United States Patent Application Publication	20250256869
Kind Code	A1
Publication Date	August 14, 2025
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Off-Center Parachute Flight Termination System Including Latch Mechanism Disconnectable by Burn Wire

Abstract

Systems, devices, and methods including: a latching mechanism comprising: a first latch configured to attach to a door of an unmanned aerial vehicle (UAV); a second latch configured to attach to a portion of the UAV distal from the first latch; a string connected between the first and second latch, where the string secures the door shut; at least two radio modules in communication with a ground control station; and at least two burn wires in contact with a portion of the string between the first latch and the second latch; where current from a backup battery passes to at least one burn wire when the burn signal is received, where the burn wire causes the connection between the first latch and the second latch to be broken and the door of the UAV is separated from the UAV.

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Family ID: **1000008561283**

Appl. No.: **19/189037**

Filed: **April 24, 2025**

Related U.S. Application Data

parent US continuation 18511069 20231116 parent-grant-document US 12338014 child US 19189037
parent US continuation 17979647 20221102 parent-grant-document US 11981429 child US 18511069
parent US continuation 17605754 20211022 parent-grant-document US 11518514 US continuation PCT/US20/29649 20200423 child US 17979647
us-provisional-application US 62838783 20190425

us-provisional-application US 62838833 20190425
us-provisional-application US 62854723 20190530

Publication Classification

Int. Cl.: **B64U70/83** (20230101); **B26F3/12** (20060101); **B64D17/34** (20060101); **B64D17/62** (20060101); **B64D17/80** (20060101); **B64U10/13** (20230101); **B64U20/65** (20230101)

U.S. Cl.:

CPC **B64U70/83** (20230101); B26F3/12 (20130101); B64D17/34 (20130101); B64D17/62 (20130101); B64D17/80 (20130101); B64U10/13 (20230101); B64U20/65 (20230101); B64U2201/20 (20230101)

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. Non-Provisional patent application Ser. No. 18/511,069, filed Nov. 16, 2023, which is a continuation of U.S. Non-Provisional patent application Ser. No. 17/979,647, filed Nov. 2, 2022, which issued as U.S. Pat. No. 11,981,429 on May 14, 2024, which is a continuation of U.S. Non-Provisional patent application Ser. No. 17/605,754, filed Oct. 22, 2021, which issued as U.S. Pat. No. 11,518,514 on Nov. 16, 2022, which is a 35 U.S.C § 371 National Stage Entry of International Application No. PCT/US2020/029649, filed Apr. 23, 2020, which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/838,783, filed Apr. 25, 2019, U.S. Provisional Patent Application No. 62/838,833, filed Apr. 25, 2019, and U.S. Provisional Patent Application No. 62/854,723, filed May 30, 2019, the contents of all of which are hereby incorporated by reference herein for all purposes.

FIELD OF ENDEAVOR
[0002] The invention generally relates to unmanned aerial vehicles (UAVs), and more particularly to flight termination of a UAV.
BACKGROUND
[0003] A flight termination system (FTS) includes onboard elements that provide for controlled termination of an aircraft's flight. An FTS may be independent from the aircraft to increase flight safety. An FTS is capable of terminating the flight of an aircraft in the case of a malfunction.
SUMMARY
[0004] A system embodiment may include: a latching mechanism, where the latching mechanism comprises: a first latch configured to attach to a door of an unmanned aerial vehicle (UAV); a second latch configured to attach to a portion of the UAV distal from the first latch; a string connected between the first latch and the second latch, where the string secures the door of the UAV shut; at least two radio modules in communication with a ground control station; and at least two burn wires in contact with a portion of the string between the first latch and the second latch; where at least one of the at least two radio modules may be configured to receive a burn signal from the ground control station, where current from a backup battery passes to at least one burn wire of the at least two burn wires when the burn signal may be received, where the burn wire melts a portion of the string causing the connection between the first latch and the second latch to be broken, and where the door of the UAV may be separated from the UAV when the connection between the first latch and the second latch may bebroken.
[0005] Additional system embodiments may include: a parachute disposed in the UAV, where the

