(19) **United States**

(12) **Patent Application Publication** (10) Pub. No.: **US 2022/0066471 A1**

von Flotow et al. (43) **Pub. Date:** **Mar. 3, 2022**

(54) **ROTORCRAFT-ASSISTED SYSTEM AND METHOD FOR LAUNCHING AND RETRIEVING A FIXED-WING AIRCRAFT**

(71) Applicant: **HOOD TECHNOLOGY CORPORATION**, HOOD RIVER, OR (US)

(72) Inventors: **Andreas H. von Flotow**, Hood River, OR (US); **Corydon D. Roeseler**, Hood River, OR (US); **Caleb Andrew Woodruff**, White Salmon, OR (US); **Daniel Pepin Reiss**, Hood River, OR (US)

(21) Appl. No.: **17/454,741**

(22) Filed: **Nov. 12, 2021**

Related U.S. Application Data

(63) Continuation of application No. 15/873,487, filed on Jan. 17, 2018, now Pat. No. 11,204,612.

(60) Provisional application No. 62/449,321, filed on Jan. 23, 2017.

Publication Classification

(51) **Int. Cl.**
G05D 1/08	(2006.01)
B64C 39/02	(2006.01)
G05D 1/10	(2006.01)
G05D 1/06	(2006.01)
B64F 1/02	(2006.01)

(52) **U.S. Cl.**
CPC *G05D 1/0858* (2013.01); *B64C 39/024* (2013.01); *G05D 1/104* (2013.01); *G05D 1/0661* (2013.01); *B64F 1/029* (2020.01); *B64C 2201/108* (2013.01); *B64C 2201/027* (2013.01); *B64C 2201/182* (2013.01); *B64C 2201/082* (2013.01); *B64C 2201/021* (2013.01); *B64C 2201/104* (2013.01); *B64C 2201/146* (2013.01)

(57) **ABSTRACT**

A rotorcraft-assisted launch and retrieval system, and a method for controlling an airborne rotorcraft which includes controlling by a controller a first feedback loop about a longitudinal roll axis of the airborne rotorcraft and controlling by the controller a second feedback loop about a horizontal pitch axis of the airborne rotorcraft, without controlling a vertical yaw axis of the airborne rotorcraft.
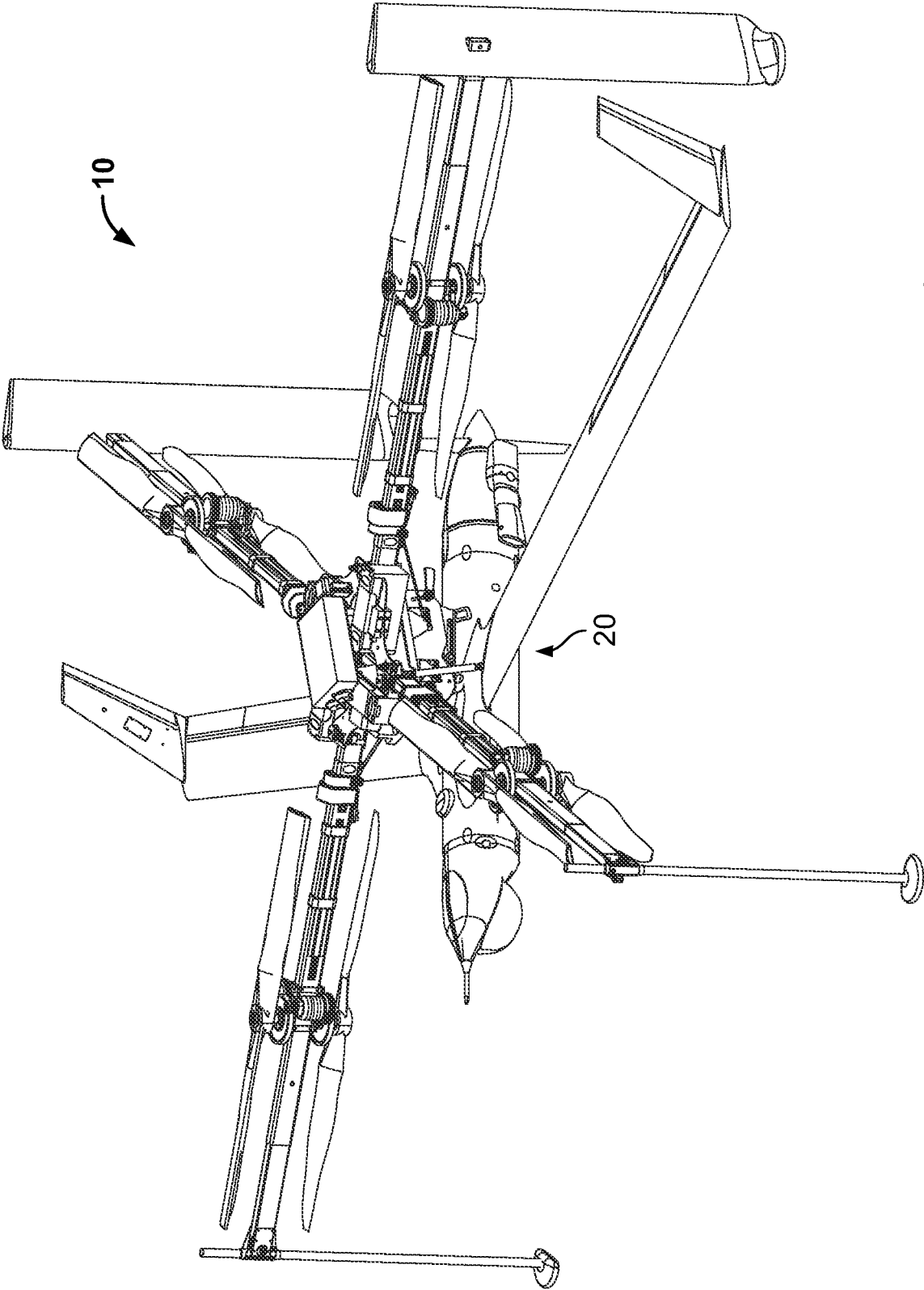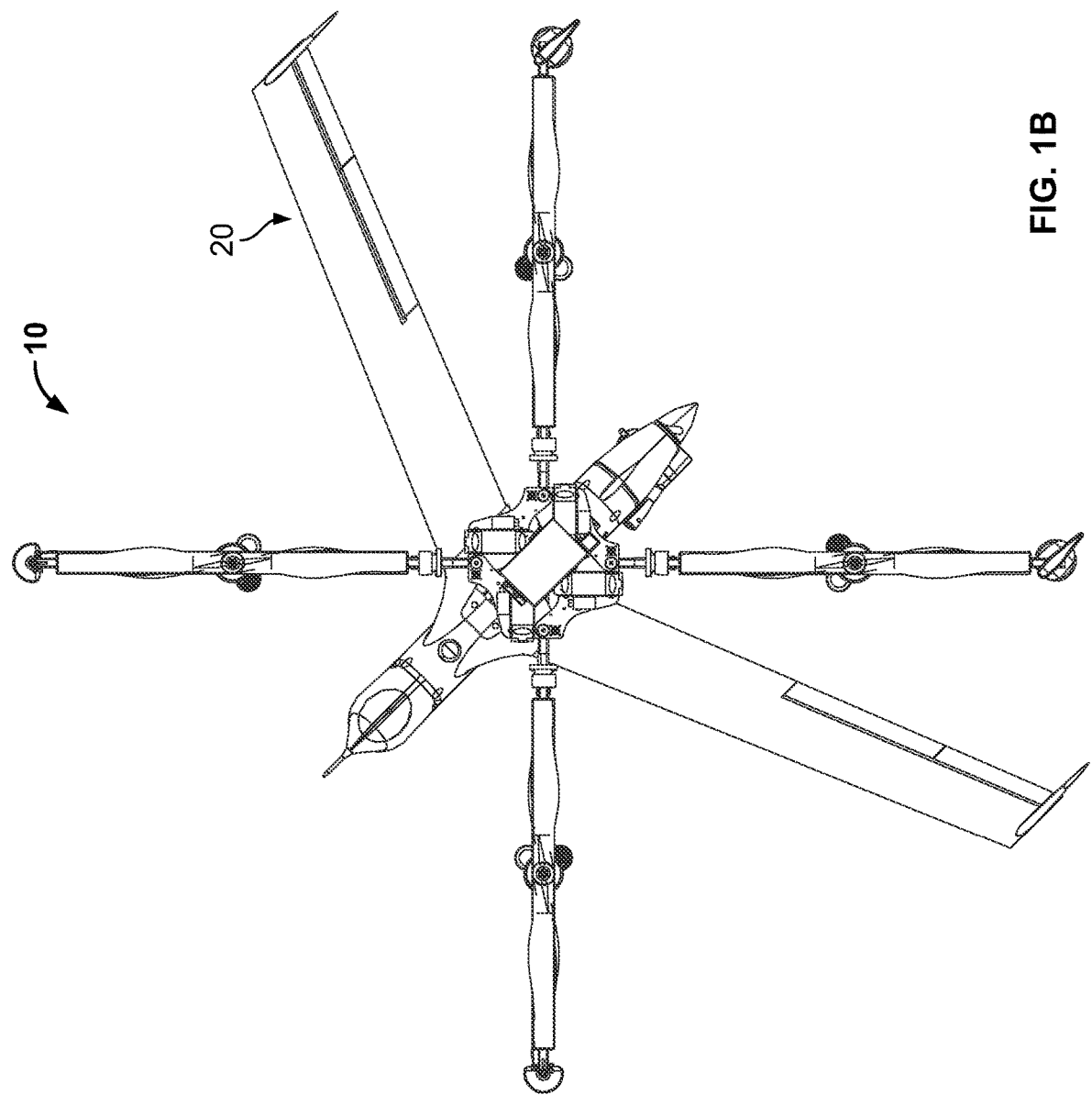
10

20

FIG. 1A

FIG. 1B

10

FIG. 1C

10
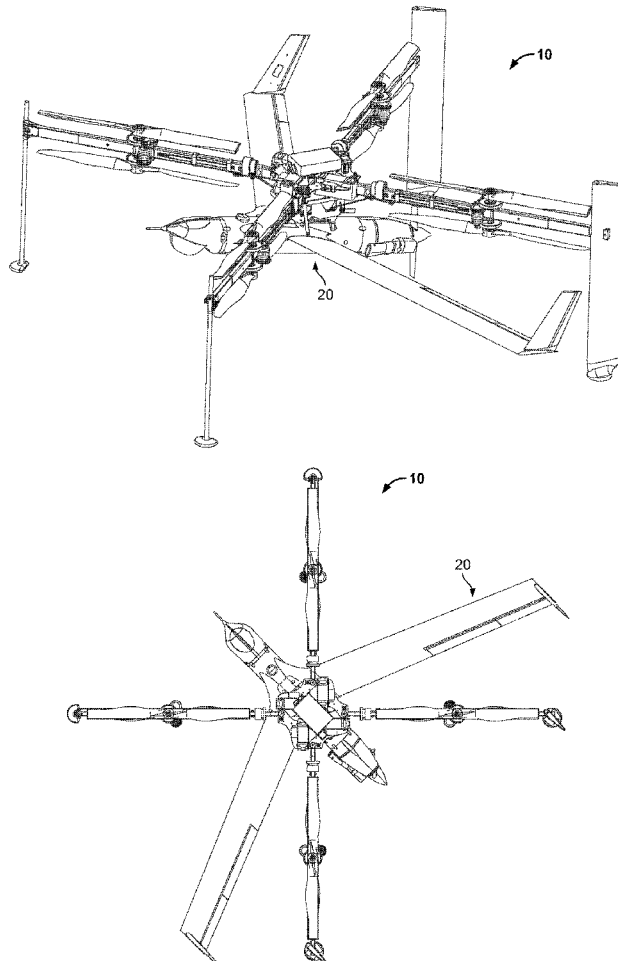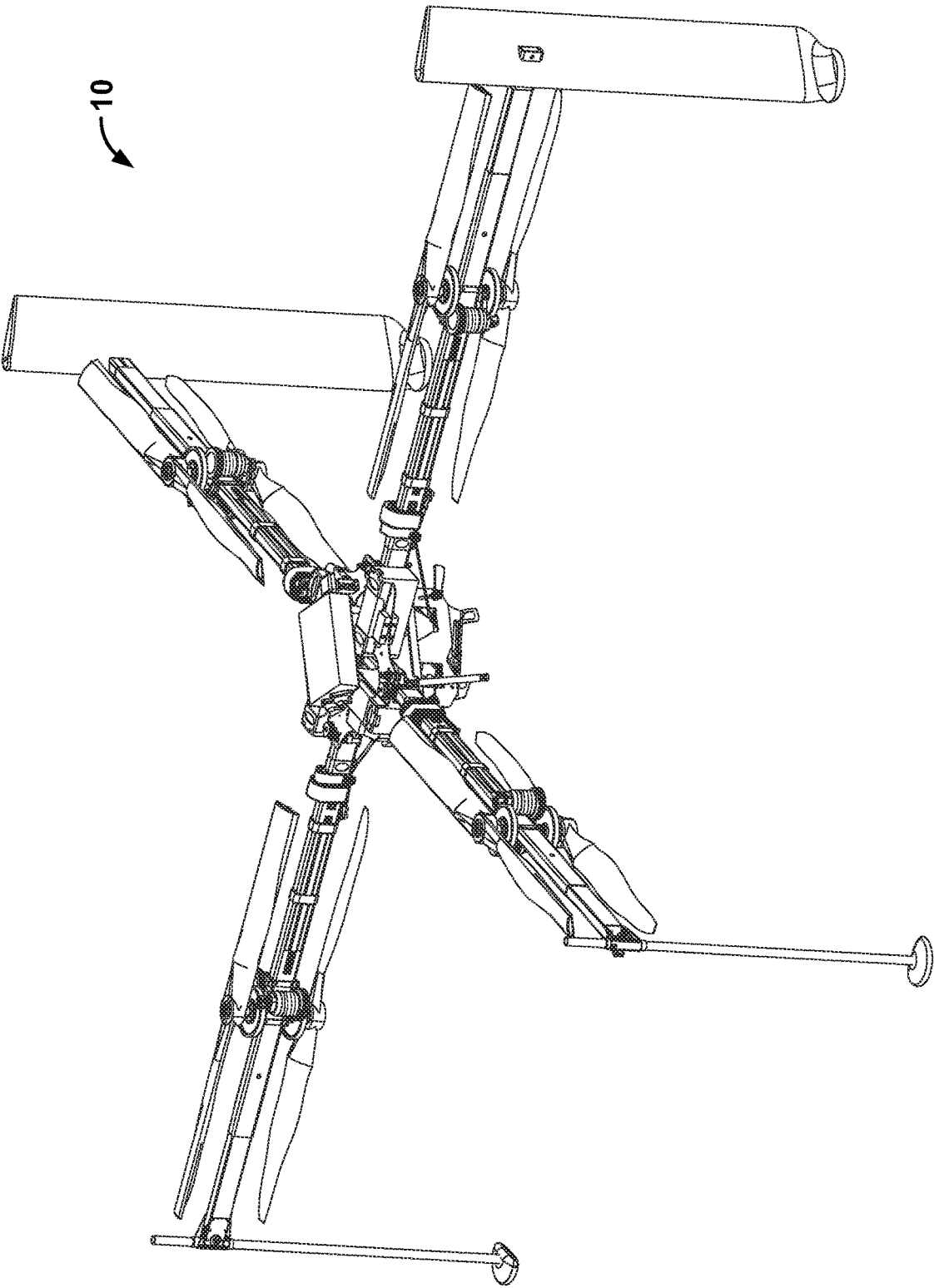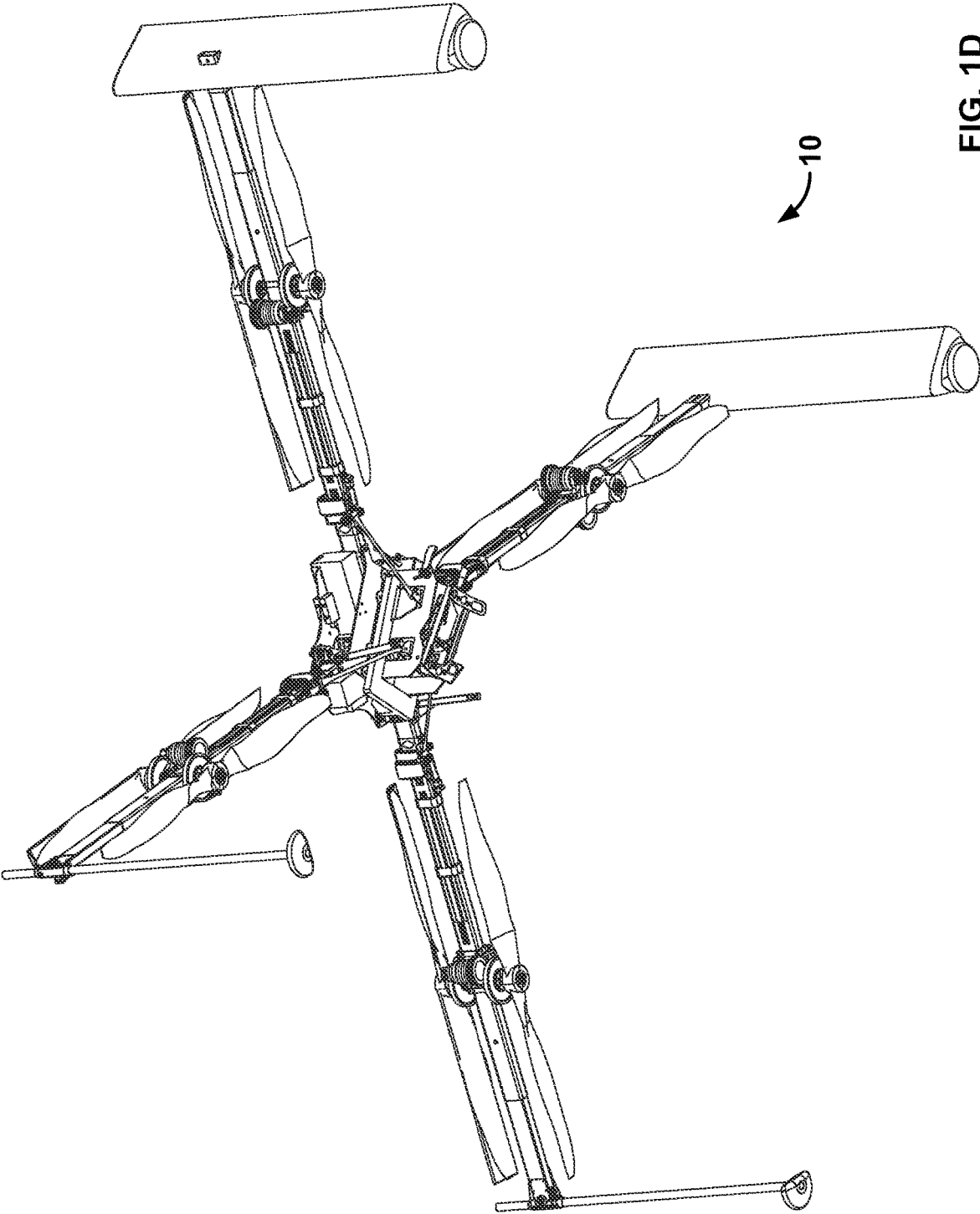
FIG. 1D
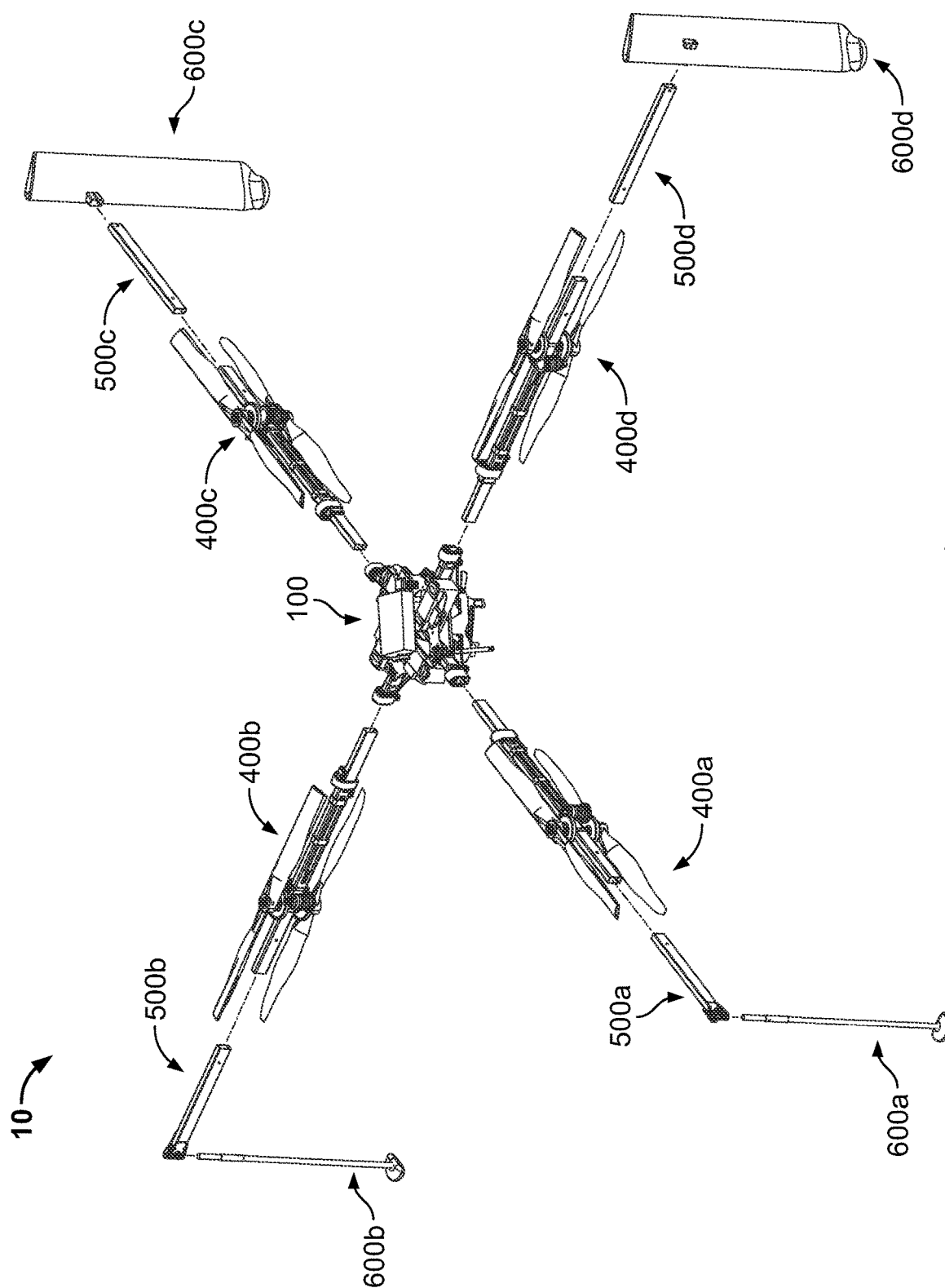
FIG. 1E

FIG. 1F

FIG. 1G

FIG. 2A

FIG. 2B

FIG. 2C

FIG. 3A

FIG. 3B

FIG. 3C

222

220a

210b

212

212

212

212

210a

212

220b

202

FIG. 3D

254

258

254a

256a

252

250

250a

250b

256b

220a

222

210b

242b

220b

244b

240b

FIG. 3E

254a
252   254   258   256a

252a

250

256b
244b
240b

242b   210b

FIG. 3F

FIG. 3G

210b

237

233b

239

234b

232b

231b

235b

238

236b

FIG. 3H

300

FIG. 4A

300

FIG. 4B

FIG. 4C

320a

α

321a

322a

310

FIG. 4D

α

320a

322a

321a

310

FIG. 4E

354

355

352
353

351

350

FIG. 4F

FIG. 4G

392

382

310

350

FIG. 4H

392

382

310

350

FIG. 4I

400a

5J

5H

5J

5H

475a

465b

465a

480

475b

410a

431

431a

420

410b

FIG. 5A

400a

410b

431

410a

420

475a

465a

465b

480

475b

FIG. 5B

420

423a

421

423

428

424

425

422

420a

422a

427a

429

426

420b

427

FIG. 5C

237

420

FIG. 5D

237

420

FIG. 5E

238

239

237

420

FIG. 5F

470a
471a
473a
472a
475a
474a
477a
478a
476a
479a
467a
462a
466a
463a
464a
464a
461a
465a
410a
490a
495a

FIG. 5G

460b

467a 466a

463a
464a
462a
461a

476a
410a

495b

465a
464a

490b

490a

495a

410a
476b

464b
465b

461b
462b
464b
463b

466b 467b

460a

FIG. 5H

FIG. 5I

470

470a

471a
472a
473a
475a

474a

477a
476a

478a
479a

461a

410a

480b

461b

477b
478b
479b
476b

474b

475b

473b
472b
471b

FIG. 5J

FIG. 6A

500a

510a

530

520

FIG. 6B

500c

510c

600a

630

632

610

620

FIG. 7A

600c

650c

650b

680

650a

FIG. 7B

670

2000b

2000a

2000

FIG. 8A

100

500d
500c
500b
500a

2300

2000b

400c

400b

600c

2200

2000a

600b

600a

400a

600d

400d

2100

FIG. 8B

2100

2121
2120
2121a
2130
2122
2123a
2123
2110a
2110b
2108
2112
2104b
2116b
2114a
2102b
2116a
2106b
2106a
2114b
2102a
2104a

FIG. 8C

FIG. 8D

FIG. 8E

FIG. 8F

FIG. 8G

FIG. 8H

2241   2242   2243   2244

2241b   2242b   2243b   2244b

2241a   2242a   2243a   2244a

FIG. 8I

2300

2338

2320

2336

2332

2310

2334

FIG. 8J

FIG. 9A

FIG. 9B

3228

3230

3224

3200

3226

3228a

3222

3220

3222a

3218

3126

3214a

3214

3214a

3212

3210a

3210b

FIG. 9C

FIG. 9D

FIG. 10A

FIG. 10B

FIG. 10C

10

5100

5200

20

5000

5300

3250

3300

3200

FIG. 10D

FIG. 10G

FIG. 10F

FIG. 10E

FIG. 10I

FIG. 10H

1500

Start

1502

Half-power
mode input signal
received
?

No

Yes

1504

Send a rotor motor control signal to each upper rotor motor
of a multicopter to reduce the output of each upper rotor
motor to a designated output that is less than the output
of each lower rotor motor of the multicopter

FIG. 11A

1050

Start

1052 — First and second arm signals that are decoupled from multicopter yaw control simultaneously received ?

No

Yes

1054 — Arm the controller of the multicopter

1056 — Send a rotor motor control signal to each rotor motor of the multicopter to control all of the rotor motors to operate at a designated rotor motor output

1058 — Designated period expired ?

No

Yes

1060 — Controller armed in half-power mode ?

No

Yes

1064 — Maintain operation of all lower rotor motors

1062 — Maintain operation of all rotor motors

1066 — Send a rotor motor control signal to each upper rotor motor to reduce the output of each upper rotor motor to a designated output that is less than the output of each lower rotor motor

FIG. 11B

1450

Start

1452
After sending a rotor motor control signal to command a
non-operating rotor motor to operate, periodically receive,
from a rotational speed sensor, a measured rotational speed
of the rotor motor

1454
Upon
expiration of a
designated period after
sending the rotor motor control signal, is
the measured rotational speed of the rotor
motor below a threshold
rotational speed
?

No

Yes

1456
Send a rotor motor control signal to
shut down the rotor motor

End

FIG. 11C

1600

1602 Receive a measured barometric pressure from a barometer

1606 Is the measured barometric pressure above a threshold barometric pressure ?

No

1608 Set a maximum rotor motor output to a first rotor motor output

Yes

1610 Set the maximum rotor motor output to a second rotor motor output that is greater than the first rotor motor output

1612 Limit the output of each rotor motor of the multicopter to the maximum rotor motor output

FIG. 11D

1000

1002 — Periodically receive a measured multicopter yaw angle from a yaw angle sensor

1004 — Periodically receive a measured multicopter roll angle from a roll angle sensor

1006 — Periodically receive a measured multicopter pitch angle from a pitch angle sensor

Start

1010 — Does the measured multicopter roll angle equal a target multicopter roll angle ?

Yes

No

1008 — Does the measured multicopter pitch angle equal a target multicopter pitch angle ?

Yes

No

1012 — Send one or more rotor motor control signals to control the one or more rotor motors to operate to eliminate the difference between the measured multicopter pitch angle and the target multicopter pitch angle and/or the difference between the measured multicopter roll angle and the target multicopter roll angle

FIG. 11E

FIG. 11F

1652 — Monitor a height of the multicopter above the ground

1654 — Monitor a measured multicopter pitch angle

1656 — Monitor multicopter GPS connectivity

Start

1660 — Fixed-wing aircraft release enabled ? — No

Yes

1666 — Release signal received ? — No

Yes

1668 — Send an actuator release signal to a release actuator to cause the release actuator to move to a release position

1658 — Does the height of the multicopter above the ground exceed a designated height above the ground, is the measured multicopter pitch angle within a designated pitch angle range, and is multicopter gps connectivity established ?

Yes — 1662 — Enable fixed-wing aircraft release

No

1650

1664 — Ignore any received release signal

1200

Start

1202

Receive a pitch angle modification
input associated with a desired
multicopter pitch angle

1204

Send one or more rotor motor control
signals to control the one or more rotor
motors to operate to change the
multicopter pitch angle to the desired
multicopter pitch angle at a rate
no greater than a maximum, finite
multicopter pitch angle rate of change

FIG. 11G

```
                              ( Start )

                                            1402
                                  ┌─────────────────────────────┐
                                  │  Control one or more rotor    │
                                  │  motors such that a multicopter│
                          ───────▶│  pitch angle does not exceed  │
                                  │  a maximum multicopter        │
                                  │  pitch angle                  │
                                  └─────────────────────────────┘

  1404
  ┌─────────────────────────────┐
  │  Receive a signal identifying one of │
  │  multiple different flight modes, each│
  │  flight mode associated with one of   │
  │  multiple different pitch angles      │
  └─────────────────────────────┘

  1406
  ┌─────────────────────────────┐
  │  Operate the multicopter in   │
  │  the identified flight mode   │
  └─────────────────────────────┘

  1408
  ┌─────────────────────────────┐
  │  Set the maximum multicopter pitch│
  │  angle to the pitch angle associated│
  │  with the identified flight mode   │
  └─────────────────────────────┘

                    1410
                         Flight mode
                  change signal identifying a
         Yes      different flight mode received     No
                              ?
```

FIG. 11H

1300

Start

1302
Receive an autonomous launch signal

1304
Determine, based at least in part on signals received from one or more sensors, a pre-launch heading of the multicopter

1306
Determine, based at least in part on the pre-launch heading of the multicopter, a launch flight path

1308
Send one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter to climb to a multicopter pre-dash location in accordance with the launch flight path

1310
Afterwards, send one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter laterally in accordance with the launch flight path

1312
While the multicopter is flying laterally and after the multicopter reaches a release velocity, send an object release command to an object release device of the multicopter to cause an object to detach from the multicopter

1314
Afterwards, send one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter to a multicopter pre-landing location in accordance with the launch flight path

FIG. 11I

1100

Start

1102 — Monitor a height of the multicopter above a landing surface

1104 — Monitor a multicopter throttle level

1106 — Is the height of the multicopter above the landing surface below a designated height above the landing surface and is the multicopter throttle level below a designated throttle level ?

