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(54) **MICRO-ROTORCRAFT SURVEILLANCE SYSTEM**

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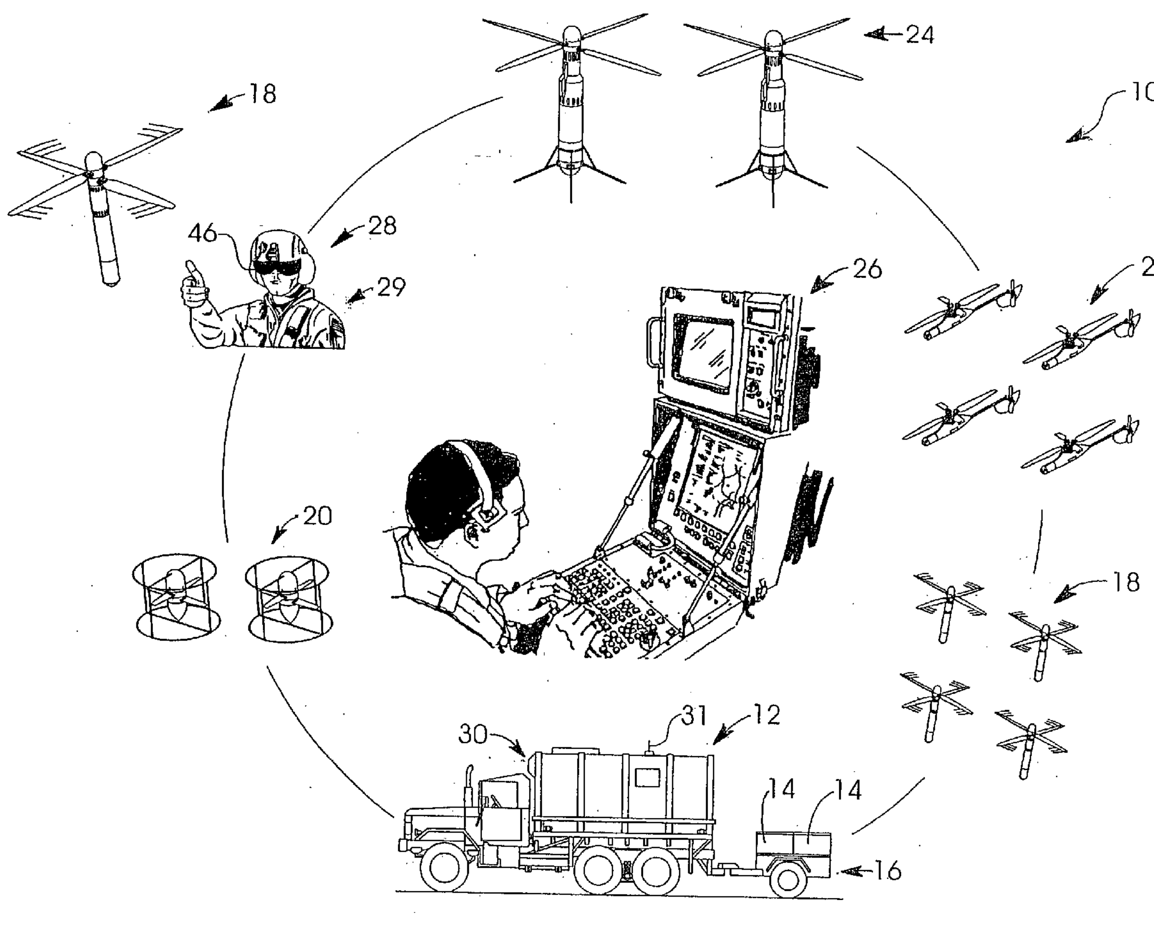
(52) **U.S. Cl.** **244/17.11**

(57) **ABSTRACT**

A flying micro-rotorcraft unit **(18, 24, 310, 330, 370)** is provided for remote tactical and operational missions. The unit **(18, 24, 310, 330, 370)** includes an elongated body **(52)** having an upper and a lower end. The body **(52)** defines a vertical axis **(60)**. The unit **(18, 24, 310, 330, 370)** further includes a navigation module **(54)** including means for determining a global position of the elongated body **(52)** during flight of the unit **(18, 24, 310, 330, 370)**. Rotor means of the unit **(18, 24, 310, 330, 370)** is coupled to the upper end of the elongated body **(52)** for generating a thrust force that acts in a direction parallel to the vertical axis **(60)** to lift the elongated body **(52)** into the air. The rotor means is located between the elongated body **(52)** and the navigation module **(54)**.



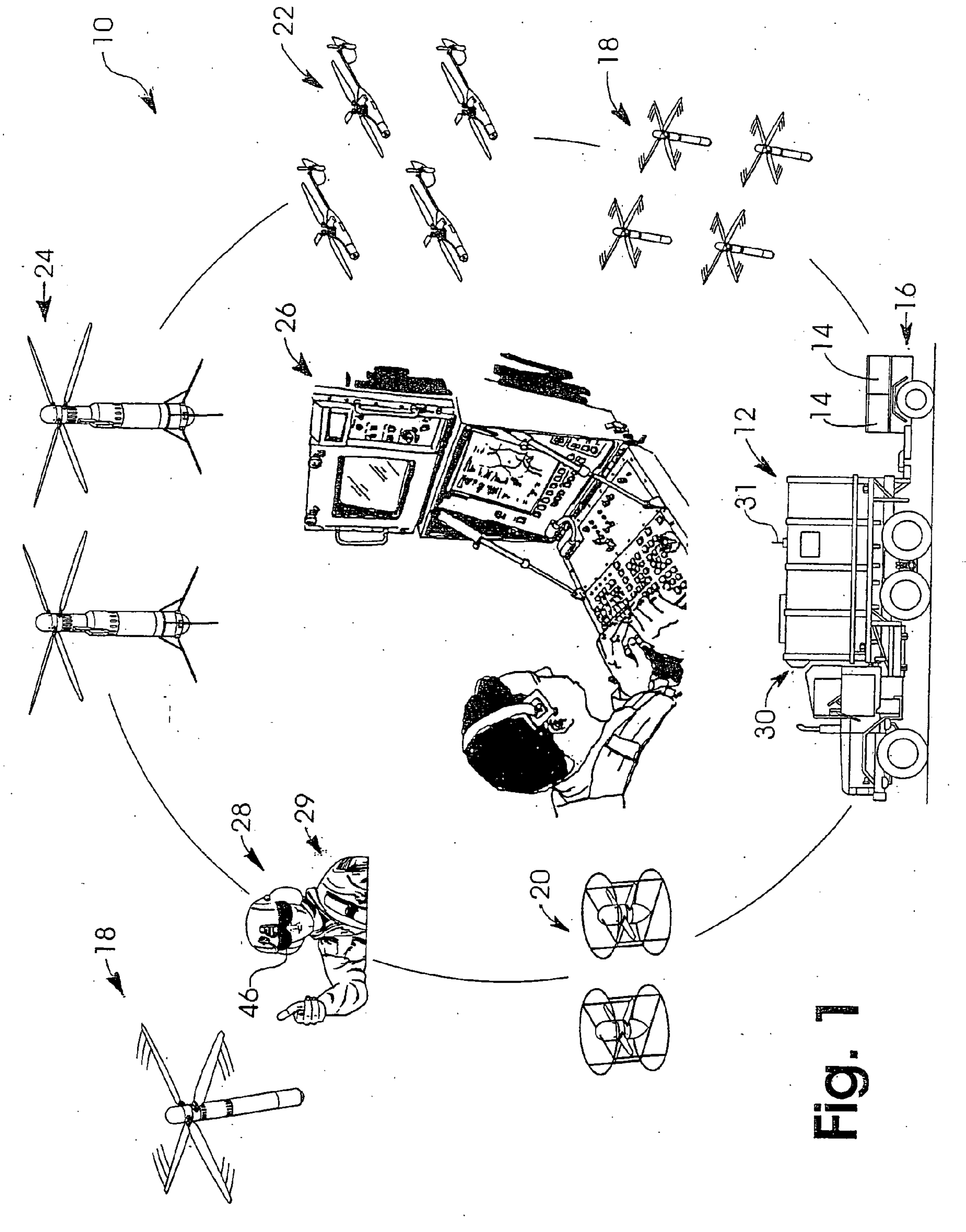


Fig. 1

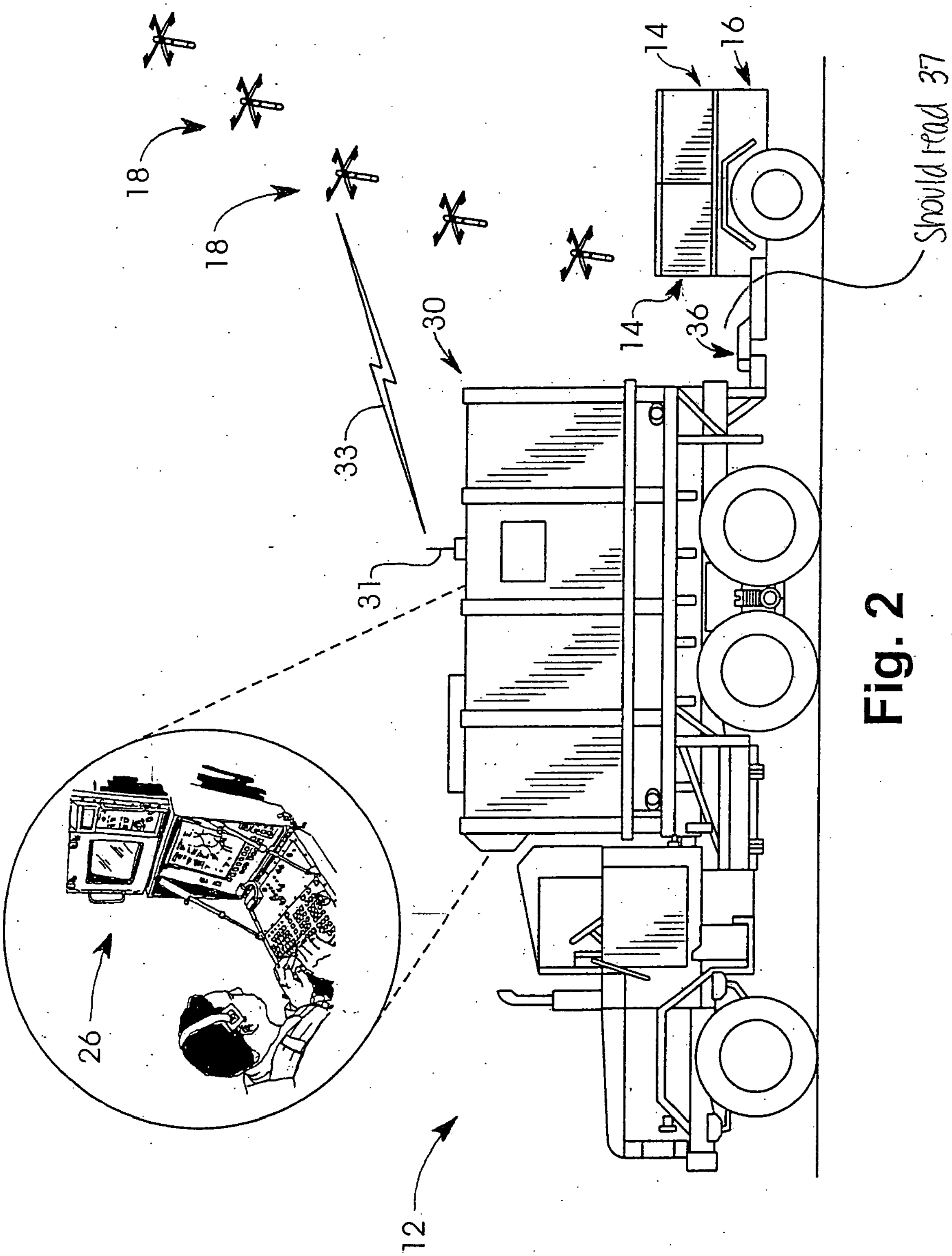


Fig. 2

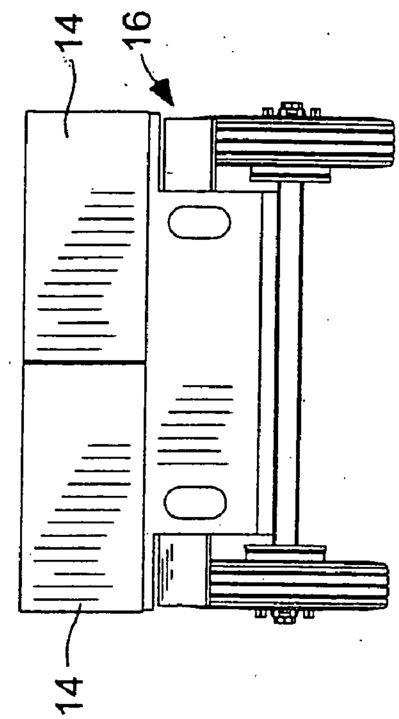


Fig. 3b

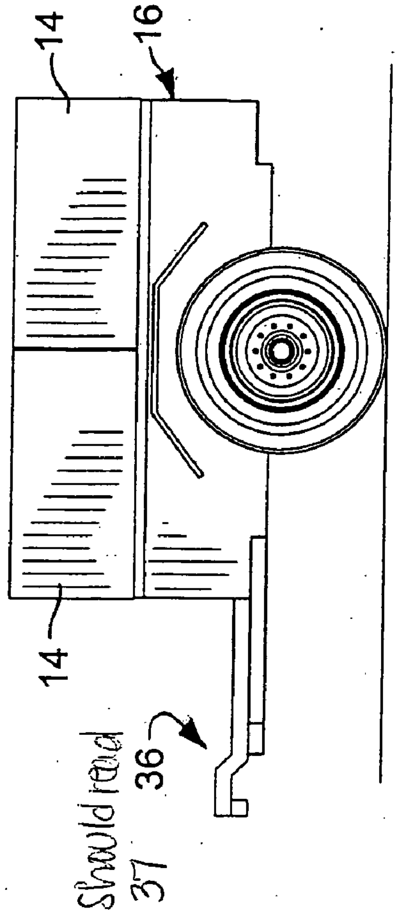


Fig. 3c

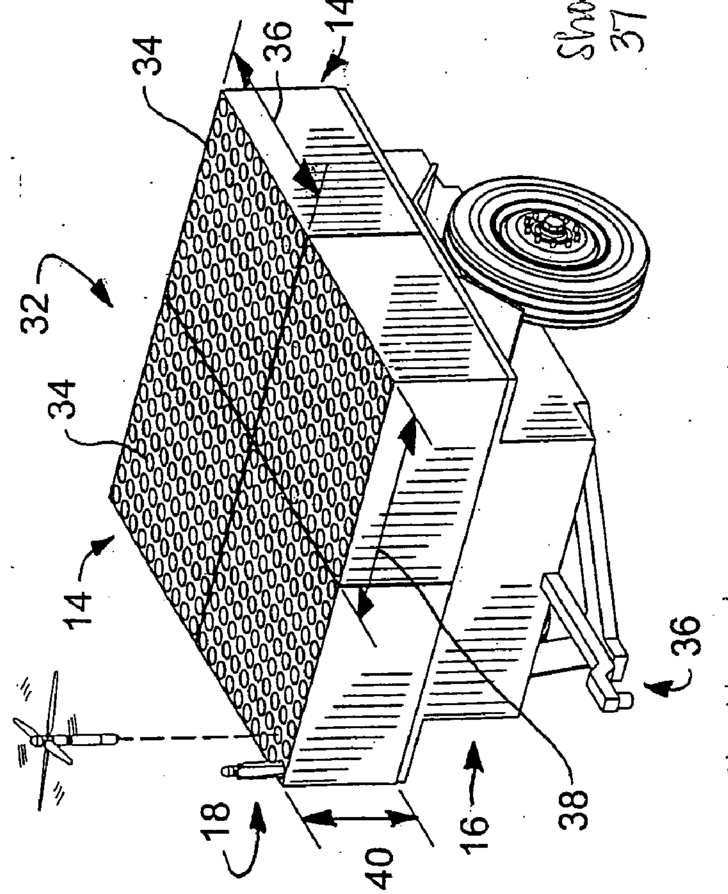


Fig. 3a

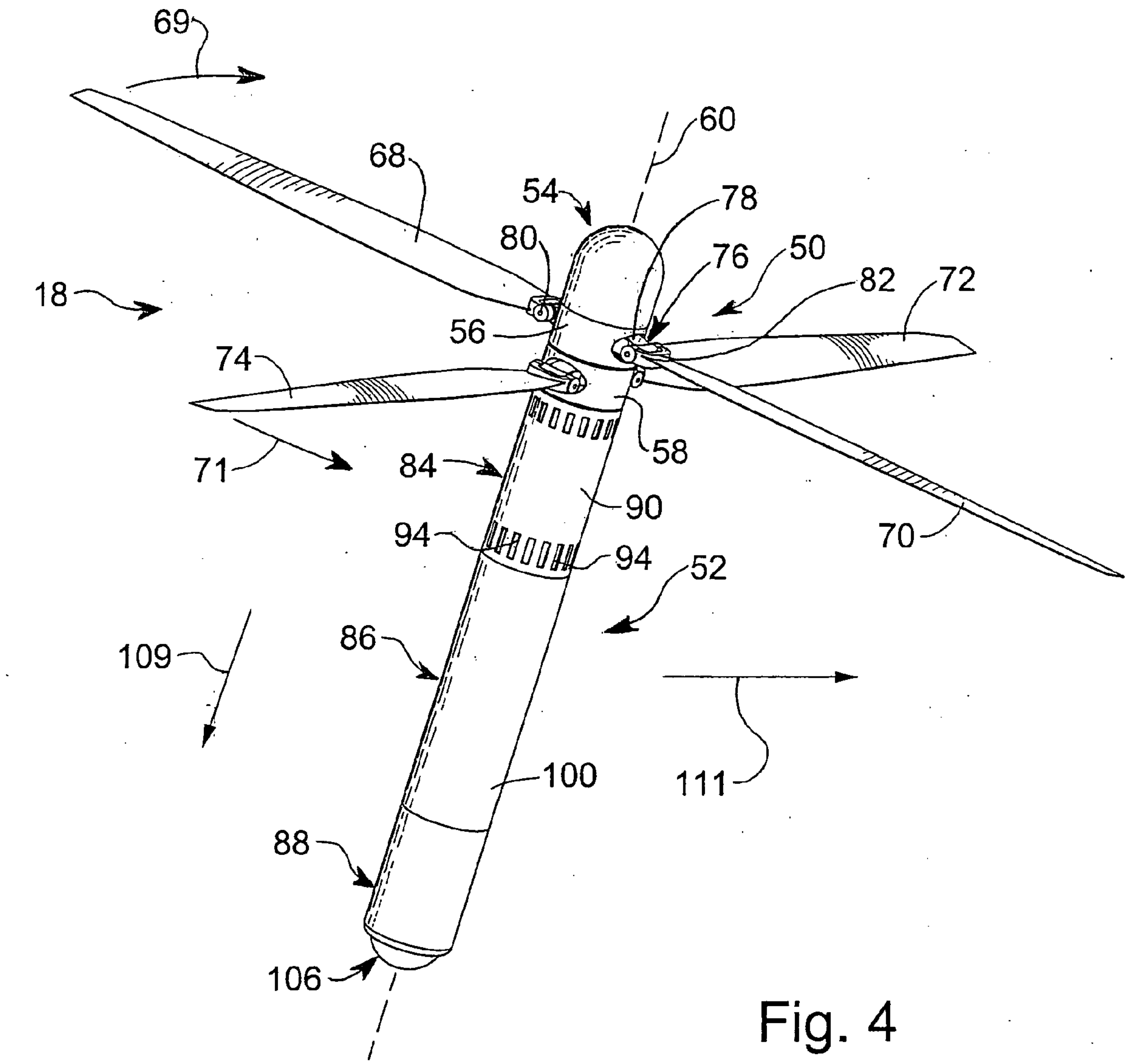

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Fig. 4

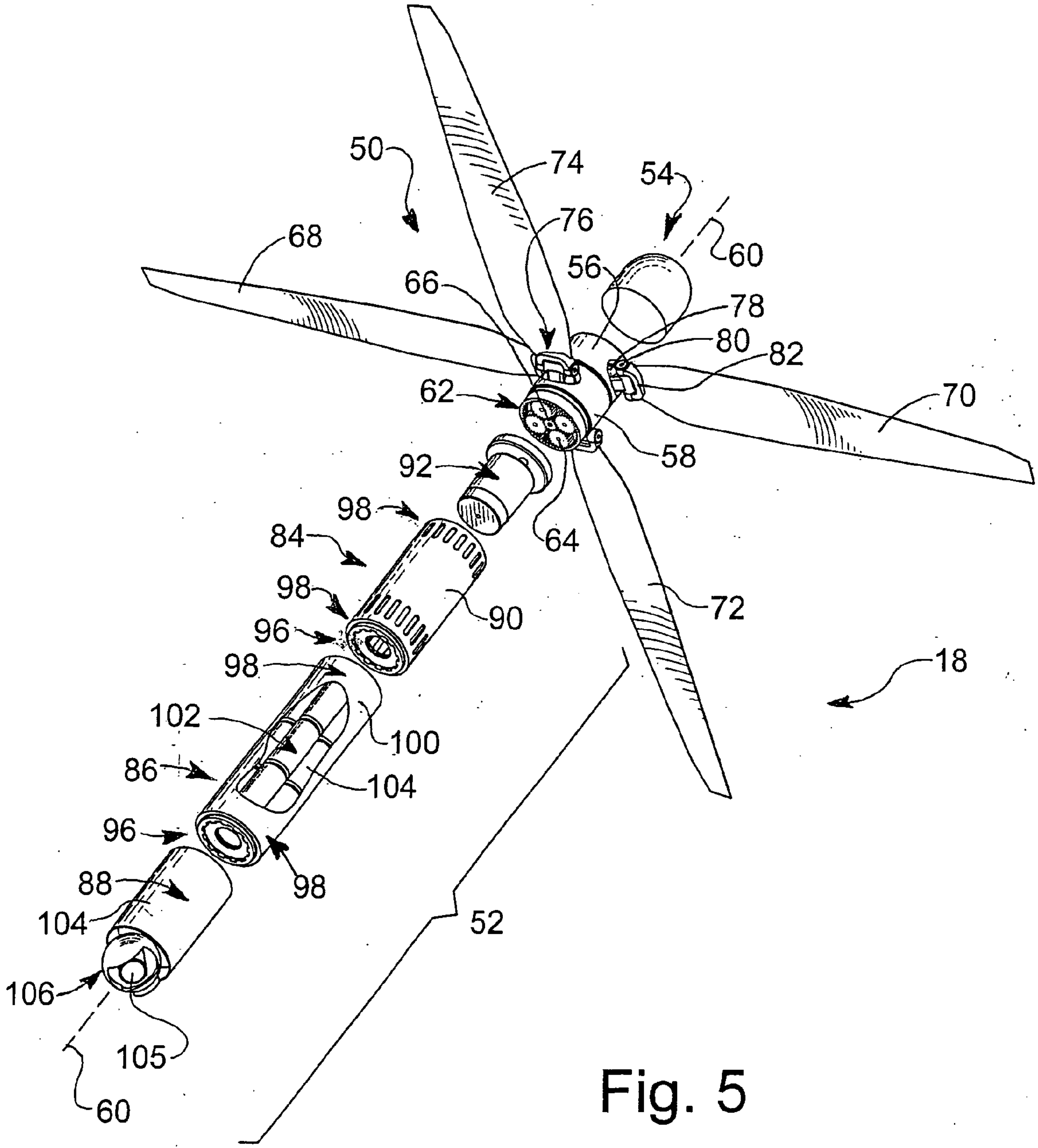
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Fig. 5