parachute may be deployed when the door of the UAV may be separated from the UAV. In additional system embodiments, the parachute may be disposed off-center of the UAV. In additional system embodiments, deploying the parachute may cause the UAV to spiral down to the ground in a controlled and predictable manner. In additional system embodiments, deploying the parachute may cause a drag force on a first side of the UAV, where the drag force slows down the first side of the UAV more than a second opposite side of the UAV inducing a torque on the UAV which results in a rotation of the UAV, and where the drag force combined with the induced torque causes the UAV to exit a current flight pattern and spiral down towards the ground.

[0006] In additional system embodiments, the at least two radio modules may include: a first radio module; and a second radio module. In additional system embodiments, the first radio module may include: an antenna; and an interface configured to receive the burn signal from the antenna, where the interface toggles the battery backup to pass current to a first burn wire of the at least two burn wires.

[0007] In additional system embodiments, the ground control station may be in communication with a terrestrial GPS receiver **130**, a terrestrial RF emitter **109**, a terrestrial RF receiver **132**, and a visual band emitter **133**. In additional system embodiments, the string may be made of a combustible material. In additional system embodiments, the at least two burn wires may be made of nichrome (NiCr).

[0008] A method embodiment may include: receiving a burn signal at an interface of a first radio module of two or more radio modules of a latching mechanism; toggling, via the interface, at least one battery backup to pass current from the battery backup to a first conducting burn wire of the first radio module, where the first conducting burn wire may be attached to a portion of a string; and melting, by the first conducting burn wire, a portion of a string connected between a first latch and a second latch, where the first latch may be configured to attach to a door of an unmanned aerial vehicle (UAV), where the second latch may be configured to attach to a portion of the UAV distal from the first latch, and where the string secures the door of the UAV shut.

[0009] Additional method embodiments may include: separating the door of the UAV from the UAV when the connection between the first latch and the second latch may be broken. Additional method embodiments may include: deploying an off-center parachute when the door of the UAV separates from the UAV. In additional method embodiments, deploying the off-center parachute causes the UAV to spiral down to the ground in a controlled and predictable manner. In additional method embodiments, deploying the parachute causes a drag force on a first side of the UAV, where the drag force slows down the first side of the UAV more than a second opposite side of the UAV inducing a torque on the UAV which results in a rotation of the UAV, and where the drag force combined with the induced torque causes the UAV to exit a current flight pattern and spiral down towards the ground.

[0010] In additional method embodiments, the string may be made of a combustible material. In additional method embodiments, the at least two burn wires may be made of nichrome (NiCr). Additional method embodiments may include: determining that the door did not separate from the UAV; receiving a second burn signal at a second interface of a second radio module of the two or more radio modules of the latching mechanism; toggling, via the second interface, the at least one battery backup to pass current from the battery backup to a second conducting burn wire of the first radio module, where the second conducting burn wire may be attached to a portion of the string; and melting, by the second conducting burn wire, a portion of the string connected between the first latch and the second latch.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principals of the invention. Like reference numerals designate corresponding parts throughout the different views. Embodiments are illustrated by way of example and not limitation in the figures of the accompanying drawings, in which:

[0012] FIG. **1** depicts a system for deployment of an off-center parachute of an unmanned aerial vehicle, according to one embodiment;

[0013] FIG. **2** illustrates a top-level functional block diagram of a computing device of the unmanned aerial vehicle of FIG. **1**, according to one embodiment;

[0014] FIG. **3** depicts a partially transparent side elevation view of the off-center parachute system of FIG. **1**, according to one embodiment;

[0015] FIG. **4** depicts a radio module associated with the off-center parachute system of FIG. **3**, according to one embodiment;

[0016] FIG. **5** depicts a process for deployment of an off-center parachute of the unmanned aerial vehicle of FIG. **1**, according to one embodiment;