No

Yes

1108 — Enable rotor motor shut down

1110 — Ignore any rotor motor shut down signals

1112 — Rotor motor shut down enabled ?

No

Yes

1114 — Rotor motor shut-down signal received ?

No

Yes

1116 — Send one or more rotor motor control signals to shut down the rotor motors

FIG. 11J

Start

1250

1252 — Establish wireless communications with a multicopter

1254 — Receive an input that identifies one of multiple different multicopter flight modes

1256 — Store, in a memory, current multicopter flight mode data that represents the identified multicopter flight mode

1258 — Send the multicopter a command to operate in the identified multicopter flight mode

1260 — Lost communications with the multicopter ?

No

1262 — Attempt to reestablish communications with the multicopter

1264 — Reestablished communications with the multicopter ?

No

Yes

1266 — Access the current multicopter flight mode data in the memory

1268 — Send the multicopter a command to operate in the multicopter flight mode represented by the current multicopter flight mode data

Yes

FIG. 11K

1350 ⌐

```
                              ( Start )
```

1352 ⌐

Receive an autonomous retrieval signal

1354 ⌐

Send one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter to a retrieval location that is a designated height above an anchor location

1356 ⌐

After the multicopter reaches the retrieval location, send one or more rotor motor control signals to control the one or more rotor motors to station-keep the multicopter relative to the anchor system

1358 ⌐

After a fixed-wing aircraft captures a flexible capture member attached to and extending below the multicopter, send one or more rotor motor control signals to one or more rotor motors of the multicopter to control the one or more rotors to descend the multicopter at a first rate of descent

1360 ⌐

After the height of the fixed-wing aircraft above a fixed-wing aircraft landing surface reaches a first height, send one or more rotor motor control signals to the one or more rotor motors to control the one or more rotors to descend the multicopter at a second rate of descent that is less than the first rate of descent

1362 ⌐

After the fixed-wing aircraft contacts the fixed-wing aircraft landing surface, send one or more rotor motor control signals to the one or more rotor motors to control the one or more rotor motors to descend the multicopter at a third rate of descent that is greater than the second rate of descent

1364 ⌐

After the height of the multicopter above a multicopter landing surface reaches a second height, send one or more rotor motor control signals to the one or more rotor motors to control the one or more rotor motors do descend the multicopter at a fourth rate of descent that is less than the third rate of descent

FIG. 11L

10a

V1

B

V2

C

V3

D

A

12

FIG. 12A
(Prior Art)

10

V12

C

V3

D

A

12

FIG. 12B

Pitch angle modification input received

FIG. 13A
(Prior Art)

Pitch angle modification input received

Tc

FIG. 13B

FIG. 14

ROTORCRAFT-ASSISTED SYSTEM AND METHOD FOR LAUNCHING AND RETRIEVING A FIXED-WING AIRCRAFT

PRIORITY

[0001] This continuation application claims priority to and the benefit of U.S. Non-Provisional patent application Ser. No. 15/873,487, filed Jan. 17, 2018, which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/449,321, filed Jan. 23, 2017, the entire contents of both of which are incorporated herein by reference.

BACKGROUND

[0002] It is well-known in the aeronautical sciences that an aircraft capable of hover and/or of slow flight is typically not well-suited to long-distance efficient cruising flight. One drawback of aircraft capable of long-distance efficient cruising flight is that such ai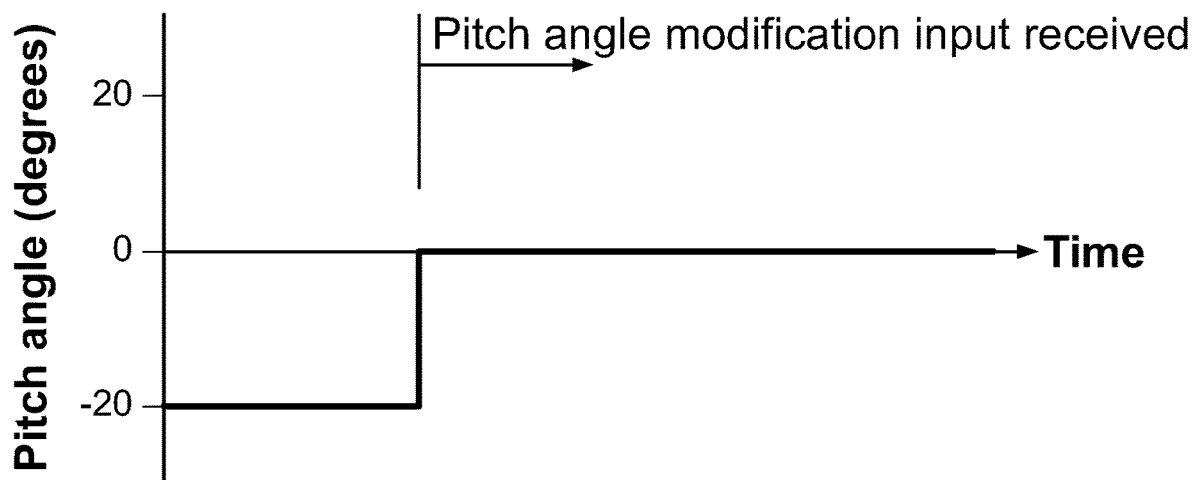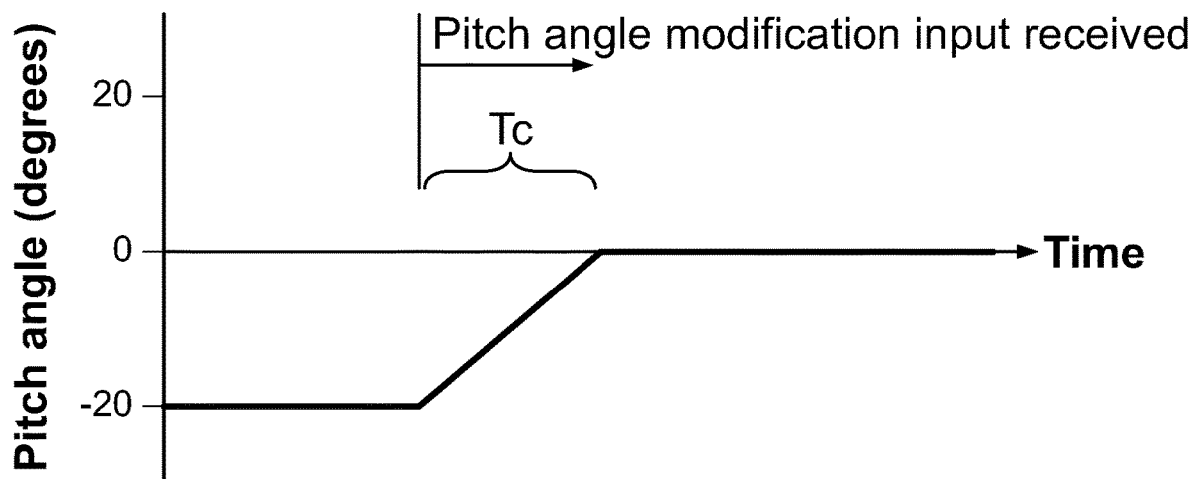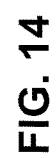rcraft typically require long runways to be utilized for take-off and landing. This becomes problematic when there is not sufficient space for the requisite runway, meaning that such aircraft may not be used. There is a need for new systems and methods by which aircraft that otherwise require a long runway may be launched and retrieved from small spaces that solve these problems.

SUMMARY

[0003] The rotorcraft-assisted launch and retrieval system of various embodiments of the present disclosure generally includes: (1) an eight-rotor modular multicopter attachable to (and detachable from) a fixed-wing aircraft to facilitate launch of the fixed-wing aircraft into wing-borne flight; (2) a storage and launch system usable to store the modular multicopter and to facilitate launch of the fixed-wing aircraft into wing-borne flight; and (3) an anchor system usable (along with the multicopter and a flexible capture member) to retrieve the fixed-wing aircraft from wing-borne flight.

[0004] Generally, to launch the fixed-wing aircraft into wing-borne flight, an operator (or operators): (1) removes the disassembled multicopter from a container of the storage and launch system; (2) assembles the multicopter; (3) mounts the fixed-wing aircraft to a launch-assist assembly of the storage and launch system; (4) attaches the fixed-wing aircraft to the multicopter; (5) remotely controls the multicopter to lift the fixed-wing aircraft to a desired altitude and to accelerate the fixed-wing aircraft to a desired speed; and (6) remotely causes the fixed-wing aircraft to detach from the multicopter, thereby releasing the fixed-wing aircraft into wing-borne flight.

[0005] Generally, to retrieve the fixed-wing aircraft from wing-borne flight, the operator (or operators): (1) attaches one end of a flexible capture member to the multicopter and the other end to the anchor system; (2) remotely controls the multicopter to fly above the anchor system until the flexible capture member is tensioned to a designated level; and (3) controls the fixed-wing aircraft to capture the flexible capture member.

[0006] Additional features and advantages of the present disclosure are described in, and will be apparent from, the following Detailed Description and the Figures.

BRIEF DESCRIPTION OF THE FIGURES

[0007] FIG. 1A is a top perspective view of one example embodiment of the multicopter of the present disclosure attached to a fixed-wing aircraft.
[0008] FIG. 1B is a top plan view of the multicopter and fixed-wing aircraft of FIG. 1A.
[0009] FIG. 1C is a top perspective view of the multicopter of FIG. 1A.
[0010] FIG. 1D is a bottom perspective view of the multicopter of FIG. 1A.
[0011] FIG. 1E is a partially-exploded top perspective view of the multicopter of FIG. 1A.
[0012] FIG. 1F is a partially-exploded bottom perspective view of the multicopter of FIG. 1A.
[0013] FIG. 1G is a block diagram showing certain electrically-controlled components of the multicopter of FIG. 1A.
[0014] FIG. 2A is a top perspective view of the hub module of the multicopter of FIG. 1A.
[0015] FIG. 2B is a bottom perspective view of the hub module of FIG. 2A.
[0016] FIG. 2C is a partially exploded top perspective view of the hub module of FIG. 2A showing the hub base separated from the saddle.
[0017] FIG. 3A is a top perspective view of the hub base of the hub module of FIG. 2A.
[0018] FIG. 3B is a bottom perspective view of the hub base of FIG. 3A.
[0019] FIG. 3C is a partially exploded top perspective view of the hub base of FIG. 3A.
[0020] FIG. 3D is an exploded top perspective view of the supports and associated mounting hardware of the hub base of FIG. 3A.
[0021] FIG. 3E is an exploded top perspective view of the isolator plate and associated mounting hardware of the hub base of FIG. 3A.
[0022] FIG. 3F is a partial cross-sectional view of one of the isolator plate mounts of the hub base of FIG. 3A taken substantially along line 3F-3F of FIG. 3C.
[0023] FIG. 3G is a partially exploded top perspective view of one of the female blind mate assemblies of the hub base of FIG. 3A.
[0024] FIG. 3H is a partial cross-sectional view of one of the flexural mounts of the female blind mate assembly of FIG. 3G taken substantially along line 3H-3H of FIG. 3C.
[0025] FIG. 4A is a top perspective view of the saddle of the hub module of FIG. 2A.
[0026] FIG. 4B is a bottom perspective view of the saddle of FIG. 4A.
[0027] FIG. 4C is a partially exploded top perspective view of the saddle of FIG. 4A.
[0028] FIGS. 4D and 4E are side elevational views of the saddle of FIG. 4A showing different positions of the saddle.
[0029] FIG. 4F is a top perspective view of the cam of the saddle of FIG. 4A.
[0030] FIG. 4G is an exploded top perspective view of the aircraft attaching/detaching assembly and the cam of the saddle of FIG. 4A.
[0031] FIG. 4H is a partial cross-sectional view of the saddle of FIG. 4A taken substantially along line 4H-4H of FIG. 4C.
[0032] FIG. 4I is a partial cross-sectional view of the saddle of FIG. 4A showing the cam in a detached rotational position taken substantially along line 4H-4H of FIG. 4C.

[0033] FIG. **5A** is a top perspective view of one of the rotor arm modules of the multicopter of FIG. **1A**.

[0034] FIG. **5B** is a bottom perspective view of the rotor arm module of FIG. **5A**.

[0035] FIG. **5C** is a top perspective view of the locking assembly of the rotor arm module of FIG. **5A**.

[0036] FIGS. **5D**, **5E**, and **5F** are side elevational views of the rotor arm module of FIG. **5A** detaching from the hub module of FIG. **2A** via the locking assembly of FIG. **5C**.

[0037] FIG. **5G** is an exploded top perspective view of one of the rotor arm assemblies and part of the rotor assembly of the rotor arm module of FIG. **5A**.

[0038] FIG. **5H** is a cross-sectional view of the rotor motor assemblies of the rotor arm module of FIG. **5A** taken substantially along line **5H-5H** of FIG. **5A**.

[0039] FIG. **5I** is an exploded top perspective view of one of the rotor motor collars and one of the rotor motor fans of the rotor arm module of FIG. **5A**.

[0040] FIG. **5J** is a cross-sectional view of the rotor assembly of the rotor arm module of FIG. **5A** taken substantially along line **5J-5J** of FIG. **5A**.

[0041] FIG. **6A** is a top perspective view of one of the front landing gear extension modules of the multicopter of FIG. **1A**.

[0042] FIG. **6B** is a top perspective view of one of the rear landing gear extension modules of the multicopter of FIG. **1A**.

[0043] FIG. **7A** is a top perspective view of one of the front landing gear modules of the multicopter of FIG. **1A**.

[0044] FIG. **7B** is a top perspective view of one of the rear landing gear modules of the multicopter of FIG. **1A**.

[0045] FIG. **8A** is a partially exploded top perspective view of the multicopter of FIG. **1A** stored in one example embodiment of the storage and launch system of the present disclosure.

[0046] FIG. **8B** is an exploded top perspective view of the storage and launch system of FIG. **8A**, the 13 modules of the multicopter of FIG. **1A**, and elements used to store the multicopter.

[0047] FIG. **8C** is a top perspective view of the launch-assist assembly of the storage and launch system of FIG. **8A** in the launch position.

[0048] FIG. **8D** is a top perspective view of the storage and launch system of FIG. **8A** with the fixed-wing aircraft mounted thereto.

[0049] FIG. **8E** is an exploded top perspective view of the fuselage-retaining assembly of the launch-assist assembly of FIG. **8C**.

[0050] FIG. **8F** is a front elevational view of the fuselage-retaining assembly of FIG. **8E**.

[0051] FIG. **8G** is a back elevational view of the fuselage-retaining assembly of FIG. **8E**.

[0052] FIG. **8H** is a top perspective view of the rotor arm module and rear landing gear module storage device of the present disclosure.

[0053] FIG. **8I** is a cross-sectional view of the rotor arm module and rear landing gear module storage device of FIG. **8H** taken substantially along line **8I-8I** of FIG. **8H**.

[0054] FIG. **8J** is a top perspective view of the hub module storage tray of the present disclosure.

[0055] FIG. **9A** is a top perspective view of one example embodiment of the anchor system of the present disclosure.

[0056] FIG. **9B** is a partially-exploded top perspective view of the anchor system of FIG. **9A**.

[0057] FIG. **9C** is an exploded top perspective view of the breakaway device of the anchor system of FIG. **9A**.

[0058] FIG. **9D** is a top perspective view of the anchor system of FIG. **9A** stored within a storage container along with other accessories.

[0059] FIG. **10A** is a partial cross-sectional view of the saddle of FIG. **4A** showing the cam in an attached rotational position and a hook of the fixed-wing aircraft attached taken substantially along line **10A-10A** of FIG. **4C**.

[0060] FIG. **10B** is a partial cross-sectional view of the saddle of FIG. **4A** showing the cam halfway between the attached rotational position and the detached rotational position and the hook of the fixed-wing aircraft being pushed off of the cam taken substantially along line **10A-10A** of FIG. **4C**.

[0061] FIG. **10C** is a partial cross-sectional view of the saddle of FIG. **4A** showing the cam in the detached rotational position and the hook of the fixed-wing aircraft detached from the cam taken substantially along line **10A-10A** of FIG. **4C**.

[0062] FIG. **10D** is a diagrammatic view of the multicopter of FIG. **1A**, the fixed-wing aircraft, the flexible capture member of the present disclosure, the breakaway device of FIG. **9C**, and the flexible capture member payout and retract device of the anchor system of FIG. **9A** just before capture.

[0063] FIG. **10E** is a cross-sectional view of the breakaway device of FIG. **9C** when the compression spring is fully extended taken substantially along a plane through the longitudinal axis of the breakaway device.

[0064] FIG. **10F** is a cross-sectional view of the breakaway device of FIG. **9C** when the compression spring is fully compressed and the finger beginning to rotate out of the breakaway sleeve taken substantially along a plane through the longitudinal axis of the breakaway device.

[0065] FIG. **10G** is a cross-sectional view of the breakaway device of FIG. **9C** when the compression spring is fully compressed and the finger has rotated out of the breakaway sleeve taken substantially along a plane through the longitudinal axis of the breakaway device.

[0066] FIG. **10H** is a diagrammatic view of the multicopter of FIG. **1A**, the fixed-wing aircraft, the flexible capture member of the present disclosure, the breakaway device of FIG. **9C**, and the flexible capture member payout and retract device of the anchor system of FIG. **9A** just after capture when the anchor system is paying out flexible capture member.

[0067] FIG. **10I** is a diagrammatic view of the multicopter of FIG. **1A**, the fixed-wing aircraft, the flexible capture member of the present disclosure, the breakaway device of FIG. **9C**, and the flexible capture member payout and retract device of the anchor system of FIG. **9A** after the fixed-wing aircraft has stopped moving and the anchor system has retracted the paid-out portion of the flexible capture member.

[0068] FIG. **11A** is a flowchart of an example process for operating the multicopter in partial-power mode.

[0069] FIG. **11B** is a flowchart of an example process for arming the controller of the multicopter independent from multicopter yaw control.

[0070] FIG. **11C** is a flowchart of an example rotor motor stall detection process.

[0071] FIG. **11D** is a flowchart of an example process for setting the maximum rotor motor output of the rotor motors of the multicopter.

[0072] FIG. 11E is a flowchart of an example process for controlling multicopter pitch and roll angles without controlling multicopter yaw angle while dashing before releasing the fixed-wing aircraft.

[0073] FIG. 11F is a flowchart of an example process for selectively enabling fixed-wing aircraft release.

[0074] FIG. 11G is a flowchart of an example process for limiting multicopter pitch angle rate of change.

[0075] FIG. 11H is a flowchart of an example process for setting the maximum multicopter pitch angle for the multicopter.

[0076] FIG. 11I is a flowchart of an example process for autonomously launching the fixed-wing aircraft using the multicopter.

[0077] FIG. 11J is a flowchart of an example process for shutting down the rotor motors of a multicopter at touchdown.

[0078] FIG. 11K is a flowchart of an example process for establishing communication between an R/C controller and a multicopter.

[0079] FIG. 11L is a flowchart of an example process for autonomously retrieving the fixed-wing aircraft using the multicopter.

[0080] FIG. 12A is a diagrammatic view of one route a prior art multicopter takes responsive to receiving an RTL signal.

[0081] FIG. 12B is a diagrammatic view of one route the multicopter of the present disclosure takes responsive to receiving an RTL signal.

[0082] FIG. 13A is a graph showing the desired multicopter pitch angle over time for an example situation for a prior art multicopter.

[0083] FIG. 13B is a graph showing the desired multicopter pitch angle over time for an example situation for one example of the multicopter of the present disclosure.

[0084] FIG. 14 shows one example launch flight path for the multicopter of the present disclosure.

DETAILED DESCRIPTION

[0085] While the features, methods, devices, and systems described herein may be embodied in various forms, there are shown in the drawings, and will hereinafter be described, some exemplary and non-limiting embodiments. Not all of the depicted components described in this disclosure may be required, however, and some implementations may include additional, different, or fewer components from those expressly described in this disclosure. Variations in the arrangement and type of the components; the shapes, sizes, and materials of the components; and the manners of attachment and connections of the components may be made without departing from the spirit or scope of the claims as set forth herein. Also, unless otherwise indicated, any directions referred to herein reflect the orientations of the components shown in the corresponding drawings and do not limit the scope of the present disclosure. This specification is intended to be taken as a whole and interpreted in accordance with the principles of the invention as taught herein and understood by one of ordinary skill in the art.

[0086] Although various processes are described below with reference to various flowcharts, many other processes of performing the acts associated with the illustrated processes may be employed. For example, the order of certain of the illustrated blocks or diamonds may be changed, certain of the illustrated blocks or diamonds may be optional, or certain of the illustrated blocks or diamonds may not be employed.

[0087] The rotorcraft-assisted launch and retrieval system of various embodiments of the present disclosure generally includes: (1) an eight-rotor modular multicopter 10 attachable to (and detachable from) a fixed-wing aircraft 20 to facilitate launch of the fixed-wing aircraft 20 into wing-borne flight; (2) a storage and launch system 2000 usable to store the modular multicopter 10 and to facilitate launch of the fixed-wing aircraft 20 into wing-borne flight; and (3) an anchor system 3000 usable (along with the multicopter 10 and a flexible capture member 5000) to retrieve the fixed-wing aircraft 20 from wing-borne flight.

[0088] Generally, to launch the fixed-wing aircraft 20 into wing-borne flight, an operator (or operators): (1) removes the disassembled multicopter 10 from a container of the storage and launch system 2000; (2) assembles the multicopter 10; (3) mounts the fixed-wing aircraft 20 to a launch-assist assembly of the storage and launch system 2000; (4) attaches the fixed-wing aircraft 20 to the multicopter 10; (5) remotely controls the multicopter 10 to lift the fixed-wing aircraft 20 to a desired altitude and to accelerate the fixed-wing aircraft 20 to a desired speed; and (6) remotely causes the fixed-wing aircraft 20 to detach from the multicopter 10, thereby releasing the fixed-wing aircraft 20 into wing-borne flight.

[0089] Generally, to retrieve the fixed-wing aircraft 20 from wing-borne flight, the operator (or operators): (1) attaches one end of a flexible capture member 5000 to the multicopter 10 and the other end to the anchor system 3000; (2) remotely controls the multicopter 10 to fly above the anchor system 3000 until the flexible capture member 5000 is tensioned to a designated level; and (3) controls the fixed-wing aircraft 20 to capture the flexible capture member 5000.

[0090] The components of one example embodiment of the multicopter 10, the storage and launch system 2000, and the anchor system 3000 are described below in connection with FIGS. 1A to 9D, followed by a detailed description of example methods for launching and retrieving the fixed-wing aircraft 20 into and from wing-borne flight using the multicopter 10, the storage and launch system 2000, and the anchor system 3000 in connection with FIGS. 10A to 10I.

[0091] The example embodiment of the systems and methods of the present disclosure shown in the drawings and described below include a multicopter. In other embodiments, the rotorcraft may include any suitable quantity of rotors (e.g., be a helicopter or a quadcopter).

1. Multicopter Components

[0092] FIGS. 1A, 1B, 1C, 1D, 1E, 1F, and 1G show the multicopter 10. The multicopter 10 is modular in that it is assembled from (and can be disassembled into) a plurality of different modules or subassemblies. The multicopter is removably attachable to: (1) the fixed-wing aircraft 20 to facilitate launch of the fixed-wing aircraft 20 into wing-borne flight, and (2) the flexible capture member 5000 to facilitate retrieval of the fixed-wing aircraft 20 from wing-borne flight.

[0093] As best shown in FIGS. 1E and 1F, the multicopter 10 includes the following 13 modules or subassemblies: a hub module 100; first, second, third, and fourth rotor arm modules 400a, 400b, 400c, and 400d; first and second front

landing gear extension modules **500***a* and **500***b*; first and second rear landing gear extension modules **500***c* and **500***d*; first and second front landing gear modules **600***a* and **600***b*; and first and second rear landing gear modules **600***c* and **600***d*.

[0094] As described in detail below, to assemble the multicopter **10** from these 13 modules or subassemblies, after removing the 13 modules from the container of the storage and launch system **2000**, an operator: (1) attaches the first, second, third, and fourth rotor arm modules **400***a*, **400***b*, **400***c*, and **400***d* to the hub module **100**; (2) attaches the first and second front landing gear extension modules **500***a* and **500***b* to the first and second rotor arm modules **400***a* and **400***b*, respectively; (3) attaches the first and second rear landing gear extension modules **500***c* and **500***d* to the third and fourth rotor arm modules **400***c* and **400***d*, respectively; (4) attaches the first and second front landing gear module **600***a* and **600***b* to the first and second front landing gear extension modules **500***a* and **500***b*, respectively; and (5) attaches the first and second rear landing gear module **600***c* and **600***d* to the first and second rear landing gear extension modules **500***c* and **500***d*, respectively.

[0095] The modularity of this multicopter is beneficial compared to non-modular or unitary multicopter construction. First, the modularity of this multicopter enables an operator to quickly and easily disassemble this relatively large multicopter into 13 smaller modules or subassemblies. The operator can compactly store these modules or subassemblies in a single container, which makes the disassembled multicopter easy to store and transport compared to the assembled multicopter. Second, if a part of this multicopter breaks, its modularity enables the operator to quickly and easily replace the module(s) or subassembly(ies) including the broken part with a properly-functioning replacement module(s) or subassembly(ies) rather than waste time repairing the broken component(s).

[0096] FIG. 1G is a block diagram of certain electrically-controlled components of the multicopter **10**. In this embodiment, although not shown in FIG. 1G, four (or any suitable quantity of) lithium-ion batteries (or any other suitable power source(s)) power these components (as described below). Specifically, for a given component, the power source may be directly electrically connected to that component to power that component or indirectly electrically connected to that component (e.g., via another component) to power that component.

[0097] The hub module **100** includes a hub base **200** and a saddle **300**. The hub base **200** includes: (1) a controller **272**; (2) a communications interface **274**; (3) an inertial measurement unit (IMU) **277**; (4) a barometer **278** (or other suitable pressure sensor); (5) a GPS receiver **285**; and (6) eight electronic speed controllers (ESCs) **265***a*, **265***b*, **265***c*, **265***d*, **265***e*, **265***f*, **265***g*, and **265***h*. The saddle **300** includes: (1) a cam servo motor **381**; and (2) a lock servo motor **391**. This is merely one example configuration, and these components may be located on any suitable part of the multicopter in other embodiments. The first rotor arm module **400***a* includes an upper rotor motor **465***a* and a lower rotor motor **465***b*. The second rotor arm module **400***b* includes an upper rotor motor **465***c* and a lower rotor motor **465***d*. The third rotor arm module **400***c* includes an upper rotor motor **465***e* and a lower rotor motor **465***f*. The fourth rotor arm module **400***d* includes an upper rotor motor **465***g* and a lower rotor motor **465***h*.

[0098] The controller **272** is electrically and communicatively connected to the telemetry link **274**, the R/C receiver **276**, the IMU **277**, the barometer **278**, the GPS receiver **285**, the ESCs **265***a* to **265***h*, the cam servo motor **381**, and the lock servo motor **391**.

[0099] The controller **272** includes a processor **272***a* and a memory **272***b*. The processor **272***a* is configured to execute program code or instructions stored in the memory **272***b* to control operation of the multicopter **10**, as described herein. The processor **272***a* may be one or more of: (1) a general-purpose processor; (2) a content-addressable memory; (3) a digital-signal processor; (4) an application-specific integrated circuit; (5) a field-programmable gate array; (6) any suitable programmable logic device, discrete gate, or transistor logic; (7) discrete hardware components; and (8) any other suitable processing device.

[0100] The memory **272***b* is configured to store, maintain, and provide data as needed to support the functionality of the multicopter **10**. For instance, in various embodiments, the memory **272***b* stores program code or instructions executable by the processor **272***a* to control the multicopter **10**. The memory **272***b* may be any suitable data storage device, such as one or more of: (1) volatile memory (e.g., RAM, which can include non-volatile RAM, magnetic RAM, ferroelectric RAM, and any other suitable forms); (2) non-volatile memory (e.g., disk memory, FLASH memory, EPROMs, EEPROMs, memristor-based non-volatile solid-state memory, etc.); (3) unalterable memory (e.g., EPROMs); and (4) read-only memory.

[0101] The communications interface **274** is a suitable wireless communication interface, such as a transceiver like an MM2 900 MHz Embedded Radio by Freewave Technologies, configured to establish and facilitate communication between the controller **272** and: (1) a computing device (such as a laptop computer, a tablet computer, or a mobile phone, not shown); and (2) an R/C controller (not shown) that the operator of the multicopter **10** controls. In operation, once the communications interface **274** establishes communication with the computing device, the controller **272** can send data (via the communications interface **274**) associated with the operation of the multicopter **10** (such as the operational status of the multicopter **10**, GPS coordinates of the multicopter **10**, rotor motor status, IMU or other sensor measurements, altitude, GPS reception health, magnetometer health, aircraft attitude, and the like) to the computing device. Once the communications interface **274** establishes communication with the R/C controller, the controller **272** can receive signals (via the communications interface **274**) from the R/C controller. More specifically, upon receipt of these signals from the R/C controller, the communications interface **274** converts these signals into a format readable by the controller **272** and sends the converted signals to the controller **272** for processing.

[0102] The above-described communication may be bidirectional or unidirectional. In some embodiments, the communications interface **274** enables the controller **272** to send data to the computing device but not receive data from the computing device. In other embodiments, the communications interface **274** enables the controller **272** to send data to the computing device and to receive data from the computing device. In some embodiments, the communications interface **274** enables the controller **272** to receive signals from the R/C controller but not send signals to the R/C controller. In other embodiments, the communications inter-

face **274** enables the controller **272** to receive signals from the R/C controller and send signals to the R/C controller.

[0103] In certain embodiments, the communications interface **274** includes separate components for communicating with the computing device (such as a telemetry link) and the R/C controller (such as an R/C receiver).

[0104] The IMU **277** includes: (1) multiple accelerometers **277***a* configured to sense the linear acceleration of the multicopter **10** with respect to three orthogonal reference axes (e.g., standard orthogonal x-, y-, and z-axes); (2) multiple gyroscopes **277***b* configured to sense the angular rotation of the multicopter **10** with respect to the pitch, yaw, and roll axes of the multicopter **10**, as is known in the art; and (3) a magnetometer **277***c* configured to enable the controller **272** to determine the heading of the multicopter **10** (i.e., the direction in which the multicopter **10** is pointed relative to Earth), as is known in the art. More specifically, the magnetometer **277***c* is configured to sense the Earth's magnetic field and transmit a signal representing the direction of the Earth's magnetic North to the controller **272**. The controller **272** is configured to use the GPS coordinates of the multicopter **10** and a global map of declination angle (the angle between the Earth's true North and the Earth's magnetic North) to determine a required correction angle. The controller **272** is configured to apply the required correction angle to the direction of the Earth's magnetic North to obtain the direction of the Earth's true North. The controller **272** then uses this information to determine the heading of the multicopter **10**. In other embodiments, a pair of GPS receivers are used instead of the magnetometer to maintain more accurate heading. This practice is especially useful when the multicopter is operating in close proximity to large iron objects—such as ship hulls—or when the difference between the Earth's magnetic North and true North is large, such as near the Earth's poles.

[0105] The accelerometers **277***a*, the gyroscopes **277***b*, and the magnetometer **277***c* continuously or periodically obtain these sensor readings and continuously or periodically transmit corresponding signals to the controller **272**, which uses these sensor readings in a variety of different ways described herein. This is merely one example IMU, and the IMU may include any suitable sensors.