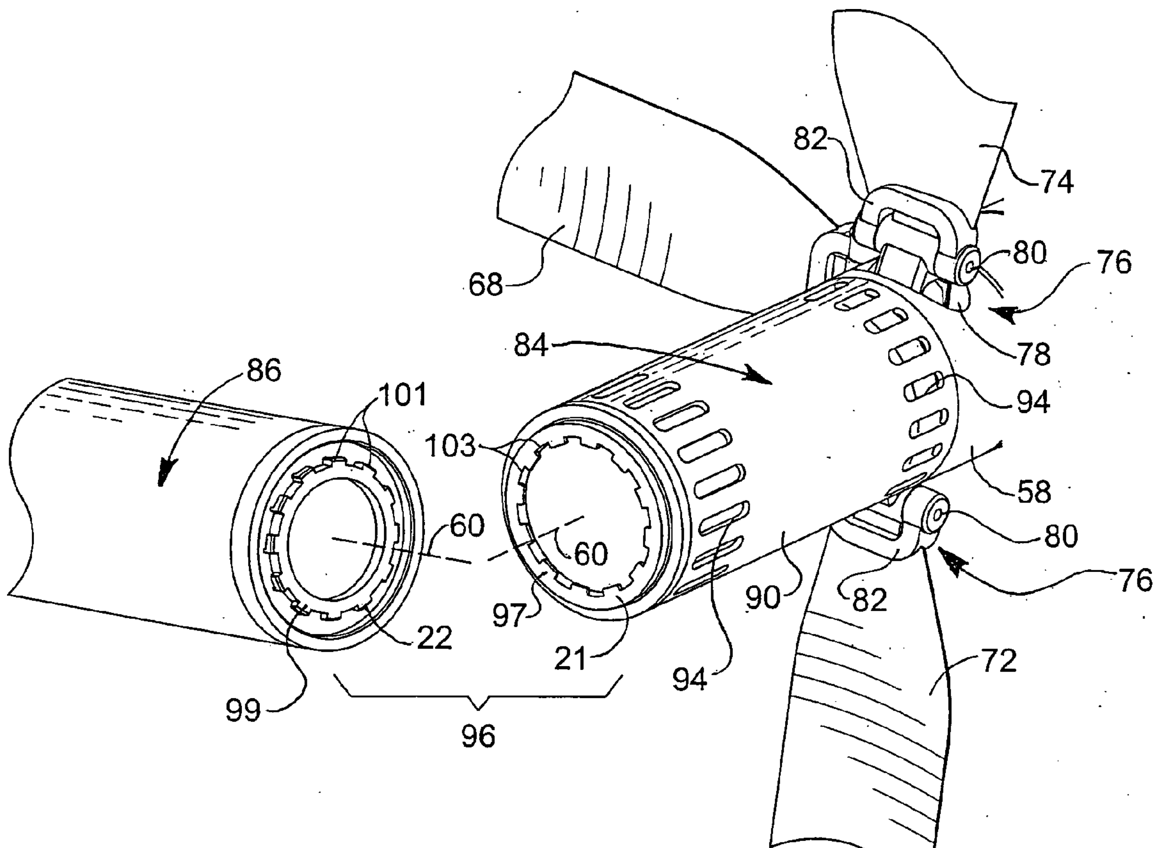
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Fig. 6

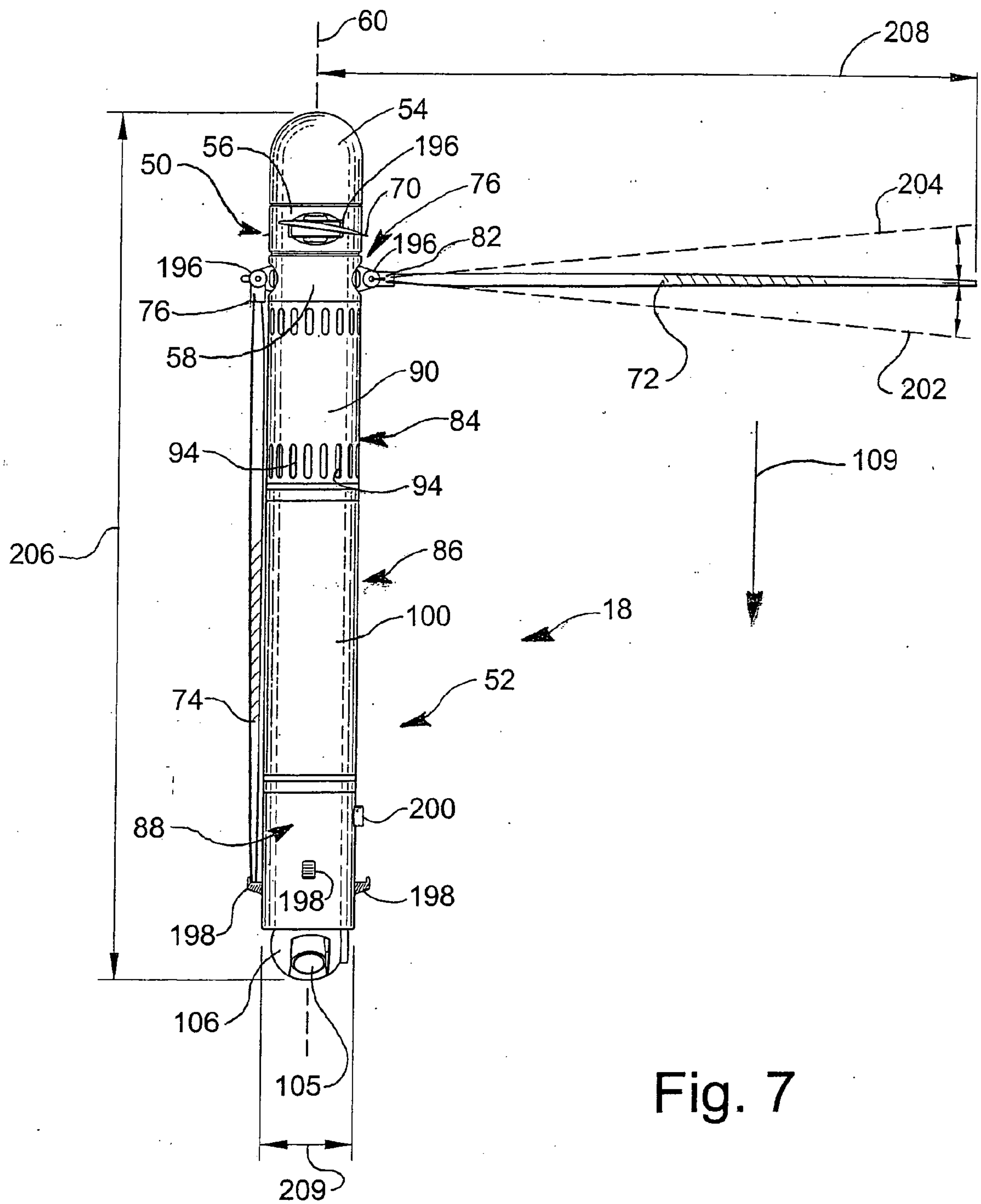
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Fig. 7

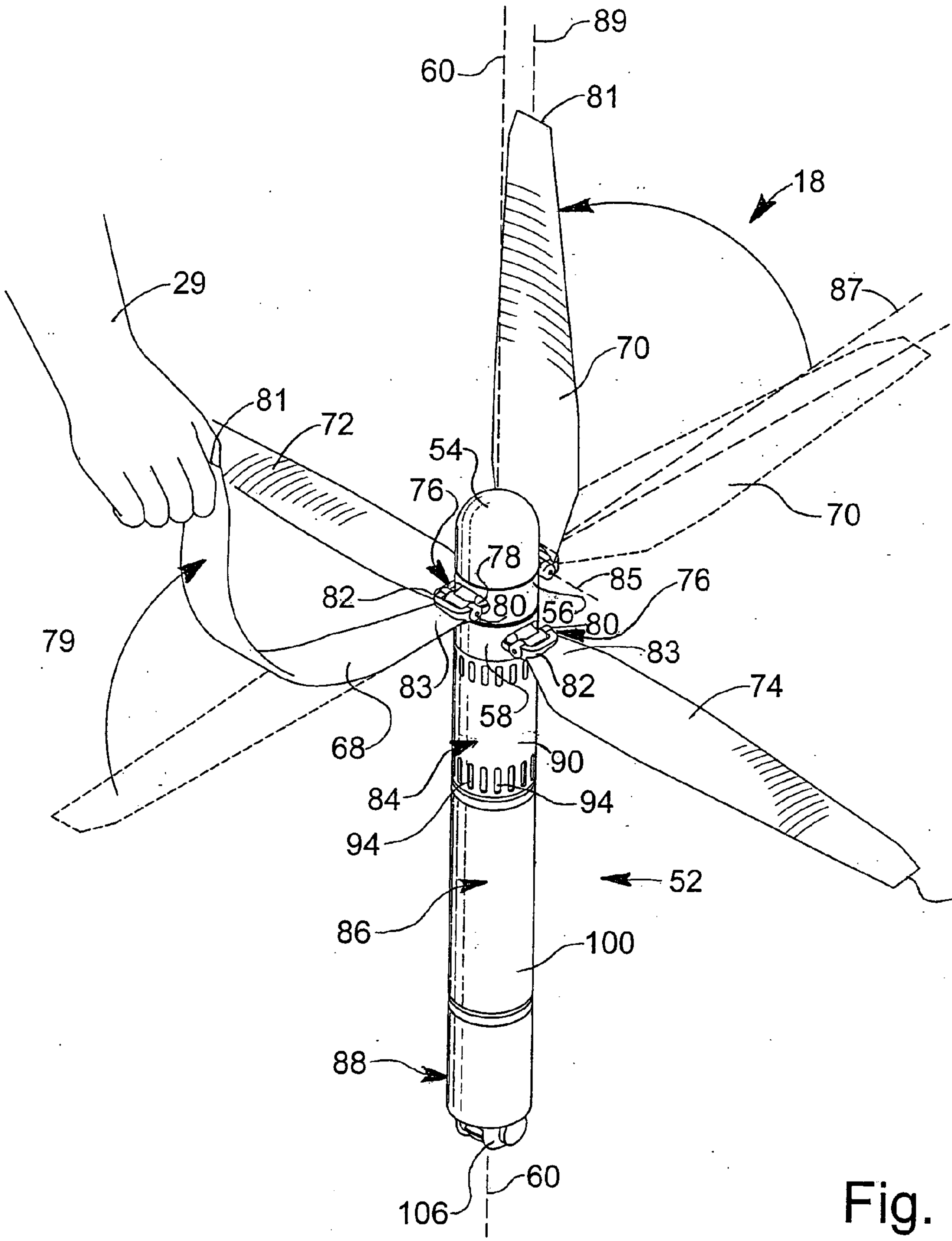
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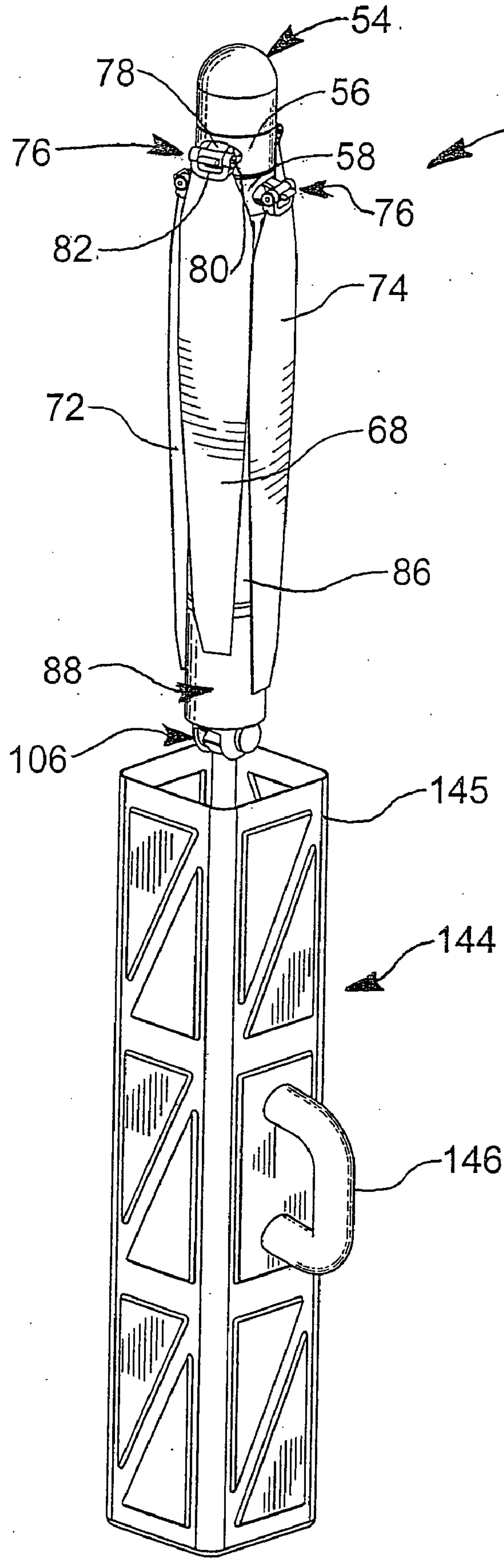
Fig. 8



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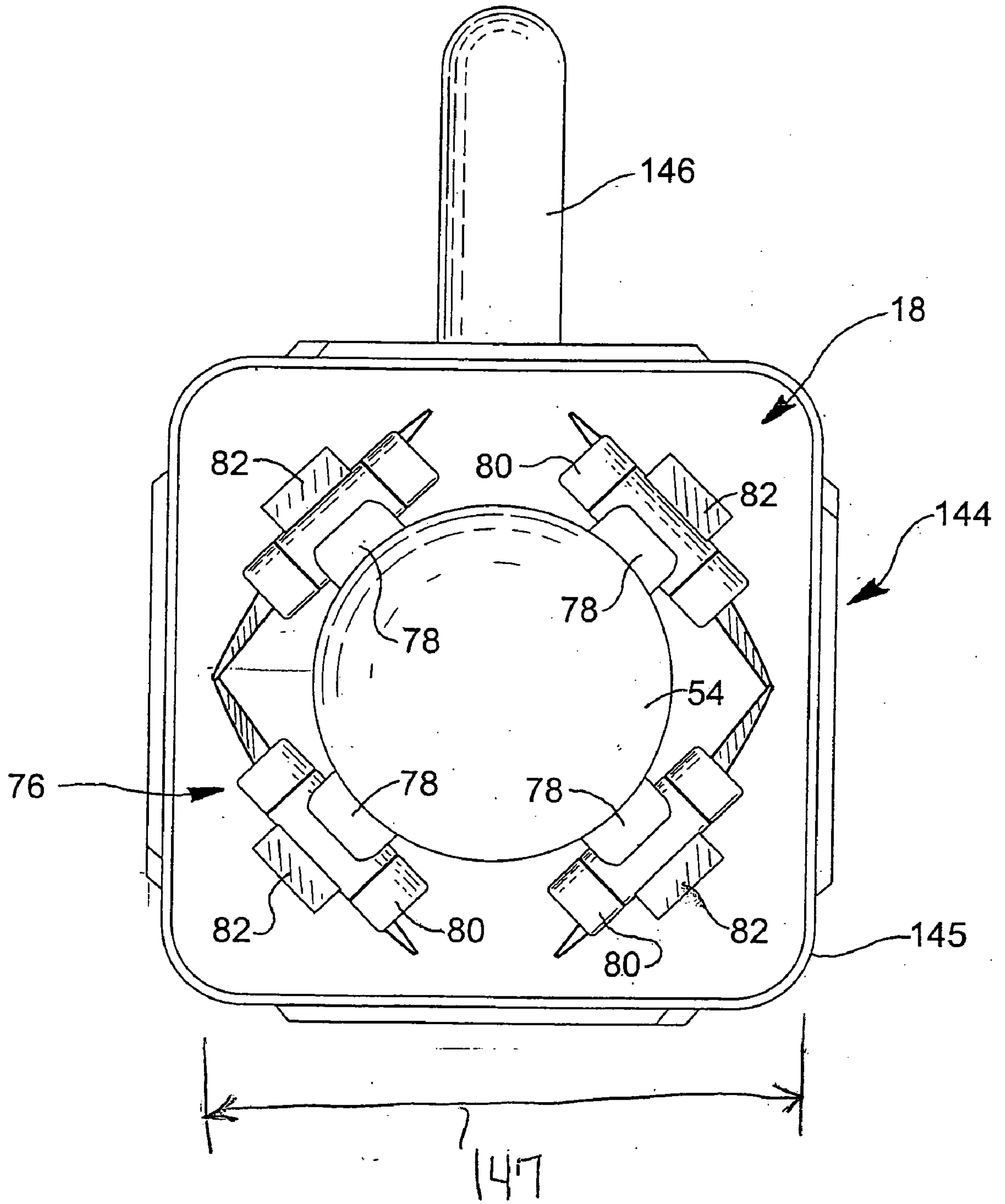