[0017] FIG. **6** depicts a flow diagram of a method for deploying an off-center parachute of an unmanned aerial vehicle, according to one embodiment;

[0018] FIG. **7** depicts a high-level flowchart of a method embodiment for a flight termination system of an unmanned aerial vehicle, according to one embodiment;

[0019] FIG. **8** shows a high-level block diagram and process of a computing system for implementing an embodiment of the system and process;

[0020] FIG. **9** shows a block diagram and process of an exemplary system in which an embodiment may be implemented; and

[0021] FIG. **10** depicts a cloud computing environment for implementing an embodiment of the system and process disclosed herein.

DETAILED DESCRIPTION

[0022] The following description is made for the purpose of illustrating the general principles of the embodiments discloses herein and is not meant to limit the concepts disclosed herein. Further, particular features described herein can be used in combination with other described features in each of the various possible combinations and permutations. Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation including meanings implied from the description as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc.

[0023] One embodiment of a flight termination system (FTS) is a self-destruct system controlled by a remote operator. Another embodiment of an FTS is a separation system that provides for separation of components, such as rockets from a fuselage in aeronautic applications. Another embodiment of an FTS is a parachute release system for safe landing in the case of power loss to the aircraft, equipment malfunction, and the like. One embodiment of the parachute system is an off-center parachute system of an unmanned aerial vehicle (UAV), wherein one parachute is disposed on a side of the UAV. Deployment of the off-center parachute causes the UAV to spiral down towards the ground, resulting in a slower and safer landing, as well as a predictable descent rate and flight path. Off-center parachute systems may include solenoids that are continuously engaged. If power is lost in the UAV, the solenoids may cause automatic deployment of the parachute. Other systems may include solenoids that automatically actuate to make the parachute deploy. Such configurations may not allow for manual operation and/or override. It is desired to have an off-center latch-string parachute system with redundancy failsafe measures with the capability for an operator to manually cause the parachute to deploy.

[0024] A system embodiment for deploying an off-center parachute of a UAV is presented. In one example, the UAV is a high altitude long endurance solar-powered aircraft. The off-center