[0106] The barometer **278** is configured to sense the atmospheric pressure and to transmit a signal representing the sensed atmospheric pressure to the controller **272**. The controller **272** is configured to use the sensed atmospheric pressure to determine: (1) the height of the multicopter **10** above sea level, as is known in the art; and (2) the height of the multicopter **10** above the ground or any other suitable reference location, as is known in the art. For instance, to determine the height of the multicopter **10** above the ground, the controller **272** uses a reference atmospheric pressure sensed by the barometer **278** while the multicopter **10** is on the ground just before takeoff to determine the height of the ground above sea level. Once the multicopter **10** is airborne, at any given point in time the controller **272** is configured to determine the height of the multicopter **10** above the ground by: (1) using the atmospheric pressure sensed by the barometer **278** to determine the height of the multicopter **10** above sea level; and (2) determining the difference between the height of the multicopter **10** above sea level and the height of the ground above sea level. This is merely one example

way of determining the height of the multicopter above a reference point. Any other suitable method may be employed.

[0107] The GPS receiver **285** is communicatively connectable with (such as via a suitable wireless protocol) GPS satellites (not shown), as is known in the art. The GPS receiver **285** is configured to receive signals from one or more of the GPS satellites, to determine the multicopter's location using those signals, and to transmit signals representing the multicopter's location to the controller **272**.

[0108] The ESC **265***a* is electrically connected to and, along with the controller **272**, controls the operation of the upper rotor motor **465***a* of the first rotor arm module **400***a*. The ESC **265***b* is electrically connected to and, along with the controller **272**, controls the operation of the lower rotor motor **465***b* of the first rotor arm module **400***a*. The ESC **265***c* is electrically connected to and, along with the controller **272**, controls the operation of the upper rotor motor **465***c* of the second rotor arm module **400***b*. The ESC **265***d* is electrically connected to and, along with the controller **272**, controls the operation of the lower rotor motor **465***d* of the second rotor arm module **400***b*. The ESC **265***e* is electrically connected to and, along with the controller **272**, controls the operation of the upper rotor motor **465***e* of the third rotor arm module **400***c*. The ESC **265***f* is electrically connected to and, along with the controller **272**, controls the operation of the lower rotor motor **465***f* of the third rotor arm module **400***c*. The ESC **265***g* is electrically connected to and, along with the controller **272**, controls the operation of the upper rotor motor **465***g* of the fourth rotor arm module **400***d*. The ESC **265***h* is electrically connected to and, along with the controller **272**, controls the operation of the lower rotor motor **465***h* of the fourth rotor arm module **400***d*.

[0109] The controller **272** is configured to send rotor motor control signals to the ESCs **265***a* to **265***h* to control operation of the rotor motors **465***a* to **465***h* in accordance with received control signals and/or control signals the controller **272** generates via any of the software subroutines disclosed herein.

[0110] Each module or subassembly of the multicopter **10** is described in further detail below.

[0111] 1.1 Hub Module

[0112] FIGS. 2A, 2B, and 2C show the hub module **100**. The hub module **100**: (1) serves as the attachment point for the rotor arm modules **400***a* to **400***d*; (2) is the portion of the multicopter **10** to which the fixed-wing aircraft **20** is attached for launch; (3) is the portion of the multicopter **10** to which the flexible capture member **5000** is attached for retrieval of the fixed-wing aircraft **20**; (4) includes the power source for the multicopter **10**; and (5) includes certain components used to control operation of the multicopter **10**.

[0113] As best shown in FIG. 2C, the hub module **100** includes a hub base **200** and a saddle **300**. The saddle **300** is attached to the underside of the hub base **200** via two brackets **120***a* and **120***b* and four struts **110***a*, **110***b*, **110***c*, and **110***d*. Each strut **110** is attached at one end to the hub base **200** and at the other end to the saddle **300**. This is merely one example of how the saddle can be attached to the hub base, and in other embodiments the saddle may be attached to the hub base in any suitable manner. For instance, in another embodiment, rather than being attached to the hub base, each strut is attached to a different rotor arm module, such as to one of the rotor motor assemblies of the rotor arm modules.

[0114] 1.1.1 Hub Base

[0115] FIGS. 3A, 3B, 3C, 3D, 3E, 3F, 3G, and 3H show the hub base **200** or components thereof. The hub base **200** is the portion of the hub module **100** that: (1) serves as the attachment point for the rotor arm modules **400a** to **400d**; (2) includes the power source for the multicopter **10**; and (3) includes certain components used to control operation of the multicopter **10**.

[0116] As best shown in FIGS. 3C and 3D, the hub base **200** includes two hollow elongated rectangular supports **210a** and **210b**. The hollow supports **210a** and **210b** interlock with one another near their centers such that the hollow supports **210a** and **210b** are oriented transversely (such as generally perpendicularly) to one another and generally form a cross shape when viewed from above or below. Reinforcing plugs **212** are disposed within the hollow supports **210a** and **210b** such that fastener receiving openings (not labeled) of the reinforcing plugs **212** vertically align with fastener receiving openings (not labeled) of the hollow supports **210a** and **210b**. Upper and lower braces **220a** and **220b** sandwich the hollow supports **210a** and **210b**. A fastener **222** threaded through the upper brace **220a**, the hollow support **210a**, the reinforcing plug **212**, the hollow support **210b**, and the lower brace **220b** holds the upper and lower braces **220a** and **220b** and the hollow supports **210a** and **210b** together. This ensures the hollow supports **210a** and **210b** remain interlocked and ensures their orientation with respect to one another does not substantially change.

[0117] The hollow supports **210a** and **210b** are attached to a hub base plate **202** via suitable fasteners (not labeled) threaded through the hollow supports **210a** and **210b** and the reinforcing plugs **212** disposed within the hollow supports **210a** and **210b**. As best shown in FIG. 2B, two stabilizers **290a** and **290b** are attached to and extend downward from either hollow support **210a** and **210b**. The free ends of the stabilizers **290a** and **290b** terminate in feet configured to contact the fixed-wing aircraft **20** to help prevent the fixed-wing aircraft **20** from rotating about its roll axis relative to the multicopter **10**. The feet are adjustable in length (e.g., are threaded such that they can be shortened by threading further into the stabilizers or lengthened by unthreading further out of the stabilizers).

[0118] As best shown in FIG. 3C, first and third isolator plate mounts **240a** and **240c** are attached (such as via lashing) to the hollow support **210a** and second and fourth isolator plate mounts **240b** and **240d** are attached (such as via lashing) to the hollow support **210b** radially-inward of the ends of the hollow supports **210a** and **210b**. Each isolator plate mount **240a-d** includes a respective first isolator plate mounting post **242a-d** defining a threaded fastener receiving opening at least partially therethrough and a second isolator plate mounting post **244a-d** defining a threaded fastener receiving opening at least partially therethrough.

[0119] An isolator plate **250** is slidably mounted to the isolator plate mounts **240a**, **240b**, **240c**, and **240d**. FIGS. 3E and 3F show how the isolator plate **250** is mounted to the isolator plate mount **240b**. For simplicity and brevity, illustrations of how the isolator plate **250** is mounted to the remaining three isolator plate mounts **240a**, **240c**, and **240d** in a similar manner are not provided.

[0120] The isolator plate **250** defines first and second mounting openings **250a** and **250b** therethrough. An elastomeric grommet **252** is installed in the first mounting opening **250a** of the isolator plate **250**. The grommet **252**

defines a first isolator plate mounting post receiving channel **252a** therethrough, and the first isolator plate mounting post **242b** is slidably received in the first isolator plate mounting post receiving channel **252a**. A fastener **254** having a stop washer **254a** beneath its head is partially threaded into the fastener receiving opening of the first isolator plate mounting post **242b**. Upper and lower conical springs **256a** and **256b**—held in place by a fastener **258** partially threaded into the fastener receiving opening of the second isolator plate mounting post **244b**—sandwich the isolator plate **250**.

[0121] The hollow support **210b** and the stop washer **254a** constrain the vertical movement of the isolator plate **250**. In other words, the isolator plate **250** can move vertically between a lower position in which the grommet **252** contacts the hollow support **210b** and an upper position in which the grommet **252** contacts the stop washer **254a**. The conical springs **256a** and **256b** act as a suspension that absorbs (or partially absorbs) vibrations of the hollow support **210b** that would otherwise be directly transferred to the isolator plate **250**, which could affect operation of certain components of the multicopter **10** (such as the controller **272**).

[0122] The relatively high mass of the batteries **260a** to **260d** and the fact that they are mounted to the isolator plate **250** and close-coupled to the controller **272** and the IMU **277** to help prevent undesired vibration of the isolator plate **250** and therefore the controller **272** and the IMU **277**. In certain embodiments, for the controller **272** to perform well, the IMU **277** must resolve accelerations on the order of 0.1 gee and rotations of 0.1 radians/second. In various embodiments, the controller **272** cannot do this reliably when (~10-gee) vibration, caused by rotor unbalance, for example, is transmitted from the airframe of the multicopter **10** to the IMU **277**. When the mass of the batteries **260a** to **260d** is used to ballast the IMU **277** on the isolator plate **250**, and the isolator plate **250** is anchored to the airframe structure through the suspension, the IMU **277** enjoys the vibration-free mounting location. By mounting the isolator plate **250** well-outboard at its corners, the IMU **277** remains sufficiently well-coupled to the airframe that pitch and roll movements are transmitted to the IMU **277**, which is able to effectively resolve these motions.

[0123] As best shown in FIGS. 3A and 3B, The following components are mounted to the isolation plate **250**: (1) the batteries **260a**, **260b**, **260c**, and **260d** (which are received in respective battery receivers (not labeled) configured to retain the batteries and to electrically connect the batteries (such as via suitable wiring electrically connectable to the batteries) to components of the multicopter to power those components); (2) the ESCs **265a** to **265h**; (3) an avionics enclosure **270** that houses a variety of components including the controller **272**, the telemetry link **274**, and the R/C receiver **276**; (4) a GPS receiver mounting bracket **280** on which the GPS receiver **285** is mounted; (5) navigation lights (not shown); and (6) a Mode C transponder (not shown).

[0124] The four open ends of the hollow supports **210a** and **210b** form rotor arm module receiving sockets that can receive one of the rotor arm modules **400a** to **400d**. Specifically, the hollow support **210a** forms a first rotor arm module receiving socket **214a** and a third rotor arm module receiving socket (not shown) and the hollow support **210b** forms a second rotor arm module receiving socket **214b** and a fourth rotor arm module receiving socket (not shown).

[0125] As best shown in FIG. 3A, female blind mate assemblies **230** are attached to the ends of the hollow

7

supports **210a** and **210b**. Specifically, a first female blind mate assembly **230a** is attached to one end of the hollow support **210a** near the first rotor arm module receiving socket **214a**, a second female blind mate assembly **230b** is attached to one end of the hollow support **210b** near the second rotor arm module receiving socket **214b**, a third female blind mate assembly **230c** is attached to the other end of the hollow support **210a** near the third rotor arm module receiving socket **214c**, and a fourth female blind mate assembly **230d** is attached to the other end of the hollow support **210b** near the fourth rotor arm module receiving socket **214d**.

[0126] The female blind mate assemblies **230** (along with the corresponding male blind mate connectors described below with respect to the rotor arm modules) facilitate: (1) mechanical attachment of the rotor arm modules **400a**, **400b**, **400c**, and **400d** to the hub module **100**; (2) power flow from the battery(ies) **260a**, **260b**, **260c**, and/or **260d** to the rotor motors **465a** to **465h** of the rotor arm modules **400a**, **400b**, **400c**, and **400d**; and (3) communication between the ESCs **265a** to **265h** and the rotor motors **465a** to **465h**.

[0127] FIGS. 3G and 3H show the second female blind mate assembly **230b**. The female blind mate assemblies **230a**, **230c**, and **230d** are similar to the second female blind mate assembly **230b** and are not separately shown or described for brevity.

[0128] The second female blind mate assembly **230b** includes: (1) a female blind mate connector **231b** including a plurality of pin receptacles (not labeled); (2) three elastomeric grommets **232b**; (3) three rigid, hollow cylindrical spacers **233b**; (4) three fasteners **234b**; (5) three nuts **235b**; (6) a mounting bracket **236b**; and (7) mounting bracket fasteners (not labeled).

[0129] Although not shown for clarity, the female blind mate connector **231b** and, particularly, the pin receptacles, are electrically connected to the corresponding ESCs **265c** and **265d** via wiring. In this example embodiment, the female blind mate connector **231b** includes 12 pin receptacles, six of which are connected to the ESC **265c** via wiring and the other six of which are connected to the ESC **265d** via wiring.

[0130] The mounting bracket **236b** is positioned at a desired location along the hollow support **210b**, and the mounting bracket fasteners are tightened to clamp the mounting bracket **236b** in place relative to the hollow support **210b**.

[0131] The female blind mate connector **231b** is flexurally mounted to the mounting bracket **236b** via the elastomeric grommets **232b**, the spacers **233b**, the fasteners **234b**, and the nuts **235b**. Specifically, the elastomeric grommets **232b** are fitted into corresponding cavities in the female blind mate connector **231b**. As best shown in FIG. 3H, each cavity includes an inwardly-projecting annular rib that fits into a corresponding annular cutout of the corresponding elastomeric grommet **232b**. The spacers **233b** are disposed within longitudinal bores defined through the elastomeric grommets **232b**. The fasteners **234b** extend through the hollow spacers **233b** and through corresponding fastener receiving openings defined through the mounting bracket **236b** into their corresponding nuts **235b**. This secures the female blind mate connector **231b** to the mounting bracket **236b**.

[0132] This flexural mount of the female blind mate connector to the mounting bracket via the elastomeric grommets is beneficial compared to a rigid connection of the

female blind mate connector to the mounting bracket. The flexural mount enables the female blind mate connector to move—via deformation of the elastomeric grommet—relative to the mounting bracket (and the rest of the hub module) when loads are applied to the female blind mate connector, such as loads imposed on the female blind mate connector by the attached rotor arm module during flight. Because the female blind mate connector is not rigidly attached to the corresponding mounting bracket, it is less likely that the pins of the male blind mate connector (described below) received by the pin receptacles of the female blind mate connector will lose electrical contact—causing the multicopter **10** to lose control of at least one of its rotor motors—when loads are applied to the female blind mate connector.

[0133] As best shown in FIG. 3H, a latch plate **237** is attached to the underside of each hollow support **210a** and **210b** below each female blind mate connector **231** attached thereto. The latch plate **237** includes a claw engager **238** and a backstop **239**. The latch plate **237** is described below with respect to the locking assemblies **420** of the rotor arm modules **400a** to **400d**.

[0134] In some embodiments, the hub module (either the hub base, the saddle, or both) or other elements of the multicopter include ballast to obtain a desired weight distribution and/or provide stability during flight.

[0135] 1.1.2 Saddle

[0136] FIGS. 4A, 4B, 4C, 4D, 4E, 4F, 4G, 4H, 4I, and 4J show the saddle **300** or components thereof. The saddle **300** is the portion of the hub module **100**: (1) to which the fixed-wing aircraft **20** is attached for launch; (2) from which the fixed-wing aircraft **20** is detached for launch; and (3) to which the flexible capture member **5000** is attached for retrieval of the fixed-wing aircraft **20**. The saddle **300** also enables the operator to vary the pitch angle of the fixed-wing aircraft **20** relative to the multicopter **10**.

[0137] As best shown in FIG. 4C, the saddle **300** includes a saddle base bracket **310** and first and second saddle side plates **320a** and **320b**. The first and second saddle side plates **320a** and **320b** are pivotably connected to opposite sides of the saddle base bracket **310** near the front end of the saddle base bracket **310**. The first and second saddle side plates **320a** and **320b** are also attached to opposite sides of the saddle base bracket **310** near the rear end of the saddle base bracket **310** via locking devices **322a** and **322b** (which are cam lever locks in this example embodiment but can be any suitable locking devices). The locking devices **322a** and **322b** extend through respective slots **321a** and **322b** defined through the respective first and second side plates **320a** and **320b**.

[0138] As shown in FIGS. 4D and 4E, the orientation of the slots **321a** and **321b** enables an operator to vary the angle α formed between a plane including the tops of the first and second saddle side plates **320a** and **320b**—to which the hub base **200** is attached—and a plane including the generally horizontally extending bottom portion of the saddle base plate **310**. Plane as used herein can mean either a physical plane or a virtual reference plane. The angle α generally corresponds to the angle formed between the hub base plate **202** of the hub base **200** and the fuselage of the fixed-wing aircraft **20** when the fixed-wing aircraft **20** is attached to the saddle **300**. To change the angle α, the operator unlocks the locking devices **322a** and **322b**, rotates the first and second side plates **320a** and **320b** relative to the saddle base bracket **310** around their pivotable attachments to the saddle base

bracket **310** to the desired rotational position (or vice-versa), and re-locks the locking devices **322**a and **322**b. In this example embodiment, the angle α is variable from about 0 degrees to about 10 degrees, though in other embodiments the angle α is variable between any suitable angles.

[0139] In certain embodiments, an operator can cause the first and second side plates to rotate relative to the saddle while the multicopter **10** is flying. For instance, the operator may desire to release the fixed-wing aircraft nose-down from a hover. Conversely, the operator may desire to release the fixed-wing aircraft nose-up (such as nose-up about 10 degrees) to facilitate launch while the multicopter is dashing forward (this nose-up pitch reduces wind drag and better-aligns the thrust vector of the fixed-wing aircraft with the desired direction of travel). The multicopter may include any suitable combination of elements to facilitate this remote pivoting, such as various motors, actuators, and the like.

[0140] As best shown in FIGS. 4A, 4B, and 4C, a stabilizing bracket **330** is attached to the first and second saddle side plates **320**a and **320**b and extends across the space between the first and second saddle side plates **320**a and **320**b. A downwardly-curved front aircraft engaging bracket **340**a is attached to the underside of the saddle base bracket **310** near the front of the saddle base bracket **310**. A downwardly-curved rear aircraft engaging bracket **340**b is attached to the underside of the saddle base bracket **310** near the rear of the saddle base bracket **310**.

[0141] As best shown in FIG. 4C, a cam **350** is rotatably attached to and extends across the width of the saddle base bracket **310** such that the cam **350** is transverse (such as generally perpendicular) to the first and second saddle side plates **320**a and **320**b. As best shown in FIGS. 4F, 4H, and 4I, the portion of the cam **350** near its longitudinal center has an irregularly-shaped profile including a first relatively wide ridge **351**, a second relatively narrow ridge **353**, and a valley **352** between the first and second ridges **351** and **353**. This irregularly-shaped profile facilitates attaching the fixed-wing aircraft **20** to the cam **350** (and therefore to the multicopter **10**) and detaching the fixed-wing aircraft **20** from the cam **350** (and therefore from the multicopter **10**), as described below with respect to FIGS. 10A, 10B, and 10C. The cam **350** also includes a cam control arm **354** and a foot **355** extending transversely (such as generally perpendicularly) from the longitudinal axis of the cam **350**.

[0142] An aircraft attaching/detaching assembly **380** attached to the saddle base bracket **310** controls rotation of the cam **350** relative to the saddle base bracket **310**. As best shown in FIG. 4G, the aircraft attaching/detaching assembly **380** includes: (1) a cam servo motor **381** having a cam servo motor shaft **381**a; (2) a cam servo motor arm **382**; (3) a cam servo motor arm lock device **382**a; (4) upper and lower servo spacers **383**a and **383**b; (5) upper and lower nut plates **384**a and **384**b; (6) fasteners **385** and nuts **385**a; (7) a cam rotation control link **386** having connectors **386**a and **386**b at either end; (8) a lock servo motor **391** having a lock servo motor shaft **391**a; and (9) a lock servo motor arm **392** terminating at one end in a lock servo motor locking extension **392**a.

[0143] The cam servo motor **381** and the lock servo motor **391** are attached to one another and to the saddle base bracket **310** via the fasteners **385** and nuts **385**a, the upper and lower servo spacers **383**a and **383**b, and the upper and lower nut plates **384**a and **384**b. The cam servo motor arm **382** is attached near one end to the cam servo motor shaft

381a and near the other end to the connector **386**a. The connector **386**b is attached to the cam control arm **354** of the cam **350**, which links the cam servo motor shaft **381**a to the cam **350**. The cam servo motor arm lock device **382**a is attached to the cam servo motor arm **382** between the connector **386**a and the cam servo motor shaft **381**a. The lock servo motor arm **392** is attached to the lock servo motor shaft **391**a. The rearwardly-extending portion of the lock servo motor arm **392** terminates in the lock servo motor locking extension **392**a, which is engageable to the cam servo motor arm lock device **382**a in certain instances.

[0144] The cam servo motor **381** controls rotation of the cam **350** relative to the saddle base bracket **310**. To rotate the cam **350**, the cam servo motor **381** rotates the cam servo motor shaft **381**a, which rotates the attached cam servo arm **382**, which in turn rotates the cam **350** via the cam rotation control link **386**. The cam servo motor **381** can rotate the cam **350** from an attached rotational position—shown in FIG. 4H—to a detached rotational position—shown in FIG. 4I (and vice-versa).

[0145] The lock servo motor **391** controls rotation of the lock servo motor arm **392** between a cam rotation-preventing rotational position—shown in FIG. 4H—and a cam rotation-enabling rotational position—shown in FIG. 4I (and vice-versa). When the cam **350** is in the attached rotational position and the lock servo motor arm **392** is in the cam rotation-preventing rotational position, the lock servo motor locking extension **392**a engages the cam servo motor arm lock device **382**a of the cam servo motor arm **382**. This prevents the cam servo motor **381** from rotating the cam **350** from the attached rotational position to the detached rotational position.

[0146] FIGS. 4H and 4I show how the cam servo motor **381** and the lock servo motor **391** operate to rotate the cam **350** from the attached rotational position to the detached rotational position. Initially, the cam servo motor **381** is in the attached rotational position and the lock servo motor **391** is in the cam rotation-preventing rotational position. Here, the lock servo motor locking extension **392**a on the end of the lock servo motor arm **392** engages the cam servo motor arm lock device **382**a of the cam servo motor arm **382**.

[0147] Since the lock servo motor locking extension **392**a is engaged to the cam servo motor arm lock device **382**a of the cam servo motor arm **382**, the cam servo motor **381** cannot rotate the cam **350** from the attached rotational position to the detached rotational position (counter-clockwise from this viewpoint).

[0148] Rotating the cam **350** from the attached rotational position to the detached rotational position is a two-step process. The operator first operates the lock servo motor **391** to rotate the lock servo motor arm **392** into the cam rotation-enabling rotational position (counter-clockwise from this viewpoint). Second, the operator operates the cam servo motor **381** to rotate the cam **350** from the attached rotational position to the detached rotational position (counter-clockwise from this viewpoint).

[0149] FIGS. 10A to 10C, described below, show how rotation of the cam from the attached rotational position to the detached rotational position causes the fixed-wing aircraft to detach from the cam.

[0150] The foot **355** controls the extent to which the cam **350** can rotate. The foot **355** is oriented such that when the cam **350** rotates a certain amount in a first direction relative to the saddle base bracket **310**, the foot **355** contacts the

saddle base bracket **310** and prevents the cam **350** from rotating any further in that first direction. Similarly, when the cam **350** rotates a particular amount in a second opposite direction relative to the saddle base bracket **310**, the foot **355** contacts the saddle base bracket **310** and prevents the cam **350** from rotating any further in that second direction. The foot **355** is angled to stop the cam **350** from rotating before it exerts an undue force on the cam rotation control link **386**, and by extension the cam motor arm **382** and the cam motor shaft **381***a*.

[0151]   1.2 Rotor Arm Modules

[0152]   The rotor arm modules **400***a* to **400***d* are mechanically attachable to and mechanically lockable to the hub module **200** and include: (1) the eight rotors of the multicopter **10**; (2) the eight rotor motors that drive these rotors; (3) gear reduction trains that couple the rotor motors to their corresponding rotors; and (4) locking assemblies that lock the rotor arm modules **400***a* to **400***d* to the hub module **100**.

[0153]   FIGS. **5A**, **5B**, **5C**, **5D**, **5E**, **5F**, **5G**, **5H**, **5I**, and **5J** show the first rotor arm module **400***a* or components thereof. The other rotor arm modules **400***b*, **400***c*, and **400***d* are similar to the first rotor arm module **400***a* and are not separately shown or described for brevity.

[0154]   As best shown in FIGS. **5A**, **5B**, **5H**, and **5J**, the first rotor arm module **400***a* includes: (1) a generally rectangular hollow elongated rotor arm **410***a*; (2) a generally rectangular hollow rotor arm extension **410***b*; (3) a locking assembly **420**; (4) a male blind mate connector **431**; (5) upper and lower rotor motor assemblies **460***a* and **460***b*; and (6) a rotor assembly **470**.

[0155]   The rotor arm extension **410***b* is attached to the rotor arm **410***a* such that part of the rotor arm extension **410***b* is disposed within the rotor arm **410***a* and the remainder of the rotor arm extension **410***b* extends from the rotor arm **410***a*. The locking assembly **420** is attached to the underside of the rotor arm **410***a* near the end of the rotor arm **410***a* from which the rotor arm extension **410***b* extends. The male blind mate connector **431** is attached to the end of the rotor arm **410***a* from which the rotor arm extension **410***b* extends. The upper and lower rotor motor assemblies **460***a* and **460***b* and the rotor assembly **470** are attached to the rotor arm **410***a* in a manner described in detail below.

[0156]   Although not shown, the open end of the rotor arm **410***a* opposite the end from which the rotor arm extension **410***b* extends forms a first front landing gear extension module receiving socket that can receive the first front landing gear extension module **500***a*, as described below.

[0157]   As best shown in FIGS. **5A**, **5B**, **5C**, **5D**, **5E**, and **5F**, the male blind mate connector **431**—along with its counterpart female blind mate connector **231***a* of the hub module **100**—facilitate: (1) mechanical attachment of the first rotor arm module **400***a* to the hub module **100**; (2) electrical power flow from the battery(ies) **260***a*, **260***b*, **260***c*, and/or **260***d* to the upper and lower rotor motors **465***a* and **465***b* of the first rotor arm module **400***a*; and (3) communication between the ESCs **265***a* and **265***b* their corresponding upper and lower rotor motors **465***a* and **465***b*.

[0158]   The male blind mate connector **431** includes a plurality of pins **431***a* configured to mate with the pin receptacles of the female blind mate connector **231***a*. Although not shown for clarity, the male blind mate connector **431** and, particularly, the pins **431***a*, are electrically connected to the corresponding upper and lower rotor motors **465***a* and **465***b* via wiring. In this example embodi-

ment, the male blind mate connector **431** includes 12 pins **431***a*, six of which are electrically connected to the upper rotor motor **465***a* via wiring and the other six of which are electrically connected to the lower rotor motor **465***b* via wiring. In this example embodiment, each motor only requires three motor leads to properly function, but the multicopter **10** includes two motor leads for each motor pole. By using two motor leads per motor pole, the multicopter **10** eliminates single-point failures (i.e., both leads would have to fail rather than just a single lead for the motor to fail).

[0159]   To attach the rotor arm module **400***a* to the hub module **100**, an operator inserts the rotor arm extension **410***b* into the first rotor arm module receiving socket **214** of the hub module **100** and slides the rotor arm module **400***a* toward the hub module **100** with enough force to mate the pins of the male blind mate connector **431** with the pin receptacles of the female blind mate connector **231***a* of the hub module **100**.

[0160]   In an alternative embodiment, rather than the hub module slidably receiving a portion of the rotor arm module to attach the rotor arm module to the hub module, the rotor arm module slidably receives a component (such as an arm) of the hub module to attach the rotor arm module to the hub module.

[0161]   As best shown in FIGS. **5C**, **5D**, **5E**, and **5F**, the locking assembly **420** includes a drawcatch **420***a* and a drawcatch lock **420***b* that: (1) facilitate attaching the first rotor arm module **400***a* to the hub module **100**; (2) lock the first rotor arm module **400***a* to the hub module **100**; and (3) facilitate detachment of the first rotor arm module **400***a* from the hub module **100**.

[0162]   As best shown in FIG. **5C**, the drawcatch **420***a* includes: (1) a base **421**; (2) a lever **422**; (3) a claw **423**; (4) a first fastener **424** (such as a clevis pin or other suitable fastener); and (5) a second fastener **425** (such as a clevis pin or other suitable fastener).

[0163]   The drawcatch lock **420***b* includes: (1) a base **426**; (2) a lock/release device **427** having a locking shelf **427***a*; (3) a pin **428** (or other suitable connector); and (4) a compression spring **429** (or other suitable biasing element).

[0164]   The base **421** is attached to the underside of the rotor arm **410***a*. The lever **422** is pivotably connected at one end to the base **421** via the first fastener **424**. The other end of the lever **422** includes a handle **422***a*. The claw **423** is pivotably connected at one end to the lever **422** via the second fastener **425**. The other end of the claw includes a latch plate engager **423***a*.

[0165]   The base **426** is attached to the underside of the rotor arm **410***a*. The lock/release device **427** is pivotably connected to the base **426** via the pin **428**. The compression spring **429** is disposed between the base **426** and the lock/release device **427** and retained in place via cavities and/or projections defined in or extending from these components (not shown).

[0166]   The lock/release device **427** is rotatable about the pin **428** from a lock rotational position to a release rotational position. The compression spring **429** biases the lock/release device **427** to the lock rotational position. To rotate the lock/release device **427** from the lock rotational position to the release rotational position, the operator pushes the lock/release device **427** inward with enough force to overcome the spring-biasing force and compress the compression spring **429**.

[0167] The operator uses the locking assembly **420** to lock the male blind mate connector **431** with the female blind mate connector **231***a* as follows. The operator rotates the handle **422***a* of the lever **422** around the first fastener **424** toward the latch plate **237** on the hollow support **210***a* of the hub module **100** and engages the claw engager **238** of the latch plate **237** with the latch plate engager **423***a* of the claw **423**. The operator then rotates the handle **422***a* around the first fastener **424** and toward the lock/release device **427** until the handle **422***a* contacts the lock/release device **427**. Continued rotation of the lever **422** forces the lock/release device **427** inward, which overcomes the spring-biasing force and begins compressing the compression spring **429**. This causes the lock/release device **427** to being rotating to the release rotational position. Once the handle **422** rotates past the locking shelf **427***a*, the spring-biasing force of the compression spring **429** causes the lock/release device **427** to rotate back to the lock rotational position. At this point, the locking shelf **427***a* prevents the handle **422** from rotating back toward the latch plate **237**, and the first rotor arm module **400***a* and the hub module **100** are locked together.

[0168] In addition to using the locking assembly **420** to lock the first rotor arm module **400***a* to the hub module **100**, the operator can use the locking assembly **420** to facilitate mating the male blind mate connector **431** with the female blind mate connector **231***a*. If the male blind mate connector **431** and the female blind mate connector **231***a* are only partially mated (or not mated at all) and the latch plate engager **423***a* of the claw **423** is engaged to the claw engager **238** of the latch plate **237**, rotating the handle **422***a* of the lever **422** around the first fastener **424** toward the lock/release device **427** to lock the handle **422***a* will pull the first rotor arm module **400***a* and the hub module **100** toward one another and cause the male blind mate connector **431** to mate with the female blind mate connector **231***a*.