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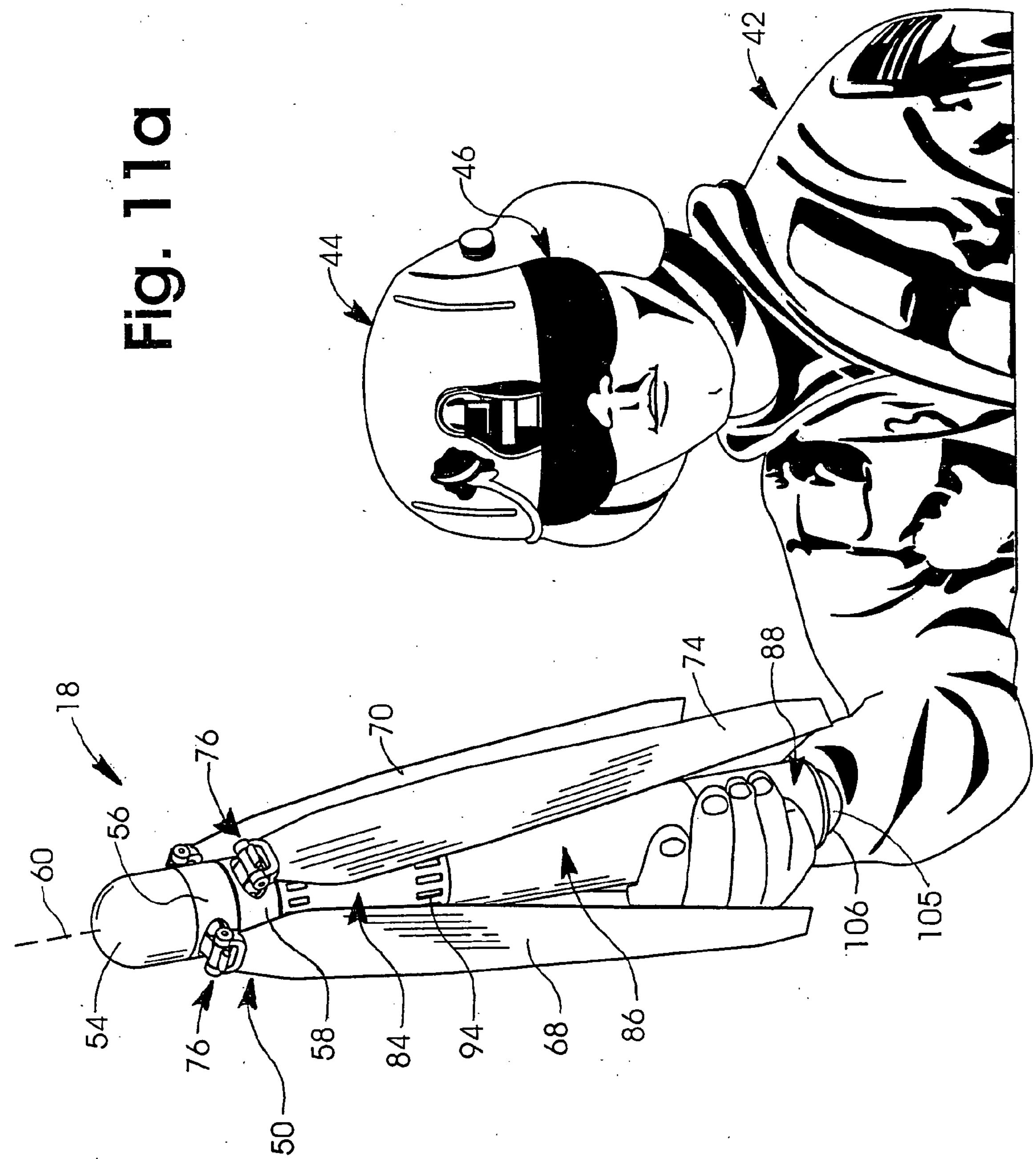
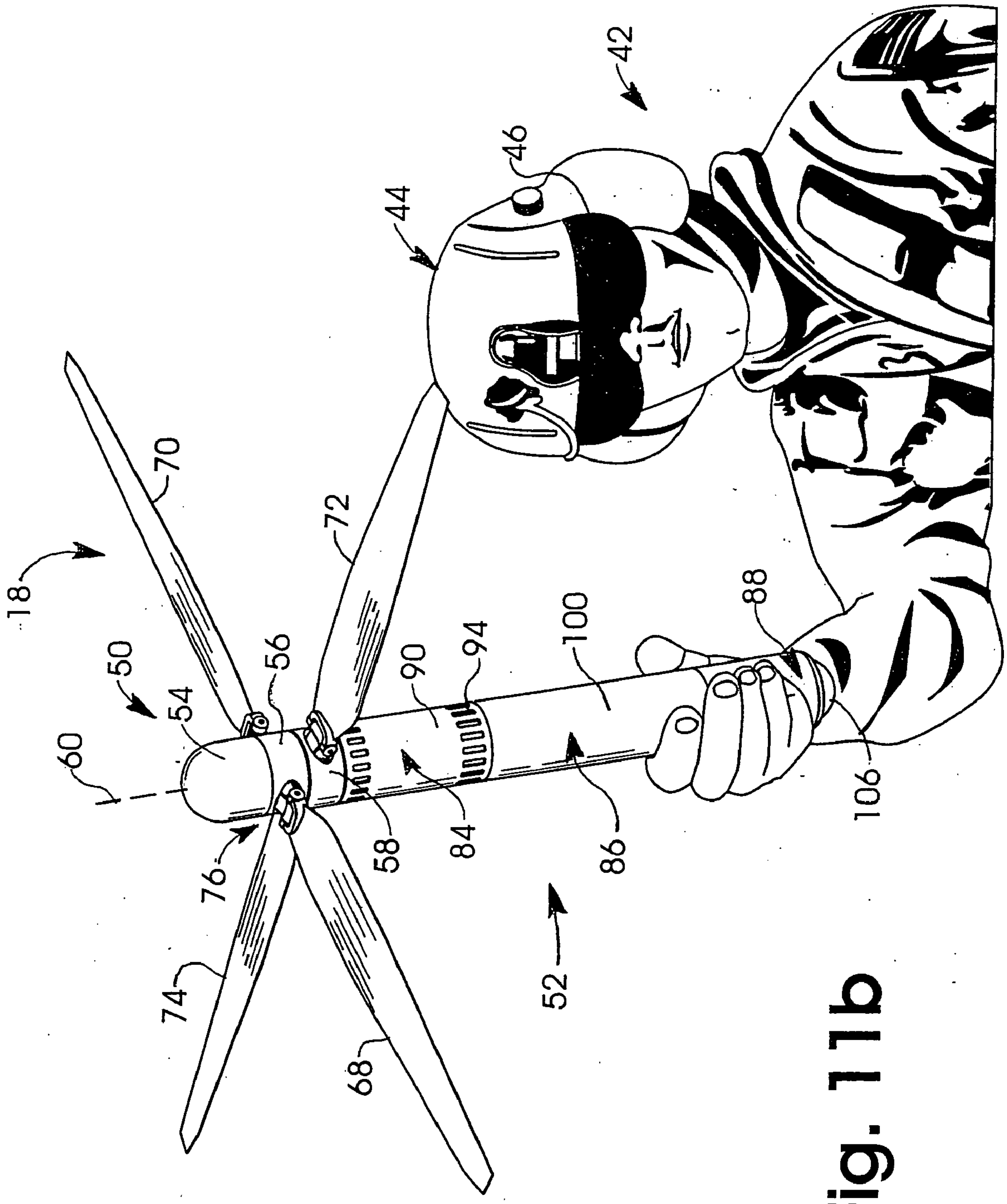


Fig. 11a



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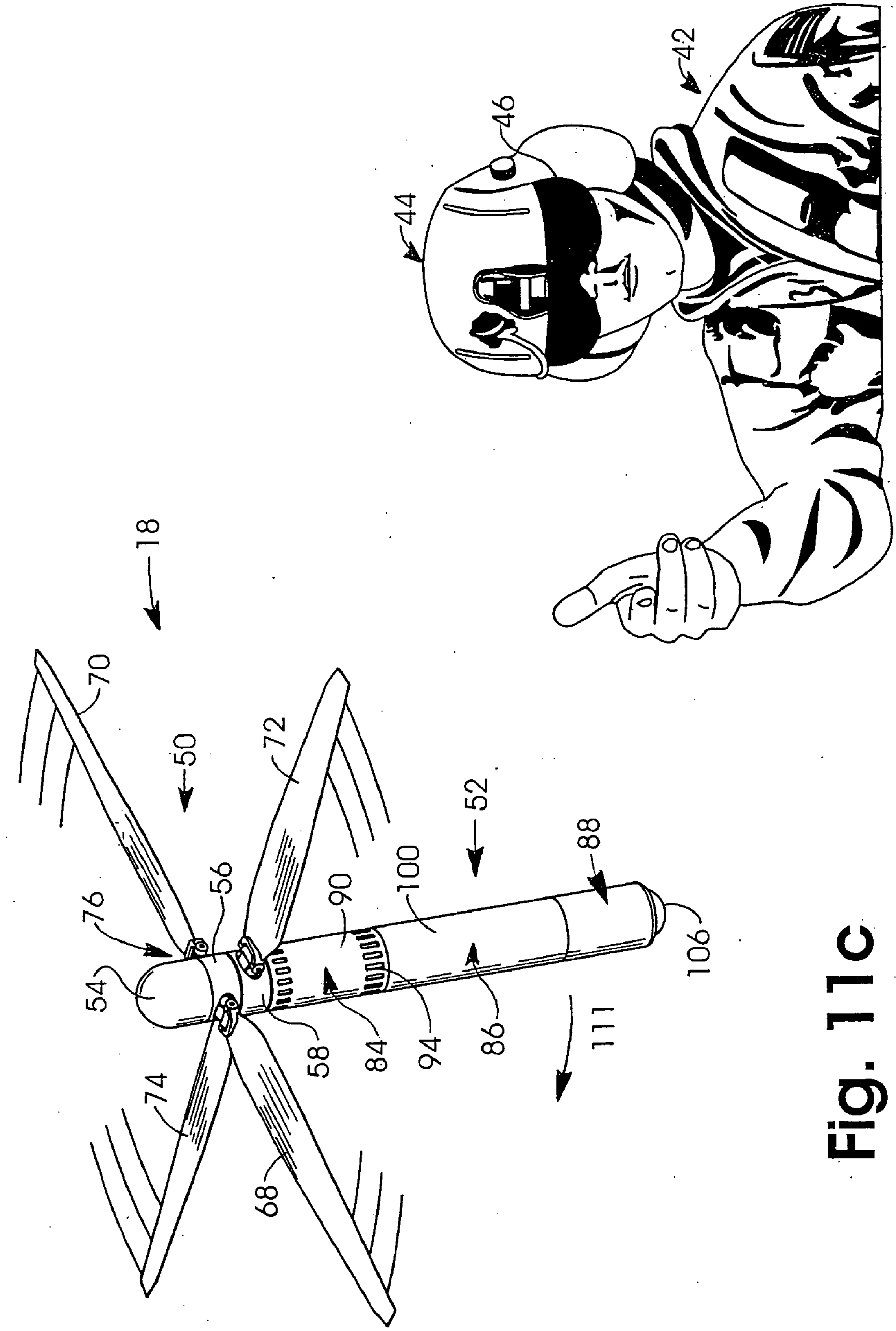

Fig. 11c

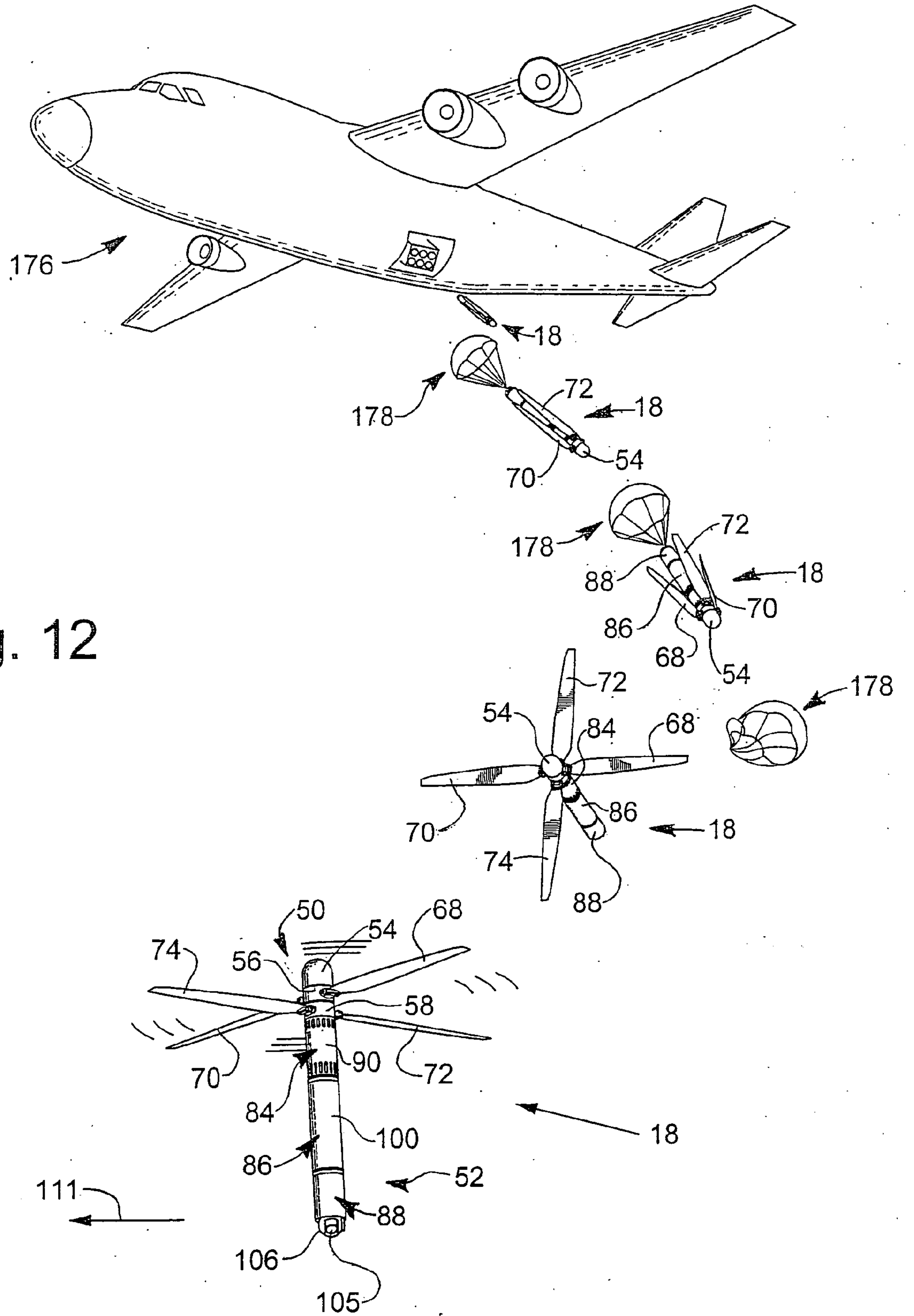
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Fig. 12

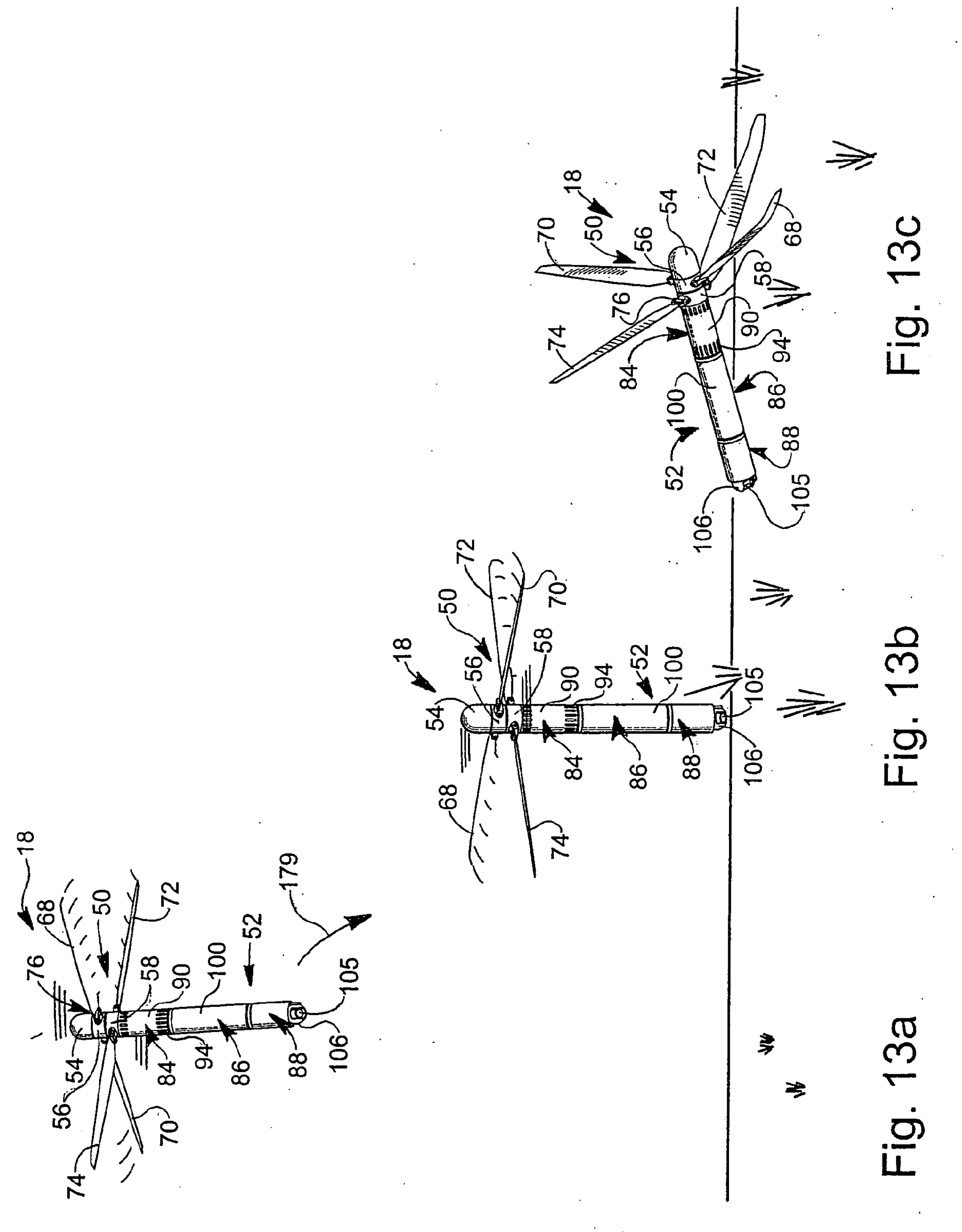
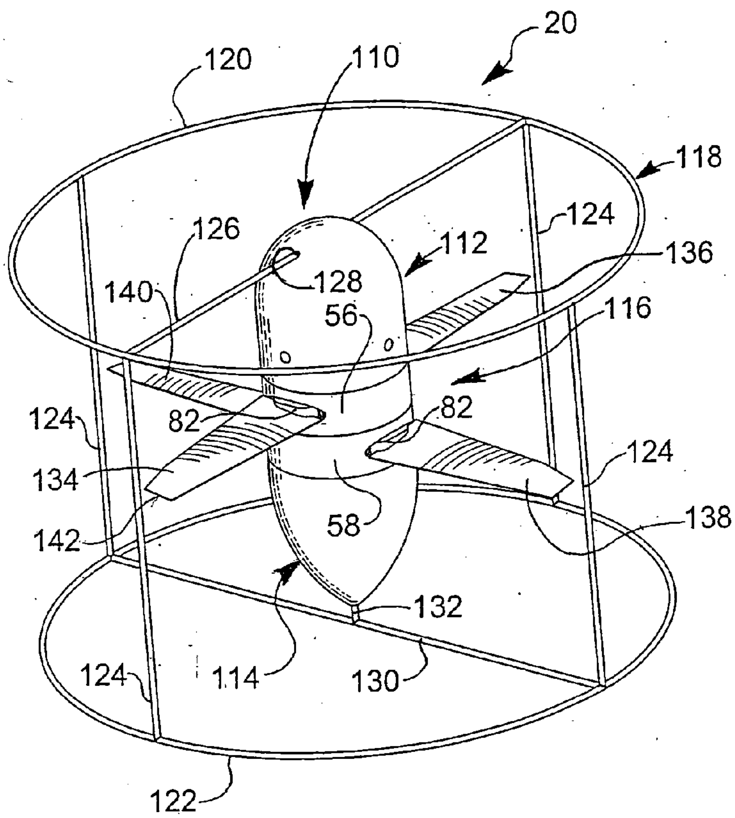


Fig. 13a

Fig. 13b

Fig. 13c



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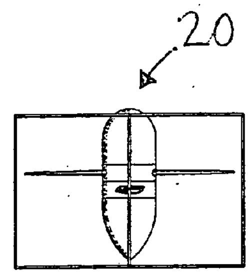

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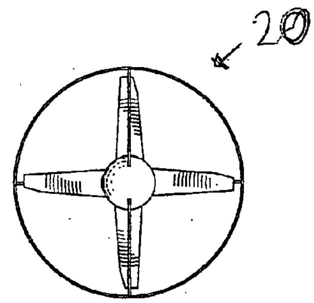

