155** are conically shaped to guide the landing gear **35** into proper alignment with a latching mechanism (not shown in FIG. **6**). The landing platform **145** is substantially planar and preferably contains a guidance marker on its surface, such as an "X", that corresponds with the location of the landing gear receptacles **145**. The UAV's sensor payload can send real-time images of the guidance marker to a remote operator who can control the UAV's position and align the landing gear **35** with the landing gear receptacles **145** during re-engagement with the UGV **20**. The conical shape of the landing gear receptacles **145** increases the allowable margin of error when landing the UAV **15** by increasing the surface area landing zone for each rigid leg **35**. Once the rigid legs **35** contact the interior of the cones **145**, the legs **35** slide down into the landing platform **145** where they are locked in place preferably by a solenoid operated latching mechanism.

The latching mechanism can be operated in many ways. In one embodiment, the latching mechanism comprises a plurality of solenoid latches corresponding with each of the plurality of landing gear receptacles. For example, the rigid legs **35** may contain through-holes near their base into which solenoid operated bolts are inserted by the latching mechanism. Alternatively, the rigid legs **35** may contain a tapered lip near their base that allows each leg **35** to easily slide into proper alignment while providing a surface that can be clamped down by solenoid operated latches that slide into place.

The latching mechanism must be strong enough to remain in a locked position when the integrated UGV **20** and UAV **15** are in flight. The rigid legs **35** and the connections to the UAV **15** must be strong enough to bear the weight of the UGV **20** for short flights to avoid obstacles. The rigid legs **35** are preferably made from lightweight high strength composite structures. The rigid legs **35** are connected to the UAV duct's internal structure, leaving the aerodynamic surface separate from structural forces. They may be permanently bonded or welded to the underlying skeletal structure or they may be bolted in place.

In one embodiment, the landing gear **35** provides an interface of electrical connector pins to transmit electrical power and control signals between the UAV **15** and the UGV **20**. The landing gear receptacles **155** ensure proper alignment of the landing gear's electrical connector pins with complementary electrical connector pins in the landing platform **145**. These

connector pins interface with the vehicle controls via electrical wire and/or fiber optics on board the UAV **15** and UGV **20**.

In one embodiment, the landing gear **35** is protected on the end of each substantially rigid leg **35** by a spring loaded cap (not shown). As the landing gear **35** contacts the landing gear receptacles **155**, the pressure exerted on the spring loaded caps causes the caps to slide to the side and the base of the landing gear receptacles **155** are configured to accommodate the volume of the cap. Alternatively, the caps operate in response to signals from the avionics controls or via a mechanical key in the landing gear receptacles **155**.

In one embodiment, the disengagement mechanism **30** comprises the UAV **15** itself, which disengages from the UGV **20** by taking off and re-engages by landing on the landing platform **145**.

Although the invention has been described in detail with particular reference to these preferred embodiments, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover in the appended claims all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above, are hereby incorporated by reference.

The invention claimed is:

1. A transforming unmanned aerial-to-ground vehicle assembly comprising:

- an unmanned aerial vehicle integrated with an unmanned ground vehicle, the integration between the unmanned aerial vehicle and the unmanned ground vehicle being strong enough to bear the weight of the unmanned ground vehicle during flight of the unmanned aerial vehicle;
- a power unit shared by the unmanned aerial vehicle and the unmanned ground vehicle;
- vehicle controls shared by the unmanned aerial vehicle and the unmanned ground vehicle;
- a disengagement mechanism to separate the unmanned ground vehicle from the unmanned aerial vehicle;
- one or more manipulator arms located on either the unmanned aerial vehicle or the unmanned ground vehicle; and
- landing gear.

2. The transforming unmanned aerial-to-ground vehicle assembly of claim **1**, wherein the unmanned aerial vehicle comprises a first ducted fan assembly, a second ducted fan assembly, and a forward payload pod affixed on a first end to the first ducted fan assembly and affixed on a second end to the second ducted fan assembly, wherein the unmanned ground vehicle comprises a power unit contained in a power unit housing, a first rearward payload pod connected to the power unit housing, a second rearward payload pod connected to the power unit housing, a base moveably connected to the power unit housing, and an ambulation mechanism moveably connected to the base, and wherein a free end of the first rearward payload pod is capable of being connected to the first ducted fan assembly and a free end of the second rearward payload pod is capable of being connected to the second ducted fan assembly.

3. The transforming unmanned aerial-to-ground vehicle assembly of claim **1**, wherein the unmanned ground vehicle is capable of transitioning between a stowed position for flight and an active position for ground ambulation.

4. The transforming unmanned aerial-to-ground vehicle assembly of claim **2**, wherein the unmanned ground vehicle is capable of transitioning between a stowed position for flight and an active position for ground ambulation, and wherein the base houses the ambulation mechanism when in the stowed

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position, and wherein the ambulation mechanism is fully extended from the base when the unmanned ground vehicle transitions into an the active position prior to separating from the unmanned aerial vehicle.