[0169] As shown in FIGS. **5**D to **5**F, the operator reverses this process to unlock the first rotor arm module **400***a* from the hub module **100**. The operator pushes the lock/release device **427** inward with enough force to overcome the spring-biasing force and to compress the compression spring **429**, which causes the lock/release device **427** to rotate to the release rotational position. This frees the handle **422***a* to rotate. Once the handle **422***a* rotates past the locking shelf **427***a*, the operator rotates the handle **422***a* of the lever **422** around the first fastener **424** toward the latch plate **237** and disengages the latch plate engager **423***a* of the claw **423** from the claw engager **238** of the latch plate **237**.

[0170] At this point, the operator can either physically pull the first rotor arm module **400***a* and the hub module **100** apart to separate the male and female blind mate connectors **431** and **231***a* or use the locking assembly **420** to aid in detachment. When using the locking assembly **420** to aid in detachment, as shown in FIG. **5**E, after disengaging the latch plate engager **423***a* from the claw engager **238**, the operator continues rotating the handle **422***a* toward the latch plate **237** until the latch plate engager **423***a* contacts the backstop **239** of the latch plate **237**. Afterward, continued rotation of the handle **422***a* toward the latch plate **237** causes the latch plate engager **423***a* to impose a pushing force against the backstop **239**, which forces the first rotor arm module **400***a* and the hub module **100** apart, as shown in FIG. **5**F.

[0171] Turning to the upper and lower rotor motor assemblies **460***a* and **460***b* and the rotor assembly **470***a*, the upper and lower rotor motors **465***a* and **465***b* of the upper and lower motor assemblies independently drive respective upper and lower rotors **475***a* and **475***b* via separate gear reduction trains.

[0172] As best shown in FIGS. **5**G and **5**H, the upper rotor motor assembly **460***a* includes: (1) an upper rotor motor mount **461***a*, (2) an upper bearing spider **462***a*, (3) an upper pinion **463***a*, (4) upper bearings **464***a*, (5) the upper rotor motor **465***a*, (6) an upper bearing **466***a*, (7) an upper bearing cup **467***a*, (8) an upper two-piece cooling fan collar **490***a*, and (9) an upper rotor motor cooling fan **495***a*.

[0173] The upper rotor motor **465***a* is attached to the upper rotor motor mount **461***a*. The bearing spider **462***a* is attached to the upper rotor motor mount **461***a*. The upper bearings **464***a* are disposed on the motor shaft (not labeled) of the upper rotor motor **465***a*. The upper drive pinion **463***a* is disposed on the upper bearings **464***a* and on the motor shaft of the upper rotor motor **465***a* such that the upper drive gear **463***a* rotates with the motor shaft. The upper bearing **466***a* within the upper bearing cup **467***a* is disposed on the motor shaft of the upper rotor motor **465***a*. The upper bearing cup **467***a* is attached to the upper bearing spider **462***a*. The upper rotor motor cooling fan **495***a* is press-fit around the bottom of the upper rotor motor **465***a* and held in place via the upper two-piece cooling fan collar **490***a*.

[0174] The lower rotor motor assembly **460***b* includes: (1) a lower rotor motor mount **461***b*, (2) a lower bearing spider **462***b*, (3) a lower pinion **463***b*, (4) lower bearings **464***b*, (5) the lower rotor motor **465***b*, (6) a lower bearing **466***b*, (7) a lower bearing cup **467***b*, (8) a lower two-piece cooling fan collar **490***b*, and (9) a lower rotor motor cooling fan **495***b*.

[0175] The lower rotor motor **465***b* is attached to the lower rotor motor mount **461***b*. The lower bearing spider **462***b* is attached to the lower rotor mount **461***b*. The lower bearings **464***b* are disposed on the motor shaft (not labeled) of the lower rotor motor **465***b*. The lower pinion **463***b* is disposed on the lower bearings **464***b* and on the motor shaft of the lower rotor motor **465***b* such that the lower pinion **463***b* rotates with the motor shaft. The lower bearing **466***b* within the lower bearing cup **467***b* is disposed on the motor shaft of the lower rotor motor **465***b*. The lower bearing cup **467***b* is attached to the lower bearing spider **462***b*. The lower rotor motor cooling fan **495***b* is press-fit around the bottom of the lower rotor motor **465***a* and held in place via the lower two-piece cooling fan collar **490***b*.

[0176] The upper cooling fan collar **490***a* and the upper rotor motor cooling fan **495***a* are shown in detail in FIG. **5**I. The lower cooling fan collar **490***b* and the lower rotor motor cooling fan **495***b* are similar to the upper cooling fan collar **490***a* and the upper rotor motor cooling fan **495***b* and are not separately shown or described for brevity.

[0177] The upper rotor motor cooling fan **495***a* includes a generally annular body that defines a plurality of cooling fan openings **496***a* through its side walls (not labeled). A collar connection lip **497***a* extends upward from body and radially-outward. A generally annular motor mounting shelf **498***a* extends radially-inward from the bottom of the body. Each of a plurality of motor seats **499***a* extends upward from the motor mounting shelf **498***a*.

[0178] The upper cooling fan collar **490***a* includes two identical collar halves **491***a* having generally half-annular bodies. An upper rotor motor mating surface **492***a* that extends around the (half) circumference of the collar half **491***a* is grooved to correspond with and mate with grooves on the exterior of the upper rotor motor **465***a*. A lip retaining

chamber **493***a* that extends around the (half) circumference of the collar half **491***a* is shaped to receive and retain the lip **497***a* of the upper rotor motor cooling fan **495***a*.

[0179] The bottom of the upper rotor motor **465***a* is disposed within the space defined by the inner cylindrical surface of the cooling fan **495***a* such that the bottom of the upper rotor motor **465***a* contacts the motor seats **499***a*. The cooling fan openings **496***a* of the cooling fan **495***a* are generally aligned with corresponding cooling fan openings of the upper rotor motor **465**. The collar halves **491** are fit onto the upper rotor motor **465***a* and the cooling fan **495***a* such that: (1) the lip retaining chambers **493***a* of the collar halves **491** receive the lip **497***a* of the upper rotor motor cooling fan **495***a*; and (2) the upper rotor motor mating surfaces **492***a* of the collar halves **491** mate with the grooves on the exterior of the upper rotor motor **465***a*. Two fasteners (not labeled) attach the collar halves **491***a* to each other to prevent separation.

[0180] The cooling fans solve two problems: (1) limited motor power output due to overheating; and (2) motors falling apart. First, the power output of the rotor motors depends to a certain extent on cooling—power output generally decreases the hotter the rotor motors get. The cooling fans enlarge the radius of the cooling fan openings of the rotor motors. The increased radius drives cooling air at a greater flow rate, which improves cooling and allows motors to be used safely at increased loads without fear of failure.

[0181] Second, the flux rings of the rotor motors are typically glued onto the end caps of the rotor motors. This attachment is not secure due to the temperatures the rotor motors reach and the vibrations that occur during flight. The cooling fan collars double as redundant load paths for the motor flux rings since they mechanically engage the grooves on the exterior of the upper rotor motor, which eliminates the chance of the flux ring working its way off of the end cap.

[0182] As best shown in FIG. 5J, the rotor assembly **470** includes a spindle **470***a* and the following components rotatably mounted to the spindle **470***a*: (1) an upper retaining ring **471***a*, (2) a lower retaining ring **471***b*, (3) upper bearings **472***a* and **477***a*, (4) lower bearings **472***b* and **477***b*, (5) upper bearing cups **473***a* and **478***a*, (6) lower bearing cups **473***b* and **478***b*, (7) an upper torque tube **474***a*, (8) a lower torque tube **474***b*, (9) an upper rotor **475***a*, (10) a lower rotor **475***b*, (11) an upper driven gear **476***a*, (12) a lower driven gear **476***b*, (13) an upper spacer **479***a*, and (14) a lower spacer **479***b*.

[0183] Turning to the upper portion of the rotor assembly **470**, the bearing **472***a* is disposed within the bearing cup **473***a*, which is fixedly attached to the top of the rotor **475***a*. The torque tube **474***a* is fixedly attached at one end to the underside of the rotor **475***a* and at the other end to top of the driven gear **476***a*. The bearing **477***a* is disposed within bearing cup **478***a*, which is fixedly attached to the underside of the driven gear **476***a*. The spacer **479***a* is disposed between the bearing **477***a* and the upper rotor motor mount **461***a*. The upper retaining ring **471***a* is seated in a groove defined around the spindle **470***a* and prevents these components from sliding off of the spindle **470***a*.

[0184] Turning to the lower portion of the rotor assembly **470**, the bearing **472***b* is disposed within the bearing cup **473***b*, which is fixedly attached to the bottom of the rotor **475***b*. The torque tube **474***b* is fixedly attached at one end to the top of the rotor **475***b* and at the other end to underside of the driven gear **476***b*. The bearing **477***b* is disposed within

the bearing cup **478***b*, which is fixedly attached to the top of the driven gear **476***b*. The spacer **479***b* is disposed between the bearing **477***b* and the lower rotor motor mount **461***b*. The lower retaining ring **471***b* is seated in a groove defined around the spindle **470***a* and prevents these components from sliding off of the spindle **470***a*.

[0185] The spindle **470***a* extends through two vertically-aligned spindle receiving openings (not labeled) defined through the rotor arm **410***a*. This prevents the spindle **470***a* from substantially translating relative to the rotor arm **410***a*. And since all of the components of the upper and lower motor assemblies **460***a* and **460***b* and the rotor assembly **470** are attached to the spindle **470***a* (directly or indirectly), the fact that the spindle **470***a* extends through the spindle receiving openings defined through the rotor arm **410***a* prevents any of the components of the upper and lower motor assemblies **460***a* and **460***b* and the rotor assembly **470** from substantially translating relative to the rotor arm **410***a*.

[0186] To prevent the upper and lower rotor motors **465***a* and **465***b* (and certain components attached thereto) from rotating relative to the rotor arm **410***a*, the upper and lower rotor motor mounts **461***a* and **461***b* are attached to both an inner bracket **480***a* and an outer bracket **480***b*. The brackets **480***a* and **480***b* are disposed around the rotor arm **410***a*, as best shown in FIGS. 5A, 5B, and 5J.

[0187] In operation, the controller **272** and the ESC **265***a* control the rate and direction of rotation of the motor shaft of the upper rotor motor **465***a*, which drives the upper pinion **463***a*, which in turn drives the upper driven gear **476***a*. Since the upper driven gear **476***a* is fixedly attached to the upper rotor **475***a* without any further gear reduction, the upper rotor **475***a* rotates at the same rate as and in the same rotational direction as the upper driven gear **476***a*. Similarly, the controller **272** and the ESC **265***b* control the rate and direction of rotation of the motor shaft of the lower rotor motor **465***b*, which drives the lower pinion **463***b*, which in turn drives the lower driven gear **476***b*. Since the lower driven gear **476***b* is fixedly attached to the lower rotor **475***b* without any further gear reduction, the lower rotor **475***b* rotates at the same rate as and in the same rotational direction as the lower driven gear **476***b*.

[0188] In this embodiment, the upper and lower rotors are generally the same size and shape. In another embodiment, the lower rotors are larger than (such as about 7% larger than) the upper rotors to compensate for the fact that the lower rotors operate in the upper rotors' downwash. Running larger lower rotors is one way to improve load sharing of upper and lower motors of a multicopter with counter-rotating blades. Another way to improve load sharing is to select a lower gear-reduction for the lower rotors. Yet another way is to select motors with higher KV (rpm/volt) values. Yet another way is to select lower rotors with coarser pitch than the upper rotors.

[0189] 1.3 Front Landing Gear Extension Modules and Landing Gear Modules

[0190] FIGS. 6A and 7A show the first front landing gear extension module **500***a* and the first front landing gear module **600***a*, respectively. The front landing gear modules (along with the rear landing gear modules, described below) support the multicopter **10** when assembled but not flying, and facilitate launch and landing of the multicopter **10** without damaging the multicopter **10**. The front landing gear extensions are used to attach the front landing gear to the respective rotor arm modules, and also enable the front

landing gear to move relative to the rotor arm modules to prevent rotor rotation in certain instances.

[0191] The second front landing gear extension module **500b** and the second front landing gear module **600b** are similar to the first front landing gear extension module **500a** and the first front landing gear module **600a** and are not separately shown or described for brevity.

[0192] The first front landing gear extension module **500a** includes a generally rectangular hollow support **510a**, a landing gear module securing device **520** attached at one end of the support **510a**, and a front landing gear locking device **530** (which is a cam lever lock in this embodiment but can be any suitable locking device) attached to the landing gear module securing device **520**.

[0193] The first front landing gear module **600a** includes a generally cylindrical leg **610**, a generally semicircular foot **620** attached to a bottom end of the leg **610**, and a collar **630** attached near the top end of the leg **610** via a fastener **632** (such as a set screw).

[0194] The front landing gear locking device **530** enables an operator to attach the first front landing gear module **600a** to the first front landing gear extension module **500a**. To do so, the operator unlocks the front landing gear locking device **530**, inserts the first front landing gear module **600a** into the landing gear module securing device **520** until the collar **630** is disposed within the landing gear module securing device **520**, and re-locks the front landing gear locking device **530**. The operator reverses this process to detach the first front landing gear module **600a** from the first front landing gear extension module **500a**.

[0195] The operator attaches the first front landing gear extension module **500a** to the first rotor arm module **400a** by inserting the end of the support **510a** opposite the end to which the landing gear module securing device **520** is attached into the front landing gear extension module receiving socket of the first rotor arm module **400a**. The operator then locks the first front landing gear extension module **500a** into place, such as using suitable fasteners.

[0196] Although not shown, the operator can move the front landing gear module further radially-inward or further radially-outward by sliding the support of the front landing gear extension module further into or further out of the rotor arm of the corresponding rotor arm module. This enables the operator to move the front landing gear module from a first position in which the front landing gear module is clear of the rotors radially-inward to a second position in which the rotors contact the front landing gear module. When in the second position, the front landing gear module prevents the rotors from rotating.

[0197] 1.4 Rear Landing Gear Extension Modules and Landing Gear Module

[0198] FIGS. 6B and 7B show the first rear landing gear extension module **500c** and the first rear landing gear module **600c**, respectively. The rear landing gear modules (along with the front landing gear modules, described above) support the multicopter **10** when assembled but not flying, and facilitate launch and landing of the multicopter **10** without damaging the multicopter **10**. The rear landing gear modules are shaped such that they act as vertical stabilizers (or fins) during flight, ensuring that the front of the multicopter **10** (and the nose of the fixed-wing aircraft **20**, if attached thereto) points generally into the airflow. The rear landing gear extensions are used to attach the rear landing gear to the respective rotor arm modules, and also

enable the rear landing gear to move relative to the rotor arm modules to prevent rotor rotation in certain instances.

[0199] The second rear landing gear extension module **500d** and the second rear landing gear module **600d** are similar to the first rear landing gear extension module **500c** and the first rear landing gear module **600c** and are therefore not separately shown or described.

[0200] The first rear landing gear extension module **500c** is an elongated rectangular hollow support **510c**.

[0201] The first rear landing gear module **600c** includes a body having a generally triangular cross-section that tapers from front to back. The body includes two side surfaces **650a** and **650b** and a front surface **650c** joining the side surfaces **650a** and **650b**. The side surfaces **650a** and **650b** are substantially longer than the front surface **650c** is wide. The body tapers at its bottom into a generally circular foot **670**. A rear landing gear extension module receiving socket is defined by a hollow rectangular support **680** extending through the body.

[0202] The operator attaches the first rear landing gear extension module **500c** to the third landing gear module **600c** by inserting one end of the support **510c** of the first rear landing gear extension module **500c** into the rear landing gear extension module receiving socket of the support **680**. The operator then locks the first rear landing gear extension module **500c** into place, such as using suitable fasteners.

[0203] The operator attaches the first rear landing gear extension module **500c** to the third rotor arm module **400c** by inserting the end of the support **510c** of the first rear landing gear extension module **500c** opposite the end to which the first rear landing gear module **600c** is attached into the rear landing gear extension module receiving socket of the third rotor arm module **400c**. The operator then locks the first rear landing gear extension module **500c** into place, such as using suitable fasteners.

[0204] Once attached, the rear landing gear modules are oriented such that the side surfaces of the rear landing gear modules are substantially aligned with the saddle side brackets **320a** and **320b** of the saddle **300**, as best shown in FIG. 1B. When the fixed-wing aircraft **20** is attached to the multicopter **10**, these side surfaces of the rear landing gear modules are substantially parallel to a generally vertical plane containing the roll axis of the fuselage of the fixed-wing aircraft **20**. The relatively long length of these side surfaces of the rear landing gear modules and their placement well-aft of the center-of-lift of the multicopter **10** cause the rear landing gear modules to act as fins. This weathervane effect ensures that the nose of the fixed-wing aircraft **20** is oriented into the airflow when airborne. Good flow alignment is critically important for spin avoidance at the moment the multicopter **10** releases the fixed-wing aircraft **20**, when the fixed-wing aircraft **20** may be operating well-below stall speed.

[0205] In certain embodiments, one or more of the landing gear modules includes a shock absorber.

[0206] 1.5 Separately Powered Upper and Lower Rotor Motors

[0207] As noted above, four batteries **260a** to **260d** power the multicopter **10**, though in other embodiments a different quantity of batteries and/or different type(s) of batteries power the multicopter. In other embodiments, any suitable power source(s), such as a fuel-based power source or a solar-based power source, may be used instead of or along with batteries.

[0208] In this embodiment, a first pair of batteries **260***a* and **260***b* are connected in series and a second pair of batteries **260***c* and **260***d* are connected in series. Here, the first pair of batteries **260***a* and **260***b* power the upper rotor motors and do not power the lower rotor motors, while the second pair of batteries **260***c* and **260***d* power the lower rotor motors and do not power the upper rotor motors. This configuration ensures that, if one pair of batteries fails, the multicopter **10** is operable in a quadcopter mode with either all four upper rotor motors (if the second pair of batteries **260***c* and **260***d* fails) or all four lower rotor motors (if the first pair of batteries **260***a* and **260***b* fails).

[0209] The multicopter **10** also includes a gang circuit that connects the two pairs of batteries in parallel to enable a single charger connected to one of the pairs of batteries to also charge the other pair of batteries. The gang circuit is overload-protected and includes an automatically resetting circuit breaker. The gang circuit is beneficial because it reduces charging time, allowing an operator to recharge both batteries in parallel when only one charger is available.

[0210] 1.6 Multicopter Operating Modes

[0211] The multicopter **10** is operable in one of two throttle modes: NORMAL throttle mode and TENSION throttle mode. The multicopter **10** is operable in three different flight modes: ALTHOLD flight mode, LOITER flight mode, and RTL flight mode. The multicopter **10** is operable in a partial-power mode to, in certain situations, improve response and save power. The basic functionality of each operating mode is described below. The operator can toggle between these operating modes using suitable switches, a touch screen, or any other suitable device on the R/C controller.

[0212] On a typical R/C controller including left and right joysticks, the left joystick is typically used for throttle, while the right joystick is typically used for left/right and fore/aft station-keeping of the multicopter.

[0213] 1.6.1 SIMPLE Control Mode

[0214] SIMPLE control mode simplifies horizontal control by tying the R/C controller's right stick commands to geo-referenced coordinates. In various embodiments, the multicopter **10** always operates in SIMPLE control mode, regardless of which of the three flight modes the multicopter **10** employs. Under SIMPLE control mode, forward right stick deflection drives the multicopter **10** in the direction in which the multicopter **10** was pointed at the instant it was armed, regardless of its yaw orientation during flight. Put differently, if the multicopter **10** was pointed North when armed but, while hovering for instance, the multicopter **10** rotated about its yaw axis such that its nose is pointed East, forward right stick deflection still drives the multicopter **10** North. While the operator may use the left stick to rotate the multicopter **10** about the yaw axis, this (rudder) input is rarely needed for launch or retrieval of the fixed-wing aircraft **20**. The rear landing gear modules ensure the multicopter **10** is pointed into the relative wind (like a weathervane), so the operator need not worry about aligning the fuselage with airflow.

[0215] 1.6.2 TENSION Throttle Mode

[0216] When the multicopter **10** operates in TENSION throttle mode, the human operator has direct control over the throttle. In various embodiments, the multicopter **10** can only be operated in TENSION throttle mode when it is operated in either ALTHOLD or LOITER flight modes. That is, the multicopter **10** cannot be operated in TENSION

throttle mode when operated in RTL flight mode. TENSION throttle mode converts throttle stick inputs to direct throttle commands, which is primarily useful for tensioning the flexible capture tether **5000** during retrieval. An astute operator will climb at a controlled rate by feathering the throttle in TENSION throttle mode, he will slow high ascent as the tether pulls tight (described below), and then he maintains light tether tension, keeping the line straight as the fixed-wing aircraft approaches. The straight line allows human observers to confirm that the line will be swept by the fixed-wing leading edge and the capture is on-target. At impact, the operator increases throttle to arrest the fixed-wing aircraft's horizontal motion and minimize altitude loss. Then he feathers the throttle back to lower the aircraft to the ground.

[0217] 1.6.3 NORMAL Throttle Mode

[0218] In NORMAL throttle mode, the autopilot interprets joystick commands as desired rate commands and applies whatever throttle is needed to achieve that climb or descent rate. When tethered to the ground the altitude controller very abruptly increases throttle to maximum (when its desired altitude is above current altitude) or it plummets to minimum throttle (when desired altitude is below current altitude) without regard for joystick position. This behavior makes it difficult or impossible for the human operator to regulate tether tension directly. Direct throttle control, offered by TENSION throttle mode, disables the altitude controller. In this mode, altitude is controlled strictly by tether length. In Tension Mode, the human operator controls tether tension directly, with throttle inputs, and the autopilot responds with lift-producing motor commands that are roughly proportional to commanded throttle position. By this technique, the retrieval process enjoys improved finesse and precise control without overworking the multicopter motors and batteries.

[0219] 1.6.4 ALTHOLD Flight Mode

[0220] ALTHOLD flight mode converts throttle commands (left stick, vertical axis) to vertical rate commands. When operating in the ALTHOLD flight mode, the multicopter **10** will attempt to maintain current altitude when the left stick is in the middle position. The multicopter **10** will attempt to climb at up to 5 meters per second (or any other suitable rate) when the left stick is pushed up to max. The multicopter **10** will descend at up to 5 meters per second (or any other suitable rate) when the left stick is pulled to min. ALTHOLD flight mode converts right stick commands to lean angle, with maximum right stick deflection corresponding to 30 degrees (or any other suitable angle). When operating in ALTHOLD flight mode, the multicopter **10** will maintain zero lean when the right stick is in the middle position and will be blown downwind. If the fixed-wing aircraft **20** is mated to the multicopter **10** and producing thrust, this thrust will drive the multicopter **10** forward unopposed by lean angle. ALTHOLD flight mode does not depend on GPS for control, and works equally well indoors and in all locations where GPS reception is spotty or denied. ALTHOLD flight mode uses a compass for navigation, which means "SIMPLE MODE" works equally well without the use of GPS. Consequently, the operator simply pushes the right joystick gently into the wind for station keeping, fully into the wind to execute a "dash" maneuver (for launch/release), and he will relax the right stick to allow the aircraft to drift downwind to return home after a dash.

Finally, the operator will deflect the right stick opposite the aircraft's ground track to minimize ground speed just before touch-down.

[0221] 1.6.5 LOITER Flight Mode

[0222] LOITER flight mode behaves like ALTHOLD flight mode in the vertical direction (i.e., converts throttle commands to vertical rate commands). Similarly, LOITER flight mode converts right stick inputs to horizontal rate commands. When operating in LOITER flight mode, the multicopter 10 attempts to maintain its current horizontal position over the Earth when the right stick is in the middle position. Maximum right stick deflection drives the multi-copter 10 in the corresponding direction at up to 20 meters per second ground speed (or any suitable rate) or the maximum achievable speed against true wind, whichever is less. LOITER flight mode depends on GPS to close feedback loops around latitude and longitude positions. The controller 272 will automatically switch itself from LOITER flight mode to ALTHOLD flight mode when GPS reception is unacceptable, and will not allow a human operator to arm in LOITER flight mode when GPS reception is unacceptable.

[0223] 1.6.6 RTL Flight Mode

[0224] Activating Return to Launch (RTL) flight mode causes the multicopter 10 to autonomously return to its home position, which in some embodiments is the place on Earth where the controller 272 was last armed (described below). When the controller 272 is armed, it stores its launch location (obtained via the GPS receiver 285) in the memory 272b. Responsive to receipt of an RTL signal from the R/C controller, the controller 272 takes over operation of the multicopter 10 and controls the multicopter 10 to fly to a pre-landing location located a particular height above the launch location. The controller 272 then automatically (or the operator manually) controls the multicopter 10 to descend and land, as described in detail below.

[0225] To save battery life and to minimize flight time, the controller 272 controls the rotor motors so the multicopter 10 takes a direct (i.e., generally straight line) route from the location where the controller 272 received the RTL signal to the pre-landing location. If the multicopter 10 is above and laterally offset from the pre-landing location, the controller 272 controls the one or more rotor motors to descend while laterally moving toward the pre-landing location to take this direct route to the pre-landing location. This is an improve-ment over certain known multicopters that, instead of taking a direct route, travel laterally until above the pre-landing location and then descend to the pre-landing location.

[0226] FIGS. 12A and 12B illustrate the improvement over the prior art. FIG. 12A is a diagrammatic view of a prior art route a known multicopter 10a takes responsive to receiving an RTL signal. This known multicopter 10a is tethered to a ground anchor via a flexible member 12 and receives the RTL signal when at initial location A in this example. In response, the multicopter 10a attempts to: (1) travel laterally to location B directly above the landing location D along vector V1; then (2) descend to pre-landing location C along vector V2; then (3) descend to landing location D along vector V3. This route causes two problems. First, it is inefficient. Second, if the flexible member 12 is too short, the multicopter 10a will never reach location B, and absent operator intervention the multicopter 10a will con-tinuously attempt to reach location B even though it will

never get there, draining its battery and, if not recognized and stopped, resulting in damage to the multicopter and potential destruction.

[0227] FIG. 12B is a diagrammatic view of one route the multicopter 10 of the present disclosure takes responsive to receiving the RTL signal. The illustration of the multicopter 10 is highly simplified here for clarity. The illustrated multicopter 10 could be replaced with the other embodi-ments of the multicopter shown and described herein. The multicopter 10 is tethered to a ground anchor via the flexible member 12 and receives the RTL signal when at initial location A in this example. In response, the multicopter 10: (1) travels laterally while descending to pre-landing location C along vector V12; then (2) descends to landing location D along vector V3. This route is more efficient than the prior art route and reduces the potential for problems caused by a short flexible member (or enables use of a shorter flexible member).

[0228] In other embodiments, rather than returning to the place on Earth where the controller 272 was last armed when the RTL signal is received from the R/C controller, the multicopter returns to any suitable designated location, such as a landing location that the operator has indicated. In some instances the landing location may be moving, such as when the landing location is on a ship at sea.

[0229] When operating in RTL mode, the controller 272 ignores left stick inputs except when executing a SHUT DOWN command, and responds to right stick inputs only during the final (vertical) descent phase. For example, the operator may use the right stick to "nudge" the multicopter 10 away from the storage and launch system 2000 to avoid interference at touchdown. Multicopter response to these nudge maneuvers will be similar to right stick inputs in LOITER flight mode, and the operator should execute them before the aircraft descends below 5 meters (or any other suitable distance) above ground level. To avoid human operator-induced oscillations and to minimize ground speed, the human operator's fingers should be kept off the control sticks during final descent and touchdown in RTL mode.

[0230] 1.6.7 Partial-Power Mode

[0231] Certain known multicopters that are configured to withstand heavy lift load conditions—such as to transport relatively heavy payloads across relatively long distances—include relatively large rotors and rotor motors that are responsive enough to keep the multicopters under control when carrying these heavy payloads. But when these known multicopters are used to transport relatively light loads (or no loads), the large rotors render the multicopters unstable. Specifically, since the rotors provide so much power and lift, they must operate at a low rotational speed to avoid unde-sired multicopter climb, but operation at a low rotational speed induces sluggish response to operator commands. This loss of control and maneuverability is especially prob-lematic when flying the multicopter in an area full of obstructions—like trees, rock formations, and buildings—that the multicopter must deftly avoid. In some instances, operators swap out the large rotors for smaller rotors before these known multicopters are used to transport relatively light loads (or no loads), but that increases down time (to account for rotor swapping), requires operators to purchase and maintain a second set of rotors and have them on hand, and isn't feasible in certain instances (such as when the multicopter drops its payload while airborne).

[0232] To solve this problem, the multicopter **10** of the present disclosure is operable in a partial-power mode in which the controller **272** controls either all of the upper rotor motors or all of the lower rotor motors to operate at their minimum output (or in another embodiment, shut down) so the multicopter **10** operates using the other four rotor motors that the controller **272** controls normally (i.e., all four upper rotor motors or all four lower rotor motors). This renders the multicopter **10** robust enough to carry heavy loads (like the fixed-wing aircraft **20**) over long distances yet nimble enough (in the partial-power mode) to fly unloaded without losing maneuverability. Operators also don't have to purchase or maintain multiple sets of rotors or waste time swapping them out.

[0233] FIG. 11A is a flowchart of an example process **1500** for operating the multicopter **10** in the partial-power mode. In various embodiments, instructions stored in the memory **272***b* and executed by the processor **272***a* of the controller **272** represent the process **1500**.

[0234] In the process **1500**, the controller monitors for receipt of a partial-power mode signal from the R/C receiver or other suitable source, as diamond **1502** indicates. Once the controller receives the partial-power mode signal, the controller automatically sends a rotor motor control signal to each of the upper rotor motors of the multicopter to reduce the output of each of the upper rotor motors to a designated output, as block **1504** indicates. The designated output is less than the output of each lower rotor motor of the multicopter. In one embodiment, for each upper rotor motor, the designated output is the minimum output of that rotor motor (i.e., the controller signals the upper rotor motors to operate at their minimum rotational speed). In another embodiment, for each upper rotor motor, the designated output is zero (i.e., the controller signals the upper rotor motors to shut down). In other embodiments, the controller sends the above-described rotor motor control signal to each of the lower rotor motors rather than the upper rotor motors.

[0235] The designated output may be any suitable measure of rotor motor output, such as rotational speed or torque.

2. Storage and Launch System

[0236] The storage and launch system **2000** is shown in FIGS. **8**A, **8**B, **8**C, **8**D, **8**E, **8**F, **8**G, **8**H, and **8**I. The storage and launch system **2000** is usable to compactly store the modular multicopter **10** in a single container after disassembly into the 13 modules and to facilitate launch of the fixed-wing aircraft **20** into wing-borne flight by acting as a launch mount for the fixed-wing aircraft **20**.

[0237] To facilitate storage of the multicopter **10** in a single container (including a container top **2000***a* and a container bottom **2000***b*), the storage and launch system **2000** includes: (1) a launch-assist assembly **2100** to which the front landing gear modules **600***a* and **600***b* are attachable; (2) a rotor arm module and rear landing gear module storage device **2200** to which the rotor arm modules **400***a* to **400***d* and the rear landing gear modules **600***c* and **600***d* are attachable; and (3) a hub module storage tray **2300** to which the hub module **100** is attachable.

[0238] To facilitate launch of the fixed-wing aircraft **20**, the launch-assist assembly **2100** is movable from a storage position into a launch position and includes certain elements on which the fixed-wing aircraft can be mounted and other elements that retain the fixed-wing aircraft **20** in a launch orientation before launch. Example embodiments of each of these elements are described below, followed by a description of an example method of storing the multicopter **10** using these example embodiments of the elements.