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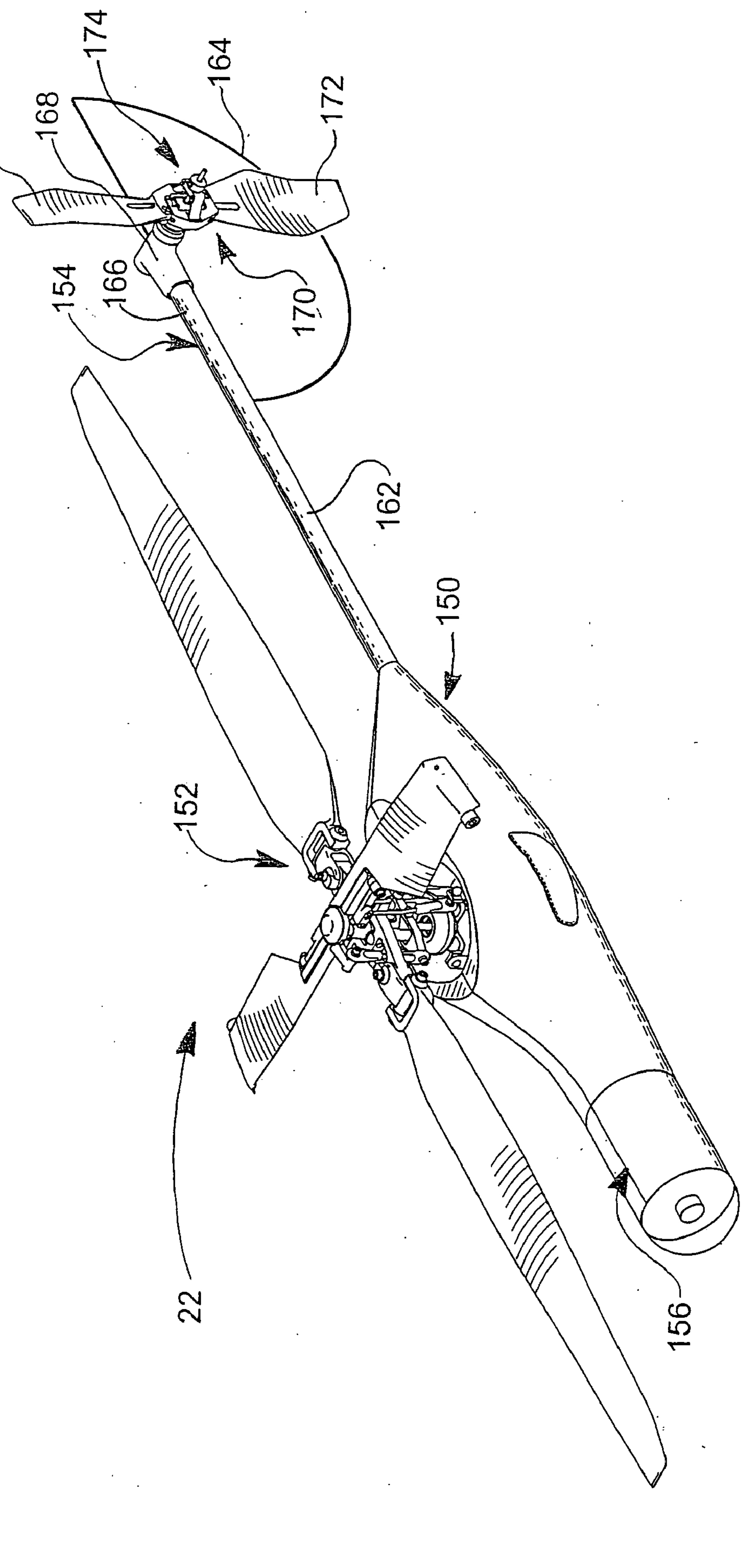

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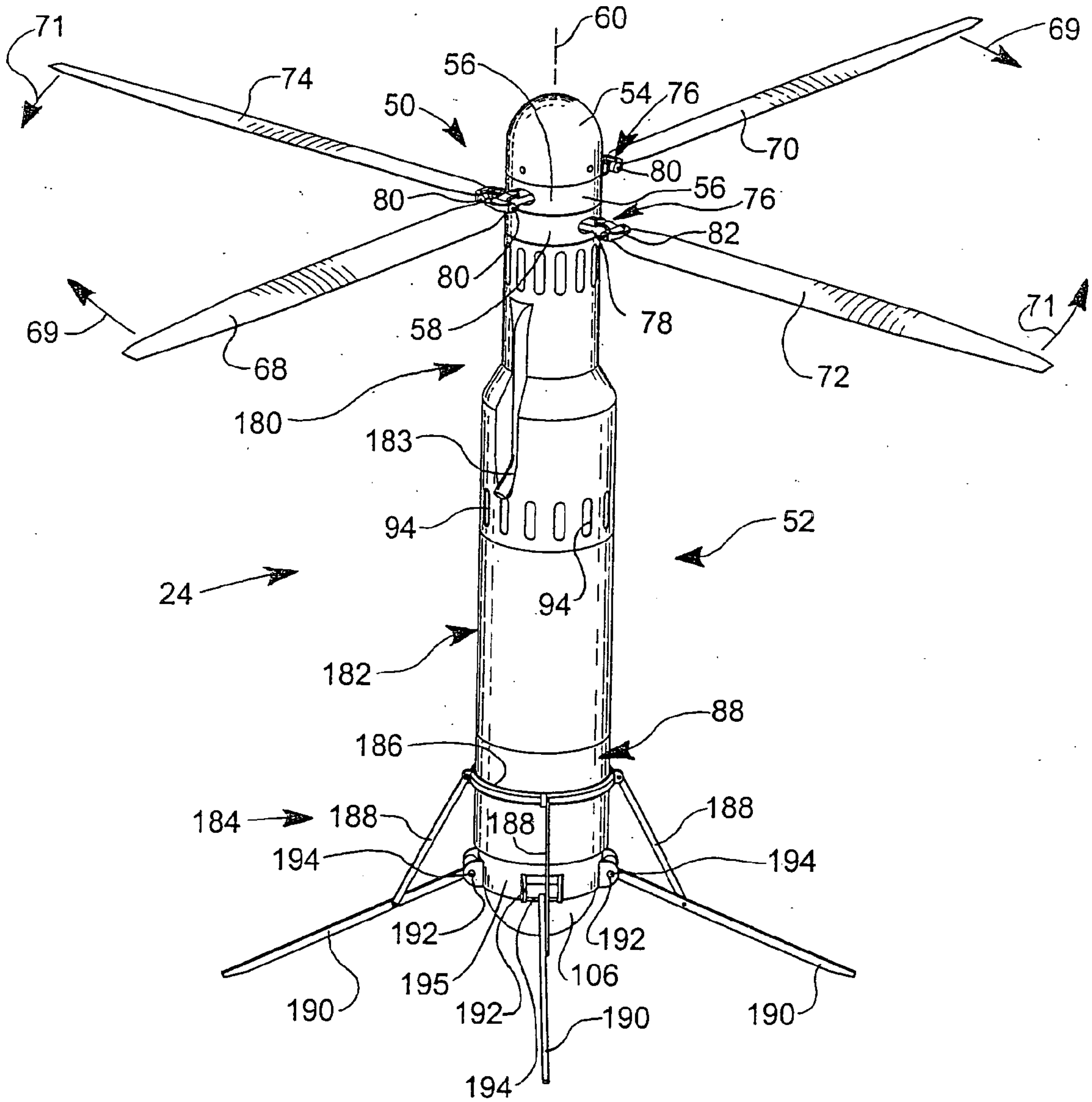
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Fig. 18

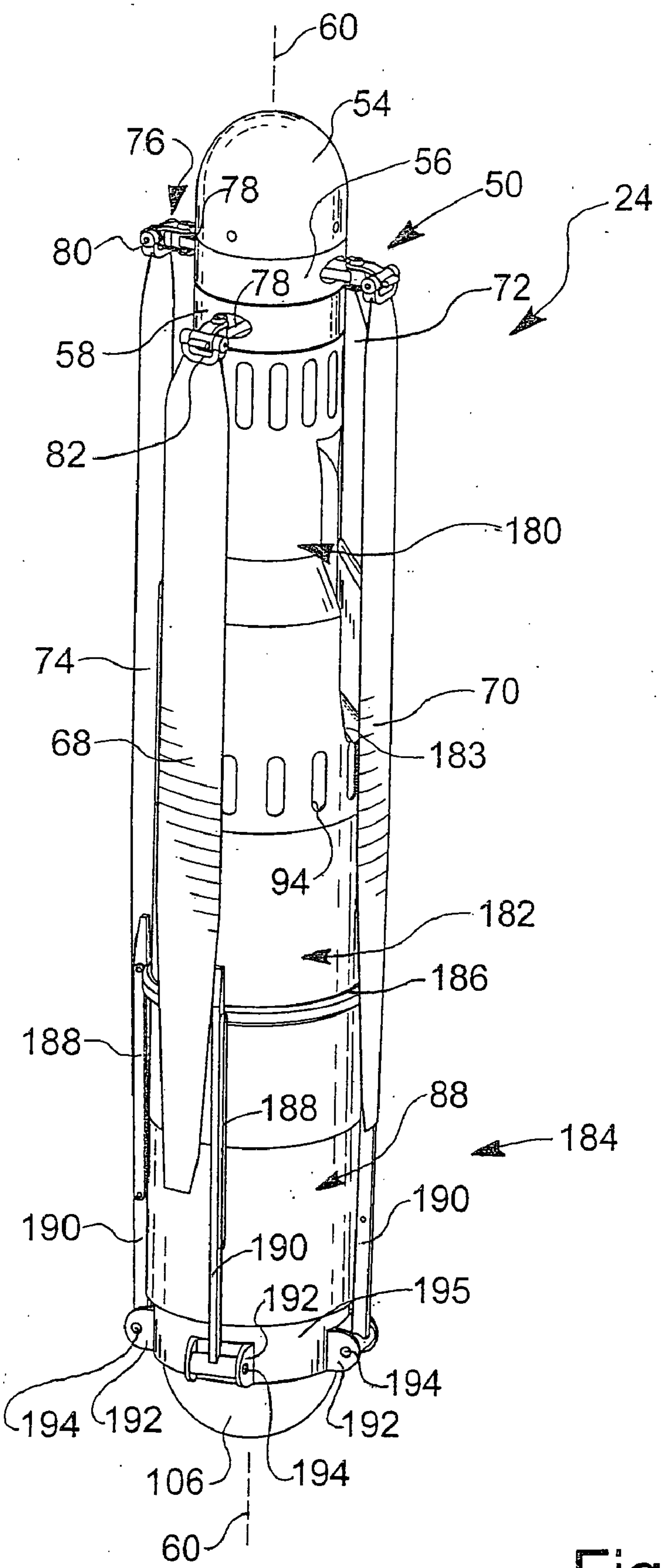
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Fig. 19

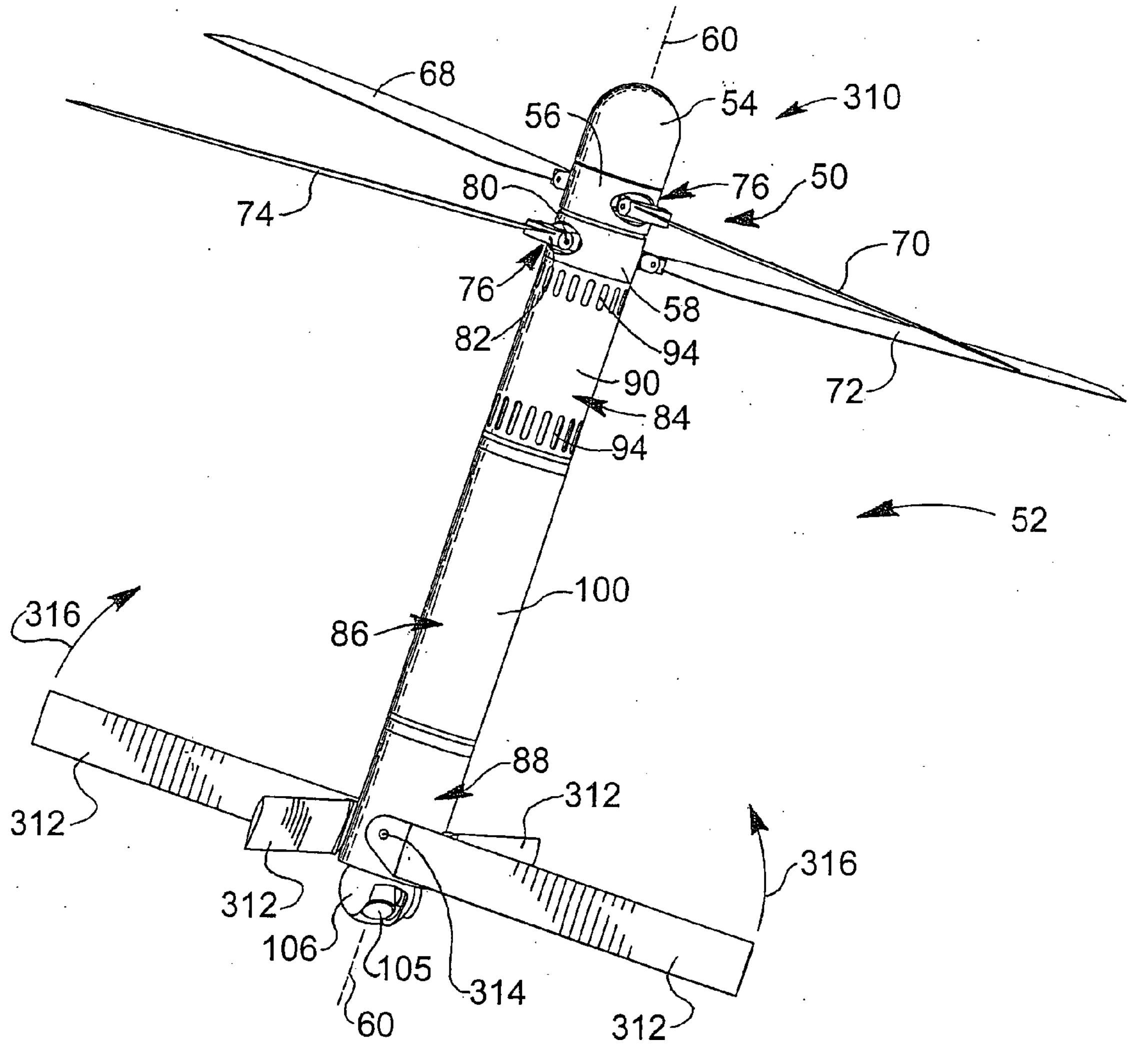
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Fig. 20

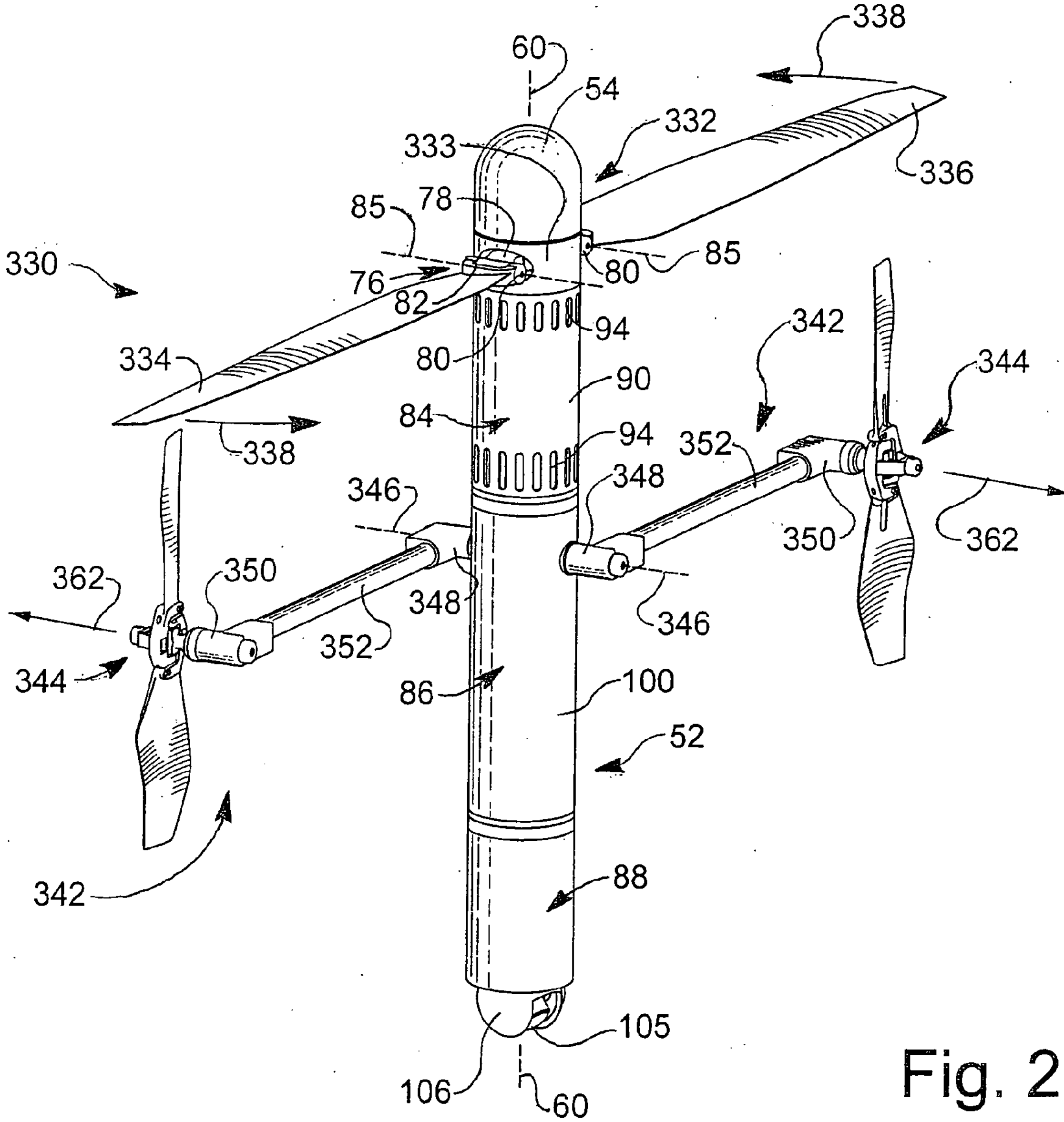
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Fig. 21

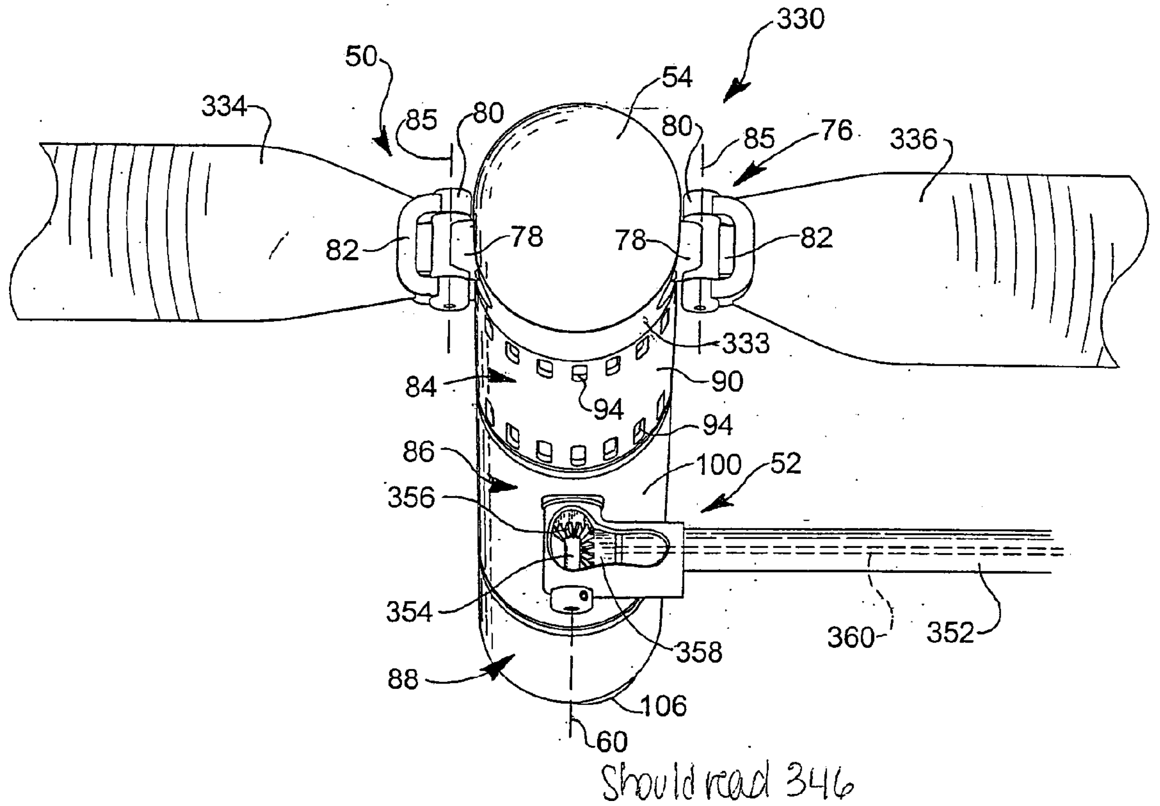
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Fig. 22