5 5. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the unmanned ground vehicle is capable of transitioning between a stowed position for flight and an active position for ground ambulation, and wherein, in the stowed position, the unmanned ground vehicle is affixed to the unmanned aerial vehicle via the first and second rearward payload pods, and the base is rotated to a substantially vertical position such that a bottom of the base faces the forward payload pod, a top of the base faces the power unit housing, and each side of the base faces one of the ducted fan assemblies.

6. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the unmanned ground vehicle is capable of transitioning between a stowed position for flight and an active position for ground ambulation, and wherein, in the active position, the base is rotated to a substantially horizontal position and the ambulation mechanism is capable of making contact with ground.

7. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the base is aerodynamically shaped.

8. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the unmanned ground vehicle is integrated with the unmanned aerial vehicle via a latching mechanism, and wherein the latching mechanism ensures proper alignment of electrical connector pins contained on both the unmanned ground vehicle and the unmanned aerial vehicle.

9. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the ambulation mechanism is a dual set of continuous tracks.

10. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the disengagement mechanism comprises a dual set of continuous tracks and the unmanned ground vehicle is integrated with the unmanned aerial vehicle via a latching mechanism, wherein the disengagement mechanism disengages the unmanned ground vehicle from the unmanned aerial vehicle by rotating front ends of the tracks toward the ground until contact and continuing to push the front ends against the ground to cause the unmanned ground vehicle to lift up and out of the latching mechanism, and wherein the disengagement mechanism re-engages the unmanned ground vehicle with the unmanned aerial vehicle by rotating back ends of the tracks upward to cause the unmanned ground vehicle to lift up and over the latching mechanism and lowering the unmanned ground vehicle into the latching mechanism.

11. The transforming unmanned aerial-to-ground vehicle assembly of claim 10, wherein the latching mechanism comprises a dovetail joint.

12. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein one of the one or more manipulator arms is located at the a top of the power unit housing.

13. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the unmanned aerial vehicle

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comprises a ducted fan assembly, which houses the shared power unit and vehicle controls and has permanently extended comprises the landing gear, and wherein the unmanned ground vehicle comprises an all terrain vehicle that comprises a landing platform formed on the a top surface of the all terrain vehicle and one or more payload pods integrated into a housing of the all terrain vehicle, and wherein the landing gear of the unmanned aerial vehicle is received by a plurality of landing gear receptacles contained in the landing platform of the unmanned ground vehicle.

14. The transforming unmanned aerial-to-ground vehicle assembly of claim 13, wherein the landing gear comprises a plurality of substantially rigid legs, and wherein the plurality of landing gear receptacles are conically shaped to guide the landing gear into proper alignment with a latching mechanism that integrates the unmanned ground vehicle with the unmanned aerial vehicle.

15. The transforming unmanned aerial-to-ground vehicle assembly of claim 14, wherein the latching mechanism comprises a plurality of solenoids corresponding with each of the plurality of landing gear receptacles.

16. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the landing gear provides an interface of electrical connector pins to transmit electrical power and control signals between the unmanned aerial vehicle and the unmanned ground vehicle.

17. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the landing gear is protected on the end of each substantially rigid leg by a spring loaded cap.

18. The transforming unmanned aerial-to-ground vehicle assembly of claim 13, wherein the disengagement mechanism comprises the unmanned aerial vehicle itself, which disengages from the unmanned ground vehicle by taking off and re-engages by landing on the landing platform.

19. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the disengagement mechanism comprises the one or more manipulator arms, the one or more manipulator arms being configured to move the unmanned ground vehicle relative to the unmanned aerial vehicle.

20. A method comprising:
with an unmanned aerial vehicle of an assembly, lifting an unmanned ground vehicle of the assembly off a ground, wherein the unmanned aerial vehicle is integrated with the unmanned ground vehicle, the assembly further comprising:
a power unit shared by the unmanned aerial vehicle and the unmanned ground vehicle;
vehicle controls shared by the unmanned aerial vehicle and the unmanned ground vehicle;
a disengagement mechanism to separate the unmanned ground vehicle from the unmanned aerial vehicle; and
one or more manipulator arms located on either the unmanned aerial vehicle or the unmanned ground vehicle; and
with the disengagement mechanism of the system, disengaging the unmanned ground vehicle from the unmanned aerial vehicle.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 8,205,820 B2
APPLICATION NO. : 12/364762
DATED : June 26, 2012
INVENTOR(S) : Emray R. Goossen et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 12, Lines 2-3 (Claim 13), "and has permanently extended comprises" should be
-- and comprises --

Signed and Sealed this
Twenty-sixth Day of February, 2013



Teresa Stanek Rea
Acting Director of the United States Patent and Trademark Office

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position, and wherein the ambulation mechanism is fully extended from the base when the unmanned ground vehicle transitions into an the active position prior to separating from the unmanned aerial vehicle.