[0239] 2.1 Launch-Assist Assembly

[0240] The launch-assist assembly **2100** is attached to the container bottom **2000***b* and is one element of the storage and launch system **2000** that facilitates launch of the fixed-wing aircraft **20**. The launch-assist assembly **2100** is movable from a position in which is lies substantially flat along the floor of the container bottom **2000***a* to enable storage of the multicopter **10** to a launch position in which it is generally spaced-apart from and upwardly-angled relative to the floor of the container bottom **2000***a* to facilitate launch of the fixed-wing aircraft **20**.

[0241] As best shown in FIG. **8**C, the launch-assist assembly **2100** includes: (1) first and second base brackets **2102***a* and **2102***b*; (2) first and second front legs **2104***a* and **2104***b*; (3) first and second rear legs **2106***a* and **2106***b*; (4) a tray **2108**; (5) first and second front landing gear module retainers **2110***a* and **2110***b*; (6) a storage device lock engager **2112**; (7) front and rear stabilizing brackets **2114***a* and **2114***b*; (8) first and second lockable gas springs **2116***a* and **2116***b*; and (9) an aircraft-engaging bracket **2120**.

[0242] The first and second base brackets **2102***a* and **2102***b* are attached to the floor of the container bottom **2000***a* near one end. The first front leg **2104***a* is pivotably attached at one end to the front end of the first base bracket **2102***a* and pivotably attached at the other end to the tray **2108**. Similarly, the second front leg **2104***b* is pivotably attached at one end to the front end of the second base bracket **2102***b* and pivotably attached at the other end to the tray **2108**. The first rear leg **2106***a* is pivotably attached at one end to the rear end of the first base bracket **2102***a* and pivotably attached at the other end to the tray **2108**. Similarly, the second rear leg **2106***b* is pivotably attached at one end to the rear end of the second base bracket **2102***b* and pivotably attached at the other end to the tray **2108**. The front stabilizing bracket **2114***a* is attached to and extends between the first and second front legs **2104***a* and **2104***b*, and the rear stabilizing bracket **2114***b* is attached to and extends between the first and second rear legs **2106***a* and **2106***b*. The first lockable gas spring **2116***a* is pivotably attached at one end to the first base bracket **2102***a* between the first front leg **2104***a* and the first rear leg **2106***a* and pivotably attached at the other end to the first front leg **2104***a* between the first base bracket **2102***a* and the tray **2108**. Similarly, the second lockable gas spring **2116***b* is pivotably attached at one end to the second base bracket **2102***b* between the second front leg **2104***b* and the second rear leg **2106***b* and pivotably attached at the other end to the second front leg **2104***b* between the second base bracket **2102***b* and the tray **2108**. The storage device lock engager **2112**, the first and second front landing gear module retainers **2110***a* and **2110***b*, and the aircraft engaging bracket **2120** are attached to the tray **2108**.

[0243] The aircraft engaging bracket **2120** includes two spaced-apart generally parallel sides **2121** and **2123** having wing engaging surfaces **2121***a* and **2123***a*, respectively, and a back **2122** transverse (such as generally perpendicular) to, extending between, and connecting the sides **2121** and **2123**. A fuselage-retaining assembly **2130** is rotatably mounted to the back plate **2122**.

[0244] The above-described pivotable attachments enable the launch assist assembly **2100** to move from: (1) a storage

position in which the first and second front legs **2104***a* and **2104***b*, the first and second back legs **2106***a* and **2106***b*, and the tray **2108** lay substantially flat along the floor of the container bottom **2000***a* (as best shown in FIGS. **8**A and **8**B); to (2) a launch position in which the first and second front legs **2104***a* and **2104***b* and the first and second back legs **2106***a* and **2106***b* extend upward from the floor of the container bottom **2000***a* such that the tray **2108** is spaced-apart from and upwardly-angled relative to the floor of the container bottom **2000***a* (as best shown in FIGS. **8**C and **8**D) (and vice-versa). The operator can lock the launch assist assembly **2100** in the launch position by locking the first and second lockable gas springs **2116***a* and **2116***b*.

[0245] When in the launch position, the launch assist assembly **2100** facilitates launch of the fixed-wing aircraft **20** by orienting the fixed-wing aircraft **20** in a desired launch orientation and retaining the fixed-wing aircraft **20** in that orientation until the operator desires to launch the fixed-wing aircraft **20**. As best shown in FIG. **8**D, in preparation for launch, the operator inserts the fuselage of the fixed-wing aircraft **20** into the fuselage-retaining assembly **2130** of the aircraft engaging bracket **2120** and lays the wings of the fixed-wing aircraft **20** atop the first and second wing engaging surfaces **2123***a* and **2123***b* of the aircraft engaging bracket **2120**.

[0246] The fuselage-retaining assembly **2130** is sized to receive the fuselage of the fixed-wing aircraft **20**. The fuselage-retaining assembly **2130** is configured such that, after it receives the fuselage, the fuselage-retaining assembly **2130** does not release the fuselage until: (1) the operator disengages a safety mechanism; and (2) a force biasing the fuselage-retaining assembly **2130** against releasing the fuselage is overcome. This prevents undesired launch of the fixed-wing aircraft **20**.

[0247] As best shown in FIGS. **8**E, **8**F, and **8**G, the fuselage-retaining assembly **2130** includes: (1) first and second pincers **2132** and **2134**; (2) first and second rollers **2136** and **2138** and corresponding nuts **2136***a* and **2138***a*; (3) a grooved clevis pin **2140** and corresponding retaining ring **2140***a*, spacer **2140***b*, and washer **2140***c*; (4) first and second spring mounting spacers **2142** and **2144** and their corresponding fasteners **2142***a* and **2144***a* and nuts **2142***b* and **2144***b*; (5) a compression spring **2146**; and (6) a safety mechanism **2150**.

[0248] The safety mechanism **2150** includes: (1) front and rear plates **2151** and **2152**; (2) fasteners **2154***a* and **2154***e*; (3) clevis pins **2154***b*, **2154***c*, and **2154***d*; (4) spacers **2156***a* and **2156***e*; (5) a rod end **2156***b*; (6) a compression spring **2158**; and (7) a handle **2160**.

[0249] The first and second pincers **2132** and **2134** are interchangeable, and have generally curved bodies that define rod end engagers **2132***a* and **2134***a*, respectively, along their outer edges and terminate at their lower ends in safety mechanism engagers **2132***b* and **2134***b*. The roller **2136** is attached via the nut **2136***a* to the upper end of the first pincer **2132**, and the roller **2138** is attached via the nut **2138***a* to the upper end of the second pincer **2134**. The rollers are rotatable with respect to their respective pincers. The first and second pincers **2132** and **2134** are pivotably connected to one another via the grooved clevis pin **2140**, the spacer **2140***b*, the washer **2140***c*, and the retaining ring **2140***a*. Although not shown, the fuselage-retaining assembly **2130** is attached to the aircraft engaging bracket **2120** via this grooved clevis pin **2140**.

[0250] In this embodiment, the first pincer is mounted on the grooved clevis pin in front of the second pincer (with respect to the view shown in FIG. **8**E), though in other embodiments the second pincer may be mounted in front of the first pincer without changing how the fuselage-retaining assembly operates.

[0251] As best shown in FIG. **8**G, the spring mounting spacer **2142** is mounted to a backwardly-extending portion of the first pincer **2132** via the fastener **2142***a* and the nut **2142***b*. Similarly, the spring mounting spacer **2144** is mounted to a backwardly-extending portion of the second pincer **2134** via the fastener **2144***a* and the nut **2144***b*. The compression spring **2146** is mounted on and extends between the spring mounting spacers **2142** and **2144**.

[0252] The first and second pincers **2132** and **2134** are movable relative to one another from: (1) a fuselage-retaining orientation in which their upper ends are separated a first distance that is smaller than the diameter of the fuselage of the fixed-wing aircraft **20** (shown in FIGS. **8**E and **8**F); to (2) a fuselage-release orientation in which their upper ends are separated a second distance that is larger than the diameter of the fuselage of the fixed-wing aircraft **20** (not shown) (and vice-versa). Thus, when the first and second pincers **2132** and **2134** are in the fuselage-retaining orientation, the fuselage of the fixed-wing aircraft cannot escape the first and second pincers **2132** and **2134** (absent further separation of the pincers), while the fuselage can escape when the first and second pincers **2132** and **2134** are in the fuselage-release orientation.

[0253] The compression spring **2146** opposes separation of the first and second pincers **2132** and **2134** and therefore biases the first and second pincers **2132** and **2134** toward the fuselage-retaining orientation. Separating the first and second pincers **2132** and **2134** causes the backwardly-extending portions of the first and second pincers **2132** and **2134** to compress the compression spring **2146**, which causes the compression spring **2146** to exert forces on the backwardly-extending portions of the first and second pincers **2132** and **2134** opposing that separation. Thus, to release the fuselage, this biasing force must be overcome.

[0254] Turning to the safety mechanism **2150**, as best shown in FIG. **8**E, the front plate **2151**, the rear plate **2152**, and the handle **2160** are attached to one another via: (1) the fastener **2154***a* extending through an opening **2152***a* in the rear plate **2152**, through the spacer **2156***a*, through an opening **2151***a* in the front plate **2151**, and into the handle **2160**; (2) the clevis pin **2154***b* extending through an opening **2152***b* in the rear plate **2152**, through an opening in the rod end **2156***b*, and through an opening **2151***b* in the front plate **2151**; (3) the clevis pin **2154***d* extending through an opening **2152***d* in the second plate and an opening **2151***d* in the front plate **2151**; and (4) the fastener **2154***e* extending through an opening **2152***e* in the rear plate **2152**, through the spacer **2156***e*, and through an opening **2151***e* in the front plate **2151**.

[0255] As best shown in FIGS. **8**E and **8**F, the safety mechanism **2150** is pivotably connected to the second pincer **2134** via the clevis pin **2154***c* extending through an opening **2152***c* in the rear plate **2152**, an opening **2134***c* in the second pincer **2134**, and an opening **2151***c* in the front plate **2151**. One end of the safety compression spring **2158** is disposed around the rod end **2156***b* and the other end of the safety compression spring **2158** is disposed around the rod end engager **2134***a* of the second pincer **2134**.

[0256] The safety mechanism **2150** is rotatable about the clevis pin **2134***c* from an engaged rotational position in which the safety mechanism **2150** prevents separation of the first and second pincers **2132** and **2134** from the fuselage-retaining orientation to the fuselage-release orientation (shown in FIGS. **8F** and **8**G) to a disengaged rotational position (not shown) in which the first and second pincers **2132** and **2134** are free to separate from the fuselage-retaining orientation to the fuselage-release orientation. The safety compression spring **2158** biases the safety mechanism **2150** into the engaged rotational position.

[0257] When in the engaged rotational position, the safety mechanism **2150** prevents separation of the first and second pincers **2132** and **2134** from the fuselage-retaining orientation to the fuselage-release orientation. Separating the first and second pincers **2132** and **2134** when the safety mechanism **2150** is in the engaged rotational position results in: (1) the safety mechanism engager **2132***b* of the first pincer **2132** engaging the clevis pin **2154***d* (since the clevis pin **2154***d* is in the path of rotation of the safety mechanism engager **2132***b* of the first pincer **2132**); and (2) the rod end engager **2134***a* of the second pincer **2134** engaging the rod end **2136***b*. This prevents the first and second pincers **2132** and **2134** from rotation relative to one another and therefore prevents further separation of the first and second pincers **2132** and **2134** to the fuselage-release orientation.

[0258] To enable the first and second pincers **2132** and **2134** to separate from the fuselage-retaining orientation to the fuselage-release orientation, the operator disengages the safety mechanism by rotating the safety mechanism **2150** from the engaged rotational position to the disengaged rotational position. To do so, the operator pulls the handle **2160** upward with enough force to overcome the spring-biasing force of the compression spring **2158** and compress the compression spring **2158** until the clevis pin **2154***d* is no longer in the path of rotation of the safety mechanism engager **2132***b* of the first pincer **2132**. At this point, the safety mechanism **2150** is in the disengaged rotational position, and the first and second pincers **2132** and **2134** can separate to the fuselage-release orientation.

[0259] In certain embodiments, a safety rope, tether, wire, cable, or other flexible member is attached to the handle (or any other suitable component) of the safety mechanism to facilitate disengaging the safety mechanism. When the flexible safety member is tensioned (such as via an operator pulling on the flexible safety member), the safety mechanism rotates from the engaged rotational position to the disengaged rotational position, thereby disengaging the safety mechanism. The flexible safety member may be relatively long, which enables the operator to stand a safe distance away from the fixed-wing aircraft during the launch process and still be able to disengage the safety mechanism.

[0260] By intentionally commanding full multicopter thrust without releasing the safety mechanism, an operator may execute a "refuse takeoff" test, which is particularly useful for confirming full-power performance of the complete electromechanical system without fear of flight-related mishap in the event that one or more components of the system should fail during the test.

[0261] 2.2 Rotor Arm Module and Rear Landing Gear Module Storage Device

[0262] The rotor arm module and rear landing gear module storage device **2200** is shown in FIGS. **8H** and **8I**. The rotor arm module and rear landing gear module storage device **2200** is the element of the storage and launch system **2000** to which the rotor arm modules **400***a* to **400***d* and the rear landing gear modules **600***c* and **600***d* can be mounted and compactly stored. The rotor arm module and rear landing gear module storage device **2200** includes: (1) a base **2205**; (2) a handle **2210**; (3) an upper rotor arm module constraining plate **2230**; (4) a lower rotor arm module constraining plate **2250**; and (5) a lock **2220** (which is a slide bolt in this embodiment but can be any suitable device).

[0263] The base **2205** defines a storage device lock engager receiving cavity **2205***a* therethrough sized to receive the storage device lock engager **2112** of the launch-assist assembly **2100**. The lock **2220** is fixedly attached to the base **2205** near the storage device lock engager receiving cavity such that the lock **2220** can engage the storage device lock engager **2112** when the storage device lock engager **2112** is received in the storage device lock engager receiving cavity **2205***a* to lock the rotor arm module and rear landing gear module storage device **2200** to the launch assist assembly **2100**.

[0264] The handle **2210** includes two opposing, spaced-apart sides **2211** and **2213** and a top **2212** extending between the sides **2211** and **2213**. The sides **2211** and **2213** are attached to the base **2205**. The side **2211** includes two surfaces **2211***a* and **2211***b* each defining a rear landing gear module receiving cavity sized and shaped to receive a portion of one of the rear landing gear modules **600***c* and **600***d*.

[0265] The upper rotor arm module constraining plate **2230** is attached to the handle **2210**. The upper rotor arm module constraining plate **2230** includes a plurality of surfaces **2230***a*, **2230***b*, **2230***c*, and **2230***d* each defining a rotor motor receiving cavity sized and shaped to receive a rotor motor of one of the rotor arm modules.

[0266] The upper rotor arm module constraining plate **2230** also includes a plurality of rotor arm module retainers **2241**, **2242**, **2243**, and **2244** disposed within an enclosing bracket **2240**. The rotor arm module retainer **2241** includes a locking tab **2241***a* extending below the upper rotor arm module constraining plate **2230** and is pivotably connected to the upper rotor arm module constraining plate **2230** via a pin **2241***b*. The rotor arm module retainer **2242** includes a locking tab **2242***a* extending below the upper rotor arm module constraining plate **2230** and is pivotably connected to the upper rotor arm module constraining plate **2230** via a pin **2242***b*. The rotor arm module retainer **2243** includes a locking tab **2243***a* extending below the upper rotor arm module constraining plate **2230** and is pivotably connected to the upper rotor arm module constraining plate **2230** via a pin **2243***b*. The rotor arm module retainer **2244** includes a locking tab **2244***a* extending below the upper rotor arm module constraining plate **2230** and is pivotably connected to the upper rotor arm module constraining plate **2230** via a pin **2244***b*.

[0267] The rotor arm module retainers are pivotable from a lock rotational position (shown in FIG. **8I**) to a release rotational position (not shown). Suitable biasing elements (such as compression spring, not shown) bias the rotor arm module retainers to the lock rotational position.

[0268] The lower rotor arm module constraining plate **2250** is attached to the handle **2210** below the upper rotor arm module constraining plate **2230**. The lower rotor arm module constraining plate **2250** includes a plurality of surfaces **2250***a*, **2250***b*, **2250***c*, and **2250***d* each defining a

rotor motor receiving cavity sized and shaped to receive a rotor motor of one of the rotor arm modules.

[0269] 2.3 Hub Module Storage Tray

[0270] The hub module storage tray **2300** is shown in FIG. 8J. The hub module storage tray **2300** is the element of the storage and launch system **2000** to which the hub module **200** is mounted for storage. The hub module storage tray **2300** includes a generally rectangular base **2310**, a handle **2320** fixedly attached to the base **2310**, and four female blind mate connector engagers **2332**, **2334**, **2336**, and **2338** fixedly attached to the base **2310**. The female blind mate connector engagers are sized and shaped to engage the top surfaces of the female blind mate connectors **231** of the hub module **100**.

[0271] 2.4 Storing the Multicopter in the Multicopter Storage Container

[0272] To store the multicopter **10** in the container of the storage and launch system **2000**, the operator first disassembles the multicopter **10** into the 13 modules or subassemblies, as described above. The operator moves the launch-assist assembly **2100** into its launch position.

[0273] The operator positions the rotor arm module and rear landing gear module storage device **2200** atop the launch-assist assembly **2100** such that the storage device lock engager **2112** of the launch-assist assembly **2100** is received in the storage device lock engager receiving cavity **2205a**. The operator engages the storage device lock engager **2112** with the lock **2220** to lock the rotor arm module and rear landing gear module storage device **2200** to the launch assist assembly **2100**.

[0274] The operator slides the rotor arm module **400a** into the space between the upper and lower rotor arm module constraining plates **2230** and **2250** of the rotor arm module and rear landing gear module storage device **2200** until: (1) the lower rotor motor is disposed within the rotor motor receiving cavities defined by the surfaces **2230b** and **2250b**; and (2) the rotor arm module retainer **2243** locks the rotor arm module **400a** into place.

[0275] The operator slides the rotor arm module **400b** into the space between the upper and lower rotor arm module constraining plates **2230** and **2250** of the rotor arm module and rear landing gear module storage device **2200** until: (1) the lower rotor motor is disposed within the rotor motor receiving cavities defined by the surfaces **2230d** and **2250d**; and (2) the rotor arm module retainer **2242** locks the rotor arm module **400b** into place.

[0276] The operator slides the rotor arm module **400c** into the space between the upper and lower rotor arm module constraining plates **2230** and **2250** of the rotor arm module and rear landing gear module storage device **2200** until: (1) the upper rotor motor is disposed within the rotor motor receiving cavities defined by the surfaces **2230c** and **2250c**; and (2) the rotor arm module retainer **2241** locks the rotor arm module **400c** into place.

[0277] The operator slides the rotor arm module **400d** into the space between the upper and lower rotor arm module constraining plates **2230** and **2250** of the rotor arm module and rear landing gear module storage device **2200** until: (1) the upper rotor motor is disposed within the rotor motor receiving cavities defined by the surfaces **2230a** and **2250a**; and (2) the rotor arm module retainer **2244** locks the rotor arm module **400d** into place.

[0278] The operator inserts the front landing gear modules **600a** and **600b** into the first and second front landing gear module retainers **2110a** and **2110b** on the tray **2108** of the launch-assist assembly **2100**.

[0279] The operator inserts the rear landing gear module **600c** into the rear landing gear module receiving cavity defined by the surface **2211b** and the rear landing gear module **600d** into the rear landing gear module receiving cavity defined by the surface **2211a**.

[0280] The operator places the landing gear extensions **500a** to **500d** in the container bottom **2000a** behind the handle **2320** of the hub module storage tray **2300**. The operator attaches the container top **2000b** to the container bottom **2000a** to complete storage.

[0281] The operator inverts the hub module **100** and engages the female blind mate connector engagers **2332**, **2334**, **2336**, and **2338** of the hub module storage tray **2300** with the female blind mate connectors **231** of the hub module **100**.

[0282] The operator moves the launch-assist assembly **2100** to the storage position.

[0283] In certain embodiments, the container top or the container bottom includes one or more handles (such as an extendable handle) or one or more wheels to facilitate moving the container. In certain embodiments, the container top or the container bottom includes one or more locks configured to lock the container top to the container bottom.

3. Anchor System

[0284] The anchor system **3000** is shown in FIGS. **9A** to **9D**. The anchor system **3000** is usable along with the multicopter **10** and the flexible capture member **5000** to retrieve the fixed-wing aircraft **20** from wing-borne flight. In this example embodiment, the anchor system **3000** is stored separately from the storage and launch system **2000**. That is, the storage and launch system **2000** is stored in one container (along with the multicopter **10**) and the anchor system **3000** is stored in another container. These containers may be to identical or different from one another.

[0285] As best shown in FIGS. **9A** and **9B**, the anchor system includes: (1) an anchor system base **3100**; (2) a breakaway device **3200** attached to the anchor system base **3100**; and (3) a flexible capture member payout and retract device **3300** attached to the anchor system base **3100**. Example embodiments of each of these elements are described below.

[0286] 3.1 Anchor System Base

[0287] As best shown in FIGS. **9A** and **9B**, the anchor system base **3100** is the element of the anchor assembly **3000** that serves as a mount for the remaining elements of the anchor system **3000**. The anchor system base **3100** includes two spaced-apart generally parallel sides **3102** and **3104** and a top **3106** transverse (such as generally perpendicular) to, extending between, and connecting the sides **3102** and **3104**.

[0288] The side **3102** defines: (1) first, second, and third braking openings **3102a**, **3102b**, and **3102c** therethrough; (2) a stator mounting opening **3102d** therethrough; and (3) a locking element engager receiving opening **3102e** therethrough. The side **3104** defines similar openings therethrough, some of which are not shown or labeled.

[0289] The top **3106** defines: (1) a fairlead mounting opening **3106***a* therethrough; (2) a U-joint mounting opening **3106***b* therethrough; and (3) a GPS receiver mounting opening **3106***c* therethrough.

[0290] A GPS receiver and U-joint mount **3816** is attached to the underside of the top **3106** of the anchor system base **3100** such that it is positioned within the cavity formed by the sides **3102** and **3104** and the top **3106**. A GPS receiver **3810** is attached to the GPS receiver and U-joint mount **3816** such that the GPS receiver **3810** extends through the GPS receiver mounting opening **3106***c* of the top **3106**. A U-joint **3814** is attached to the GPS receiver and U-joint mount **3816** via bolt **3818** such that the U-joint **3814** extends through the U-joint mounting opening **3106***b* of the top **3106**.

[0291] A fairlead **3812** is attached to the upper surface of the top **3106** such that a flexible capture member receiving opening **3812***a* defined through the fairlead **3812** is generally aligned with the fairlead mounting opening **3106***a* of the top **3106**.

[0292] Backing plates **3116***a*, **3116***b*, and **3116***c* are attached to the exterior surface of the side **3102** such that they generally cover the braking openings **3102***a*, **3102***b*, and **3102***c*, respectively. Backing plates **3116***d*, **3116***e*, and **3116***f* are attached to the exterior surface of the side **3104** such that they generally cover respective braking openings (not shown). The backing plates **3116***a* to **3116***f* are made of iron in this embodiment. Magnets **3318***a* are attached to the backing plate **3116***a* such that the magnets **3318***a* extend through the braking opening **3102***a*, magnets **3318***b* are attached to the backing plate **3116***b* such that the magnets **3318***b* extend through the braking opening **3102***b*, and magnets **3318***c* are attached to the backing plate **3116***c* such that the magnets **3318***c* extend through the braking opening **3102***c*. Similar magnets are attached to the backing plates **3316***d*, **3316***e*, and **3316***f*. FIG. **9B** shows the magnets' position relative to the first flange of the flexible capture member and payout device (described below).

[0293] A rotation prevention device **3120** is also attached to the exterior surface of the side **3102** near the locking element engager receiving opening **2102***e* of the side **3012**. The rotation prevention device **3120** includes a mount **3122** (such as a pillow block bearing), a retract spring (not shown), and a pawl **3124** pivotably attached to the mount **3122**. A locking element engager **3126** extends from the free end of the pawl **3124**. The rotation prevention device **3120** is attached to the side **3102** such that the locking element engager **3126** extends through the locking element engager receiving opening **3102***e*. The pawl **3124** is rotatable about its pivotable attachment to the mount **3122** from a locked position in which the locking element engager **3126** contacts the end cap **3314** and can engage the locking element **3314***a* and an unlocked position in which the locking element engager does not contact the end cap **3314** and cannot engage the locking element **3314***a*. The rotation-prevention device **3120** automatically retracts in the payout direction, and it remains clear as the flexible capture member payout and retract device (described below) retracts the flexible capture member post-capture. This automatically-retracting rotation prevention device **3120** enables an operator to preload the flexible capture member payout and retract device during preflight and, upon impact during capture, the flexible capture member payout and retract device can retract more flexible capture member length than it paid out.

This feature is particularly useful for minimizing pendula swing of the fixed wing aircraft **20** as it is lowered to the ground post-capture.

[0294] 3.2 Breakaway Device

[0295] As best shown in FIG. **9C**, the breakaway device **3200** enables the multicopter **10** to maintain a desired tension in the flexible capture member **5000** before the fixed-wing aircraft **20** captures the flexible capture member **5000** during retrieval. The breakaway device **3200** prevents the flexible capture member payout and retract device **3300** from paying out or retracting the flexible capture member **5000** until a tension in the flexible capture member **5000** reaches a certain threshold during retrieval. The breakaway device **3200** includes: (1) a generally cylindrical hollow shaft **3210**; (2) a lower retaining ring **3212**; (3) a generally annular collar **3214**; (4) a compression spring **3216**; (5) an upper retaining ring **3218**; and (6) a breakaway sleeve **3220**.

[0296] The shaft **3210** defines an upper retaining ring seat **3210***a* near its upper end in which the upper retaining ring **3218** is seated such that the upper retaining ring **3218** cannot slide along the shaft **3210** and a plurality of grooves forming a lower retaining ring seat **3210***b* in which the lower retaining ring **3212** is seated such that the lower retaining ring **3212** cannot slide along the shaft **3210**.

[0297] The collar **3214** is slidably mounted around the shaft **3210** between the upper retaining ring **3218** and the lower retaining ring **3212**. The collar includes a plurality of breakaway sleeve retainers **3214***a* that extend radially-outward from the outer surface of the collar **3214**.

[0298] The compression spring **3216** is slidably mounted around the shaft **3210** between the upper retaining ring **3218** and the collar **3214**.

[0299] The breakaway sleeve **3220** includes a generally cylindrical hollow body **3222** and a cap **3224** at its upper end. The lower end of the body **3222** defines a plurality of breakaway sleeve retainer receiving slots **3222***a* therethrough. The breakaway sleeve retainer receiving slots **3222***a* are open at one end, extend generally upward and circumferentially around the body **3222**, and dip slightly downward before terminating. A finger **3228** is pivotably attached to the cap **3224** via a suitable fastener **3230** (such as a grooved clevis pin and retaining ring). The body **3222** and the cap **3224** define a finger escape slot **3226** therethrough. The finger **3228** is rotatable from a rotational position in which the free end **3228***a* of the finger **3228** is located within the interior of the breakaway sleeve **3220** to a rotational position in which the free end **3228***a* is outside of the interior of the breakaway sleeve **3220** (after passing through the finger escape slot **3226**).

[0300] The breakaway sleeve **3220** is removably attachable to the collar **3214** via the breakaway sleeve retainers **3214***a* and the breakaway sleeve retainer receiving slots **3222***a*. To attach the breakaway sleeve **3220** to the collar **3214**, the operator: (1) aligns the openings of the breakaway sleeve retainer receiving slots **3222***a* of the breakaway sleeve **3220** with the breakaway sleeve retainers **3214***a* of the collar **3214**; (2) pushes downward on the breakaway sleeve **3220** to slightly compress the compression spring **3216** until the openings of the breakaway sleeve retainer receiving slots **3222***a* receive the breakaway sleeve retainers **3214***a*; (3) rotates the breakaway sleeve **3220** with respect to the collar **3214** such that the breakaway sleeve retainers travel through and to the end of their respective breakaway sleeve retainer receiving slots **3222***a* (clockwise with respect

to the view shown in FIG. **9**C); and (4) releases the breakaway sleeve **3220**, which enables the compression spring **3216** to extend and lock the breakaway sleeve retainers **3214***a* within their respective breakaway sleeve retainer receiving slots **3222***a*. To detach the breakaway sleeve **3220** form the collar **3214**, the operator reverses the process.

[0301] The breakaway device **3220** is fixedly attached to the U-joint **3814** of the anchor system base **3100**.

[0302] 3.3 Flexible Capture Member Payout and Retract Device

[0303] As best shown in FIG. **9**B, the flexible capture member payout and retract device **3300** absorbs a portion of the kinetic energy of the fixed-wing aircraft **20** after the fixed-wing aircraft **20** captures the flexible capture member **5000** by paying out part of the flexible capture member **5000** after capture from a spool while simultaneously applying various braking forces to the spool to slow the aircraft. As the aircraft slows and comes to a stop, flexible capture member payout and retract device **3300** retracts at least part of the paid-out flexible capture member **5000** to generally prevent the now-dangling fixed-wing aircraft **20** from swinging around below the multicopter **10**.

[0304] The flexible capture member payout and retract device **3300** includes: (1) a stator **3310**; (2) a drum **3312** rotatably mounted to the stator **3310**; (3) a first electrically conductive flange **3314** having a locking element **3314***a* extending therefrom and fixedly attached to one end of the drum **3312**; and (4) a second electrically conductive flange **3316** fixedly attached to the opposite end of the drum **3312**.

[0305] The flexible capture member payout and retract device **3300** is attached to the anchor system base **3100** via the stator **3310**. Specifically, the flexible capture member payout and retract device **3300** is attached to the anchor system base **3100** such that the stator **3310** extends between the first and second stator mounting openings **3102***d* and **3104***d* of the first and second sides **3102** and **3104** of the anchor system base **3100**.

[0306] Although not shown, the flexible capture member payout and retract device **3300** also includes a suitable biasing element—such as a power spring—disposed within the interior of the drum **3312**. Inside the drum **3312**, the arbor end of the power spring is anchored to the stator **3310**. Upon impact, during retrieval, the power spring is forced to wrap around the stator **3310**, transferring wraps from the drum **3312** to the stator **3310** inside the flexible capture member payout and retract device **3300**. After the kinetic energy of the fixed-wing aircraft **20** has been absorbed, the power spring works to retract (i.e., reverse payout) of the flexible capture member. This payout reversal helps in two ways: (1) it attenuates the backswing tendency of the captured fixed-wing aircraft **20**, and (2) it allows the operator to begin a controlled descent of the fixed-wing aircraft **20** to the ground.

[0307] 3.4 Flexible Capture Member

[0308] As best shown in FIG. **10**D, a flexible capture member **5000** is attachable to the multicopter **10** and the anchor system **3000** to facilitate retrieval of the fixed-wing aircraft **20** from wing-borne flight. The flexible capture member **5000** includes: (1) an elastic portion **5100**; (2) a capture portion **5200**; and (3) a retractable portion **5300**.

[0309] The elastic portion **5100** is a bungee or similar element, and is attachable at one end to the cam **350** of the hub module **100** and at the other end to the capture portion **5200**. The elastic portion may be rigged such that a portion

of the strain energy is directed into a damping element such as a metal ring or a one-way pulley. By rigging the elastic portion as a compliant damper (as opposed to a spring), more energy is absorbed during capture, and undesirable ricochet is minimized.