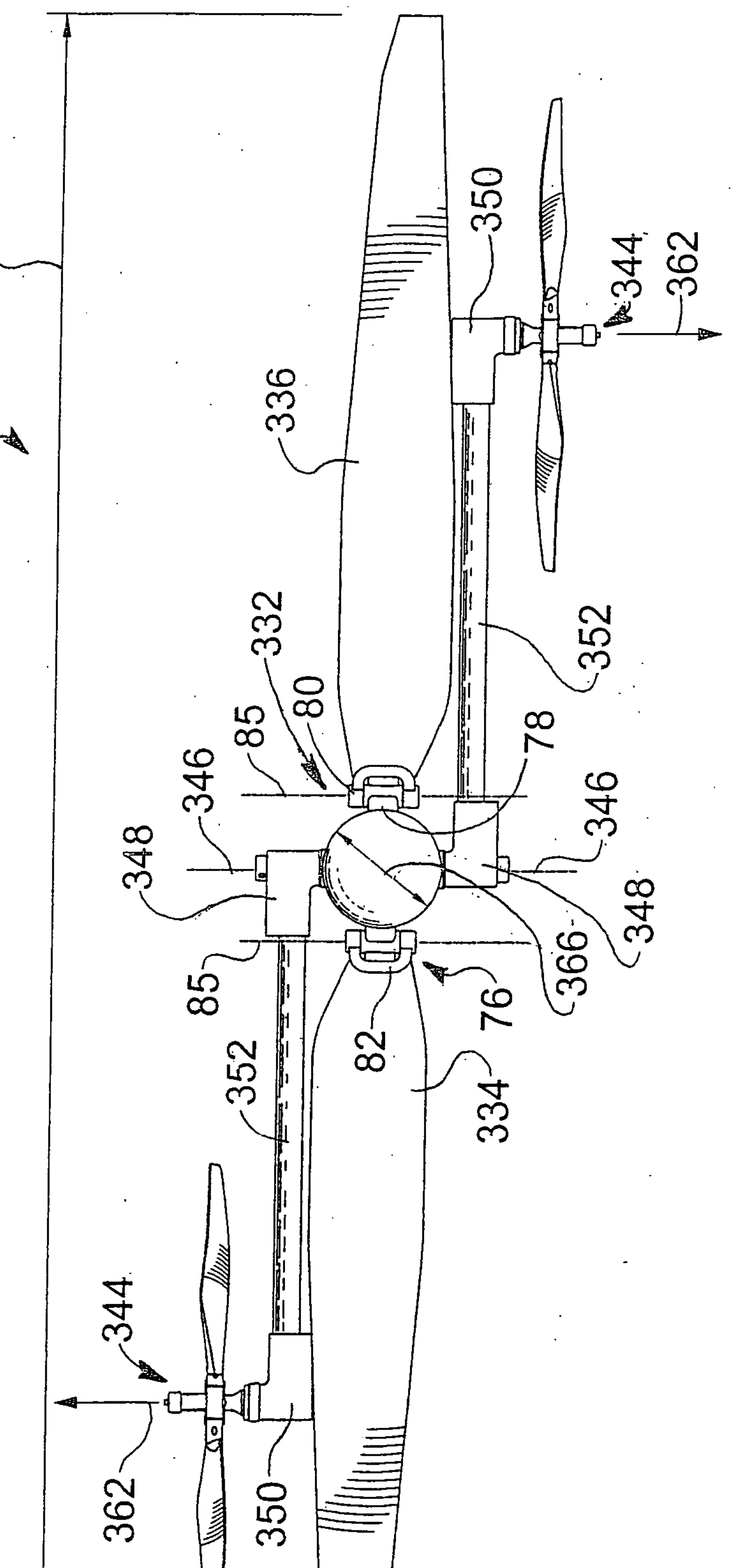
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Fig. 23

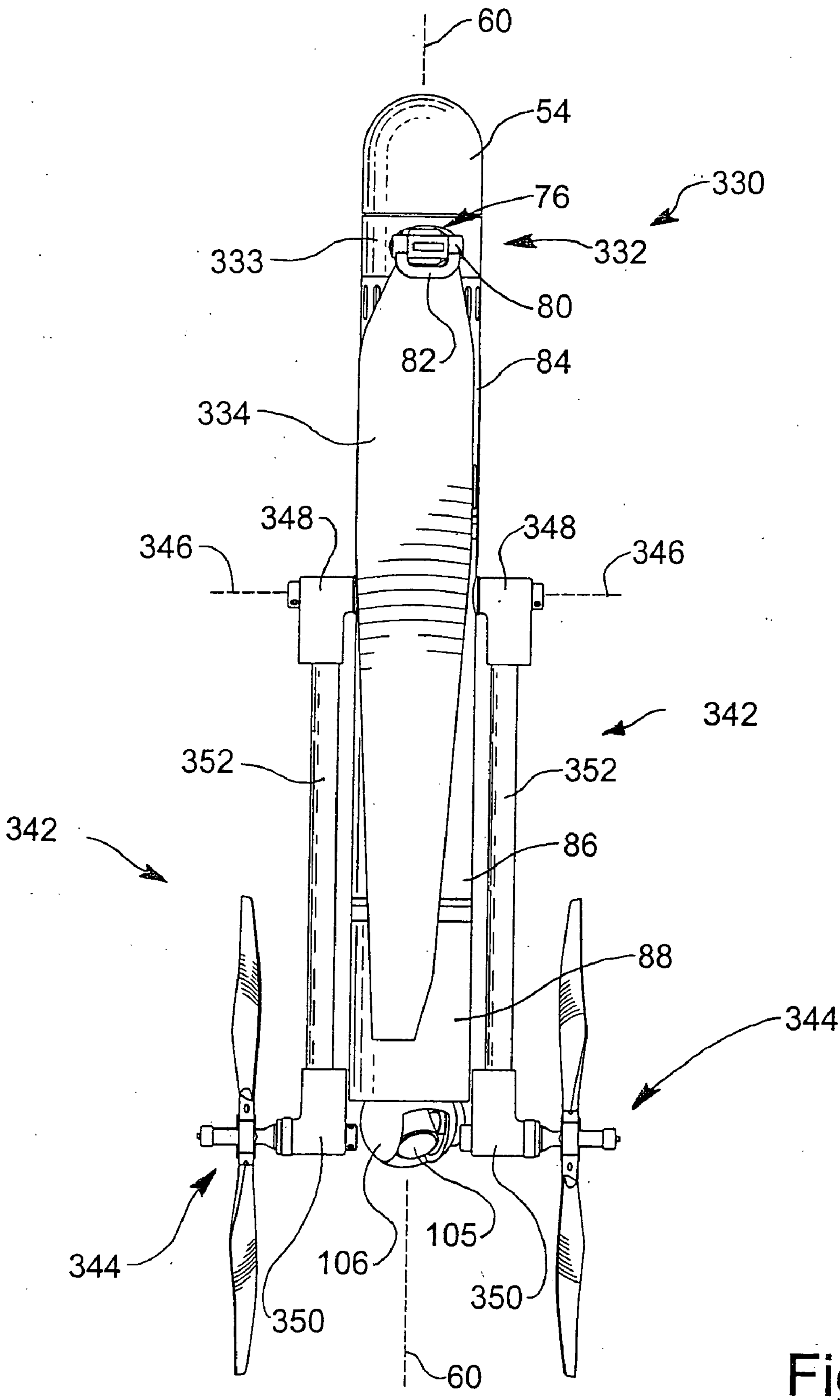
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Fig. 24

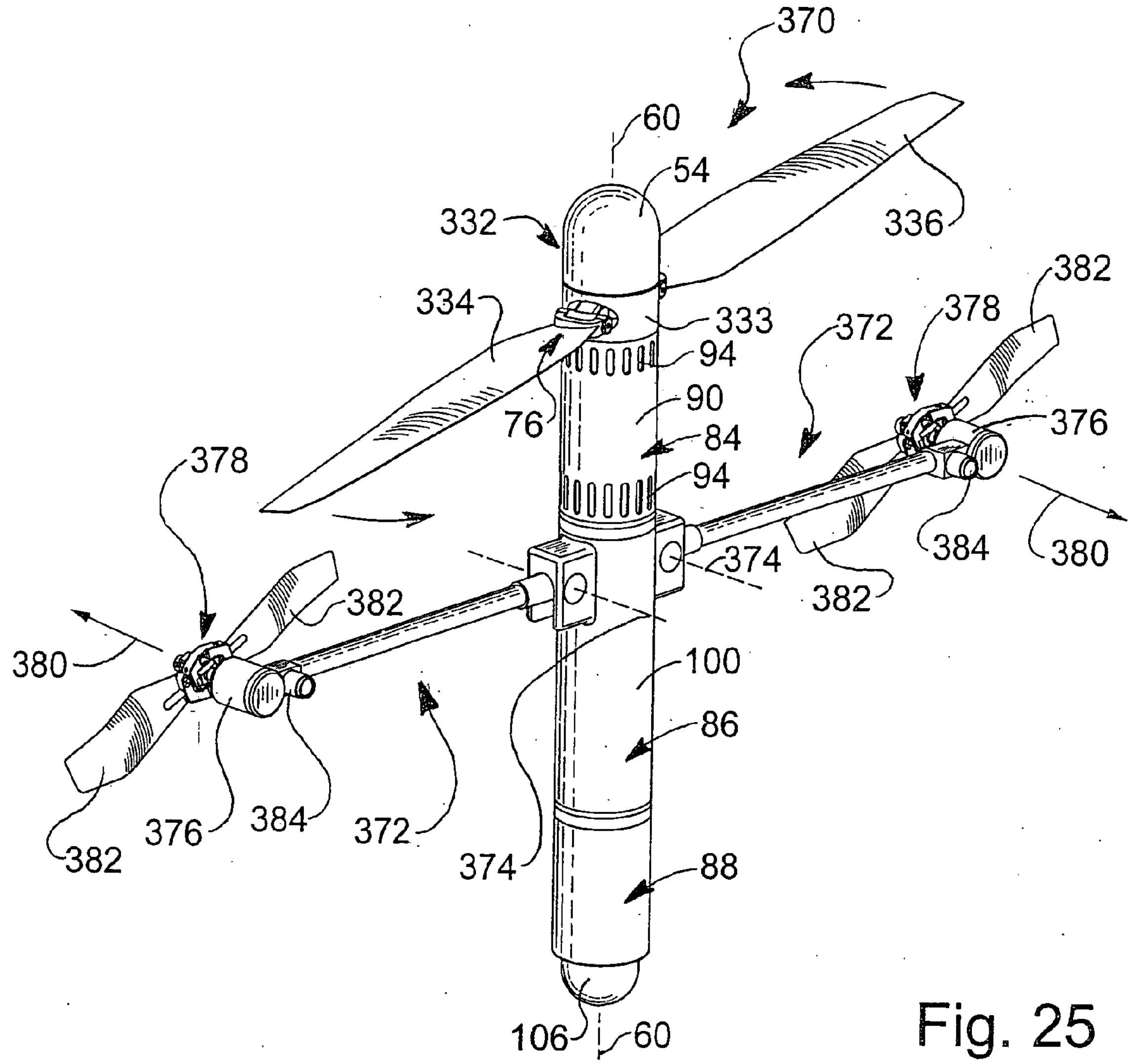
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Fig. 25

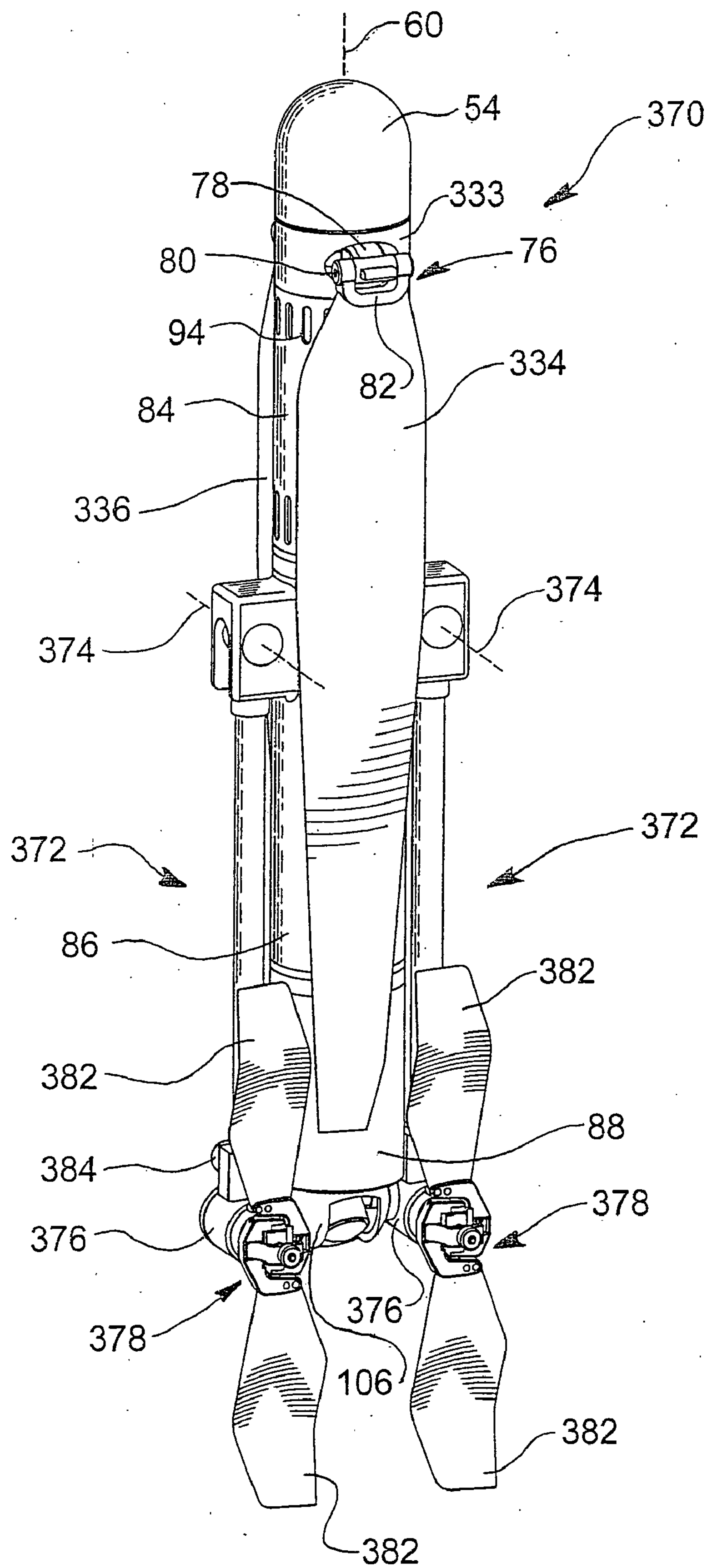
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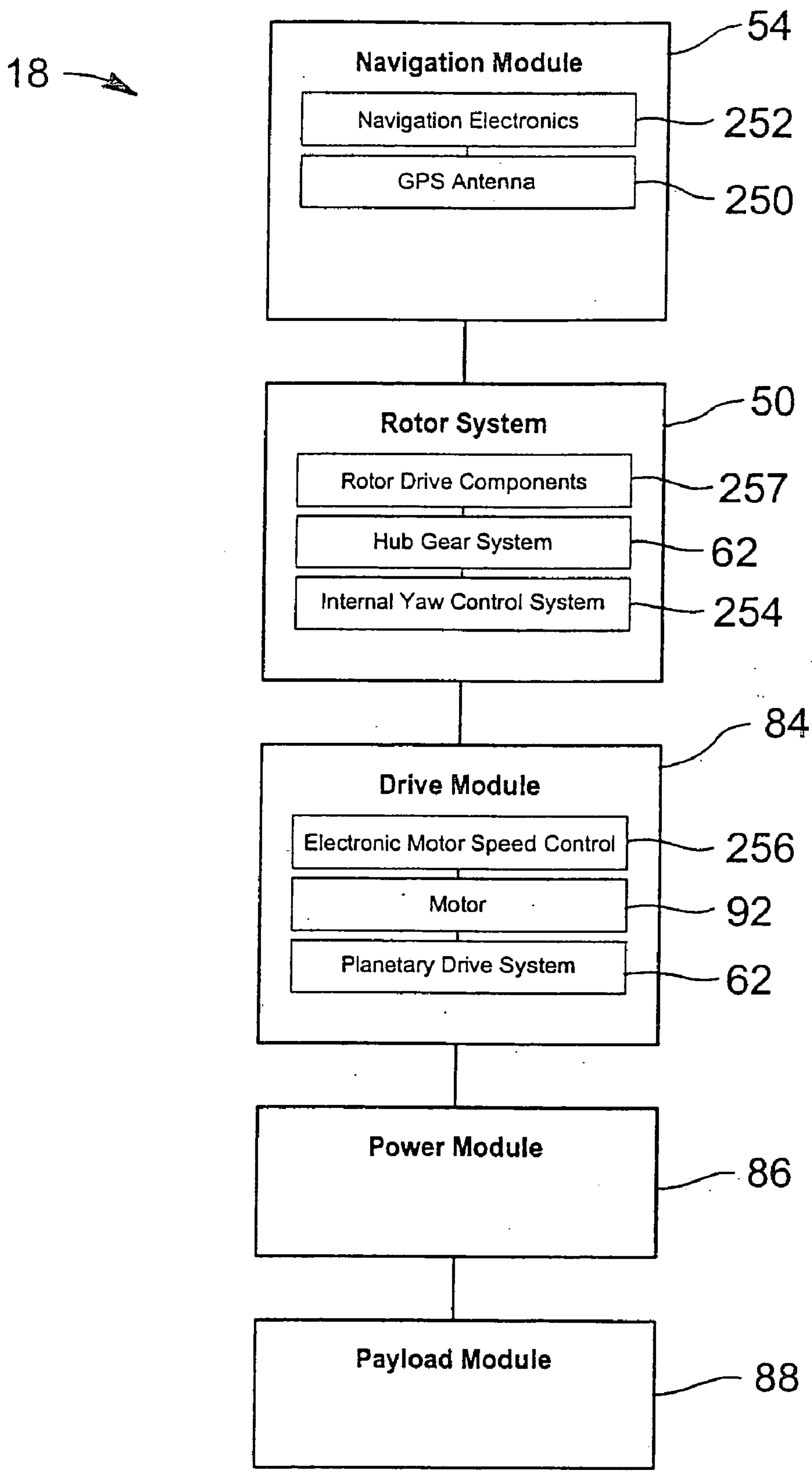
Fig. 26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GPS Antenna
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Rotor System
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Rotor Drive Components
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Hub Gear System
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Internal Yaw Control System
254
Drive Module
84
Electronic Motor Speed Control
256
Motor
92
Planetary Drive System
62
Power Module
86
Payload Module
88

Fig. 27

MICRO-ROTORCRAFT SURVEILLANCE SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Ser. Nos. 60/342,680, filed Dec. 21, 2001 and 60/372,308, filed Apr. 12, 2002, the disclosure of each of which is hereby incorporated by reference herein.

BACKGROUND

[0002] The present disclosure relates to unmanned aerial devices. Particularly, the present disclosure relates to hand-held, remotely operated devices for tactical operations.

[0003] Modem warfare and law enforcement are increasingly characterized by extensive guerilla and counter-terrorism operations conducted by small tactical units of para-military personnel. These units are tasked to root out and defend against hostile forces and/or criminal elements that threaten the unit or the public. Unfriendly forces frequently hide themselves from view or exploit the local terrain to gain tactical advantage or escape from pursuers. In the presence of hostile forces, a simple brick wall, barbed wire fence, body of water, high building or even a large open area devoid of cover can be an insurmountable obstacle when time is of the essence and tactical resources (such as, for instance, a ladder, boat or aircraft) are unavailable. An active threat (such as hostile forces or an armed suspect) can make the situation deadly.

[0004] Stealth and surprise are important elements of tactical advantage; especially where the position and composition of opposing forces is unknown. Visible indications, loud noises, and predictable actions can reveal friendly forces and expose them to hostile fire and casualties. Tactical forces need an unobtrusive, real-time way to visualize their surroundings and objective, reconnoiter the terrain, detect hostile forces and project force at a distance.

[0005] Ballistic methods of surveillance, wherein a projectile or other device is brought to an altitude to descend passively (sometimes with a parachute or other aerodynamic means of control), may have limitations. Ballistic devices generally have limited time aloft, cannot rise and descend repeatedly under their own power and cannot maintain prolonged horizontal flight. This may act to limit their radius of effectiveness and tactic usefulness.

[0006] In this age of technology, warfare and law enforcement are increasingly automated and computerized through the use of drones—robotic vehicles that allow their operators to perform tasks and gather information from a distance without exposing themselves to potentially dangerous situations. Current drones, however, have many practical limitations. Some, such as wheeled vehicles, are restricted to use over smooth, solid surface. Others, such as remotely controlled airplanes must operate at relatively high altitudes to avoid crashing into the local terrain, and require special means of deployment and recovery such as long runways, for example. Most available drones also suffer from lack of portability, and significant support equipment is required for their proper operation.

[0007] Robotic rotorcraft, such as radio controlled helicopters, are typically complex, expensive and may be prone to severe damage. In the normal course of operation and maneuvering, the rotor blades of traditional helicopters can come into contact with a body portion of the helicopter or the local terrain which can often leading to the destruction and operational loss of the helicopter. Due to their size and configuration, available robotic rotorcraft may also be relatively cumbersome to operate, transport and store.

[0008] What is needed is a robotic system that can extend the situational awareness of tactical forces and enhance their ability to deploy sensors and deliver ordnance with high accuracy. Ideally, the system should be simple, compact and expendable to allow for losses in the field. A light weight, portable system would be highly desirable.

SUMMARY

[0009] The present disclosure comprises one or more of the following features discussed below, or combinations thereof:

[0010] A hand-held, miniature flying micro-rotorcraft unit provides remote surveillance, tactical, operational and communication capabilities. The hand-held micro-rotorcraft unit is capable of being deployed anywhere to fly remotely and navigate through various obstacles and over various terrain. The hand-held unit includes a small, elongated body defining a vertical axis. The elongated body includes a plurality of interchangeable, modular components including a power module, a drive module, a payload module, and a navigation module. Extendable/retractable elements are provided to couple to the elongated body, and to be extended during flight to perform various operational functions.