5 5. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the unmanned ground vehicle is capable of transitioning between a stowed position for flight and an active position for ground ambulation, and wherein, in the stowed position, the unmanned ground vehicle is affixed to the unmanned aerial vehicle via the first and second rearward payload pods, and the base is rotated to a substantially vertical position such that a bottom of the base faces the forward payload pod, a top of the base faces the power unit housing, and each side of the base faces one of the ducted fan assemblies.

10 6. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the unmanned ground vehicle is capable of transitioning between a stowed position for flight and an active position for ground ambulation, and wherein, in the active position, the base is rotated to a substantially horizontal position and the ambulation mechanism is capable of making contact with ground.

15 7. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the base is aerodynamically shaped.

20 8. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the unmanned ground vehicle is integrated with the unmanned aerial vehicle via a latching mechanism, and wherein the latching mechanism ensures proper alignment of electrical connector pins contained on both the unmanned ground vehicle and the unmanned aerial vehicle.

25 9. The transforming unmanned aerial-to-ground vehicle assembly of claim 2, wherein the ambulation mechanism is a dual set of continuous tracks.

30 10. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the disengagement mechanism comprises a dual set of continuous tracks and the unmanned ground vehicle is integrated with the unmanned aerial vehicle via a latching mechanism, wherein the disengagement mechanism disengages the unmanned ground vehicle from the unmanned aerial vehicle by rotating front ends of the tracks toward the ground until contact and continuing to push the front ends against the ground to cause the unmanned ground vehicle to lift up and out of the latching mechanism, and wherein the disengagement mechanism re-engages the unmanned ground vehicle with the unmanned aerial vehicle by rotating back ends of the tracks upward to cause the unmanned ground vehicle to lift up and over the latching mechanism and lowering the unmanned ground vehicle into the latching mechanism.

35 11. The transforming unmanned aerial-to-ground vehicle assembly of claim 10, wherein the latching mechanism comprises a dovetail joint.

40 12. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein one of the one or more manipulator arms is located at the a top of the power unit housing.

45 13. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the unmanned aerial vehicle

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comprises a ducted fan assembly, which houses the shared power unit and vehicle controls and has permanently extended comprises the landing gear, and wherein the unmanned ground vehicle comprises an all terrain vehicle that comprises a landing platform formed on the a top surface of the all terrain vehicle and one or more payload pods integrated into a housing of the all terrain vehicle, and wherein the landing gear of the unmanned aerial vehicle is received by a plurality of landing gear receptacles contained in the landing platform of the unmanned ground vehicle.

10 14. The transforming unmanned aerial-to-ground vehicle assembly of claim 13, wherein the landing gear comprises a plurality of substantially rigid legs, and wherein the plurality of landing gear receptacles are conically shaped to guide the landing gear into proper alignment with a latching mechanism that integrates the unmanned ground vehicle with the unmanned aerial vehicle.

15 15. The transforming unmanned aerial-to-ground vehicle assembly of claim 14, wherein the latching mechanism comprises a plurality of solenoids corresponding with each of the plurality of landing gear receptacles.

20 16. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the landing gear provides an interface of electrical connector pins to transmit electrical power and control signals between the unmanned aerial vehicle and the unmanned ground vehicle.

25 17. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the landing gear is protected on the end of each substantially rigid leg by a spring loaded cap.

30 18. The transforming unmanned aerial-to-ground vehicle assembly of claim 13, wherein the disengagement mechanism comprises the unmanned aerial vehicle itself, which disengages from the unmanned ground vehicle by taking off and re-engages by landing on the landing platform.

35 19. The transforming unmanned aerial-to-ground vehicle assembly of claim 1, wherein the disengagement mechanism comprises the one or more manipulator arms, the one or more manipulator arms being configured to move the unmanned ground vehicle relative to the unmanned aerial vehicle.

40 20. A method comprising:
with an unmanned aerial vehicle of an assembly, lifting an unmanned ground vehicle of the assembly off a ground, wherein the unmanned aerial vehicle is integrated with the unmanned ground vehicle, the assembly further comprising:
45 a power unit shared by the unmanned aerial vehicle and the unmanned ground vehicle;
vehicle controls shared by the unmanned aerial vehicle and the unmanned ground vehicle;
a disengagement mechanism to separate the unmanned ground vehicle from the unmanned aerial vehicle; and
50 one or more manipulator arms located on either the unmanned aerial vehicle or the unmanned ground vehicle; and
with the disengagement mechanism of the system, disengaging the unmanned ground vehicle from the unmanned aerial vehicle.

* * * * *