[0310] The capture portion **5200** is a rope or similar element (such as Spectra rope) attachable at one end to the elastic portion **5100** and at the other end to the retractable portion **5300**. The capture portion **5200** is the portion of the flexible capture member **5000** that the fixed-wing aircraft **20** captures during retrieval. Here, the capture portion **5200** is thicker near its ends (such as within 12 feet of each end) that it is in its center. In one embodiment, both ends of the capture portion terminate in a Brummel eye splice in which the buried tails constitute the thicker portion of the capture portion **5200**.

[0311] The retractable portion **5300** is a rope or similar element attachable at one end to the capture portion **5200**, partially wound around the drum **3312** of the flexible capture member payout and retract device **3300**, and attached to the flexible capture member payout and retract device **3300**. The retractable portion may be further improved by inserting an elastic member inside the core of the rope. The elastic member shortens the rope as it slackens and is wound onto the drum. During payout, the elastic member allows the rope to lengthen as it leaves the drum, and a lossy payout device is formed. This detail is especially helpful during a dynamic braking event, in which spool inertia and limited power spring stroke can impart undesirable acceleration spikes on the aircraft.

[0312] 3.5 Accessories Container and Other Components

[0313] As best shown in FIG. **9**D, the anchor system **3000** is attached to the container bottom **4000***a* of an anchor system and accessory storage container to enable easy and compact storage of the anchor system **3000** and various accessories, such as (but not limited to): (1) a battery charger **4010** usable to recharge the batteries **260***a* to **260***d* of the multicopter **10**; (2) an engine cooling system **4020** usable during pre-launch of the fixed-wing aircraft **20** to cool the engine of the fixed-wing aircraft **20**; (3) two generators **4030***a* and **4030***b*; (4) the flexible capture member **5000**; (5) an R/C transmitter stand that helps enforce geo-referenced joystick commands of the R/C controller; (6) extra nozzles for the engine cooling system; (7) a fire extinguisher; (8) shovels; (9) hard hats; (10) a parallel cable usable to enable the generators **4030***a* and **4030***b* to load-share; (11) an extra fuel tank; (12) spare hooks for the fixed-wing aircraft **20**; (13) a laptop computer; and (14) weights for ballast.

4. Methods of Operation

[0314] As described in detail below: (1) the multicopter **10** and the storage and launch system **2000** are usable to facilitate launch of the fixed-wing aircraft **20** into wing-borne flight; and (2) the multicopter **10**, the anchor system **3000**, and the flexible capture member **5000** are usable to facilitate retrieval of the fixed-wing aircraft **20** from wing-borne flight.

[0315] 4.1 Multicopter-Assisted Fixed-Wing Aircraft Launch Method

[0316] The multicopter-assisted fixed-wing aircraft launch method begins with the multicopter **10** disassembled and stored in the storage and launch system **2000**, as best shown in FIGS. **8**A and **8**B. The operator unpacks the 13 modules

and moves the launch-assist assembly **2100** of the storage and launch system **2000** to its launch position, as best shown in FIG. **8C**.

[0317] The operator mounts the fixed-wing aircraft **20** to the launch-assist assembly **2100** by: (1) disengaging the safety mechanism **2150** of the fuselage-retaining assembly **2130**, which enables the pincers **2132** and **2134** to separate from the fuselage-retaining orientation to the fuselage-release orientation; (2) lowering the fuselage of the fixed-wing aircraft **20** between the pincers **2132** and **2134** (the fact that the safety mechanism **2150** is disengaged enables weight of the fixed-wing aircraft **20** to force the pincers **2132** and **2134** to separate to receive the fuselage); (3) positioning the wings of the fixed-wing aircraft **20** on the wing engaging surfaces **2121***a* and **2123***a* of the aircraft engaging bracket **2120** of the launch-assist assembly **2100**; and (4) engaging the safety mechanism **2150**, which prevents the pincers **2132** and **2134** from separating to the fuselage-release position and retains the fuselage of the fixed-wing aircraft **20** between the pincers **2132** and **2134**. FIG. **8D** shows the fixed-wing aircraft **20** mounted to the launch-assist assembly **2100** in this manner.

[0318] The operator selects the appropriate cooling nozzle for the engine cooling system **4020** based on the type of fixed-wing aircraft **20** used. The operator attaches that cooling nozzle to the engine cooling system **4020** and hangs the engine cooling system **4020** on the back of the aircraft engaging bracket **2120** of the launch-assist assembly **2100** such that the engine of the fixed-wing aircraft **20** is in the cooling nozzle's path.

[0319] The operator switches an idle power circuit of the multicopter **10** to a closed state (from an open state) to power certain components of the multicopter **10**—such as the GPS receiver **285**, the controller **272**, the IMU **277**, the telemetry link **274**, the R/C receiver **276**, the barometer **278**, the cam servo motor **381**, and the lock servo motor **391**—to enable various preflight checks (e.g., as operating mode status checks, throttle response checks, attitude indicator response checks, heading accuracy checks, and R/C range checks) to be performed. Switching the idle power circuit to the closed state does not power the rotor motors. The idle power circuit thus (when closed) enables the operator to conduct most preflight checks without having to worry about accidentally switching on one or more of the rotor motors.

[0320] As shown in FIG. **10A**, the operator then attaches the hub module **100** to the fixed-wing aircraft **20** by: (1) operating the cam servo motor **381** (either manually or remotely via the R/C controller) to rotate the cam **350** to the attached rotational position (clockwise from this viewpoint); (2) operating the lock servo motor **391** (either manually or remotely via the R/C controller) to rotate the lock servo motor arm **392** into the cam rotation-preventing rotational position (clockwise from this viewpoint) such that the lock servo motor locking extension **392***a* on the end of the lock servo motor arm **392** engages the cam servo motor arm lock device **382***a* of the cam servo motor arm **382**; and (3) seating a rearwardly-curved hook **21** attached to the fuselage of the fixed-wing aircraft **20** on the cam **350** such that hook generally rests on the ridge **351** of the cam **350** and the tip of the hook is disposed in the valley **353** of the cam **350**.

[0321] At this point the fixed-wing aircraft **20** is attached to the cam **350** (and the hub base **100**), the fuselage of the fixed-wing aircraft **20** contacts the front and rear aircraft engaging brackets **340***a* and **340***b* (to prevent rotation about

the pitch and yaw axes of the fixed-wing aircraft **20**), and the stabilizers **290***a* and **290***b* contact the wings of the fixed-wing aircraft **20** (to prevent rotation about the roll axis of the fixed-wing aircraft **20**).

[0322] Since the lock servo motor locking extension **392***a* is engaged to the cam servo motor arm lock device **382***a* of the cam servo motor arm **382**, the cam servo motor **381** cannot rotate the cam **350** from the attached rotational position to the detached rotational position (counter-clockwise from this viewpoint). This prevents undesired detachment of the fixed-wing aircraft **20** from the cam **350** (and the multicopter **10**).

[0323] After the hub module **100** is attached to the fixed-wing aircraft **20**, the operator: (1) attaches the front and rear landing gear modules **600***a* to **600***d* to their respective front and rear landing gear extension modules **500***a* to **500***d*; (2) attaches the front and rear landing gear extension modules **500***a* to **500***d* to their respective rotor arm modules **400***a* to **400***d*; and (3) attaches and locks the rotor arm modules **400***a* to **400***d* to the hub module **100** to complete assembly of the multicopter **10**.

[0324] The operator ensures the front and rear landing gear modules **600***a* to **600***d* are not in the path of rotation of the rotors of their corresponding rotor arm modules **400***a* to **400***b*, and connects the main power line of the multicopter **10** to switch a main power circuit to a closed state (from an open state). Unlike the idle power circuit, the main power circuit (when closed) is capable of delivering current sufficient to drive the rotor motors and cause the multicopter **10** to fly.

[0325] At this point, the operator uses the R/C controller to arm the controller **272**. This causes the controller **272** to, as described below, send rotor motor control signals to all of the rotor motors to cause those rotor motors to operate and the rotors to spin, regardless of the flight mode in which the controller **272** was armed. The arming process enables the operator to ensure that the rotor motors are all operational before the multicopter **10** takes flight. Also, in this example embodiment, the controller **272** prevents the multicopter **10** from taking off until the controller **272** has been armed, which provides a failsafe against undesired take off.

[0326] To arm the controllers of certain known multicopters, an operator must provide an input to the R/C controller that causes the R/C controller to send a mixed throttle and yaw signal to the R/C receiver of the multicopter (e.g., move the left joystick down and to the right). In response, the controller arms and forces the multicopter to rotate about its yaw axis in accordance with the yaw component of the mixed throttle and yaw signal. This is problematic in that it induces unwanted yaw movement in the multicopter, and becomes even more problematic as the multicopter's size increases.

[0327] To solve this problem, the multicopter **10** of the present disclosure divorces the arming process from multicopter yaw control so the mere act of arming the multicopter **10** does not intentionally induce unwanted yaw movement. That is, the multicopter **10** does not actively attempt to induce yaw movement while arming (since it doesn't receive a signal to command it to do so), though minimal yaw movement may occur in certain scenarios due to environmental conditions and/or characteristics of the multicopter **10**. For instance, if the multicopter **10** is on a ship at sea, the ship may move to unintentionally the multicopter **10** to rotate in yaw after arming.

[0328] FIG. 11B is a flowchart of an example process **1050** for arming the controller of the multicopter independent from multicopter yaw control. In various embodiments, instructions stored in the memory **272***b* and executed by the processor **272***a* of the controller **272** represent the process **1050**.

[0329] The process **1050** begins after the main power circuit of the multicopter has been closed to power the rotor motors. The controller monitors for simultaneous receipt of a first arm signal and a second arm signal from the R/C controller or other suitable source, as diamond **1052** indicates. The first and second arm signals are both decoupled from (i.e., independent from) multicopter yaw control. Responsive to simultaneously receiving the first arm input signal and the second arm signal the controller automatically arms, as block **1054** indicates.

[0330] In this example embodiment, the R/C controller sends the first arm signal responsive to the operator moving a designated joystick (the throttle joystick) to a particular position and sends the second arm signal responsive to the operator actuating a designated pushbutton. So, for instance, the controller arms responsive to the signals the R/C controller sends the R/C receiver when the operator holds the designated joystick in the particular position and then actuates the designated pushbutton. These are merely examples, and any suitable action (decoupled from yaw control) may cause the R/C controller to send either of the first and second arm signals.

[0331] In an alternative embodiment, the controller is configured to arm responsive to receiving a single arm signal from the R/C controller. In this embodiment, the R/C controller is configured to send that single arm signal to the controller responsive to actuation of an input device (such as a pushbutton) while a designated joystick is held in a particular position. In this embodiment, the R/C controller is not configured to send the single arm signal responsive to actuation of the input device while the joystick is not held in the particular position.

[0332] Returning to the process **1050**, after the controller is armed, the controller sends a rotor motor control signal to each rotor motor of the multicopter to control the rotor motors to operate at a designated rotor motor output, as block **1056** indicates. In this example embodiment, the designated rotor motor output is greater than the minimum rotor motor output, though in other embodiments the designated rotor motor output may be the minimum rotor motor output. The controller monitors for the expiration of a designated period, as diamond **1058** indicates.

[0333] Once the designated period expires, the controller determines whether it was armed in partial-power mode (described above), as diamond **1060** indicates. If the controller was not armed in partial-power mode, the controller maintains operation of all of the rotor motors, as block **1062** indicates. But if the controller was armed in partial-power mode, the controller: (1) maintains operation of all of the lower rotor motors, as block **1064** indicates; and (2) sends a rotor motor control signal to each upper rotor motor to reduce the output of each upper rotor motor to a designated output that is less than the output of each lower rotor motor (such as the minimum output), as block **1066** indicates.

[0334] Certain known multicopters do not monitor for rotor motor stalls after their controllers command non-operating rotor motors to begin operating (e.g., immediately after arming the controller). This is problematic because undetected rotor motor stalls can lead to destruction of the rotor motor or other components of the multicopter. For instance, assume a rotor of known multicopter is stuck on an obstacle and can't rotate. If the controller of this known multicopter commands the corresponding rotor motor to operate, the rotor motor stalls since the stuck rotor prevents the rotor motor from operating. If not detected, power continues to flow to the rotor motor and could cause it to burst into flames or otherwise damage itself.

[0335] To solve this problem, the controller **272** of the multicopter **10** performs a rotor motor stall detection process after commanding a non-operating rotor motor to operate. This enables the controller **272** to detect when a rotor motor stalls and shut it down to prevent damage to the rotor motor or any other components of the multicopter **10**.

[0336] FIG. 11C is a flowchart of an example rotor motor stall detection process **1450**. In various embodiments, instructions stored in the memory **272***b* and executed by the processor **272***a* of the controller **272** represent the process **1450**.

[0337] The process **1450** begins after the controller sends a rotor motor control signal to command a non-operating rotor motor (or in other embodiments, a motor operating below a designated rotational speed) to operate. After doing so, the controller periodically receives, from a rotational speed sensor (such as an RPM sensor) configured to detect the rotational speed of the rotor motor output shaft, a measured rotational speed of the rotor motor, as block **1452** indicates. Upon expiration of a designated period after sending the rotor motor control signal, the controller determines whether the measured rotational speed of the rotor motor is below a threshold rotational speed, as diamond **1454** indicates. If not, the controller determines that the rotor motor is operating properly and the process **1450** ends. But if the controller determines at diamond **1454** that the measured rotational speed of the rotor motor is below the threshold rotational speed, the controller determines that the rotor motor has stalled and automatically sends a rotor motor control signal to shut down the rotor motor, as block **1456** indicates. In this embodiment, the threshold rotational speed is about equal to the rotational speed a properly operating rotor motor would have following expiration of the designated period after receiving the rotor motor control signal, though in other embodiments the rotational speed is lower than this ideal rotational speed to account for non-ideal conditions.

[0338] In other embodiments, the controller is configured to monitor the back electromotive force of the rotor motors, which is the voltage that occurs in electric motors where there is relative motion between the armature of the motor and the magnetic field from the motor's windings. The magnitude of back electromotive force correlates to the rotational speed of the motor, which enables the controller to use the back electromotive force to determine whether a rotor motor has stalled. In these embodiments, for a given rotor motor, after the controller sends a rotor motor control signal to command a non-operating motor to operate, the controller is configured to monitor the back electromotive force of that rotor motor. If the back electromotive force is below a certain threshold back electromotive force upon expiration of a designated period after the controller sends the rotor motor control signal, the controller determines that the rotor motor has stalled and sends a rotor motor control

signal to shut down the rotor motor. The threshold back electromotive force generally correlates with the threshold rotational speed.

[0339] In certain embodiments, if the measured rotational speed (or measured back electromotive force) is below the threshold rotational speed (or threshold back electromotive force) for any one of the rotor motors, the controller is configured to send rotor motor control signals to all of the rotor motors to shut down the rotor motors. This prevents the multicopter from operating when one (or more) rotor motors are stalled.

[0340] Certain known multicopters are operable at a variety of different heights above sea level and, therefore, in a variety of different atmospheric pressures. To operate in a variety of different atmospheric pressures, and particularly in the relatively thin atmosphere relatively high above sea level, these known multicopters have relatively powerful rotor motors and relatively large rotors to enable the multicopters to generate lift in the thin air. But these powerful rotor motors and large rotors can be problematic when operating in the thicker air relatively close to sea level. Specifically, the rotor motors must work harder to drive the large rotors in the more dense air, which causes the rotor motors to generate more heat (relative to the heat generated in lower atmospheric pressures) and therefore have a higher risk of overheating and failing.

[0341] To solve this problem, the controller 272 of the multicopter 10 varies the maximum rotor motor output based on barometric pressure, which corresponds to the height of the multicopter 10 above sea level. Specifically, the controller 272 limits the maximum rotor motor outputs when the multicopter 10 is operating in an area with a high barometric pressure, e.g., relatively close to sea level. Conversely, the controller 272 enables relatively high maximum rotor motor outputs when the multicopter 10 is operating in an area with a relatively low barometric pressure, e.g., relatively high above sea level. Since the air near sea level is relatively thick, capping the maximum rotor motor outputs near sea level still enables the multicopter to generate the lift required to operate without overheating.

[0342] FIG. 11D is a flowchart of an example process 1600 for setting the maximum rotor motor output of the rotor motors of the multicopter 10. In various embodiments, instructions stored in the memory 272b and executed by the processor 272a of the controller 272 represent the process 1600.

[0343] In this example embodiment, the process 1600 begins when the controller is armed (described above). The controller receives a measured barometric pressure from the barometer, as block 1602 indicates. The controller determines whether the measured barometric pressure is above a threshold barometric pressure, as diamond 1606 indicates. In this example embodiment, the threshold barometric pressure corresponds to the barometric pressure at about 5,000 feet above sea level, though the threshold barometric pressure may be any suitable pressure.

[0344] If the controller determines at diamond 1606 that the measured barometric pressure is below the threshold barometric pressure, the controller sets a maximum rotor motor output to a first rotor motor output, as block 1608 indicates. But if the controller determines at diamond 1606 that the measured barometric pressure is above the threshold barometric pressure, the controller sets the maximum rotor motor output to a second rotor motor output, as block 1610

indicates. The second rotor motor output is greater than the first rotor motor output. After setting the maximum rotor motor output to the first or second rotor motor output, the controller automatically limits the output of each rotor motor of the multicopter to the maximum rotor motor output as block 1612 indicates (i.e., the first or second rotor motor output). In this embodiment, the second rotor motor output is 100% of the rotor motors' maximum available output, while the first rotor motor output is 85% of the rotor motors' maximum available output, though these values may differ in other embodiments.

[0345] In this example embodiment, the controller sets the maximum rotor motor output for the rotor motors when the controller is armed. The controller does not change that maximum rotor motor output until it is armed again. In other embodiments, the controller periodically repeats the process 1600 to enable it to dynamically change the maximum rotor motor output for the rotor motors while operating. This may be beneficial in areas in which the multicopter may be used both below and above the designated height above sea level. While the process 1600 is described with respect to two rotor motor outputs, three or more different rotor motor outputs may be available in other embodiments, with each rotor motor output being associated with a different range of heights above sea level.

[0346] In other embodiments, the controller makes the above determinations based on whether the height of the multicopter above sea level, which is determined based on the measured barometric pressure, is above a threshold height.

[0347] The maximum rotor motor output may be any suitable measure of rotor motor output, such as rotational speed or torque.

[0348] After the controller 272 has armed and determined that the rotor motors are operating properly, the operator begins the engine start-up procedure for the fixed-wing aircraft 20. At this point, as described in more detail below, the multicopter 10 is manually or autonomously controlled (or a combination of both) to release the fixed-wing aircraft 20 into free flight according to the following general steps: (1) flying the multicopter 10 to a pre-dash location a particular distance above the ground; (2) dashing the multicopter 10 laterally until achieving a particular airspeed suitable for release; (3) releasing the fixed-wing aircraft 20; (4) stopping the multicopter's dash; (5) flying the multicopter 10 to a pre-landing location a particular distance above a landing location; and (6) descending to the landing location.

[0349] In one example, the operator selects the ALTHOLD flight mode for the multicopter 10. The operator (or an assistant) disengages the safety mechanism 2150 of the fuselage-retaining assembly 2130, which enables the pincers 2132 and 2134 to separate from the fuselage-retaining orientation to the fuselage-release orientation. The operator advances the throttle to begin vertically climbing and lift the fixed-wing aircraft 20 from between the pincers 2132 and 2134 (which are free to separate and release the fuselage of the fixed-wing aircraft 20 since the safety mechanism 2150 is disengaged). Once the multicopter 10 and attached fixed-wing aircraft 20 have reached a designated pre-dash height above ground, the operator controls the multicopter 10 to begin dashing forward to generate enough airspeed to release the fixed-wing aircraft 20 into free flight.

[0350] Certain known multicopters employ feedback control when in flight to ensure that their pitch, roll, and yaw angles approach or equal target pitch, roll, and yaw angles (set by their controllers in response to operator and/or software commends) and ensure the multicopter is operating as desired. Whenever the controller of one of these multicopters determines that the multicopter's pitch, roll, and/or yaw angle has deviated from the desired pitch, roll, and/or yaw angle, the controller controls one or more rotor motors of the multicopter to move the multicopter to correct the error, such as by changing the speed at which the rotor motor drives its corresponding rotor and/or the direction in which the rotor motor rotates the rotor.

[0351] Use of yaw angle feedback control could be problematic for the multicopter 10 because it could rotate the multicopter 10 in yaw so the fixed-wing aircraft 20 is pointed in an undesirable direction—such as transverse to the wind—when released. This could make it more difficult for the fixed-wing aircraft 20 to successfully enter free-flight, and introduces the potential for destruction of the fixed-wing aircraft 20.

[0352] The multicopter 10 of the present disclosure solves this problem by not controlling the yaw angle of the multicopter 10 while dashing, instead enabling the multicopter 10 to self-align itself relative to the wind. More specifically, while the multicopter 10 is dashing, the controller 272 is configured to monitor the actual pitch and roll angles of the multicopter 10 and to use feedback control to ensure those actual pitch and roll angles approach or equal the desired pitch and roll angles of the multicopter 10 during flight (as determined by the controller 272 based on operator and/or software commands). While the controller 272 is also configured to monitor the actual yaw angle of the multicopter 10, the controller 272 is configured so it does not intentionally control the yaw angle of the multicopter 10. That is, the controller 272 does not actively attempt to perform yaw angle control via rotor motor operation, though minimal yaw movement may occur in certain scenarios due to environmental conditions and/or characteristics of the multicopter 10.

[0353] Rather, the controller 272 enables the multicopter 10 to freely rotate about its yaw axis to self orient. As described above, the multicopter 10 includes rear landing gear 600c and 600d that has large vertical surfaces and that function as fins in flight. The aerodynamic forces acting on the rear landing gear 600c and 600d (and in particular the large vertical surfaces) orient the multicopter 10 about its yaw axis so the fuselage of the fixed-wing aircraft 20 (when attached to the multicopter 10) is generally aligned with the slipstream. This lack of yaw control ensures that the fixed-wing aircraft 20 is properly oriented with respect to the wind upon its release from the multicopter 10.

[0354] FIG. 11E is a flowchart of an example process 1000 for controlling multicopter pitch and roll angles without controlling multicopter yaw angle while dashing before releasing the fixed-wing aircraft. In various embodiments, instructions stored in the memory 272b and executed by the processor 272a of the controller 272 represent the process 1000.

[0355] The process 1000 begins once the multicopter has reached a desired pre-dash height above ground and has begun dashing to achieve the airspeed required to release the fixed-wing aircraft into free flight. The controller periodically receives: (1) a measured multicopter yaw angle (relative to a yaw angle reference plane) from a yaw angle sensor, as block 1002 indicates; (2) a measured multicopter roll angle (relative to a roll angle reference plane) from a roll angle sensor, as block 1004 indicates; and (3) a measured multicopter pitch angle (relative to a pitch angle reference plane) from a pitch angle sensor, as block 1006 indicates. In this example embodiment, the IMU operates as the yaw, pitch, and roll angle sensors, though in other embodiments the multicopter may include any suitable sensors.

[0356] The controller periodically monitors: (1) for the measured multicopter pitch angle to deviate from a target multicopter pitch angle (in this embodiment, 20 degrees nose down, though any other suitable angle may be used), as diamond 1008 indicates; and (2) for the measured multicopter roll angle to deviate from a target multicopter roll angle (in this embodiment, 0 degrees, though any other suitable angle may be used), as diamond 1010 indicates. The controller does so without monitoring for the measured multicopter yaw angle to deviate from any target multicopter yaw angle.

[0357] Responsive to the measured multicopter pitch angle deviating from (i.e., not being equivalent to) the target multicopter pitch angle (or in other embodiments deviating from the target multicopter pitch angle by at least a first designated amount, such as more than one percent), the controller automatically sends one or more rotor motor control signals to control the one or more rotor motors of the multicopter to operate to eliminate the difference between the measured multicopter pitch angle and the target multicopter pitch angle, as block 1012 indicates. Responsive to the measured multicopter roll angle deviating from (i.e., not being equivalent to) the target multicopter roll angle (or in other embodiments deviating from the target multicopter roll angle by at least a second designated amount, such as more than one percent), the controller automatically sends one or more rotor motor control signals to control the one or more rotor motors of the multicopter to operate to eliminate the difference between the measured multicopter roll angle and the target multicopter roll angle, as block 1012 indicates. The controller does so without controlling the one or more rotor motors of the multicopter to actively change the multicopter yaw angle, instead enabling the multicopter to self-orient in yaw using its rear landing gear.

[0358] In this example embodiment, the controller 272 performs the process 1000 when the multicopter 10 is in the ALTHOLD flight mode, regardless of whether the fixed-wing aircraft 20 is attached to the multicopter 10. This simplifies piloting the multicopter 10 by eliminating the need for the operator to precisely control the pitch angle of the multicopter 10.

[0359] In various embodiments, the multicopter 10 only enables release of the fixed-wing aircraft 20 when certain conditions (or a single condition) are met. This ensures that the fixed-wing aircraft 20 is released only when conditions for a successful release exist, which reduces the potential for damage to the fixed-wing aircraft 20 and the multicopter 10.

[0360] FIG. 11F is a flowchart of an example process 1650 for enabling fixed-wing aircraft release. In various embodiments, instructions stored in the memory 272b and executed by the processor 272a of the controller 272 represent the process 1650.

[0361] The controller 272 monitors: (1) a height of the multicopter above the ground (such as by using barometric pressure measured by the barometer, as described above), as

block **1652** indicates; (2) a measured multicopter pitch angle (such as by using a pitch angle sensor like the IMU, as described above), as block **1654** indicates; and (3) whether GPS connectivity is established for the multicopter (such as based on feedback from the GPS receiver), as block **1656** indicates.

[0362] The controller monitors whether: (1) the height of the multicopter above the ground exceeds a designated height above the ground; (2) the measured multicopter pitch angle is within a designated pitch angle range; and (3) GPS connectivity is established for the multicopter, as diamond **1658** indicates. If all three conditions are met, the controller enables fixed-wing aircraft release, as block **1662** indicates. If all three conditions are not met, the controller ignores any received release signal (i.e., does not enable fixed-wing aircraft release), as block **1664** indicates.

[0363] The controller also monitors whether fixed-wing aircraft release is enabled, as diamond **1660** indicates. While fixed-wing aircraft release is enabled, the controller monitors for receipt of a release signal from the R/C controller or other suitable source, as diamond **1666** indicates. Responsive to receiving the release signal while fixed-wing aircraft release is enabled, the controller automatically sends an actuator release signal to a release actuator, in this example embodiment the cam servo motor, to cause the release actuator to move to a release position, as block **1668** indicates, to release the fixed-wing aircraft into free flight.

[0364] These are merely three example conditions, and any quantity of suitable conditions (such as a subset of at least one of the above three conditions or conditions different from the above three conditions) may be employed. In some embodiments, the controller monitors whether the barometric pressure measured by the barometer exceeds a designated barometric pressure (instead or in addition to monitoring the height of the multicopter above the ground). In other embodiments, the controller measures the GPS connectivity of the fixed-wing aircraft, and doesn't enable release unless the fixed-wing aircraft has GPS connectivity.

[0365] In this example embodiment, the lock servo motor arm must also be moved into the cam rotation-enabling rotational position before the fixed-wing aircraft can be released into free flight. The multicopter therefore includes software-based and hardware-based failsafes to ensure the fixed-wing aircraft is released only when conditions for a successful release exist and the operator desires release. In certain embodiments, the controller doesn't enable the lock servo motor arm to move to the cam rotation-enabling rotational position until one or more of the above conditions are met. These conditions may be the same as or different from the condition(s) that must be met to enable fixed-wing aircraft release.

[0366] More specifically, detaching the fixed-wing aircraft **20** from the cam **350** (and the multicopter **10**) is a two-step process, as shown in FIGS. **10**A to **10**C. To detach the fixed-wing aircraft **20** from the cam **350** (and the multicopter **10**), the operator first remotely controls the lock servo motor **391** (via the R/C controller) to rotate the lock servo motor arm **392** into the cam rotation-enabling rotational position (counter-clockwise from this viewpoint). Second, the operator remotely controls the cam servo motor **381** (via the R/C controller) to rotate the cam **350** from the attached rotational position to the detached rotational position (counter-clockwise from this viewpoint). As shown in the progression from FIGS. **10**B to **10**C, as the cam servo motor **381** rotates the

cam **350** from the attached rotational position to the detached rotational position, the valley **352** and the ascending edge of the ridge **353** forces the hook **21** off of the cam **350**, thereby detaching the fixed-wing aircraft **20** from the cam **350** (and the multicopter **10**).

[0367] After the fixed-wing aircraft **20** detaches from the multicopter **10**, the multicopter **10** reduces its pitch angle (such as from 20 degrees nose down to 0 degrees) to stop dashing and reduce its airspeed before traveling to a desired landing area, described below.

[0368] Certain known multicopters enable abrupt step changes in multicopter pitch angle. That is, the controllers of these known multicopters enable an infinite pitch angle rate of change. This is problematic when one of these multicopters that is dashing with a pitch angle of, for instance, 20 degrees nose down receives a control signal to reduce its pitch angle to 0 degrees to stop dashing. Since this known multicopter enables a step change in the pitch angle, the multicopter controls its front rotor motors to rapidly accelerate (and/or its back rotor motors to rapidly decelerate) to attempt to instantly change the pitch angle to 0 degrees. This rapid acceleration of the front rotor motors (or rapid deceleration of the back rotor motors) coupled with the fast forward airspeed acting on the fast-spinning front rotors leads to significant pitch-up overshoot, which may cause the multicopter to back flip and tumble to the ground.

[0369] The abrupt pitch up problem is exacerbated when these known multicopters dash beyond radio range. When communication with these multicopters is lost, these multicopters automatically transition to RTL flight mode, which causes the desired pitch angle to instantly change from the nose down (dashing) angle to zero or even nose up in a single time step.

[0370] FIG. **13**A is a graph showing the desired multicopter pitch angle over time for an example situation for a prior art multicopter. Here, the desired multicopter pitch angle is the multicopter pitch angle that the prior art multicopter controller attempts to achieve by controlling the rotor motors. In this example, the prior art multicopter is dashing with a pitch angle of 20 degrees nose down when it receives an instruction to stop dashing and achieve a pitch angle of 0 degrees. Since this prior art multicopter enables a step change in the pitch angle, the prior art multicopter controls its front rotor motors to rapidly accelerate (and/or its back rotor motors to rapidly decelerate) to attempt to instantly change the pitch angle to 0 degrees, as shown by the infinite slope in the graph upon receipt of the pitch angle modification input.

[0371] The multicopter **10** of the present disclosure solves this problem by limiting the multicopter pitch angle rate of change to ensure a smooth pitch angle transition over a particular period of time. FIG. **11**G is a flowchart of an example process **1200** for limiting multicopter pitch angle rate of change.

[0372] The process **1200** begins once the rotor motors of the multicopter begin driving the rotors. The controller receives a pitch angle modification input associated with a desired multicopter pitch angle, as block **1202** indicates. In response, the controller sends one or more rotor motor control signals to control the one or more rotor motors to operate to change the multicopter pitch angle to the desired multicopter pitch angle at a rate no greater than a maximum, finite multicopter pitch angle rate of change, as block **1204** indicates. That is, while the multicopter is flying, the con-

troller automatically prevents operation of the rotor motors in such as way as to change the multicopter pitch angle at a rate greater than the maximum pitch angle rate of change.