[0011] A rotor means is coupled to an upper end of the hand-held elongated body for rotation about the vertical body axis to lift the hand-held elongated body into the air. The rotor means is driven by drive means located within the drive module. The rotor means may include a pair of upper rotor blades coupled to a first rotatable hub, a pair of lower rotor blades coupled to a second rotatable hub, and means for supporting the first and second rotatable hubs for rotation about the vertical body axis in opposite directions.

[0012] The power module includes a power supply for energizing the drive means. The navigation module includes means for determining a global position of the hand-held elongated body during flight of the micro-rotorcraft unit. The payload module may include explosive or incendiary munitions, and biological or chemical sensors, for example.

[0013] Features of the present disclosure will become apparent to those skilled in the art upon consideration of the following detailed description of illustrative embodiments exemplifying the best mode of carrying out the disclosure as presently perceived.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The detailed description particularly refers to the accompany figures in which:

[0015] **FIG. 1** is a diagrammatic view of an integrated micro-rotorcraft system of the present disclosure for providing remote surveillance of an area showing a mobile command center of the system and various micro-rotorcraft units of the system which are in communication with the mobile command center;

[0016] **FIG. 2** is a side view of the illustrative mobile command center of the system showing an all-terrain vehicle of the command center, an operator and computer network within the mobile command center, and a trailer for hauling micro-rotorcraft units therewith;

[0017] **FIG. 3***a* is a perspective view of the trailer shown in **FIG. 2** showing four mobile base units carried on the trailer, and further showing each mobile base unit including multiple storage cavities or tubes for stowing various micro-rotorcraft units therein;

[0018] **FIG. 3***b* is a rear view of the trailer of **FIG. 3***a;*

[0019] **FIG. 3***c* is a side view of the trailer of **FIGS. 3***a* and **3***b;*

[0020] **FIG. 4** is a perspective view of a hand-held surveillance micro-rotorcraft unit showing the unit including a co-axial, counter-rotating rotor system and an elongated body having interchangeable modular components coupled to the rotor mechanism;

[0021] **FIG. 5** is an exploded perspective view of the micro-rotorcraft unit shown in **FIG. 4** showing a first module or component of the body coupled to the rotor system and including a motor, a second, or middle, module including a battery pack, and a third, or end, module for carrying a payload;

[0022] **FIG. 6** is a perspective view of a modular coupling attachment mechanism of the unit shown in **FIGS. 4 and 5** showing an end of each modular component having a toothed coupling ring of the coupling mechanism;

[0023] **FIG. 7** is a side elevation view of the rotorcraft unit of **FIGS. 4-6** showing a spring-loaded rotor blade element retained in a storage configuration, and also showing the element extendable toward a flight configuration and having a nominal flapping angle when in the flight configuration;

[0024] **FIG. 8** is a perspective view of the unit of **FIGS. 4-7** showing the flexible rotor blades of the rotor system being bent by the hand of an operator to illustrate the durability of the rotor blade;

[0025] **FIG. 9** is a perspective view of the unit of **FIGS. 4-8** showing the unit in the stowed position for storage into a storage tube or carrying case of the present disclosure;

[0026] **FIG. 10** is a top view of the unit and carrying case showing the unit stowed within the case for transport by an operator,

[0027] **FIGS. 11***a***-11***c* shows first, second and third steps in manually deploying the unit;

[0028] **FIG. 12** is a perspective view showing a method of deploying the rotorcraft unit of **FIGS. 4-10** from an aircraft in flight;

[0029] **FIGS. 13***a***-13***c* are perspective views of the rotorcraft unit of **FIGS. 4-10** showing first, second and third steps in landing or recovering the unit;

[0030] **FIG. 14** is a perspective view of another micro-rotorcraft unit for use with the integrated system of the present disclosure showing the micro-rotorcraft unit including an outer wire cage, a central body coupled to the cage, and rotor blades coupled to the body;

[0031] **FIG. 15** is a side view of the micro-rotorcraft unit shown in **FIG. 7**;

[0032] **FIG. 16** is a top view of the micro-rotorcraft unit shown in **FIGS. 7 and 8**;

[0033] **FIG. 17** is a perspective view of yet another micro-rotorcraft unit for use with the integrated system of the present disclosure showing the micro-rotorcraft unit including a body, a rotor system with rotor blades attached to the body, and a tail having a rudder and another set of rotor blades attached thereto;

[0034] **FIG. 18** is a perspective view of still another micro-rotorcraft unit for use with the integrated system of the present disclosure showing the unit including an elongated body, a rotor system coupled to the body at an upper end, and a landing gear system, shown in a landing configuration, coupled to the body at a lower end of the body to allow the unit to stand upright as shown;

[0035] **FIG. 19** is a perspective view of the micro-rotorcraft unit of **FIG. 18** showing the landing gear system and the rotor blades of the rotor system in a stowed or retracted position;

[0036] **FIG. 20** is a perspective view of another rotorcraft unit of the present disclosure showing the unit having a co-axial counter-rotating rotor system with rotor blade elements appended to an upper end of an elongated body portion, aerodynamic fin elements appended to a lower end of the body, and the rotor blade elements and fin elements being shown extended in a flight configuration;

[0037] **FIG. 21** is a perspective view of another rotorcraft unit of the present disclosure showing the unit having a single rotor system with rotor blade elements appended to an upper end of the elongated body, and also disclosing mechanically driven, variable-thrust yaw control elements appended to a mid-section of the body, and showing the yaw control elements extended in a flight configuration;

[0038] **FIG. 22** is a perspective view of the unit shown in **FIG. 21** (with portions broken away) showing the yaw elements extended in the flight configuration, and a yaw control arm attachment elbow shown in cutaway to reveal a mechanical drive mechanism inside;

[0039] **FIG. 23** is a top view of the unit shown in **FIGS. 21 and 22** showing the rotor blade and yaw control elements extended in the flight configuration;

[0040] **FIG. 24** is a side view of the unit shown in **FIGS. 21-23** showing the rotor blade and yaw control elements folded in a stowed configuration;

[0041] **FIG. 25** is a perspective view of yet another rotorcraft unit of the present disclosure showing the unit having a single rotor system appended to an upper end of the body, and electrically driven variable thrust yaw-control elements and sensors appended to a mid-section of the body, and showing the yaw control elements extended in a flight configuration;

[0042] **FIG. 26** is a perspective view of the unit shown in **FIG. 25** showing the rotor blade and yaw-control elements folded in a stowed configuration; and

[0043] **FIG. 27** is a diagrammatic view of the unit shown in **FIGS. 4-8** showing the interchangeable modular components of the unit, and also showing various sub-components of each module.

DETAILED DESCRIPTION OF THE DRAWINGS

[0044] An integrated micro-rotorcraft system **10** includes a mobile command center **12** and various radio-controlled or self-guided micro-rotorcraft units, described in detail below. Illustrative components of integrated system **10** are shown in **FIG. 1**, for example. In general, the micro-rotorcraft units of integrated system **10** are miniature to provide remote surveillance and communication capabilities. Each unit is linked to the mobile command center **12** via an integrated data network. As is discussed in more detail below, each of the micro-rotorcraft units is able to survey remote areas and relay back real-time information including pictures of the tactical situation from numerous perspectives. Further, each unit is capable of rapidly deploying assets to new areas. The micro-rotorcraft units are able to act in coordination with each other and with the mobile command center **12** to perform a desired function such as search and rescue, observation, inspection, sampling, etc.

[0045] Micro-rotorcraft units may be remotely controlled by operators at the mobile command center **12** and may be pre-programmed to perform a set of instructions autonomously in the event that contact is lost between the particular micro-rotorcraft unit and the mobile command unit **12**, or when insuring stealth or secrecy is required. In this autonomous mode, micro-rotorcraft units operate without direct input from the mobile command unit **12** and are capable of sending data to a data hub without revealing the position of the data hub.

[0046] Due at least in part to their small size, each micro-rotorcraft unit is capable of acting as an anti-personnel weapon by locating and striking individual combatants silently and from any direction. Illustrative system **10** may include up to one thousand micro-rotorcraft units. Each unit includes a payload module which may comprise video cameras (visible light and infrared), sensors (biological and chemical), munitions (explosive and incendiary), etc. Further each unit includes a navigation system, telemetry uplink and downlink capability, and autonomous autopilot capability. System **10** is capable of fusing a picture of the environment and taking coordinated action. Fitted with telemetry and data uplink/downlink electronics, each micro-rotorcraft unit may be operated from a central command center, a satellite, or an orbiting aircraft, such as a fixed-wing "Predator" drone, for example.

[0047] Looking again to **FIG. 1**, system **10** includes mobile command center **12**, mobile base units **14** carried on a trailer **16** coupled to mobile command center **12**, and illustrative micro-rotorcraft units **18**, **20**, **22**, and **24**. System **10** also includes micro-rotorcraft units **310**, **330**, **370**, shown in **FIGS. 20-26**, as well. Within mobile command center **12** exists an integrated network **26**, including various computers, monitors, etc., which allows units **18**, **20**, **22**, **24**, **310**, **330**, **370** to cooperate with each other and to remotely relay information to mobile command center **12**. A video display and downlink helmet **28** of system **10** further communicates with units **18**, **20**, **22**, **24**, **310**, **330**, **370** to allow an operator **29** wearing helmet **28**, but located away from mobile command center **12** and network **26**, to receive data from and remotely control units **18**, **20**, **22**, **24**, **310**, **330**, **370**, as is described in more detail below.

[0048] In operation, a pilot or operator **29** may be provided with display helmet **28**, also shown in **FIGS. 11*a*-11*c***, including video display glasses **46** which receive a video image from the camera or cameras **105** located at the base of payload module **88** to allow pilot or operator **29** to control the flight path of unit **18** (or any other unit) through a small joystick (not shown) or other portable control device, for example. An on-board autopilot program enhances pilot control and stabilizes the aircraft in three dimensions (yaw, pitch, and roll).

[0049] Alternatively, unit **18** includes on-board electronics which can be pre-programmed to follow a specified flight path based on GPS coordinates, for example. Preprogrammed flight reduces pilot workload so operator **29** is better able to observe the surrounding terrain projected through video display glasses **46** of helmet **28**. Preprogrammed flight is also useful in fixed surveillance operations where station-keeping is important, such as in search and rescue operations, for example, where an orthogonal grid search pattern may be desirable, and tactical operations, for example, where autonomous munitions may be intended to hit stationary targets such as buildings or parked aircraft, for example, or targets outside of the range of the telemetry system.

[0050] Helmet **28** may also be programmed to sense motion of the head of operator **29** in order to control video camera **105** of unit **18**. For example, upward and downward motion can slew camera **105** up and down, while side-to-side motion can rotate body **52** of unit **18** about body axis **60** thus providing a control system responsive to the natural movements of operator **29** in order to simplify the operator training which may be required to operate unit **18**.

[0051] Looking now to **FIG. 2**, a more detailed view of the mobile command center **12** is provided. Illustrative mobile command center **12** includes an all-terrain vehicle **30**. As shown in **FIG. 2**, trailer **16** is hitched to vehicle **30** and includes various mobile base units **14** carried thereon as is described below. In addition to vehicle **30**, mobile command center **12** includes antenna **31** in communication with the network and computer system **26** to provide remote two-way communication with the various micro-rotorcraft units being deployed. Thus, antenna **31** is able to download data from the micro-rotorcraft units and upload data to the micro-rotorcraft units.

[0052] As mentioned above, mobile command center **12** includes various computer network systems **26**, such as those illustratively shown in **FIG. 2**, which may be operated by users or personnel within mobile command center **12**. Mobile command center **12** coordinates deployment of micro-rotorcraft units and processes data downloaded from deployed micro-rotorcraft units to support large-scale tactical operations, for example. Mobile command center **12** controls the systems onboard each micro-rotorcraft unit. These systems may be coordinated by mobile command center **12** to collect data or attack hostile forces remotely from any direction, over any terrain, obstacle or boundary, including geographical, physical, or political boundaries.

[0053] Integrated computer network system **26** within mobile command center **12** can process and display graphically all data downloaded from one or more deployed micro-rotorcraft units. This data may be combined with other sources of data, including remote sensors, satellites, manned aircraft ground units, etc., to present a fused, real-time picture of the tactical situation. As is discussed further below, data from sensors onboard the micro-rotorcraft units can help to locate and track chemical and/or biological releases, radioactive fallout, wanted persons or hostile forces, for example.

[0054] The illustrative vehicle **30** of mobile command center **12** is about 35 feet (4.57 meters) long, 15 (4.57 meters) feet wide, and 15 (4.57 meters) feet tall. The weight of the illustrative mobile command center **12** when unmanned or empty is approximately 20,000 pounds. Mobile command center **12** is capable of holding a crew of six and is powered by a gas generator (not shown). Although mobile command center **12** is disclosed and described above, it is within the scope of this disclosure for integrated system **10** to include a mobile command center **12** having other suitable specifications.

[0055] As mentioned above, a trailer **16** is hitched to mobile command center **12** by trailer hitch **36**. As shown in **FIGS. 3***a*-**3***c*, illustrative trailer **16** is provided to carry an array **32** of mobile base units **14** of integrated system **10**. Each illustrative mobile base unit **14** supports up to 100 micro-rotorcraft units and includes various power and data connections (not shown). As shown in **FIG. 3***a*, each mobile base unit **14** includes multiple cavities **34** for stowing various micro-rotorcraft units therein, such as unit **18**, for example. The power and data connections (not shown) are located within each cavity **34** so that when a micro-rotorcraft unit is stowed within a particular cavity **34**, that unit is automatically connected to the power and data network **26**. When linked to and used in conjunction with the mobile command center **12**, the power connection automatically recharges the batteries (if provided) of each micro-rotorcraft unit placed therein, uploads data such as targeting information to each micro-rotorcraft , and launches each micro-rotorcraft unit. The power and data connections of mobile base units **14** may be remotely coupled to computer network **26** of mobile command center **12**.

[0056] As shown in **FIG. 3***a*, individual mobile base units **14** can be combined to produce a mobile base unit array **32** capable of holding large numbers of micro-rotorcraft units to support large scale tactical operations. As shown in **FIGS. 3***a*-**3***c*, mobile base units **14** are carried on trailer **16**. However, it is also within the scope of this disclosure for mobile base units **14** to be transported by other suitable means, such as on trucks or aircraft such as helicopters, for example. Electric power is supplied to each mobile base unit **14** via a host vehicle or an optional gas-powered electric generator (not shown), for example.

[0057] The illustrative mobile base units **14** of system **10** each have a length **36** of 4 feet (1.22 meters), a width **38** of 4 feet (1.22 meters), and a height **40** of 2 feet (0.61 meters). As mentioned above, each illustrative mobile base unit **14** has the capacity to hold up to 100 micro-rotorcraft units. Further, illustrative mobile base units **14** each weigh approximately 100 pounds when empty and approximately 400 pounds when fully loaded with micro-rotorcrafts units. Illustratively, the power required for each mobile base unit **14** is at approximately 12 to 30 volts of direct current.

[0058] Looking now to **FIGS. 4 and 5**, micro-rotorcraft unit **18** of system **10** is provided. Unit **18** is miniature in size and includes a rotor system **50**, an elongated modular body **52**, and a navigation system module **54** having global positioning system (GPS) network capabilities. Illustrative navigation module **54** houses a GPS antenna **250** and associated electronics **252** (see **FIG. 27**). The navigation system of unit **18** may be satellite based, such as the GPS network described above, radio based including radio aids such as Omega, LORAN TACON, and VOR, for example, or the navigation system may be self-contained, such as an inertial navigation system, for example. Additionally, unit **18**, and all other units described herein, may be navigated by remote control signals from mobile command center **12** or operator **29** with helmet **28**, for example.

[0059] Illustrative rotor system **50** is also miniature in size and includes a first hub **56** and a second hub **58** coupled to first hub **56** to create a co-axial rotor system. Navigation module **54** is coupled to upper hub **56** of rotor system **50**, as shown in **FIGS. 4 and 5**. First and second hubs **56, 58** are capable of rotating in the same direction and in opposite directions about a body axis **60** of unit **18**. As shown in **FIG. 5**, a gear system **62** is provided for operating hub **58** which illustratively includes four peripheral gears **64** in communication with a central gear **66** which is connected to a motor **92**. A similar gear system (not shown) is provided for operation of hub **56**.

[0060] Rotor system **50** further includes upper blades **68, 70** coupled to first hub **56** and lower blades **72, 74** coupled to second hub **58**. Upper blades **68, 70** generally rotate in direction **69** and are collectively and cyclically pitchable. Lower rotor blades **72, 74** generally rotate in direction **71** and are also collectively and cyclically pitchable. Although upper blades **68, 70** are shown to rotate in direction **69** and lower blades **72, 74** are shown to rotate in direction **71**, it is within the scope of this disclosure for blades **68, 70** to rotate in direction **71** and for blades **72, 74** to rotate in direction **69**. Body **52** of unit **18** generally does not rotate with rotor system **50**, but maintains a stable heading (yaw) orientation through operation of an internal yaw control system **254** (see **FIG. 27**).

[0061] As shown more clearly in **FIG. 6**, each blade **68, 70, 72, 74** is coupled to the respective hub **56, 58** by a hinge **76** so that each blade **68, 70, 72, 74** is movable between an extended position, as shown in **FIGS. 4**, and **5** and a retracted or stowed position, as shown in **FIGS. 9 and 11***a*. In the stowed position, blades **68, 70, 72, 74** lie generally adjacent to body **52** and in parallel relation to body axis **60**. While in the extended position, however, blades **68, 70, 72, 74** are generally perpendicular to axis **60**. In addition to allowing blades **68, 70, 72, 74** to move between the stowed position and the retracted position, hinges **76** also permit each respective blade **68, 70, 72, 74** to pivot so that blades **68, 70, 72, 74** are able to steer unit **18** in various directions for maneuvering around various obstacles and over certain terrain.

[0062] As shown in **FIGS. 4, 5** and **6**, each hinge **76** includes a base **78** coupled to the respective hub **56, 58**, a pin **80** coupled to base **78**, and a grip **82** coupled to pin **80** and to respective blade **68, 70, 72, 74**. Grip **82** is pivotable about an axis **85** through pin **80** to move the respective blade between the extended and stowed positions. Pin **80** and grip **82** are both rotatable together in a clockwise direction and a counter-clockwise direction relative to base **78** to rotate the respective blade attached thereto about an axis (not shown) along a length of each respective blade in order to steer and maneuver unit **18**. Hinges **76** are operable independently of each other.

[0063] Illustrative rotor blades **68**, **70**, **72**, **74** are molded of a high-impact plastics material such as, for example, nylon, polycarbonate, polyphenylene oxide, or flexible polyurethane and can withstand repeated crashes and rough handling, as is described in more detail below, with little or no damage. As shown in **FIG. 8**, for example, rotor blade **68** is shown being flexed by an operator **29** through a flexing angle **79** of up to 180 degrees where a tip **81** of blade **68** touches a root **83** of blade **68**. Rotor blade **70**, for example, is shown foldable about flapping axis **85** through pin **80** past an upper flapping limit **87** until a rotor blade longitudinal axis **89** is generally parallel to body axis **60**. In addition to improving durability of unit **18**, folding rotor blades **68**, **70**, **72**, **74** past an upper flapping limit **87** toward axis **60** can improve launch stability of unit **18** when deployed from aircraft at high speed.

[0064] Unlike some aerial devices that passively derive lift through autorotation of a rotor system and passage of air upward through a rotor system, unit **18** is self-propelled and derives lift by forcing air downward through rotor system **50**. However, unit **18** may also operate to passively derive lift through autorotation of a rotor system and passage of air upward through the rotor system. In operation, motor **92** drives rotor system **50** to develop a thrust force in direction **109** (as shown in **FIG. 4**) that lifts unit **18** into the air. Cyclic thrust forces from upper and lower rotor blades **68**, **70**, **72**, **74** tilt rotor system **50** relative to the horizontal, and tilt body **52**, axis **60** and thrust direction **109** relative to the vertical, so that unit **18** flies generally in a horizontal flight direction **111**.

[0065] While rotor system **50** is disclosed and described above as having cyclically pitchable rotor blades **68**, **70**, **72**, **74** for lateral flight control, rotor system **50** may also be gimbaled to tilt relative to elongated modular body **52**. Tilt of rotor system **50** relative to the horizontal, while body **52** remains substantially vertical, redirects thrust force **109** away from to the vertical so that unit **18** flies in a generally horizontal flight direction **111**. Tilt of rotor system **50** relative to body **52** effectively kinks or bends body **52** below rotor system **50**. Motor **92** may be directly coupled to rotor system **50** and configured to tilt along with rotor system **50**, or may be fixed within body **52** and connected to rotor system **50** via universal joint means (not shown).