parachute system may include a string that keeps a latch. The string may include two redundant burn wires attached thereto to melt the string and make the parachute deploy. M ore specifically, if the string is burned by at least one of the burn wires, then the latch opens to cause deployment of the parachute. This dual burn wire configuration provides an independent and redundant system to eliminate possible failure of one of the systems. The redundancy also functions as a failsafe in case one of the burn wires malfunctions.
[0025] In the present embodiments, at each side where the wire is attached to the string, the wire may melt the string. Additionally, each wire may be associated with circuitry, including a radio, an antenna, and an interface. The circuitry may be configured to receive a command signal, wirelessly or by wire, from an operator to deploy the parachute and the aircraft spirals down to the ground. This configuration provides for the flexibility of an operator to transmit a command signal for manual deployment of the parachute.
[0026] With reference to FIG. **1**, a system **100** for deployment of an off-center parachute of an unmanned aerial vehicle (UAV) **110** is illustrated. UAVs are aircraft with no onboard pilot and may fly autonomously or remotely. In one embodiment, the UAV **110** is a high altitude long endurance aircraft. In one embodiment, the UAV **110** may have one or more motors, for example, between one and forty motors, and a wingspan between 100 feet and 400 feet. In one embodiment, the UAV **110** has a wingspan of approximately 260 feet and is propelled by a plurality of motors, for example, ten electric motors. The electric motors of the UAV **110** may be powered by a solar array covering a portion of the surface of the wing, resulting in zero emissions. Flying at an altitude of approximately 65,000 feet above sea level and above the clouds, the UAV **110** is designed for continuous, extended missions of up to months without landing.
[0027] The UAV **110** functions optimally at high altitude due at least in part to the lightweight payload of the UAV and is capable of considerable periods of sustained flight without needing to land. In one embodiment, the UAV **110** may weigh approximately 3,000 lbs and may include wing panel sections and a center panel, providing for efficient assembly and disassembly of the UAV **110** due to the attachability and detachability of the wing panel sections to each other and/or to the center panel.
[0028] The off-center parachute deployment system **100** allows for a stable and predictable landing of a UAV that has lost power or has experienced other difficulties, rendering the UAV unable to maintain flight. This may be achieved by an operator **106** at a ground station **104** triggering the deployment of a parachute on the UAV **110**. The parachute may be located on one side of the UAV **110**, causing the UAV **110** to spiral down for a controlled and predictable descent once the parachute is deployed.
[0029] In one embodiment, activation of the off-center parachute deployment system **100** may shut off control of the motor or other flight controls; therefore, the UAV **110** may not stop the turn resulting from the off-center parachute deployment. In the event that the activation was inadvertent or caused by an anomaly, a command may be sent by the operator **106** to the off-center parachute deployment system **100** to re-enable control of the motor or other flight controls. This may allow the UAV **110** to stop the initiated turn and to regain some level of control over the landing pattern.
[0030] In one embodiment, the UAV **110** descends and lands at a landing area **102** for general repairs, maintenance, and the like. The aircraft **110** may be re-launched at a later time. In another embodiment, the UAV **110** descends to a site not at the landing area **102**, rather at a place generally below the flight pattern traveled by the aircraft **110**.
[0031] In one embodiment, the landing area **102** is of a circular shape allowing for approach and take-off from the landing area **102** in any direction. Other landing area shapes are possible and contemplated. The landing area may be paved with asphalt or concrete. In other embodiment, the landing area may be made of grass or another organic material.
[0032] The ground control station **104** may be in communication with the UAV **110**. The ground control station **104** may be the central hub for the aircraft control. With respect to FIG. **1**, the UAV

110 is in a geostationary flight pattern within the stratospheric layer of the atmosphere and may be within a beam width of a terrestrial radio frequency (RF) emitter associated with the ground station. In one embodiment, the UAV **110** may be within a beam width of a terrestrial GPS receiver **130** associated with the ground station **104**. The GPS receiver **130** may be configured to provide the position of the ground station **104** and the landing site to operators at the ground station **104** and to the UAV **110**. As described in detail below, each UAV **110** may include a dedicated GPS receiver for calculating the position of the UAV **110** and may communicate an associated position data to the ground station **104** over a terrestrial RF receiver **132** in communication with the ground station **104**.

[0033] A terrestrial RF emitter **109** may emit signals to the UAV **110** so the UAV **110** will know the location of the ground station **104** and/or a landing site. Other emitters configured for terrestrial communication with the UAV **110** may be included, such as a visual band emitter **133**. In one embodiment, the terrestrial RF emitter **109** may emit signals to the UAV **110** to generally communicate commands to the UAV **110**.

[0034] In one embodiment, the operator **106** is located at the ground control station **104** for management of the off-center parachute deployment from the UAV **110**. It is possible to have more than one operator for management of the UAV **110**. If the UAV **110** has lost power or experienced other difficulties rendering the UAV **110** unable to maintain flight, the operator **106** may trigger the descent of the aircraft **110** by deploying the off-center parachute. In another embodiment, the operator **106** may be located remotely from the ground control station **104** and/or landing site **102**.