[0373] FIG. **13**B is a graph showing the desired multicopter pitch angle over time for an example situation for one example of the multicopter of the present disclosure. In this example, the prior art multicopter is dashing with a pitch angle of 20 degrees nose down when it receives an instruction to stop dashing and achieve a pitch angle of 0 degrees. Since the multicopter limits the pitch angle rate of change, the multicopter controls its front rotor motors to accelerate (and/or its back rotor motors to decelerate) to change the pitch angle to 0 degrees over a period Tc (such as but not limited to 1 to 3 seconds) to ensure the pitch angel rate of change is no greater than a finite pitch angle rate of change, as shown by the finite slope in the graph following receipt of the pitch angle modification input.

[0374] In addition to limiting the rate of change of the multicopter pitch angle, the controller is configured to limit the multicopter pitch angle based on the flight mode in which the multicopter **10** is operating. In flight modes in which the multicopter **10** is typically loaded (i.e., in which the fixed-wing aircraft **20** is attached to the multicopter **10**), the controller limits the pitch angle to a relatively shallow pitch angle (such as 20 degrees nose down), since the multicopter **10** travels relatively fast through the air when loaded. But in flight modes in which the multicopter **10** is typically unloaded (i.e., in which the fixed-wing aircraft **20** is not attached to the multicopter **10**), the controller limits the pitch angle to a relatively larger pitch angle (such as 30 degrees nose down), since the multicopter **10** travels relatively slowly through the air when unloaded. The steeper pitch angle enables the unloaded multicopter **10** to fly in strong winds without adversely affecting multicopter performance.

[0375] FIG. **11**H is a flowchart of an example process **1400** for setting the maximum multicopter pitch angle for the multicopter. In various embodiments, instructions stored in the memory **272**b and executed by the processor **272**a of the controller **272** represent the process **1400**.

[0376] The process **1400** begins upon arming the controller **272**, and the controller automatically controls the one or more rotor motors during multicopter operation such that a multicopter pitch angle does not exceed a maximum multicopter pitch angle (which may be stored in the memory), as block **1402** indicates. The controller looks to the selected flight mode to determine the maximum multicopter pitch angle.

[0377] More specifically, the controller receives a signal identifying one of multiple different flight modes, such as upon arming, as block **1404** indicates. Each flight mode is associated with one of multiple different pitch angles. The controller operates the multicopter in the identified flight mode, as block **1406** indicates, and sets the maximum multicopter pitch angle to the pitch angle associated with the identified flight mode, as block **1408** indicates. The controller then monitors for receipt of a flight mode change signal identifying a different flight mode, as diamond **1410** indicates. Responsive to receipt of the flight mode change signal, the process **1400** returns to block **1406**.

[0378] In other embodiments, the multicopter includes a sensor (such as a weight sensor or a position sensor) configured to sense whether the fixed-wing aircraft is attached to the multicopter. In these embodiments, the controller determines the maximum multicopter pitch angle based on whether the fixed-wing aircraft is attached to the multicopter (based on sensor feedback). The maximum multicopter pitch angle is larger when the fixed-wing aircraft is not attached to the multicopter than it is when the fixed-wing aircraft is attached to the multicopter.

[0379] After detachment, the operator may switch the multicopter **10** to partial-power mode and recover the multicopter **10** to a pre-landing location above a desired landing location either manually via ALTHOLD and/or LOITER flight modes or semi-autonomously via RTL flight mode.

[0380] While a manually controlled launch sequence is described above, the controller **272** is also configured to autonomously launch the fixed-wing aircraft with limited operator input. This feature reduces the potential for operator error that may result in failed launches or damage to the multicopter and/or the fixed-wing aircraft.

[0381] FIG. **11**I is a flowchart of an example process **1300** for autonomously launching the fixed-wing aircraft **20** using the multicopter **10**. In various embodiments, instructions stored in the memory **272**b and executed by the processor **272**a of the controller **272** represent the process **1300**.

[0382] The process **1300** begins when the controller receives an autonomous launch signal from the R/C controller or other suitable source, as block **1302** indicates. The controller determines, based at least in part on signals received from one or more sensors (such as the magnetometer or a GPS equivalent), a pre-launch heading of the multicopter, as block **1304** indicates. The controller determines, based at least in part on the pre-launch heading of the multicopter, a launch flight path, as block **1306** indicates. In this example embodiment, the launch flight path shape is predetermined, and the controller orients the launch flight path based on the pre-launch heading of the multicopter. That is, the controller assigns precise GPS coordinates to a general launch flight path shape in accordance with the heading of the multicopter.

[0383] The controller automatically sends one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter to climb to a pre-dash location in accordance with the launch flight path, as block **1308** indicates. Afterwards, the controller automatically sends one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter laterally in accordance with the launch flight path, as block **1310** indicates.

[0384] While the multicopter is flying laterally and after the multicopter reaches a release velocity (or in other embodiments a release position), the controller automatically sends an object release command to an object release device of the multicopter to cause an object to detach from the multicopter, as block **1312** indicates. For instance, the multicopter sends an unlock command to the lock servo motor followed by a release command to the cam servo motor to cause the fixed-wing aircraft to detach from the multicopter into free flight. Afterwards, the controller automatically sends one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter to a pre-landing location in accordance with the launch flight path, as block **1314** indicates. Afterwards, the controller either automatically lands the multicopter or cedes control to the operator, who manually controls the multicopter to land.

[0385] FIG. **14** shows one example launch flight path **6000**. In this example, the multicopter **10** and attached fixed-wing aircraft **20** ascend from launch location A to

pre-dash location B along vector V**1**. In this example, this is a 200 meter ascent at 5 meters/second. The illustrations of the multicopter **10** and the fixed-wing aircraft **20** are highly simplified here for clarity. The illustrated multicopter **10** and fixed-wing aircraft **20** could be replaced with the other embodiments of the multicopter and fixed-wing aircraft shown and described herein. After reaching the pre-dash location B, the multicopter **10** and attached fixed-wing aircraft **20** fly laterally (sometimes called "dash") to release location C along vector V**2**. In this example, the dash is conducted at 20 meters per second and the release point C is about 400 meters from the pre-dash location B. In this example, the multicopter **10** unlocks the locking mechanism that prevents release of the fixed-wing aircraft **20** at 350 meters from pre-dash location B. The multicopter **10** releases the fixed-wing aircraft **20** at release location C and stops dashing upon reaching post-dash location D. In this example, post-dash location D is 500 meters from pre-dash location B. The multicopter **10** conducts a turn from post-dash location D to location E along curve C**3**. In this example, the turn is a 100 meter turn. The multicopter **10** travels laterally while descending to pre-landing location F above landing location G along vector V**4**. In this example, pre-landing location F is 7 meters above landing position G. The multicopter **10** descends to landing location G along vector V**5**. In this example, landing location G is 5 meters from launch location A.

[0386] Regardless of whether the multicopter **10** is manually or autonomously controlled, once the multicopter **10** reaches the pre-landing location, certain conditions must be met before the controller **272** enables the rotor motors to shut down and the multicopter **10** to land on the landing surface.

[0387] Certain known multicopters are configured to shut down their rotor motors only after the multicopters have touched down onto a landing surface. More specifically, these known multicopters are configured to, after receiving a command to land: (1) begin descending; (2) monitor the multicopter's rate of descent; and (3) after the multicopter's rate of descent is below a preset threshold for a designated time period (e.g., after the multicopter has stopped descending for that designated time period), enable the rotor motors to be shut down.

[0388] This type of "has-landed" logic for enabling rotor motor shut down is problematic, especially in windy conditions, because the rotor motors are still driving their corresponding rotors after the multicopter has landed but before the designated time period has expired. Rotor motors operating at even their minimum output generates lift that, while not large enough to cause the multicopter to climb, makes it much easier for wind sweeping across the landing surface to cause the multicopter to begin skating along the landing surface. Strong wind may even cause the multicopter to tumble.

[0389] The multicopter **10** of the present disclosure solves this problem by enabling rotor motor shut down while the multicopter is airborne (when certain conditions are satisfied) rather than waiting for auto-land logic to disarm the multicopter. Since the rotor motors are shut down before touchdown, the rotor motors stop spinning before, during, or shortly after touchdown. The rotors therefore do not generate lift after touchdown, meaning that the multicopter is stable at touchdown and less likely to be affected by wind sweeping along the landing surface

[0390] FIG. **11**J is a flowchart of an example process **1100** for shutting down the rotor motors of a multicopter at touchdown. In various embodiments, instructions stored in the memory **272***b* and executed by the processor **272***a* of the controller **272** represent the process **1100**.

[0391] The process **1100** begins once the rotor motors of the multicopter begin driving the rotors. The controller monitors: (1) a height of the multicopter above a landing surface such as the ground (such as by using barometric pressure measured by the barometer, as described above), as block **1102** indicates; and (2) monitors a throttle level of the multicopter, as block **1104** indicates.

[0392] The controller monitors whether: (1) the height of the multicopter above the landing surface is below a designated height above the landing surface; and (2) the multicopter throttle level is below a designated throttle level, as diamond **1106** indicates. If both conditions are met, the controller enables rotor motor shut down, as block **1108** indicates. If both conditions are not met, the controller ignores any received rotor motor shut down signals, as block **1110** indicates. In one embodiment, the controller determines the height of the multicopter above the landing surface by using the barometric pressure obtained by the barometer, as described above. In another embodiment, the controller monitors whether the barometric pressure measured by the barometer is below a designated barometric pressure, which generally correlates to the designated height above the landing surface. The designated height above the landing surface is selected such that the multicopter will not be damaged via a free fall from that height. The height may be, for instance, 1 to 5 meters or any other suitable height.

[0393] The controller also monitors whether rotor motor shut down is enabled, as diamond **1112** indicates. While rotor motor shut down is enabled, the controller monitors for receipt of a rotor motor shut down signal from the R/C controller or other suitable source, as diamond **1114** indicates. Responsive to receiving the rotor motor shut down signal while rotor motor shut down is enabled, the controller sends one or more rotor motor control signals to shut down the rotor motors, as block **1116** indicates, thereby enabling the multicopter to free fall onto the landing surface as the rotors stop spinning.

[0394] In other embodiments, additional criteria, such as ground speed below a certain threshold, may be added.

[0395] In certain embodiments, the operator may desire to launch the fixed-wing aircraft **20** from a location in which GPS is unavailable (e.g., from the ground in a heavily-wooded or mountainous region). In one such embodiment, the operator may use a GPS repeater to acquire a GPS fix for the fixed-wing aircraft and/or the multicopter during pre-flight. In this case, the GPS repeater might have a GPS receiving antennae on the roof of a building, on a hilltop, or flying in an aircraft, while pre-flight is happening in the GPS-denied location. The GPS-denied location may be a lower floor in the same building as the one that has the GPS receiver on the roof. In this case, the operator may decide to seal-off the preflight area (i.e., close the garage door) to avoid multipath GPS jamming. After preflight is completed, the repeater may be switched off and the seal breached to allow the aircraft to exit the preflight area and begin attempts to acquire GPS directly. Once launched, the fixed-wing aircraft **20** will acquire that GPS satellite constellation once able to do so (such as when the multicopter **10** and attached fixed-wing aircraft **20** climb high enough to acquire GPS).

This process is shortened, as the GPS receiver enjoys familiarity with the prevailing satellite constellation.

[0396] In other embodiments in which the operator desires to launch the fixed-wing aircraft **20** from a location in which GPS is unavailable, rather than using a GPS repeater to acquire and pre-load a desired GPS satellite constellation to the fixed-wing aircraft **20**, the operator simply climbs the multicopter **10** and attached fixed-wing aircraft **20** high enough to acquire GPS. At that point, the fixed-wing aircraft **20** acquires the desired GPS satellite constellation, and launch proceeds as described above. The operator can abort launch should the fixed-wing aircraft **20** not be able to acquire GPS. This offers a unique advantage over traditional (ground-based) launch systems that cannot operate from GPS-denied locations, as the fixed-wing aircraft owner would not accept the risk that GPS would be acquired (on faith) during the first few moments of flight.

[0397] In certain embodiments, the R/C controller operates as a state machine to ensure that the flight mode status is not lost or changed when communication between the R/C controller and the communications interface **274** of the multicopter **10** is interrupted. Certain known multicopters are configured to wirelessly communicate with R/C controllers (or any other type of controller), which send control signals input by an operator to the autopilot of the multicopter, which in turn controls operation of the multicopter (and specifically, the rotor motors) based on the control signals. Known R/C controllers include a mechanical flight mode selection switch that is movable between multiple positions. Each position is associated with a different one of multiple different flight modes. The position of the flight mode selection switch determines the desired flight mode, and the R/C controller signals the multicopter to operate in that desired flight mode.

[0398] One problem with this mechanical flight mode selection switch is that an operator can accidentally jostle the switch (e.g., by dropping the R/C controller or hitting it against something) and move it to a different position, which causes the R/C controller to signal the multicopter to switch to an undesired flight mode. Another problem is that certain remote control hardware assemblies are not available with multi-position maintain switches, only pushbuttons.

[0399] The R/C controller of the present disclosure solves this problem by eliminating the mechanical flight mode selection switch in favor of multiple distinct pushbuttons, each of which is associated with a different one of multiple flight modes. The R/C controller also operates as a state machine to "remember" the selected flight mode when the R/C controller loses communication with the multicopter **10**, which enables the R/C controller to automatically resume that same flight mode when it reestablishes communication with the multicopter **10**.

[0400] FIG. **11K** is a flowchart of an example process **1250** for establishing communication between an R/C controller and a multicopter. In various embodiments, instructions stored in an R/C controller memory and executed by an R/C controller processor represent the process **1250**.

[0401] The process **1250** begins and the R/C controller establishes wireless communications with the multicopter, as block **1252** indicates. The R/C controller receives an input—such as actuation of a pushbutton—that identifies one of multiple different multicopter flight modes, as block **1254** indicates. The R/C controller stores, in an R/C controller memory, current multicopter flight mode data that

represents the identified multicopter flight mode, as block **1256** indicates. The R/C controller sends the multicopter a command to operate in the identified multicopter flight mode, as block **1258** indicates.

[0402] The R/C controller then monitors to determine whether it has lost communications with the multicopter, as diamond **1260** indicates. Responsive to determining that it has lost communications with the multicopter, the R/C controller automatically attempts to reestablish communications with the multicopter, as block **1262** indicates. The R/C controller determines whether it has successfully reestablished communications with the multicopter, as diamond **1264** indicates. If not, the process **1250** returns to block **1262**.

[0403] Once the R/C controller has reestablished communications with the multicopter, the R/C controller automatically accesses the current multicopter flight mode data in the memory, as block **1266** indicates. The R/C controller then automatically sends the multicopter a command to operate in the multicopter flight mode represented by the current multicopter flight mode data, as block **1268** indicates.

[0404] The R/C controller of the present disclosure solves the problems with prior art mechanical flight mode selection switches by providing dedicated pushbutton flight mode selectors that reduce the potential to accidentally switch the flight mode. The fact that the R/C controller is a state machine enables quick and easy automatic flight mode resumption following a loss and reestablishment of communications with the multicopter.

[0405] 4.2 Multicopter-Assisted Fixed-Wing Aircraft Retrieval Method

[0406] To retrieve the fixed-wing aircraft **20** from wing-borne flight, the operator positions the anchor system **3000** at a desired retrieval location. The operator attaches the free end of the flexible capture member **5000** (which is the free end of the elastic portion **5100** in this embodiment) to the cam **350** of the multicopter **10**. The other end of the flexible capture member **5000** is attached to the flexible capture member payout and retract device **3300**. A length of the flexible capture member **5000** (particularly, the retractable portion **5300**) is fed through the fairlead **3812** and wound around the drum **3312**.

[0407] As best shown in FIGS. **10D**, **10E**, **10F**, and **10G**, the operator fixedly attaches (e.g., by knotting) a breakaway ring **3250** to the flexible capture member **5000** at a particular point (such as 200 feet or any other suitable distance from upper end of the flexible capture member **5000**). The operator attaches the breakaway ring **3250** to the breakaway device **3200** as follows: (1) the operator removes the breakaway sleeve **3220** from the collar **3214**; (2) the operator rotates the finger **3228** outside of the interior of the breakaway sleeve **3220**; (3) the operator slides the breakaway ring **3250** onto the finger **3228**; (4) the operator rotates the finger **3228** back inside the interior of the breakaway sleeve **3220**; and (5) the operator attaches the breakaway sleeve **3220** to the collar **3214** to trap the finger **3228** within, thereby retaining the breakaway ring **3250** on the finger **3228**.

[0408] The operator closes the idle power circuit of the multicopter **10** to perform various preflight checks, as described above, and then closes the main power circuit to power the rotor motors. The operator then arms the controller **272**, as described above. At this point, as described in more detail below, the multicopter **10** is manually or autonomously controlled (or a combination of both) to capture the

fixed-wing aircraft **20** from free flight and land the fixed-wing aircraft and the multicopter **10** according to the following general steps: (1) flying the multicopter **10** to a retrieval location a particular distance above the anchor system **3300**; (2) station keeping the multicopter **10** relative to the anchor system **3300** until the fixed-wing aircraft **20** captures the flexible capture member **5000**; (3) descending the multicopter **10** until the fixed-wing aircraft **20** contacts a fixed-wing aircraft landing surface; (4) flying the multicopter **10** to a multicopter pre-landing location a particular distance above a landing location; and (5) descending the multicopter **10** to the landing location.

[0409] In one example, the operator selects the LOITER or ALTHOLD flight mode and TENSION throttle mode for the multicopter **10**. The operator ensures the GPS receiver **3810** of the anchor system **3300** has acquired sufficient GPS satellites to enable the fixed-wing aircraft **20** to locate the anchor system **3300** with an acceptable level of uncertainty.

[0410] As the fixed-wing aircraft approaches the anchor system **3300**, the operator remotely controls the multicopter **10** to climb to a designated altitude above the anchor system **300** and maintain a particular tension (such as 20 pounds) in the portion of the flexible capture member **5000** extending between the multicopter **10** and the breakaway ring **3250**. This tension is less than the force required to compress the compression spring **3216** of the breakaway device **3200** (about 100 to 150 pounds in this example embodiment). The multicopter **10** station keeps relative to the anchor system **3300** while above the anchor system **3300**. Above in this context, unless described otherwise, means vertically spaced apart from.

[0411] As shown in FIG. **10**H, the fixed-wing aircraft **20** is flown toward, contacts, and captures part of the capture portion **5000**b of the flexible capture member **5000** in a manner similar to that described in U.S. Pat. No. 6,264,140, the entire contents of which are incorporated herein by reference. Specifically, the fixed-wing aircraft **20** is flown toward the capture portion **5200** of the flexible capture member **5000** such that the leading edge of one of the wings of the fixed-wing aircraft **20** contacts the capture portion **5200**. After the leading edge of the wing contacts the capture portion **5200**, continued movement of the fixed-wing aircraft **20** relative to the capture portion **5200** causes the capture portion **5200** to slide away from the fuselage of the fixed-wing aircraft **20** along the leading edge of the wing toward the end of the wing until a tether capture device (not shown) near the end of the wing captures part of the capture portion **5200**.

[0412] When the fixed-wing aircraft **20** contacts the flexible capture member **5000**, the operator advances the throttle of the multicopter **10** to maximum for a predetermined period of time (such as 3 seconds), then slowly reduces the throttle to arrest motion and allow the fixed-wing aircraft to controllably descend.

[0413] FIGS. **10**E, **10**F, and **10**G show the breakaway device **3300** releasing the breakaway ring **3250** during capture, thereby enabling the anchor system **3000** to begin paying out the retractable portion **5300** of the flexible capture member **5000** wound around the drum **312** of the flexible capture member payout and retract device **3300** to absorb the kinetic energy of and slow the fixed-wing aircraft **20**.

[0414] FIG. **10**E shows the breakaway device **3300** before capture. The fixed-wing aircraft **20** contacting the flexible

capture member **5000** tensions the flexible capture member **5000**. Since the flexible capture member **5000** is attached to the breakaway sleeve **3220** via the breakaway ring **3250** this tension imposes a lifting force on the breakaway sleeve **3220** and the collar **3214** to which the breakaway sleeve **3220** is attached. As best shown in FIG. **10**F, if this lifting force is large enough to overcome the biasing force of the compression spring **3216**, this lifting force causes the collar **3214** to slide upward relative to the shaft **3210** and compress the compression spring **3216**. As best shown in FIGS. **10**F and **10**G, once the compression spring **3216** is compressed a designated amount, the finger **3228** is free to escape the breakaway sleeve **3220** through the finger escape slot **3226**. At this point, the tension in the flexible capture member **5000** causes the finger **3228** to rotate out of the breakaway sleeve **3220**, thereby releasing the breakaway ring **3250**.

[0415] Once the breakaway device **3200** releases the breakaway ring **3250**, continued motion of the fixed-wing aircraft **20** causes the flexible capture member payout and retract device **3300** to begin paying out the retractable portion **5300** of the flexible capture member **5000**, initially wound around the drum **3312**. As the flexible capture member payout and retract device **3300** pays out the retractable portion **5300** of the flexible capture member **5000**, the flexible capture member payout and retract device **3300** dampens this payout—and absorbs the kinetic energy of the fixed-wing aircraft **20**—in two ways: (1) the biasing element within the drum **3312** biasing the drum **3312** to its initial rotational position and against the rotation that results in payout of the flexible capture member (described above); and (2) eddy current braking (described below).

[0416] As indicated above, the electrically-conductive flanges **3314** and **3316** of the flexible capture member payout and retract device **3300** enable eddy currents to flow as the flanges move in the vicinity of the magnets attracted to the backing plates attached to the anchor system base **3100** to which the flexible capture member payout and retract device **3300** is attached. As the flanges **3314** and **3316** rotate with the drum **3312** relative to the anchor system base **3100**—such as while the flexible capture member payout and retract device **3300** pays out the flexible capture member **5000** during retrieval of the fixed-wing aircraft **20**—the flanges **3314** and **3316** move past the stationary magnets. This induces eddy currents to flow, and the resulting drag force tends to oppose rotation of the drum **3312**. The eddy current drag force increases with increasing speed and therefore the payout speed is limited.

[0417] The fixed-wing aircraft **20** eventually stops moving and dangles below the multicopter **10**, as best shown in FIG. **10**I. At this point, the biasing element within the drum **3312** biases the drum **3312** to reverse spin direction, which retracts the retractable portion **5300** of the flexible capture member back into the anchor system **3300**. Specifically, this causes the retractable portion **5300** of the flexible capture member to wind back onto the drum **3312**. In some embodiments, the flexible capture member payout and retract device is configured to retract only part of the flexible capture member—such as the retractable portion—while in other embodiments the flexible capture member payout and retract device is configured to retract all or substantially all of the flexible capture member. The flexible capture member payout and retract device in certain embodiments includes a motor-driven payout spool (such as a spool used for fishing

or parasailing), a capstan winch (such as those used for anchoring a yacht) a clothes wringer, or a stuff sack, such as those used in sport climbing.

[0418] Once the tether capture device of the fixed-wing aircraft **20** captures the part of the capture portion **5200**, the tether capture device holds that part of the capture portion **5200** such that the fixed-wing aircraft **20** does not slide down the flexible capture member **5000**. If, however, the tether capture device does not initially prevent the fixed-wing aircraft from sliding down the flexible capture member **5000** and the fixed-wing aircraft **20** begins sliding, the increasing thickness of the capture portion **5200** will eventually arrest this sliding. In other embodiments, rather than (or in addition to) being thicker at its ends than in its middle, the capture portion **5200** is knotted along its length (such as every few feet) to prevent the fixed-wing aircraft **20** from sliding down the capture portion **5200** after capture.

[0419] After capture, the operator may engage NORMAL throttle mode to improve control of his descent rate as the flexible capture member **5000** slackens and the fixed-wing aircraft **20** is lowered to the landing surface. Thereafter, the operator may engage the partial-power mode and control the multicopter **10** to descend until it reaches ground, at which point the operator shuts down the rotor motors.

[0420] While a manually controlled retrieval sequence is described above, the controller **272** may also be configured to autonomously retrieve the fixed-wing aircraft with limited operator input. This feature reduces the potential for operator error that may result in failed retrieval or damage to the multicopter and/or the fixed-wing aircraft.

[0421] FIG. 11L is a flowchart of an example process **1350** for autonomously retrieving the fixed-wing aircraft **20** using the multicopter **10**. In various embodiments, instructions stored in the memory **272***b* and executed by the processor **272***a* of the controller **272** represent the process **1350**.

[0422] The process **1300** begins when the controller receives an autonomous retrieval signal from the R/C controller, as block **1352** indicates. The controller determines, based on GPS coordinates of the anchor assembly (described above), a retrieval location that is a designated height above the anchor assembly, and automatically sends one or more rotor motor control signals to control the one or more rotor motors to fly the multicopter to the retrieval location, as block **1354** indicates. After the multicopter reaches the retrieval location, the controller automatically sends one or more rotor motor control signals to control the one or more rotor motors to station-keep the multicopter relative to the anchor system, as block **1356** indicates. For fixed base operations, this station keeping coincides with a fixed set of GPS coordinates. But for moving base operations (e.g., when the anchor assembly is on a ship at sea), station keeping over the anchor assembly is achieved by tracking the movement of the anchor assembly and maintaining a position over it.

[0423] After the fixed-wing aircraft captures the flexible capture member attached to and extending below the multicopter, the controller (either automatically or in response to operator input) sends one or more rotor motor control signals to one or more of the rotor motors of the multicopter to control the one or more rotors to descend the multicopter at a first rate of descent, as block **1358** indicates. After the height of the fixed-wing aircraft relative to a fixed-wing aircraft landing surface reaches a first height, the controller automatically sends one or more rotor motor control signals

to the one or more rotor motors to control the one or more rotors to descend the multicopter at a second rate of descent that is less than the first rate of descent, as block **1360** indicates. In other words, the controller decreases the multicopter's rate of descent as the fixed-wing aircraft approaches its landing surface. The first height may be determined based on a target capture height of the fixed-wing aircraft. For instance, if the multicopter station keeps at 200 feet above the landing surface and the fixed-wing aircraft is controlled to capture the flexible capture member 100 feet above the landing surface, the controller determines the first height based on the fact that the flexible capture fixed wing aircraft must descend 100 feet before contacting the landing surface.

[0424] After the fixed-wing aircraft contacts the fixed-wing aircraft landing surface, the controller (automatically or in response to operator input) sends one or more rotor motor control signals to the one or more rotor motors to control the one or more rotor motors to descend the multicopter at a third rate of descent that is greater than the second rate of descent, as block **1362** indicates. That is, the controller increases the multicopter's rate of descent after the fixed-wing aircraft has safely landed. After the height of the multicopter above a multicopter landing surface reaches a second height, the controller automatically sends one or more rotor motor control signals to the one or more rotor motors to control the one or more rotor motors to descent the multicopter at a fourth rate of descent that is less than the third rate of descent, as block **1364** indicates. That is, the controller decreases the multicopter's rate of descent as the multicopter approaches its landing surface. In certain embodiments, the first and third rates are the same and the second and fourth rates are the same.

[0425] In other embodiments, rather than make the above determinations based on the multicopter's height, the controller does so indirectly based on the barometric pressure sensed by the barometer, as described above.

[0426] In certain embodiments, the operator desires to retrieve the fixed-wing aircraft **20** from a location in which GPS is unavailable. In these embodiments, the operator attaches the GPS receiver **3810**—normally attached to the anchor system **3000**—to the multicopter **10**. This enables the GPS receiver **3810** to acquire GPS once the multicopter **10** climbs to the desired altitude for retrieval.

5. Methods of Operation and Apparatus Summarization

[0427] 5.1 Partial-Power Mode Method of Operation and Apparatus

[0428] It should be appreciated from the above that various embodiments of the present disclosure includes a method for operating a multicopter in a partial-power mode, the method comprising: receiving a partial-power mode signal; and responsive to receipt of the partial-power mode signal, for each rotor motor of a first set of rotor motors of the multicopter, controlling, by a controller, that rotor motor to operate at no more than a designated rotor motor output, wherein the designated rotor motor output is less than an output of each rotor motor of a second set of rotor motors of the multicopter. In various such embodiments, the multicopter includes multiple upper rotor motors and multiple lower rotor motors, and wherein the first set of rotor motors includes each upper rotor motor of the multicopter and the second set of rotor motors includes each lower rotor motor of the multicopter. In various such embodiments, the mul-

ticopter includes multiple arms and each arm includes one of the upper rotor motors and one of the lower rotor motors. In various such embodiments, the designated output is a minimum rotor motor output. In various such embodiments, the designated output is zero output. In various such embodiments, the multicopter includes multiple upper rotor motors and multiple lower rotor motors, and wherein the first set of rotor motors includes each upper rotor motor of the multicopter and the second set of rotor motors includes each lower rotor motor of the multicopter. In various such embodiments, the method includes receiving the partial-power mode signal via a communications interface. In various such embodiments, the designated rotor motor output includes a designated rotor motor rotational speed. In various such embodiments, the designated rotor motor rotational speed is a minimum rotor motor rotational speed. In various such embodiments, the method includes, responsive to receipt of the partial-power mode signal, not modifying, by the controller, output of the rotor motors of the second set of rotor motors.

[0429] It should be appreciated from the above that various embodiments of the present disclosure include a multicopter comprising: multiple arms; a first set of multiple rotor motors, each rotor motor of the first set of rotor motors attached to a different one of the arms; a second set of multiple rotor motors, each rotor motor of the second set of rotor motors attached to a different one of the arms; and a controller configured to, responsive to receipt of a partial-power mode signal, for each rotor motor of the first set of rotor motors, control that rotor motor to operate at no more than a designated rotor motor output, wherein the designated rotor motor output is less than an output of each rotor motor of the second set of rotor motors. In various such embodiments, the multicopter includes multiple upper rotor motors and multiple lower rotor motors, and wherein the first set of rotor motors includes each upper rotor motor of the multicopter and the second set of rotor motors includes each lower rotor motor of the multicopter. In various such embodiments, the designated output is a minimum rotor motor output. In various such embodiments, the designated output is zero output. In various such embodiments, the multicopter includes multiple upper rotor motors and multiple lower rotor motors, and wherein the first set of rotor motors includes each upper rotor motor of the multicopter and the second set of rotor motors includes each lower rotor motor of the multicopter. In various such embodiments, the multicopter includes a communications interface communicatively connectable to a device to receive the partial-power mode signal. In various such embodiments, the designated rotor motor output includes a designated rotor motor rotational speed. In various such embodiments, the designated rotor motor rotational speed is a minimum rotor motor rotational speed. In various such embodiments, the controller is configured, responsive to receipt of the partial-power mode signal, not modify output of the rotor motors of the second set of rotor motors.