[0066] Body **52** of unit **18** is coupled to rotor system **50** and extends along axis **60** of unit **18**, as shown in **FIGS. 4, 5, 7** and **8**. As is discussed in more detail below, body **52** is small in size so that micro-rotorcraft unit **18** is hand-held and may be carried or transported by a single operator. As mentioned above, body **52** is modular and includes multiple interchangeable components. Illustratively, body **52** includes a drive module **84**, a power module **86**, and a payload module **88**. As shown in **FIGS. 4, 5, 7** and **8**, for example, drive module **84** is coupled to rotor system **50**, power module **86** is coupled to drive module **84**, and payload module **88** is coupled to power module **86**. The modular components of body **52** are interchangeable with each other if a different order along axis **60** is desired. It is also within the scope of this disclosure to include a unit **18** having other suitable modular components, as well, in addition to those illustrated in the accompanying figures. Illustratively, body **52** is approximately 15-19 inches (38.10-48.26 cm) in length.

[0067] As shown in **FIG. 5**, drive module **84** includes an outer cover **90** and a power component, such as an electric motor **92**, received within cover **90**. Module **84** also houses planetary drive system **62** and an electronic motor speed controller **256** (see **FIG. 27**). The electronic motor speed controller is coupled to motor **92**. Illustratively, motor **92** is a compact, 400-watt, high-efficiency brushless electric motor capable of operating silently to maintain stealth and secrecy of unit **18** as unit **18** travels over various obstacles and terrain. However, it is within the scope of this disclosure to include other suitable motors and/or power components as well. For example, drive module **84** may house an internal combustion engine. Cover **90** includes air vents **94** to help prevent motor **92** from overheating within cover **90**.

[0068] As shown in **FIGS. 5 and 6**, a module coupling **96** is provided so that each module of body **52** may be easily coupled to and uncoupled from each other. Module coupling **96** includes toothed female coupling ring **97** coupled to one end of each module and a male coupling ring **99** coupled to the other end of each module.

[0069] As shown in **FIG. 6**, toothed female coupler ring **97** of modular quick-change coupling **96** is appended to the lower end of drive module **84**, and toothed male coupling ring **99** is appended to the upper end of power module **86**. Female coupling ring **97** and male coupling ring **99** cooperate to form quick-disconnect module coupling **96**. A plurality of male teeth **101**, each having a ramp profile and dead-stop for cam-action locking, are provided on male coupling ring **99**. An equal number of female receiving areas **103** are provided in female coupling ring **97**.

[0070] In operation, male coupling ring **99** is inserted into female coupling ring **97** with a quick twisting action thereby securely retaining drive module **84** to power module **86**. Modules **54**, **84**, **86**, **88** and hubs **56**, **58** each have a similar coupling which makes them quickly interchangeable. For instance, a depleted battery power module **86** need not be recharged, but can be quickly replaced at the end of a flight. In a similar fashion, payload module **88** (which is shown to be adapted for use with video camera **105**) may be quickly replaced at the end of a mission with an alternative payload module (not shown) having a chemical sensor adapted for use in a different mission, for example.

[0071] Similar to drive module **84**, power module **86** also includes an outer cover **100**. Battery pack **102** of module **86** is contained within cover **100**. Batteries **104** of pack **102** may be rechargeable, such as Li-polymer batteries, or single use such as $LiMnO_2$ batteries, for example, and may have an operating life of 1 to 3 hours, for example. As shown in **FIG. 5**, power module **86** also includes module coupling **96** at each end **98** of cover **100**.

[0072] Payload module **88** also includes a cover **104**. Payload module **88** is provided to carry various items within cover **104** such as explosive or incendiary munitions and biological and chemical sensors. Payload module **88** is coupled to a lower end of power module **86** and contains mission specific computer electronics, autopilot systems, sensors and/or explosive warhead (not shown).

[0073] Payload module **88** also accommodates a pivotable video camera **105** and a camera pivot mount **106** for slewing camera **105** in a vertical direction. Video camera **105** may also rotate 360 degrees about axis **60** to survey and take pictures of the surrounding terrain and environment for relay back to mobile command center **12**, for example. Video camera **105** allows a remote operator to silently look into windows, see over hills, observe from great heights, and operate over any terrain or obstacle.

[0074] Although unit **18** is miniature in size, unit **18** is capable of carrying a variety of payloads ranging from visible and infrared video cameras to electromagnetic and chemical sensors, for example. Unit **18** is able to carry such sensors over long distances and at great heights above the local terrain. This can dramatically increase the situational awareness of forces on the ground, for example.

[0075] Illustrative payload module **88** is capable of carrying four to sixteen ounces of plastic explosives allowing unit **18** to act as a highly potent expendable munition for special operations where stealth and precision are required. Unit **18** is also able to act as a target beacon for much larger laser guided munitions dropped from an orbiting aircraft, for example.

[0076] A feature of unit **18** is that much of the weight of elongated body **52**, such as for instance, batteries **102** in power module **86** and payloads (not shown) in payload module **88**, is located far below the effective plane of rotation of rotor system **50**. The pendulum effect of this offset weight being drawn downward by gravity can act to passively stabilize co-axial rotor system **50** and unit **18** in flight in the roll and pitch directions.

[0077] Several units **18** can be deployed with various payload modules to form a system of guided sensors providing a picture of the environment from many perspectives and vantage points simultaneously. **FIG. 2** shows the central computerized command center **12** controlling units **18** of the current disclosure via electronic telemetry uplink and downlink **33**.

[0078] Looking now to **FIG. 7**, unit **18** includes additional features such as torsion springs **196** for biasing each rotor blade **68**, **70**, **72**, **74** away from their folded or retracted configuration generally parallel to body axis **60**. Blade latches **198** are provided to retain blades **68**, **70**, **72**, **74** in the folded configuration until blade latches **198** are unengaged by an operator by means of a surface control such as a thumb button **200**, for example, or by remote control.

[0079] Springs **196** are configured to extend blades **68**, **70**, **72**, **74** only to a lower flapping limit **202**. Blades **68**, **70**, **72**, **74** are then free to flap in flight between an upper flapping limit **204**, about ten degrees above the horizontal, and lower flapping limit **202**, about ten degrees below the horizontal. Flapping motion of blades **68**, **70**, **72**, **74** above upper flapping limit **204** and below lower flapping limit **202** are resisted by springs **196** or other means.

[0080] A body length **206** of illustrative unit **18** is about 17-19 inches (43.18-48.26 cm), while a blade span **208** is about 14.5 inches (36.83 cm), thus making unit **18** miniature or small in size. Unit **18** generally has an aspect ratio of greater than about 2:1, but is often in the range of 5:1 to 10:1. The term "aspect ratio" is herein defined as the ratio between body length **206** and mean body diameter **209**. Body axis **60** is defined as the axis of longest dimension of body portion **52**. For the purpose of determining aspect ratio, the body length includes the sum of the lengths of all coupled body modules taken along the body axis including the length of the rotor system module and all modules coupled to the rotor system module. Looking now to **FIGS. 9 and 10**, unit **18** is configured for storage in a storage compartment or carrying case **144**. Carrying case **144** includes a hollow body **145** and a handle **146** coupled to body **145**. Body **145** is generally square in cross-section to accommodate folded rotor blades **68**, **70**, **72**, **74** and other folding elements of unit **18**. Side length **147** of body **145** is about 4 inches (10.16 cm). When blades **68**,**70**, **72**, **74** are folded to the stowed position, illustrative unit **18** has a diameter of about 4 inches (10.16 cm) inches.

[0081] With such a small or miniature size, and a weight of approximately 3 pounds, a single operator **29** can carry up to ten units **18** in a backpack. Other specifications of the illustrative unit **18** include a length of body **52** of approximately 18 inches (45.72 cm), a diameter of rotor system **50** of approximately 30 inches (76.20 cm), a maximum horizontal speed of approximately 30-40 miles per hour (depending on the payload weight), a maximum vertical speed of approximately 10 to 15 feet per second (3.05-4.57 meters per second) (also depending on the payload weight), a maximum altitude of approximately 7,000 feet (2,133 meters), a payload of 4 to 16 ounces, a range of approximately 5 to 60 miles, a hover accuracy of plus or minus approximately 3 feet 91.44 cm), and a gust tolerance of approximately 30 miles per hour. Video camera **105**, navigation module **54**, the telemetry uplink and downlink, autonomous autopilot and those things carried within payload module **88** are considered to be part of the payload which unit **18** can carry. Although various specifications of unit **18** are disclosed and described herein, it is within the scope of this disclosure for unit **18** to have other suitable specifications and operational capabilities as well.

[0082] Unit **18** can be quickly reconfigured within a few seconds for a variety of roles in remote surveillance and tactical operations via interchangeable payload and power modules. Because of the miniature size of unit **18**, a single operator is able to reconfigure the interchangeable modules of unit **18** in a generally fast and efficient manner. Illustrative unit **18** includes video camera **105**; however, unit **18** may also be fitted with more sophisticated telemetry and data uplink electronics to be operated from a satellite or orbiting aircraft, such as a Predator drone, for example. Unit **18** can enhance situational awareness and project force at extreme distances irrespective of the intervening terrain or presence of hostile forces. Unit **18** can be configured in the field for a variety of missions quickly and economically.

[0083] Unit **18** can be controlled by central computer system **26**. Multiple units **18** may be launched en masse from mobile base unit **14**, for example, to form a swarm of miniature cruise missiles for use in search-and-rescue operations or anti-personnel operations against entrenched or concealed combatants, for example. Further, unit **18** may be dropped from an aircraft to reconnoiter closer to the ground much like a sono-buoy is dropped into the ocean from a ship or helicopter to search for submarines, for example.

[0084] **FIGS. 11***a*-**11***c* illustrate a first manual method for deploying and operating unit **18**. As mentioned before, hand-held unit **18** is miniature in size to allow operator **29** to grasp body **52** of unit **18** and hold unit **18** in a near-vertical orientation in preparation for flight, as shown in **FIG. 11***a*, for example. Body **52** is adapted to the human hand and is about 2 inches (5.08 cm) in diameter in the illustrative embodiment shown. Rotor blades **68, 70, 72, 74** are loosely folded along body **52** in the stowed position.

[**0085**] In **FIG. 11***b*, operator **29** manually or remotely causes blades **68, 70, 72, 74** to extend from their stowed configuration to a flight or extended configuration (as by pushbutton **200** shown in **FIG. 7**, for example). In **FIG. 11***c*, operator **29** then initiates powered rotation of rotor system **50** manually or through remote means, and unit **18** flies away under its own power in direction **111**, for example. Illustrative unit **18** does not require landing gear for deployment because unit **18** is hand-launched.

[**0086**] **FIG. 12** illustrates an automatic method of deploying unit or units **18** from an aircraft **176** fitted with multiple storage carriers **144**. Unit **18** is ejected from aircraft **176** and a parachute **178** appended to one end of unit **18** is deployed to slow and stabilize the flight of unit **18** as unit **18** descends to a lower altitude. Next, extendable elements, such as rotor blades **68, 70, 72, 74** are extended into their flight configurations. Parachute **178** is then released and rotor blades **68, 70, 72, 74** are driven under power provided by modules **84, 86** so that unit **18** is capable of flying away under its own power in a generally horizontal direction **111**.

[**0087**] Refer now back to **FIG. 3***a* which illustrates an automatic method of deploying unit **18** from mobile base unit **14**. Prior to launch, unit or units **18** must be loaded into mobile base units **14**. To load unit **18**, an operator **29** folds the blades **68, 70, 72, 74** of unit **18** to the retracted or stowed position and inserts unit **18** into the receptacle or cavity **34** of mobile base unit **14**, as shown in **FIG. 3***a*, for example. As mentioned above data and electrical connections are automatically established. To launch unit **18**, as shown in **FIG. 3***a*, mobile base unit **14** automatically raises unit **18** into a launch position. Unit **18** is then directed to open rotor blades **68, 70, 72, 74** to the extended position and fly away under its own power. Although the manual and automatic methods for deploying a micro-rotorcraft unit discussed above are made with reference to unit **18**, it is within the scope of this disclosure for the other units **20, 22,24, 310, 330, 370** described herein to be deployed in the same or similar manner.

[**0088**] **FIGS. 13***a***-13***c* illustrate a method for landing or recovering unit **18**. Illustrative unit **18** does not require any landing gear because rotor blades **68, 70, 72, 74** are foldable upward and downward toward body axis **60**, and, at the end of a flight, body **52** simply tips sideways onto the ground. In **FIG. 13***a*, unit **18** is shown descending from altitude in direction **179**. In **FIG. 13***b*, unit **18** has descended to a point where the lower end of body **52** is resting on or near the ground at which time power to rotor system **50** is automatically shut off. In **FIG. 13***c*, rotor system **50** has decelerated to the point where the vertical orientation of body **52** can no longer be maintained causing unit **18** to fall on its side with rotor blades **68, 70, 72, 74** flexing and folding past a flapping angle of about 10 degrees upon contact with the ground to reduce the possibility of crash damage. The operator **29** is then able to stow folded unit **18** in a backpack or the trunk of a car. Because of the features of unit **18**, unit **18** can be landed repeatedly in this manner with little or no damage. It is within the scope of this disclosure, however, to provide landing gear for unit **18** to allow unit **18** to land in an upright position, for example.

[**0089**] Looking now to **FIGS. 14-16**, another micro-rotorcraft unit **20** is provided for use with integrated system **10**. Unit **20** is also miniature in size and includes a central body **110** having an upper portion **112**, a lower portion **114**, and a rotor system **116** coupled to and positioned between the upper and lower portions **112, 114**. Unit **20** further includes an outer cage **118** coupled to central body **10**. Particularly, cage **118** is coupled to upper portion **112** and lower portion **114** of body **110**.

[**0090**] Illustrative cage **118** includes a circular upper base **120**, a circular lower base **122**, and four vertical supports **124** coupled to and extending between each of the upper and lower bases **120, 122**. An upper, horizontal support **126** is coupled to upper base **120** and upper portion **112** of central body **110**. Illustratively, support **126** is received in part through an aperture **128** of upper portion **112**. However, it is within the scope of this disclosure to couple support **126** to upper portion **112** in other suitable ways such as welding, for example. A lower, horizontal support **130** is coupled to lower base **122** by a small vertical support **132**. Illustratively, body **110** is generally centered within cage **118**. Illustrative cage **118** is made of titanium memory wire. However, it is within the scope of this disclosure for cage **118** to be made of other suitable materials such as plastics, etc. Cage **118** protects rotor blades **134, 136, 138, 140** from contacting walls, floors, ceilings, etc. as unit **20** flies around or through various obstacles and terrain inside of buildings or other interior spaces. Cage **118** of unit **20** allows unit **20** to take off from a standing position, rather than having to be launched from mobile base unit **14**, for example.

[**0091**] Rotor system **116** of unit **20** is similar to rotor system **50** of unit **18**, described above. As such, co-axial rotor system **116** includes first hub **56** and second hub **58**. Two oppositely extending blades **134, 136** are coupled to first hub **56**, and oppositely extending blades **138, 140** are coupled to second hub **58** to rotate in opposite directions. Each blade **134, 136, 138, 140** is coupled to respective hub **56, 58** by a type of clamp or grip **82**. Like unit **18**, blades **134, 136, 138, 140** of unit **20** are free to flap in flight within a flapping zone above and below the horizontal. Unlike blades **68, 70, 72, 74** of unit **18**, illustrative blades **134, 136, 138, 140** of unit **20** are not movable to a stowed position. However, it is within the scope of this disclosure to couple blades **134, 136, 138, 140** to respective hubs **56, 58** with hinges **76** to allow blades **134, 136, 138, 140** to move to a stowed position.

[**0092**] As shown in **FIGS. 15 and 16**, blades **134, 136, 138, 140** are contained within cage **118**. Illustratively, and outer end **142** of each blade **134, 136, 138, 140** is spaced apart from vertical supports **124** and does not interfere with vertical supports **124**. Blades **134, 136, 138, 140** are also collectively and cyclically pitchable in order to steer and maneuver unit **20**.

[**0093**] Unit **20** also includes a motor (not shown) and batteries (not shown). . Further, unit **20** may also include a GPS navigation system, a visible light and infrared video cameral, telemetry uplink and downlink for communication with integrated network **26** of mobile command center **12**. Unit **20** may also operate autonomously on autopilot, and may carry explosive and/or incendiary munitions and biological and/or chemical sensors. Each of these components operate like those described above with respect to unit **18**.

Further, each of these components may be contained within upper or lower portions **112**, **114**.

[**0094**] The small size of unit **20** allows a single operator **42** to be able to carry up to four units **20** in a field pack. Illustrative unit **20** weighs approximately eight ounces, has a rotor blade diameter of approximately 12 inches (30.48 cm), a height of approximately 8 inches (20.32 cm), a maximum horizontal speed of approximately 15 miles per hour, a maximum vertical speed of approximately 6 feet per second (1.83 meters per second), a maximum altitude of approximately 6,000 feet (1,830 meters), a maximum payload of approximately 3 ounces, a range of approximately 7 miles, a hover accuracy within about 6 inches (15.24 cm), and a gust tolerance of about 10 miles per hour.

[**0095**] Looking now to **FIG. 17**, another micro-rotorcraft unit **22** is provided for use with system **10**. Illustrative unit **22** is also miniature in size and includes a body **150**, a rotor system **152** coupled to body **150**, and a tail **154** coupled to body **150** as well. Similar to units **18**, **20**, discussed above, body **150** carries a silent electric motor (not shown) and rechargeable and/or single use batteries. A payload module **156** is coupled to body **150** and may include one or more of the following: a visible light and/or infrared video camera, a GPS navigation system, telemetry uplink and downlink with integrated system **26**, autonomous autopilot software, explosive and/or incendiary munitions, and biological and/or chemical sensors. Illustrative unit **22** is capable of carrying a payload of approximately 4 to 8 ounces.

[**0096**] Illustrative rotor system **152** of unit **22** includes four flexible plastic rotor blades **158** coupled to a central hub **160** of rotor system **152**. Blades **158** are foldable for compact storage and flexible to withstand repeated crashes and rough handling with little or no damage. As a result, unit **20** requires no landing gear and can be landed or recovered by way of the method illustrated in **FIG. 13***a*-**13***c*.

[**0097**] Tail assembly **154** of unit **22** includes an elongated boom **162**, a semi-circular rotor guard **164** coupled to boom **162** and positioned to extend beyond an end **166** of boom **162**. A gearbox **168** of tail assembly **154** is coupled to end **166** of boom **162** and variable thrust tail rotor system **170** is coupled to gearbox **168**. Tail rotor system **170** includes two oppositely extending blades **172** coupled to a central hub **174** of tail assembly **154**.

[**0098**] Illustrative units **22** are approximately 2.5 pounds allowing a single operator to carry up to ten units **22** in a field pack. Illustrative rotor system **152** has a rotor diameter of 24 inches (60.96 cm). A length of each unit **22** is approximately 30 inches (76.20 cm). Each unit **22** can attain a maximum horizontal speed of approximately 50 miles per hour, a maximum vertical speed of approximately 10 to 15 feet per second (3.05 to 4.57 meters per second), and a maximum altitude of approximately 7,000 feet (2,133 meters). Unit **22** has a range of approximately 20 to 60 miles with a hover accuracy of approximately plus or minus one foot (30.48 cm). Unit **22** is capable of carrying a payload of approximately 4 to 8 ounces at 30 miles per hour.

[**0099**] Looking now to **FIGS. 18 and 19**, another illustrative micro-rotorcraft unit **24** is provided for use with system **10**. Unit **24** is similar in appearance to unit **18** in that unit **24** includes various interchangeable modules forming vertically extending, elongated body **52**. For example, unit **24** includes navigation module **54**, rotor system **50** coupled to navigation module **54**, payload module **88**, and video camera and/or sensor equipment **106** coupled to payload module **88**. As mentioned above with respect to unit **18**, the video camera may be a visible light and/or an infrared video camera, and the sensors may be biological and/or chemical sensing sensors among other. Unit **24** is also miniature in size for manual deployment by an operator, as discussed above with respect to unit **18**.

[**0100**] Rotor system **50** of unit **24** is the same as or similar to rotor system **50** of unit **18** discussed above. Rotor system **50** includes upper blades **68**, **70**, and lower blades **72**, **74** and the associated rotor drive components **257** (see **FIG. 27**) housed in upper and lower hubs **56**, **58**. Upper rotor blades **68**, **70** are collectively and cyclically pitchable and generally rotate in rotor rotation direction **69**. Lower rotor blades **72**, **74** are collectively and cyclically pitchable and generally rotate in rotor rotation direction **71**. Unit **24** is powered by an internal combustion gas engine (not shown) having an exhaust tube **183**.

[**0101**] Unit **24** further includes a drive module **180** coupled to rotor system **50**, and a power module **182** coupled to drive module **180**. Drive module **180** includes an internal combustion gas fueled engine (not shown) and air vents **94** to prevent the engine from overheating, for example. Power module **182** includes a fuel tank (not shown) containing fuel for the gas fueled engine. The engine of unit **24** is a highly efficient diesel fuel engine. Illustratively, enough diesel fuel may be provided to permit unit **24** to fly for approximately two to four hours. A recoil pull-start (not shown) is provided for easy starting.

[**0102**] As mentioned above with respect to unit **18**, rotor system **50** includes flexible plastic rotor blades **68**, **70**, **72**, **74** which fold downward to a stowed position for compact storage. Plastic blades **68**, **70**, **72**, **74** can withstand repeated crashes and rough handling with little or no damage. Although illustrative blades **68**, **70**, **72**, **74** are made of plastic, it is within the scope of this disclosure to include rotor blades made of other materials such as metals, fibrous composites, etc.