[0035] The operator **106** may control various aspects of the UAV **110**. For example, it is possible that the return of a UAV is on a pre-determined schedule, such as every **100** days. However, if the UAV **110** loses power and needs to descend ahead of schedule, the operator **106** may override the schedule and trigger the UAV **110** to deploy the associated parachute and descend to the landing site **102** or another site if the UAV **110** is at a distance is considered to be too far away from the landing site **102**, for example, out of visual range. While the operator **106** is depicted as a person, the operator **106** may be a processor having addressable memory, such as shown in FIG. **2**. The control of the UAV **110** and/or deployment of the parachute on the UAV **110** may be via the operator **106** in some embodiments. In other embodiments, control of the UAV **110** and/or deployment of the parachute on the UAV **110** may be via the ground control station **104**, an autonomous system, a semi-autonomous system, or the like. In some embodiments, the ground control station **104** may include the terrestrial GPS receiver **130**, terrestrial RF emitter **109**, terrestrial RF receiver **132**, and/or visual band emitter **133**. In other embodiments, the ground control station **104** may be in communication with the terrestrial GPS receiver **130**, terrestrial RF emitter **109**, terrestrial RF receiver **132**, and/or visual band emitter **133**.

[0036] FIG. **2** illustrates an example of a top-level functional block diagram of a computing device **108** operated by the operator of the ground control station. The computing device **108** comprises a processor **138**, such as a central processing unit (CPU), addressable memory **140**, an external device interface **142**, e.g., an optional universal serial bus port and related processing, and/or an Ethernet port and related processing, and an optional user interface **144**, e.g., an array of status lights and one or more toggle switches, and/or a display, and/or a keyboard and/or a pointer-mouse system and/or a touch screen. Optionally, the addressable memory may, for example, be: flash memory, eprom, and/or a disk drive or other hard drive. These elements may be in communication with one another via a data bus **146**. In some embodiments, via an operating system **148** such as one supporting a web browser **150** and applications **152**, the processor **138** may be configured to execute steps to for deployment of an off-center parachute of a UAV.

[0037] The terrestrial RF emitter **109**, as shown in FIG. **1**, may be in communication with the processor **138** of FIG. **2**. More specifically, the operator **106** may execute a command at the computing device **108** with the application **152**. The processor **138** may process the command and communicate to the RF emitter **109** to emit a radio frequency signal to be received by the UAV **110**.

In one embodiment, the RF emitter **109** is configured to emit an RF signal to the UAV **110** for deployment of an off-center parachute.

[0038] With respect to FIG. **3**, the UAV **110** may have a door **114** disposed on one side **117** (see also FIG. **1**) of the UAV **110**. The UAV **110** of FIG. **3** is shown as partially transparent so as to illustrate the components in the disclosed system and method. The door **114** may be secured shut with a locking mechanism, such as a latching mechanism **116**. The latching mechanism **116** is capable of releasing a parachute **118** (see FIG. **5**). In one embodiment, the latching mechanism **116** may be comprised of a first panel **116**A secured to the door **114** and a second panel **116**B attached to a body **111**, such as the fuselage of the UAV **110**. In another embodiment, both latch panels **116**A,B are attached to the door **114**. In yet another embodiment, both latch panels **116**A,B are attached to the body **111**. The panels **116**A,B may be made of light-weight, durable material such as carbon fiber, titanium, aluminum, and the like. In one embodiment, the first and second panels **116**A,B are made of the same material. In another embodiment, the first and second panels **116**A,B are made of different materials.

[0039] In one embodiment, latching mechanism **116** further includes a string **120** attached to the panels **116**A,B for securing the door **114** shut or in a closed position. More specifically, a first end **120**A of the string **120** is attached to the first panel **116**A, and a second end **120**B of the string **120** is attached to the second panel **116**B. The latching mechanism **116** may be held closed by the string **120** under tension. In one embodiment, when the string **120** is burned, the door **114** may swing away from the fuselage due to gravity and the door **114** may then become detached from the UAV **110** due to the wind force. Configured as such, the string-latch connection ensures that the door **114** is secured shut. In one embodiment, the string **120** is made of lightweight nylon kernmantle (e.g., paracord or 550 cord). Other string materials are possible, such as polyester. The string **120** may be a braided sheath with a high number of interwoven strands for extra strength. In some embodiments, the string **120** may be a rope. In some embodiments, the string **120** may be any combustible material. In some embodiments, a portion of the string **120** may be made from any combustible material.