[0430] 5.2 Arming without Yaw Input Method of Operation and Apparatus

[0431] It should be appreciated from the above that various embodiments of the present disclosure includes a method for arming a controller of a rotorcraft, the method comprising: receiving, by a communications interface, an arm signal that is decoupled from any rotorcraft yaw control signal; and responsive to receipt of the arm signal, arming,

by the controller, itself without intentionally inducing rotorcraft yaw movement. In various such embodiments, the rotorcraft includes multiple rotor motors, and which includes, after arming the controller, controlling, by the controller, the rotor motors to operate at a designated rotor motor output. In various such embodiments, the method includes controlling, by the controller, the rotor motors to operate at the designated rotor motor output for a designated period. In various such embodiments, the rotorcraft includes a first set of rotor motors and a second set of rotor motors, and the method includes, if the controller was armed in a partial-power mode, after expiration of the designated period, for each rotor motor of the first set of rotor motors, controlling, by the controller, that rotor motor to operate at no more than a designated rotor motor output, wherein the designated rotor motor output is less than an output of each rotor motor of the second set of rotor motors. In various such embodiments, the rotorcraft includes multiple upper rotor motors and multiple lower rotor motors, and wherein the first set of rotor motors includes each upper rotor motor of the rotorcraft and the second set of rotor motors includes each lower rotor motor of the rotorcraft. In various such embodiments, the rotorcraft includes multiple arms and each arm includes one of the upper rotor motors and one of the lower rotor motors. In various such embodiments, the designated output is a minimum rotor motor output. In various such embodiments, the rotorcraft includes multiple upper rotor motors and multiple lower rotor motors, and wherein the first set of rotor motors includes each upper rotor motor of the rotorcraft and the second set of rotor motors includes each lower rotor motor of the rotorcraft.

[0432] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a communications interface configured to receive to receive an arm signal from a remote device, wherein the arm signal is decoupled from any rotorcraft yaw control signal; and a controller configured to arm responsive to receipt of the arm signal without intentionally inducing rotorcraft yaw movement. In various such embodiments, the rotorcraft includes multiple rotor motors, and wherein the controller is configured to, after arming, control the rotor motors to operate at a designated rotor motor output. In various such embodiments, the controller is configured to control the rotor motors to operate at the designated rotor motor output for a designated period. In various such embodiments, the rotorcraft includes a first set of rotor motors and a second set of rotor motors, and wherein the controller is configured to, if armed in a partial-power mode, after expiration of the designated period, for each rotor motor of the first set of rotor motors, control that rotor motor to operate at no more than a designated rotor motor output, wherein the designated rotor motor output is less than an output of each rotor motor of the second set of rotor motors. In various such embodiments, the rotorcraft includes multiple upper rotor motors and multiple lower rotor motors, and wherein the first set of rotor motors includes each upper rotor motor of the rotorcraft and the second set of rotor motors includes each lower rotor motor of the rotorcraft. In various such embodiments, the rotorcraft includes multiple arms and each arm includes one of the upper rotor motors and one of the lower rotor motors. In various such embodiments, the designated output is a minimum rotor motor output. In various such embodiments, the rotorcraft includes multiple upper rotor motors and multiple lower rotor motors,

and wherein the first set of rotor motors includes each upper rotor motor of the rotorcraft and the second set of rotor motors includes each lower rotor motor of the rotorcraft.

[0433] 5.3 Rotor Motor Stall Detection Method of Operation and Apparatus

[0434] It should be appreciated from the above that various embodiments of the present disclosure include method for detecting a rotor motor stall before rotorcraft launch, the method comprising: (1) for a designated period after sending a signal commanding a rotor motor to operate, receiving, by a controller and from a rotational speed sensor, a measured rotational speed of the rotor motor; and (2) if the measured rotational speed of the rotor motor is below a threshold rotational speed upon expiration of the designated period, controlling, by the controller, the rotor motor to shut down. In various such embodiments, the rotorcraft includes multiple rotor motors, and which includes performing (1) and (2) for each of the rotor motors. In various such embodiments, the method includes, if the measured rotational speed of any one of the rotor motors is below the threshold rotational speed upon expiration of the designated period, controlling, by the controller, all of the rotor motors to shut down. In various such embodiments, the method includes periodically receiving, by the controller and from the rotational speed sensor, the measured rotational speed of the rotor motor. In various such embodiments, the designated period includes a period of time.

[0435] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a rotor motor; a rotational speed sensor operatively connected to the rotor motor to measure a rotational speed of the rotor motor; and a controller configured to: (1) for a designated period after sending a signal commanding the rotor motor to operate, receive, from the rotational speed sensor, the measured rotational speed of the rotor motor; and (2) if the measured rotational speed of the rotor motor is below a threshold rotational speed upon expiration of the designated period, control the rotor motor to shut down. In various such embodiments, the rotorcraft includes multiple rotor motors, and wherein the controller is configured to perform (1) and (2) for each of the rotor motors. In various such embodiments, if the measured rotational speed of any one of the rotor motors is below the threshold rotational speed upon expiration of the designated period, the controller is configured to control all of the rotor motors to shut down. In various such embodiments, the rotational speed sensor is configured to periodically send the measured rotational speed of the rotor motor to the controller. In various such embodiments, the designated period includes a period of time.

[0436] It should be appreciated from the above that various embodiments of the present disclosure includes a method for detecting a rotor motor stall before rotorcraft launch, the method comprising: (1) for a designated period after sending a signal commanding a rotor motor to operate, monitoring, by a controller, a back electromotive force generated by the rotor motor; and (2) if the back electromotive force generated by the rotor motor is below a threshold back electromotive force rotational speed upon expiration of the designated period, controlling, by the controller, the rotor motor to shut down. In various such embodiments, the rotorcraft includes multiple rotor motors, and the method includes performing (1) and (2) for each of the rotor motors. In various such embodiments, the method

includes, if the back electromotive force of any one of the rotor motors is below the threshold back electromotive force upon expiration of the designated period, controlling, by the controller, all of the rotor motors to shut down. In various such embodiments, the method includes periodically monitoring, by the controller, the back electromotive force generated by the rotor motor. In various such embodiments, the designated period includes a period of time.

[0437] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a rotor motor; and a controller configured to: (1) for a designated period after sending a signal commanding the rotor motor to operate, monitor a back electromotive force generated by the rotor motor; and (2) if the back electromotive force generated by the rotor motor is below a threshold back electromotive force upon expiration of the designated period, control the rotor motor to shut down. In various such embodiments, the rotorcraft includes multiple rotor motors, and wherein the controller is configured to perform (1) and (2) for each of the rotor motors. In various such embodiments, if the back electromotive force of any one of the rotor motors is below the threshold back electromotive force upon expiration of the designated period, the controller is configured to control all of the rotor motors to shut down. In various such embodiments, the controller is configured to periodically monitor the back electromotive force generated by the rotor motor. In various such embodiments, the designated period includes a period of time.

[0438] 5.4 Setting Maximum Rotor Motor Output Method of Operation and Apparatus

[0439] It should be appreciated from the above that various embodiments of the present disclosure includes a method for setting a maximum output of a rotor motor of a rotorcraft, the method comprising: (1) measuring, by a barometer, a barometric pressure; (2) determining, by a controller, whether the measured barometric pressure is above a threshold barometric pressure; (3) setting, by the controller, the maximum output based on whether the measured barometric pressure is above the threshold barometric pressure; and (4) limiting, by the controller, an output of the rotor motor to the maximum output. In various such embodiments, the method includes: if the measured barometric pressure is below the threshold barometric pressure, setting, by the controller, the maximum output to a first rotor motor output; and if the measured barometric pressure is above the threshold barometric pressure, setting, by the controller, the maximum output to a second rotor output that is different from the first rotor motor output. In various such embodiments, the second rotor motor output is greater than the first rotor motor output. In various such embodiments, the method includes, if the measured barometric pressure is equal to the threshold barometric pressure, setting, by the controller, the maximum output to the second rotor output. In various such embodiments, the method includes setting, by the controller, the maximum output based on whether the measured barometric pressure is above the threshold barometric pressure responsive to the controller arming itself. In various such embodiments, the method includes repeating (2) to (3) at least once. In various such embodiments, the method includes setting the maximum output includes storing, in a memory, data representing the maximum output.

[0440] It should be appreciated from the above that various embodiments of the present disclosure include a rotor-

craft comprising: a barometer configured to measure barometric pressure; a rotor motor; and a controller configured to: (1) determine whether the measured barometric pressure is above a threshold barometric pressure; (2) set a maximum output of the rotor motor based on whether the measured barometric pressure is above the threshold barometric pressure; and (3) limit an output of the rotor motor to the maximum output. In various such embodiments, the controller is configured to: if the measured barometric pressure is below the threshold barometric pressure, set the maximum output to a first rotor motor output; and if the measured barometric pressure is above the threshold barometric pressure, set the maximum output to a second rotor output that is different from the first rotor motor output. In various such embodiments, the second rotor motor output is greater than the first rotor motor output. In various such embodiments, the controller is configured to, if the measured barometric pressure is equal to the threshold barometric pressure, set the maximum output to the second rotor output. In various such embodiments, the controller is configured to set the maximum output based on whether the measured barometric pressure is above the threshold barometric pressure responsive to the controller arming itself. In various such embodiments, the controller is configured to repeat (1) to (2) at least once. In various such embodiments, the rotorcraft includes a memory, and wherein the controller is configured to set the maximum output by storing data representing the maximum output in the memory.

[0441] 5.5 No Yaw Control Method of Operation and Apparatus

[0442] It should be appreciated from the above that various embodiments of the present disclosure includes a method for controlling an airborne rotorcraft, the method comprising: controlling by a controller a first feedback loop about a longitudinal roll axis of the airborne rotorcraft and controlling by the controller a second feedback loop about a horizontal pitch axis of the airborne rotorcraft, without controlling a vertical yaw axis of the airborne rotorcraft. In various such embodiments, the yaw control of the airborne rotorcraft is provided by one or more fins of the rotorcraft. In various such embodiments, one of the fins of the rotorcraft aligns airflow with the longitudinal axis of a fixed-wing aircraft during a launch phase of the fixed-winged aircraft flight. In various such embodiments, the yaw control of the airborne rotorcraft is provided by manual input from a joystick. In certain circumstances, the autopilot maintains no heading preference so, to perform a launch with a slight tailwind, it is sometimes necessary for the manual pilot to provide yaw input to orient the airborne aircraft, and then to dash in the direction the nose is pointed.

[0443] It should be appreciated from the above that various embodiments of the present disclosure includes a method for controlling an airborne rotorcraft, the method comprising: measuring, by a roll angle sensor, a roll angle of the rotorcraft; measuring, by a pitch angle sensor, a pitch angle of the rotorcraft; monitoring, by a controller, the measured roll angle; monitoring, by the controller, the measured pitch angle; responsive to the measured roll angle differing from a target roll angle by at least a first designated amount, controlling, by the controller, one or more rotor motors of the rotorcraft to operate to eliminate the difference between the measured roll angle and the target roll angle; responsive to the measured pitch angle differing from a target pitch angle by at least a second designated amount,

controlling, by the controller, the one or more rotor motors to operate to eliminate the difference between the measured pitch angle and the target pitch angle; and enabling, by the controller, the rotorcraft to self-orient about its yaw axis in flight. In various embodiments, the method includes measuring, by a yaw angle sensor, the yaw angle of the rotorcraft.

[0444] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a roll angle sensor configured to measure a roll angle of the rotorcraft; a pitch angle sensor configured to measure a pitch angle of the rotorcraft; one or more rotor motors; and a controller configured to: monitor the measured roll angle and responsive to the measured roll angle differing from a target roll angle by at least a first amount, control the one or more rotor motors to operate to eliminate a difference between the measured roll angle and the target roll angle; monitor the measured pitch angle and responsive to the measured pitch angle differing from a target pitch angle by at least a second amount, control the one or more rotor motors to operate to eliminate a difference between the measured pitch angle and the target pitch angle; and enable the rotorcraft to self-orient about its yaw axis in flight. In various embodiments, the rotorcraft includes a yaw angle sensor configured to measure a yaw angle of the rotorcraft.

[0445] 5.6 Conditioned Fixed-Wing Aircraft Release Method of Operation and Apparatus

[0446] It should be appreciated from the above that various embodiments of the present disclosure includes a method for controlling a rotorcraft, the method comprising: monitoring, by a controller, for satisfaction of a release condition; enabling, by the controller, an actuator of the rotorcraft to move to a release position to when the release condition is satisfied; and responsive to receipt of a release signal while movement of the actuator to the release position is enabled, controlling, by the controller, the actuator to move to the release position. In various embodiments, the method includes not enabling, by the controller, the actuator to move to the release position when the release condition is not satisfied. In various embodiments, the method includes, responsive to receipt of the release signal while movement of the actuator to the release position is not enabled, not controlling, by the controller, the actuator to move to the release position. In various embodiments, the release condition is at least partially satisfied when a pitch angle of the rotorcraft is within a designated pitch angle range. In various embodiments, the method includes measuring, by a pitch angle sensor, the pitch angle of the rotorcraft. In various embodiments, the rotorcraft includes a global-positioning system receiver, and wherein the release condition is at least partially satisfied when the global-positioning system receiver has established global-positioning system connectivity. In various embodiments, the release condition is at least partially satisfied when a height of the rotorcraft above ground is greater than a designated height. In various embodiments, the method includes determining, by the controller, the height of the rotorcraft above ground.

[0447] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a communications interface configured to receive a release signal; an actuator movable between an attach position and a release position; and a controller configured to: monitor for satisfaction of a release condition; enable the actuator to move from the attach position to the

release position when the release condition is satisfied; and responsive to receipt, by the communications interface, of the release signal while movement of the actuator to the release position is enabled, control the actuator to move to the release position. In various embodiments, the controller is configured to not enable the actuator to move to the release position when the release condition is not satisfied. In various embodiments, the controller is configured to, responsive to receipt, by the communications interface, of the release signal while movement of the actuator to the release position is not enabled, not control the actuator to move to the release position. In various embodiments, the release condition is at least partially satisfied when a pitch angle of the rotorcraft is within a designated pitch angle range. In various embodiments, the rotorcraft includes a pitch angle sensor configured to measure the pitch angle of the rotorcraft. In various embodiments, the rotorcraft includes a global-positioning system receiver, and wherein the release condition is at least partially satisfied when the GPS receiver has established global-positioning system connectivity. In various embodiments, the release condition is at least partially satisfied when a height of the rotorcraft above ground is greater than a designated height. In various embodiments, the controller is configured to determine the height of the rotorcraft above ground.

[0448] 5.7 Limiting Rotorcraft Pitch Angle Rate of Change Method of Operation and Apparatus

[0449] It should be appreciated from the above that various embodiments of the present disclosure includes a method for limiting a pitch angle of a rotorcraft, the method comprising: receiving, by a communications interface, a signal associated with a desired pitch angle that differs from a current pitch angle of the rotorcraft; and controlling, by the controller, one or more rotor motors of the rotorcraft to operate to change the current pitch angle to the desired pitch angle at a rate no greater than a maximum, finite pitch angle rate of change.

[0450] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a communications interface configured to receive a signal associated with a desired pitch angle that differs from a current pitch angle of the rotorcraft; one or more rotor motors; and a controller configured to, responsive to receipt of the signal, control the one or more rotor motors to operate to change the current pitch angle to the desired pitch angle at a rate no greater than a maximum, finite pitch angle rate of change.

[0451] 5.8 Setting Maximum Rotorcraft Pitch Angle Method of Operation and Apparatus

[0452] It should be appreciated from the above that various embodiments of the present disclosure includes a method for setting a maximum pitch angle of a rotorcraft, the method comprising: receiving, by a communications interface, a signal associated with a desired one of multiple different flight modes, each flight mode associated with one of multiple different pitch angles; operating, by the controller, the rotorcraft in accordance with the desired flight mode; setting, by the controller, the maximum pitch angle of the rotorcraft to the pitch angle associated with the desired flight mode; and controlling, by the controller, one or more rotor motors of the rotorcraft during flight such that a pitch angle of the rotorcraft does not exceed the maximum pitch angle. In various such embodiments, setting the maximum pitch

angle includes storing, by the controller, data representing the maximum pitch angle in a memory.

[0453] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a communications interface configured to receive a signal associated with a desired one of multiple different flight modes, each flight mode associated with one of multiple different pitch angles; one or more rotor motors; and a controller configured to, responsive to receipt of the signal: operate the rotorcraft in accordance with the desired flight mode; set a maximum pitch angle of the rotorcraft to the pitch angle associated with the desired flight mode; and control the one or more rotor motors during flight such that a pitch angle of the rotorcraft does not exceed the maximum pitch angle. In various such embodiments, the rotorcraft includes a memory, and wherein the controller is configured to set the maximum pitch angle by storing data representing the maximum pitch angle in the memory.

[0454] 5.9 Autonomous Launch Method of Operation and Apparatus

[0455] It should be appreciated from the above that various embodiments of the present disclosure includes a method for launching a fixed-wing aircraft using a rotorcraft, the method comprising: receiving, via a communications interface, an autonomous launch signal; responsive to receipt of the autonomous launch signal, determining, by a controller and based at least in part on signals received from one or more sensors, a pre-launch heading of the rotorcraft; determining, by the controller and based at least in part on the pre-launch heading, a launch flight path; controlling, by the controller and based on rotorcraft location information, one or more rotor motors of the rotorcraft to fly the rotorcraft in accordance with the launch flight path; and controlling, by the controller, an actuator to disconnect the fixed-wing aircraft from the rotorcraft while the rotorcraft is flying in accordance with the launch flight path. In various such embodiments, the one or more sensors include a magnetometer. In various such embodiments, data representing a shape of the launch flight path is stored in a memory of the controller. In various such embodiments, determining the launch flight path includes determining, by the controller and based at least in part on the pre-launch heading, global-positioning system coordinates corresponding to the launch flight path. In various such embodiments, the rotorcraft location information includes a location of the rotorcraft on Earth. In various such embodiments, the rotorcraft location information includes global-positioning system coordinates. In various such embodiments, the method includes monitoring, by a global-positioning system receiver of the rotorcraft, the global-positioning system coordinates of the rotorcraft. In various such embodiments, the method includes aborting, by the controller, the launch if the global-positioning system receiver loses global-positioning system connectivity during the launch.

[0456] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a communications interface configured to receive an autonomous launch signal; one or more sensors; one or more rotor motors; an actuator; and a controller configured to: responsive to receipt of the autonomous launch signal, determine, based at least in part on signals received from one or more sensors, a pre-launch heading of the rotorcraft; determine, based at least in part on the pre-launch heading, a launch flight path; control, based on

rotorcraft location information, the one or more rotors to fly the rotorcraft fly in accordance with the launch flight path; and control the actuator to disconnect a fixed-wing aircraft from the rotorcraft while the rotorcraft is flying in accordance with the launch flight path. In various such embodiments, the one or more sensors include a magnetometer. In various such embodiments, data representing a shape of the launch flight path is stored in a memory of the controller. In various such embodiments, the controller is configured to determine the launch flight path by determining, based at least in part on the pre-launch heading, global-positioning system coordinates corresponding to the launch flight path. In various such embodiments, the rotorcraft location information includes a location of the rotorcraft on Earth. In various such embodiments, the rotorcraft location information includes global-positioning system coordinates. In various such embodiments, the rotorcraft includes a global-positioning system receiver configured to monitor the global-positioning system coordinates of the rotorcraft. In various such embodiments, the controller is configured abort the launch if the global-positioning system receiver loses global-positioning system connectivity during the launch.

[0457] 5.10 Rotor Motor Shut Down Method of Operation and Apparatus

[0458] It should be appreciated from the above that various embodiments of the present disclosure includes a method of operating a rotorcraft, the method comprising: monitoring, by a controller, for satisfaction of a rotor motor shut-down condition; enabling, by the controller, rotor motor shut down when the rotor motor shut-down condition is satisfied; and responsive to receipt of a rotor motor shut-down signal while rotor motor shut down is enabled and the rotorcraft is airborne, controlling, by the controller, each rotor motor of the rotorcraft to shut down. In various such embodiments, the method includes not preventing, by the controller, rotor motor shut down until the rotor motor shut-down condition is satisfied. In various such embodiments, the method includes, responsive to receipt of the rotor motor shut-down signal while rotor motor shut down is prevented, not controlling, by the controller, each rotor motor of the rotorcraft to shut down. In various such embodiments, the rotor motor shut-down condition is at least partially satisfied when a height of the rotorcraft above a landing surface is below a designated height. In various such embodiments, the method includes monitoring, by the controller, the height of the rotorcraft above the landing surface. In various such embodiments, the method includes measuring, by a barometer, a barometric pressure and determining, by the controller, the height of the rotorcraft above the landing surface based at least in part on the measured barometric pressure. In various such embodiments, the rotor motor shut-down condition is at least partially satisfied when a throttle level of each rotor motor is below a designated throttle level. In various such embodiments, the method includes monitoring, by the controller, the throttle level of each rotor motor.

[0459] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: one or more rotor motors; and a controller configured to: monitor for satisfaction of a rotor motor shut-down condition; enable rotor motor shut down when the rotor motor shut-down condition is satisfied; and responsive to receipt of a rotor motor shut-down signal while rotor motor shut down is enabled and the rotorcraft is airborne,

control each rotor motor of the rotorcraft to shut down. In various such embodiments, the controller is configured to prevent rotor motor shut down until the rotor motor shut-down condition is satisfied. In various such embodiments, the controller is configured to, responsive to receipt of the rotor motor shut-down signal while rotor motor shut down is prevented, not control each rotor motor of the rotorcraft to shut down. In various such embodiments, the rotor motor shut-down condition is at least partially satisfied when a height of the rotorcraft above a landing surface is below a designated height. In various such embodiments, the controller is configured to monitor the height of the rotorcraft above the landing surface. In various such embodiments, the rotorcraft includes a barometer configured to measure a barometric pressure, and wherein the controller is configured to determine the height of the rotorcraft above the landing surface based at least in part on the measured barometric pressure. In various such embodiments, the rotor motor shut-down condition is at least partially satisfied when a throttle level of each rotor motor is below a designated throttle level. In various such embodiments, the controller is configured to monitor the throttle level of each rotor motor.

[0460] 5.11 State-Based Remote Controller Method of Operation and Apparatus

[0461] It should be appreciated from the above that various embodiments of the present disclosure includes a method of establishing communications with a rotorcraft, the method comprising: establishing, by a communications interface, communications with a rotorcraft; receiving, by an input device, an input that identifies one of multiple different flight modes; storing, by a controller and in a memory, current rotorcraft flight mode data that represents the identified flight mode; and sending, to the rotorcraft and by the communications interface, a command to operate in the identified flight mode. In various such embodiments, the method includes, responsive to losing communications with the rotorcraft: attempting, by the communications interface, to reestablish communications with the rotorcraft; after communications with the rotorcraft are reestablished, accessing, by the controller, the current rotorcraft flight mode data stored in the memory; and sending, to the rotorcraft and by the communications interface, a command to operate in the flight mode represented by the current rotorcraft flight mode data.

[0462] It should be appreciated from the above that various embodiments of the present disclosure include a remote controller comprising: a communications interface configured to establish communications with a rotorcraft; one or more flight mode selection devices; and a controller including a processor and a memory, the controller configured to: responsive to receipt, by one of the one or more flight mode selection devices, of an input that identifies one of multiple different flight modes, store in the memory current rotorcraft flight mode data that represents the identified flight mode; and cause the communications interface to send to the rotorcraft a command to operate in the identified flight mode. In various such embodiments, the controller is configured to, responsive to losing communications with the rotorcraft: cause the communications interface to attempt to reestablish communications with the rotorcraft; after communications with the rotorcraft are reestablished, access the current rotorcraft flight mode data stored in the memory; and cause the communications interface to send to the rotorcraft

a command to operate in the flight mode represented by the current rotorcraft flight mode data.

[0463] 5.12 Autonomous Retrieval Method of Operation and Apparatus

[0464] It should be appreciated from the above that various embodiments of the present disclosure includes a method for retrieving a fixed-wing aircraft from flight using a rotorcraft, the method comprising: receiving, via a communications interface, an autonomous retrieval signal; responsive to receipt of the autonomous retrieval signal, controlling, by a controller, one or more rotor motors of the rotorcraft to fly the rotorcraft to a retrieval location above a ground anchor; after the rotorcraft reaches the retrieval location, controlling, by the controller, the one or more rotor motors to station-keep the rotorcraft relative to the ground anchor; after a fixed-wing aircraft captures a flexible capture member attached to the rotorcraft, controlling, by the controller, the one or more rotor motors to descend the rotorcraft at a first rate of descent; and after the fixed-wing aircraft reaches a first height above a fixed-wing aircraft landing surface, controlling, by the controller, the one or more rotor motors to descend the rotorcraft at a second rate of descent that is less than the first rate of descent until the fixed-wing aircraft reaches the fixed-wing aircraft landing surface. In various such embodiments, the method includes: after the fixed-wing aircraft lands on the fixed-wing aircraft landing surface, controlling, by the controller, the one or more rotor motors to descend the rotorcraft at a third rate of descent that is greater than the second rate of descent; and after the fixed-wing aircraft reaches a second height above a rotorcraft landing surface, controlling, by the controller, the one or more rotor motors to descend the rotorcraft at a fourth rate of descent that is less than the third rate of descent. In various such embodiments, the first and third rates of descent are the same. In various such embodiments, the second and fourth rates of descent are the same. In various such embodiments, the fixed-wing aircraft landing surface and the rotorcraft landing surface are the same surface.

[0465] It should be appreciated from the above that various embodiments of the present disclosure include a rotorcraft comprising: a communications interface configured to receive an autonomous retrieval signal; one or more rotor motors; and a controller configured to: responsive to receipt of the receiving, via a communications interface, an autonomous retrieval signal; responsive to receipt of the autonomous retrieval signal, control the one or more rotor motors to fly the rotorcraft to a retrieval location above a ground anchor; after the rotorcraft reaches the retrieval location, control the one or more rotor motors to station-keep the rotorcraft relative to the ground anchor; after a fixed-wing aircraft captures a flexible capture member attached to the rotorcraft, control the one or more rotor motors to descend the rotorcraft at a first rate of descent; and after the fixed-wing aircraft reaches a first height above a fixed-wing aircraft landing surface, control the one or more rotor motors to descend the rotorcraft at a second rate of descent that is less than the first rate of descent until the fixed-wing aircraft reaches the fixed-wing aircraft landing surface. In various such embodiments, the controller is configured to: after the fixed-wing aircraft lands on the fixed-wing aircraft landing surface, control the one or more rotor motors to descend the rotorcraft at a third rate of descent that is greater than the second rate of descent; and after the fixed-wing aircraft reaches a second height above a rotorcraft landing surface,

control the one or more rotor motors to descend the rotorcraft at a fourth rate of descent that is less than the third rate of descent. In various such embodiments, the first and third rates of descent are the same. In various such embodiments, the second and fourth rates of descent are the same. In various such embodiments, the fixed-wing aircraft landing surface and the rotorcraft landing surface are the same surface.

[0466] Various changes and modifications to the embodiments described herein will be apparent to those skilled in the art. These changes and modifications can be made without departing from the spirit and scope of the present subject matter and without diminishing its intended advantages. It is intended that such changes and modifications be covered by the appended claims.

What is claimed is:

1. A method for detecting a stall of a rotor motor of an unmanned rotorcraft before launch of the rotorcraft, the method comprising:

(a) for a designated period after sending a signal commanding a rotor motor to operate, receiving, by a controller and from a rotational speed sensor, a measured rotational speed of the rotor motor; and

(b) responsive to the measured rotational speed of the rotor motor being below a threshold rotational speed upon expiration of the designated period, causing the rotor motor to shut down.

2. The method of claim 1, wherein responsive to the measured rotational speed of the rotor motor being below the threshold rotational speed upon expiration of the designated period, causing, by the controller, the rotor motor to shut down.

3. The method of claim 1, wherein responsive to the measured rotational speed of the rotor motor being below the threshold rotational speed upon expiration of the designated period, automatically causing, by the controller, the rotor motor to shut down.

4. The method of claim 1, wherein responsive to the measured rotational speed of the rotor motor being below the threshold rotational speed upon expiration of the designated period, transmitting a signal to the R/C controller.

5. The method of claim 4, wherein the signal transmitted to the R/C controller relates to the measured rotational speed of the rotor motor being below the threshold rotational speed.

6. The method of claim 4, wherein the signal transmitted to the R/C controller relates to shut down of the rotor motor.

7. The method of claim 1, wherein the rotorcraft includes multiple rotor motors, and which includes performing (a) and (b) for each of the rotor motors.

8. The method of claim 7, which includes, responsive to the measured rotational speed of any one of the rotor motors being below the threshold rotational speed upon expiration of the designated period, causing any quantity of the multiple rotor motors to shut down completely or operate at reduced power.

9. The method of claim 1, which includes periodically receiving, by the controller and from the rotational speed sensor, the measured rotational speed of the rotor motor.

10. The method of claim 1, wherein the designated period includes a period of time.

11. A method for detecting a stall of a rotor motor of an unmanned rotorcraft before launch of the rotorcraft, the method comprising:

(a) for a designated period after sending a signal commanding a rotor motor to operate, monitoring, by a controller, a back electromotive force generated by the rotor motor; and

(b) responsive to the back electromotive force generated by the rotor motor being below a threshold back electromotive force upon expiration of the designated period, causing the rotor motor to shut down.

12. The method of claim 11, wherein responsive to the back electromotive force generated by the rotor motor being below a threshold back electromotive force rotational speed upon expiration of the designated period, causing, by the controller, the rotor motor to shut down.

13. The method of claim 11, wherein responsive to the back electromotive force generated by the rotor motor being below a threshold back electromotive force rotational speed upon expiration of the designated period, automatically causing, by the controller, the rotor motor to shut down.

14. The method of claim 11, wherein responsive to the back electromotive force generated by the rotor motor being below a threshold back electromotive force rotational speed upon expiration of the designated period, transmitting a signal to the R/C controller.

15. The method of claim 14, wherein the signal transmitted to the R/C controller relates to the measured rotational speed of the rotor motor being below the threshold rotational speed.

16. The method of claim 14, wherein the signal transmitted to the R/C controller relates to shut down of the rotor motor.

17. The method of claim 11, wherein the rotorcraft includes multiple rotor motors, and which includes performing (a) and (b) for each of the rotor motors.

18. The method of claim 17, which includes, responsive to the zero-crossing frequency of back electromotive force generated by any one of the rotor motors being below a threshold back electromotive force rotational speed upon expiration of the designated period, causing any quantity of the multiple rotor motors to shut down or operate at reduced power.

19. The method of claim 11, wherein the designated period includes a period of time.

20. A method for detecting a stall of a rotor motor of an unmanned rotorcraft before launch of the rotorcraft, the method comprising:

(a) for a designated period after sending a signal commanding a rotor motor to operate, receiving, by a controller signals indicating rotational speed of the rotor motor; and

(b) responsive to the signals indicating that the rotational speed of the rotor motor is below a threshold rotational speed upon expiration of the designated period, causing the rotor motor to shut down.

21. The method of claim 20, wherein responsive to the signals indicating that the rotational speed of the rotor motor is below the threshold rotational speed upon expiration of the designated period, causing, by the controller, the rotor motor to shut down.

22. The method of claim 20, wherein responsive to the signals indicating that the rotational speed of the rotor motor is below the threshold rotational speed upon expiration of the designated period, automatically causing, by the controller, the rotor motor to shut down.

23. The method of claim 20, wherein responsive to the signals indicating that the rotational speed of the rotor motor is below the threshold rotational speed upon expiration of the designated period, transmitting a signal to the R/C controller.

24. The method of claim 23, wherein the signal transmitted to the R/C controller relates to the rotational speed of the rotor motor being below the threshold rotational speed.

25. The method of claim 23, wherein the signal transmitted to the R/C controller relates to shut down of the rotor motor.

26. The method of claim 20, wherein the rotorcraft includes multiple rotor motors, and which includes performing (a) and (b) for each of the rotor motors.

27. The method of claim 26, which includes, responsive to the signals indicating that the rotational speed of any one of the rotor motors is below the threshold rotational speed upon expiration of the designated period, causing the rotor motors to shut down.

28. The method of claim 20, wherein the designated period includes a period of time.

* * * * *