[**0103**] Each illustrative miniature unit **24** is approximately 4-5 pounds allowing one operator to carry up to six units **24** each within protective carrying case **144**, for example. The rotor blade diameter of rotor system **50** is approximately 36 to 48 inches (1.22 meters), the length of body **52** of unit **24** is approximately 36 inches (91.44 cm). The illustrative unit **24** is able to accelerate to a maximum horizontal speed of approximately 30 miles per hour, a maximum vertical speed of approximately 10 to 15 feet per second (4.57 meters per second), and to ascend to a maximum altitude of approximately 7,000 feet (2,133 meters). Illustrative unit **24** can carry a payload of approximately 1 to 2 pounds and can survey a range of up to approximately 180 miles while remaining in communication with integrated network **26**. Unit **24** has a hover accuracy of plus or minus approximately 4 feet (1.22 meters) and a gust tolerance of approximately 30 miles per hour.

[**0104**] A miniature landing assembly **184** of unit **24** is coupled to payload module **88**. Landing assembly **184** allows unit **24** to stand upright for landing and/or take-off, and allows unit **24** to be launched without the use of mobile base unit **14**, for example. Landing assembly **184** includes a circular ring or brace **186** around payload module **88** and slideable along axis **60** and upper leg supports **188** each being pivotably coupled to brace **186** at one end, and pivotably coupled to a respective landing leg **190** of assembly **184** at another end. Illustratively, landing assembly **184** includes four support legs **188** equally spaced about brace **186** and four corresponding landing legs **190**. However, it is within the scope of this disclosure to include a landing assembly having any suitable number of legs to maintain the body **110** of unit **24** in an upright position as shown in **FIG. 18**, for example.

[**0105**] Each lower leg **190** of landing assembly **184** is coupled to a hinge **192** by a pin **194** to allow each lower leg **190** to pivot about pin **194**. Each hinge **192** is coupled to a lower ring or brace **195** around payload module **88**. As shown in **FIG. 18**, landing assembly **184** is in an extended or launch position. Landing assembly **184** is movable between this launch position and a stowed position shown in **FIG. 19**. In the stowed position, upper legs **188** and lower legs **190** are pivoted upwardly to lie adjacent to body **110** of unit **24** in parallel relation to body axis **60**. When landing assembly **184** (and rotor system **50**) are in the stowed position, unit **24** may be placed within carrying case **144** for a user to easily carry and transport. As described above, carrying case **144** includes a hollow tube **145** for receiving unit **24** therein and a handle **146** coupled to tube **145** for a user to grasp when transporting carrying case **144**.

[**0106**] In operation, rotorcraft unit **24** sits passively on the ground atop landing assembly **184**. During launch, rotor system **50** is activated to develop a generally downward thrust force that lifts unit **24** into the air. Landing assembly **184**, including landing legs **190**, can either remain attached to unit **24** in flight and for subsequent landings, or can be dropped off or left on the ground to reduce flying weight.

[**0107**] Looking now to **FIG. 20**, another micro-rotorcraft unit **310** of the present disclosure is provided for use with system **10**. Unit **310** has variable pitch, aerodynamic fins **312** coupled to payload module **88**. Each fin **312** is pivotable about a hinge point **314** in direction **316** for storage alongside body portion **50**. Like landing gear assembly **184**, fins **312** may also be detached or dropped off in flight. Fins **312** can be used for yaw control during hovering flight, to increase directional stability in high-speed forward flight, and as landing or launch legs, for example.

[**0108**] In one method of deployment of the unit **310**, fins **312** extend as unit **310** is dropped from an airplane at altitude. Rotor blades **68**, **70**, **72**, **74** remain retracted alongside body portion **50** immediately after unit **310** is deployed. Fins **312** guide unit **310** in a controlled descent from altitude until such time as rotor blades **68**, **70**, **72**, **74** are extended. Once blades **68**, **70**, **72**, **74** are extended for flight, fins **312** may drop off to allow unit **310** to continue on its own power. Similar to the micro-rotorcraft units described above, unit **310** is also miniature in size and may be hand-held for manual deployment by an operator as well.

[**0109**] Looking now to **FIGS. 21-24**, another micro-rotorcraft unit **330** is provided. Unit **330** has a single rotor lifting system **332** including cyclically and collectively pitchable rotor blades **334**, **336** rotating in direction **338** that are foldable about a folding axis **340** through each hinge pin **80**. Rotor system **332** also includes a hub **333** to which each blade **334**, **336** is coupled.

[**0110**] Yaw control outriggers **342** of unit **330** include collectively pitchable rotor systems **344** that fold or retract alongside power module **86** about a hinge axis **346** on rotatable gearboxes **348** coupled to power module **86**. A gearbox **350** supports each rotor system **344** on an outer end of boom **352** and contains bevel gears (not shown). Yaw control outriggers **342** are movable between an extended position, as shown in **FIG. 21**, and a folded or retracted position, as shown in **FIG. 24**.

[**0111**] As shown in **FIG. 22**, a drive shaft **354** within each rotatable gearbox **348** extends generally perpendicularly from power module **86** and drives a bevel gear **356**. Bevel gear **356** drives a second bevel gear **358** which is connected to drive shaft **360** inside boom **352**. Drive shaft **352** is connected to rotor system **334** which produces a variable thrust force in direction **362** (shown in **FIG. 21**) to counter the torque generated by rotor system **332** and to control rotation of unit **330** about generally vertical body axis **60**. As shown in **FIG. 23**, an illustrative rotor span **364** is 29 inches (73.66 cm), and a diameter **366** of body **52** is 2 inches (5.08 cm). Thus, unit **330** is miniature in size as well.

[**0112**] Looking now to **FIGS. 25 and 26**, yet another micro-rotorcraft unit **370** is provided for use with system **10**. Unit **370** includes outrigger arms **372** each pivotable about a folding axis **374**. Outrigger arms **372** are similar to arms **342** of unit **330** with the exception that outrigger arms **372** are each equipped with a variable speed electric motor **376** driving fixed-pitch rotors **378** have blades **382**. In stable hovering flight, each rotor **372** develops a thrust force in direction **380** to counter the torque produced by blades **334**,**336**. While outrigger arms **372** are generally shown extending from a middle portion of body **52**, it is within the scope of the current disclosure to connect each outrigger arm **372** anywhere on body **52** and particularly at the lower end of body **52** so outrigger arms **372** can also act as landing legs.

[**0113**] One feature of variable speed electric motors **376** is that no complex gears or drive shafts are required to drive each rotor system **378**. Fixed-pitch rotors **378** can be simpler and lighter than collective-pitch rotors (such as rotors **344** of unit **330**). Each outrigger arm **372** is also fitted with a video camera **384** providing a human operator (not shown) with stereo vision and/or range-sensing capabilities.

[**0114**] As used herein, rotor blades, landing legs, aerodynamic fins, sensor arms, and yaw control outriggers are all known and referred to as "extendable-retractable elements" and generally share a common trait of being foldable or retractable alongside the respective elongated body portion of each unit.

[**0115**] The small or miniature size of each of units **18**, **20**, **22**, **24**, **310**, **330**, **370** allows a remote operator to silently look into windows, see over hills, observe from great heights and operate over any terrain or obstacle. Multiple units can be fused into the integrated data network **26** to cooperate with each other for large scale missions, for example. System **10**, with units **18**,**20**, **22**, **24**, **310**, **330**,**317** disclosed herein, is provided to extend situational awareness of tactical forces, and to enhance the ability of the forces to accurately deliver sensors and ordnance. As mentioned above, each miniature unit is provided with interchangeable body modules for quickly adapting each unit to various configurations for any number of tasks, as a particular situation may require. System **10** provides a means and methods for deploying, recovering, and storing the micro-rotorcraft units disclosed herein.

[0116] The telemetry system of each unit **18**, **20**, **22**, **24**, **310**, **330**, **370** transmits sensor information to remote operators either in the field or within mobile command center **12**. Each unit **18**, **20**, **22**, **24**, **310**, **330**, **370** may be ideal for long-term perimeter surveillance and networked systems. Although the units disclosed herein are small or miniature in size, multiple units **18**,**20**, **22**, **24**, **310**, **330**, **370** working together may collect data to allow a remote operator to observe wide geographic areas from great heights and for extended time periods.

[0117] Units **18**, **20**, **22**,**24**, **310**, **330**, **370** may be programmed to operate individually, or in multiples to create a coordinated group of units **18**,**20**,**22**, **24**, **310**, **330**, **370**. In addition to military uses, other applications of system **10** with units **18**, **20**, **22**,**24**, **310**, **330**, **370** include law enforcement such as for search-and-rescue missions, drug interdiction, surveillance, sampling of emissions and pollutants and other special situations, for example. System **10** also has applications in scientific research such as for atmospheric sampling and remote inspection, and within business such as for construction oversight, surveying, inspection of difficult to reach or hazardous areas and aerial photography, for example.

[0118] The various units **18**, **20**, **22**, **24**, **310**, **330**, **370** described above may be provided in a hand-held, miniature, flying micro-rotorcraft unit kit. In other words, one or more of the component parts, or any combination thereof, may be provided within a kit for assembly at a micro-rotorcraft assembly site, for example. Each kit may therefore be assembled to provide a miniature flying surveillance machine (or rotorcraft unit) operable by remote control.

[0119] In one illustrative embodiment, the kit includes hand-held payload module **88** including means (such as video camera **105**, biological and/or chemical sensors, and/or an infra-red camera, for example) for conducting surveillance activities during flight. The kit also includes a hand-held lift generator module, such as rotor system **50**, or other rotor systems described above. The lift generator module includes first hub **56** supported for rotation about vertical axis **60** in first direction **69** to rotate the first pair of rotor blades **68**, **70** coupled to the first hub **56**, and second hub **58** supported for rotation about vertical axis **60** in second direction **71** to rotate the second pair of rotor blades **72**, **74** coupled to second hub **58**.

[0120] The kit further includes a hand-held power module, such as modules **86** or **182**, for example, containing a supply of energy, and a hand-held drive module, such as modules **84**, **180**, for example, including means for rotating the first and second hubs **56**, **58** in opposite directions about vertical axis **60** to turn rotor blades **68**, **70**, **72**, **74** to generate a thrust force that acts in a direction parallel to the vertical axis **60** using energy stored in the hand-held power module **86**, **182**. The kit also includes a quick-disconnect module coupling, such as coupling **96**. The quick-disconnect module coupling of the kit is adapted to be installed at a junction between each pair of adjacent modules to retain each pair of adjacent modules in fixed relation to one another to unite the modules in series to cause the thrust force generated by the hand-held lift generator module to lift the united payload, power, and drive modules into the air to initiate flight.

[0121] The kit may also include one or more of the following: a hand-held navigation module, such as module **54**, comprising means for determining a global position of the hand-held elongated body **50** during flight, a landing gear system, such as system **184**, and anti-torque mechanisms such as aerodynamic fins **312** and/or yaw control outriggers **342**, **372** for stabilizing the micro-rotorcraft unit in the yaw direction. Additionally, it is within the scope of this disclosure for the micro-rotorcraft unit kit to include any one or more components and combinations thereof described above with respect to units **18**, **20**, **22**, **24**, **310**, **330**, **370**.

[0122] Although this invention has been described in detail with reference to certain embodiments, variations and modifications exist within the scope and spirit of the invention as described and defined in the following claims.

1. A hand-held, miniature flying micro-rotorcraft unit comprising

a plurality of interchangeable, modular components coupled to one another to form a hand-held elongated body defining a vertical axis, and

rotor means coupled to an upper end of the hand-held elongated body for rotation about the vertical axis to lift the hand-held elongated body into the air, the rotor means being driven by drive means located within one of the interchangeable modular components of the hand-held elongated body.

2. The unit of claim 1, wherein the hand-held elongated body is generally cylindrical in shape and each modular component is also generally cylindrical in shape.

3. The unit of claim 1, wherein each modular component includes a first module coupler at a first end of the component, and a second module coupler at a second end of the component, and wherein the first module coupler of one of the modular components is adapted to be coupled to the second module coupler of another of the modular components.

4. The unit of claim 3, wherein the first module coupler includes a first toothed ring positioned to lie about the vertical axis and having outwardly extending teeth, and wherein the second module coupler includes a second toothed ring positioned to lie about the vertical axis and having inwardly extending teeth defining detents therebetween, the detents being adapted to receive the outwardly extending teeth of the first toothed ring.

5. The unit of claim 4, wherein each of the outwardly extending teeth of the first toothed ring include an outer end having an angled cam surface.

6. The unit of claim 1, wherein the plurality of modular components includes a navigation module comprising means for determining a global position of the hand-held elongated body during flight of the micro-rotorcraft unit, a rotor hub assembly of the rotor means, a drive module including the drive means, a power module including means for energizing the drive means, and a payload module comprising at least one of munitions, a biological sensor, a chemical sensor, a video camera, and an infrared camera.

7. The unit of claim 6, wherein the rotor hub assembly is coupled to and positioned between the navigation module and the drive module, and wherein the power module is coupled to the drive module, and the payload module is coupled to the power module so that the navigation module and the payload module are positioned to lie at opposite ends of the hand-held elongated body.

8. The unit of claim 6, wherein the payload module further includes autonomous autopilot means for controlling the directional stability, including yaw, pitch, and roll, of the of the hand-held, miniature, flying micro-rotorcraft unit during flight.

9. The unit of claim 1, wherein the rotor means includes a first hub, a plurality of rotor blades coupled to the hub, means for supporting the first hub for rotation about the vertical axis, and hinge means for coupling each rotor blade to the hub so that each rotor blade is movable between an extended position generally perpendicular to the vertical axis and a retracted position generally parallel to the vertical axis.

10. The unit of claim 9, wherein the hinge means includes spring means for normally biasing each rotor blade to the extended position.

11. The unit of claim 10, further including latch means coupled to the hand-held elongated body for maintaining each rotor blade in the retracted position against the bias of the spring means.

12. The unit of claim 1, further including landing means coupled to the hand-held elongated body for supporting the hand-held elongated body prior to flight and upon landing.

13. The unit of claim 12, wherein the landing means includes a plurality of landing legs each being pivotably coupled to the hand-held elongated body for movement between a landing position to support the hand-held elongated body in a generally upright position and a stowed position wherein each landing leg is generally parallel to the vertical axis of the hand-held elongated body.

14. The unit of claim 1, further including anti-torque means coupled to the hand-held elongated body for countering a torque generated by the rotor means to control rotation of the unit about the vertical axis.

15. The unit of claim 14, wherein the anti-torque means includes a first and second yaw control outrigger each including a boom having a first end coupled to the body and being positioned to lie generally perpendicular to the vertical axis, and rotor means coupled to a second end of the boom for rotation about an axis generally perpendicular to the boom and the vertical axis.

16. The unit of claim 14, wherein the anti-torque means includes a plurality of fins coupled to the band-held elongated body and positioned to extend away from the hand-held elongated body in a direction generally perpendicular to the vertical axis.

17. The unit of claim 1, further comprising telemetry uplink and downlink systems located within the hand-held elongated body and configured to receive information from a command center and configured to send information to the command center.

18. A hand-held, miniature, flying micro-rotorcraft unit comprising

a hand-held elongated body having an upper end and a lower end and defining a vertical axis,

a navigation module comprising means for determining a global position of the elongated body during flight of the micro-rotorcraft unit, and

rotor means coupled to the upper end of the hand-held elongated body and located between the hand-held elongated body and the navigation module for generating a thrust force that acts in a direction parallel to the vertical axis to lift the hand-held elongated body into the air.

19. The unit of claim 18, wherein the rotor means includes a pair of upper rotor blades coupled to a first rotatable hub, a pair of lower rotor blades coupled to a second rotatable hub, and means for supporting the first and second rotatable hubs for rotation about the vertical axis in opposite directions.

20. The unit of claim 19, wherein the second rotatable hub is positioned to lie between the hand-held elongated body and first rotatable hub and the navigation module is coupled to the first rotatable hub.

21. The unit of claim 19, wherein the rotor means further includes first means for rotating the first hub in a first rotational direction and for collectively and cyclically pitching the upper rotor blades as the upper rotor blades rotate in the first rotational direction and second means for rotating the second hub in an opposite second rotational direction and for collectively and cyclically pitching the lower rotor blades as the lower rotor blades rotate in the second rotational direction.

22. The unit of claim 19, wherein the rotor means further includes hinge means for coupling each of the upper rotor blades to the first rotatble hub and each of the lower rotor blades to the second rotatble hub so that each rotor blade is movable between an extended position generally perpendicular to the vertical axis and retracted position generally parallel to the vertical axis to permit the rotor blades to pivot so as to the steer micro-rotorcraft unit in flight in various directions to maneuver around various obstacles and over certain terrain.

23. The unit of claim 19, wherein the rotor means further includes hinge means for coupling each of the upper rotor blades to the first rotatable hub and each of the lower rotor blades to the second rotatable hub so that each rotor blade is movable between an extended position generally perpendicular to the vertical axis and a retracted position generally parallel to the vertical axis to permit the rotor blades to pivot so as to steer the micro-rotorcraft unit in flight in various directions to maneuver around various obstacles and over certain terrain.

24. The unit of claim 19, wherein the hand-held elongated body comprises a drive module comprising motor means for driving the rotor means to develop sufficient thrust to lift the hand-held elongated body into the air and to cause the upper and lower rotor blades to generate cyclic thrust forces to tilt the rotor means relative to the horizontal to cause the micro-rotorcraft unit to fly in a generally upwardly and horizontal flight direction.

25. The unit of claim 23, wherein the hand-held elongated body further includes a payload module comprising at least one of explosive or incendiary munitions and biological and chemical sensors.

26. The unit of claim 23, wherein the hand-held elongated body further includes a power module located between the payload module and the drive module and the power module provides means for energizing the motor means.

27. The unit of claim 19, wherein the rotor means further includes a planetary gear system located in each of the first and second rotatable hubs and each planetary gear system is configured to rotate the rotatable hub associated therewith about the vertical axis.

28. The unit of claim 27, wherein the hand-held elongated body comprises a drive module comprising motor means for operating the planetary gear systems to rotate the hubs and the upper and lower rotor blades about the vertical axis to develop sufficient thrust to lift the hand-held elongated body into the air.

29. The unit of claim 28, wherein the drive module and the rotor means cooperate to define means for forming a quick-disconnect module coupling between the drive module and rotor means.

30. A hand-held, miniature, flying micro-rotorcraft unit kit having component parts capable of being assembled at a micro-rotorcraft assembly site to provide a miniature flying surveillance machine operable by remote control, the kit comprising the combination of

a hand-held payload module including means for conducting surveillance activities during flight,

a hand-held lift generator module comprising a first hub supported for rotation about a vertical axis in a first direction to rotate a first pair of rotor blades coupled to the first hub, and a second hub supported for rotation about the vertical axis in a second direction to rotate a second pair of rotor blades coupled to the second hub,

a hand-held power module containing a supply of energy,

a hand-held drive module including means for rotating the first and second hubs in opposite directions about the vertical axis to turn the rotor blades to generate a thrust force that acts in a direction parallel to the vertical axis using energy stored in the hand-held power module, and

a quick-disconnect module coupling adapted to be installed at a junction between each pair of adjacent modules to retain each pair of adjacent modules in fixed relation to one another to unite the modules in series to cause the thrust force generated by the hand-held lift generator module to lift the united payload, power, and drive modules into the air to initiate flight.

31. The kit of claim 30, wherein the hand-held drive, power, and payload modules are united in series using quick-disconnect module couplings to produce a hand-held elongated body having an upper end and a lower end and the hand-held lift generator module is coupled to the upper end of the hand-held elongated body.

32. The kit of claim 31, wherein the hand-held elongated body is about **20** inches in length and about two inches in width.

33. The kit of claim 31, further comprising a hand-held navigation module comprising means for determining a global position of the hand-held elongated body during flight and wherein the hand-held navigation module is adapted to be coupled to the hand-held lift generator module using the quick-disconnect module coupling to position the hand-held lift generator module between the hand-held elongated body and the hand-held navigation module.

34. A co-axial rotorcraft capable of sustained horizontal flight comprising

an elongated body having an elongated body axis,

a first rotor blade connected to the elongated body and rotatable in a first rotation direction about a first rotor axis substantially parallel to the body axis,

a second rotor blade connected to the elongated body and rotatable in a second rotation direction about a second rotor axis substantially parallel to the body axis, the second rotation direction being opposite of the first rotation direction, and

the elongated body is supported in flight by the first and second rotor blades with the body axis in a generally vertical orientation.

35. The rotorcraft of claim 34 further having a body aspect ratio being greater than 2:1.

36. The rotorcraft of claim 34 wherein the first rotor blade has a first root portion adjacent to the elongated body, a first tip portion spaced apart from the first root portion, a first blade axis extending between the first root portion and the first end portion, and the first rotor blade is foldable toward the body axis about a first folding axis perpendicular to the body axis to position the first blades axis in parallel relation to the body axis.

37. The rotorcraft of claim 34 wherein the elongated body further includes a first body module and a second body module, and the first and second body modules are connected with a quick-change module coupling.

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