[0040] With respect to FIG. **5**, an off-center parachute **118** is contained in the UAV **110** behind the door **114**. The parachute **118** may provide a controlled and predictable descent of the UAV **110** in the case of unexpected loss of power to the UAV **110** or another catastrophic anomaly. By deploying the single parachute **118** on the side **117** of the UAV, i.e., off center, the UAV **110** will spiral down to the ground. More specifically, when the parachute **118** is deployed, the parachute may cause a drag force, e.g., aerodynamic drag, on the side **117** of the UAV **110**. Since the parachute **118** is located on the side **117** and not in the center of the UAV **110**, the drag force slows down the one side **117** more than the other side of the UAV **110**. This causes a twisting force, or torque on the UAV **110**, resulting in rotation of the UAV **110**. The drag force combined with the induced torque will cause the UAV **110** to exit the current flight pattern and spiral down towards the ground.

[0041] The amount of drag and rotation experienced by the UAV **110**, and hence, the rate of descent may be based on the size, shape, and location of the parachute in the UAV **110**. The temporal rate of decrease in altitude may be referred to as the rate of descent or sink rate. More specifically, the parachute **118** may be of a size that is substantially large enough to generate a desired descent or sink rate.

[0042] In one embodiment, the parachute **118** may, for example, be approximately 11 feet in diameter with an effective drag area of approximately 143 square feet, thus generating a sea level equivalent sink rate of approximately 200 feet per minute. The sea level equivalent sink rate may be a function of the drag coefficient, the density of air, and velocity of the UAV **110**. Additionally, the location of the off-center parachute **118** may be located at a distance from the center of the UAV **110** such that as the UAV **110** turns, the UAV **110** does not become unstable while turning. In one embodiment, the parachute **118** may be placed a distance of, for example, 37 feet from the center of the UAV **110**, or approximately 14% wingspan of the UAV **110**.

[0043] In the event that power for steering or general yaw control movement is restored for the UAV **110** after a triggering event or failure, then the turning of the UAV **110** may be stopped. In one embodiment, power is restored to the motor **112** to allow for steering control of the UAV **110**. In another embodiment, the UAV **110** has more than one motor **112** and turning of the UAV **110** may be controlled by giving each motor **112** a different thrust, allowing the turning of the UAV **110** to be halted. Other factors may be relevant for descent rate, such as the density of air at the altitude of parachute deployment, and the drag coefficient of the parachute.

[0044] In one embodiment, the parachute **118** is a so-called drogue parachute, which is smaller than a conventional parachute that might otherwise tear apart due to the speed of the UAV **110**. In one embodiment, the parachute **118** is made of Nylon. Other parachute materials are possible and contemplated, such as canvas, silk, Terylene, Dacron, and Kevlar. The parachute may have a diameter between five feet and twenty feet on a tether between twenty feet and fifty feet in length. Other parachute diameters and tether lengths are possible and contemplated based on the size of the UAV.

[0045] As shown in FIG. **3**, the latching mechanism **116** maintains the door **114** securely shut. In order to release the latching mechanism **116** and deploy the parachute **118**, the string **120** must be severed. To that end, two or more identical burn wires **122**A,B are spaced along the string **120**. In one embodiment, the burn wires **122**A,B are made of nichrome (NiCr), which is typically a combination of various alloys of nickel and chromium as well other possible elements, such as iron and platinum. The burn wires **122**A,B are a poorly conducting material (e.g., have low thermal conductivity) and may be used for heating, and, hence, burning of the string **120**. The burn wires **122**A,B may also conduct electricity inefficiently, e.g., have low thermal conductivity, in order to heat up. Furthermore, the wires **122**A,B may develop an outer layer of chromium oxide, which is thermodynamically stable in air. Otherwise, the burn wires **122**A,B would oxidize quickly in air when heated, and become brittle and likely break. The burn wires **122**A,B may include a first burn wire **122**A and a second burn wire **122**B.

[0046] Attached to each of the burn wires **122**A,B are one or more respective radio modules **124**A,B. The radio modules **124**A,B contain electronic elements that allow for communication with the RF emitter **109**, as well as electronics for heating the burn wires **122**A,B to burn the string **120** and deploy the parachute **118**. In one embodiment, the radio modules may be one-way radio modules for receiving signals from the RF emitter **109**. In another embodiment, the radio modules **130** may be two-way radio modules that may receive signals from the RF emitter **109** and transmit signals to the RF receiver **132**, as shown in FIG. **1**. In one embodiment, the two radio modules **124**A,B are identical. In another embodiment, one of the radio modules may have additional circuitry elements. One of the radio modules **124**A may be affixed to the door **114** and the other module **124**B may be attached to the body **111** of the UAV **110**, or vice versa. In another embodiment, both of the modules **124**A,B are attached to the door **114**. In yet another embodiment, both of the modules **124**A,B are attached to the body **111** of the UAV **110**. Accordingly, any combination of the above may be implemented. While two burn wires **122**A,B and two radio modules **124**A,B are shown, any number of burn wires and radio modules are possible and contemplated.

[0047] With respect to FIG. **4**, a radio module, such as radio module **124**A, may have an antenna **126** for receiving a radio frequency signal from the RF emitter **109**, as shown in FIG. **1**. The antenna **126** may be tuned to the same frequency as the RF emitter **109**, as shown in FIG. **1**. The antenna **126** may be made of metal. In one example, each antenna **126** may be made of copper. Other materials are possible, such as aluminum or stainless steel. The radio module **124**A may also have an interface **128**, e.g., an array of status lights, sensors and one or more toggle switches, and/or a touch screen.

[0048] In one aspect of the embodiments, the operator **106**, as shown in FIG. **1**, executes a command to deploy the off-center parachute **118**, as shown in FIG. **5**, for a controlled descent and predictable crash landing at a location in the case of power loss to the UAV **110** or some other anomaly. Typically, when power is lost to the UAV **110**, there is a backup battery onboard. The backup power may be used to power the radio modules **124**A,B. If the UAV **110** is at high altitude, the operator may wish to deploy the parachute **118** for a controlled descent and a predictable crash landing location. If the UAV **110** is already close enough to the ground, then the UAV **110** may descend with the backup power provided or with regenerative power supplied by motors of the UAV **110**.

[0049] In one embodiment, when power is lost in the UAV **110** the parachute **118** does not automatically deploy. Rather, the autopilot mechanism of the UAV **110** may begin to land the plane as soon as power is lost, and deployment of the parachute is manually controlled by the operator **106**. More specifically, the operator **106** may execute a command at the computing device **108** with the application **152**. The processor **138** may process the command and communicate to the RF emitter **109** to emit a radio frequency signal to be received by the UAV **110**. In one embodiment, a radio frequency burn signal **129** is sent from the RF emitter **109** to one of the radio modules **124**A of the UAV **110**. If the radio module **124**A does not receive the signal or it is malfunctioning, the operator **106** executes a command to transmit the RF burn signal **129**, as shown in FIG. **1**, to radio module **124**B associated with the second burn wire **122**B. This provides for a redundant and independent system. In another embodiment, the radio frequency burn signal **129**, as shown in FIG. **1**, is sent from the RF emitter **109** to both of the radio modules **124**A,B simultaneously, and both burn wires **122**A,B are activated.

[0050] In another embodiment, the RF burn signal **129** may be transmitted to a flight control computer (FCC) **107** (see FIG. **1**) onboard the UAV **110**. The FCC **107** may be in communication with either or both of the radio modules **124**A,B to direct the burn signal **129** to the burn wires **122**A,B. In another embodiment, the FCC **107** onboard the UAV **110** may determine that an emergency landing is needed and thereby executes a command to deploy the off-center parachute **118** for a controlled descent and predictable crash landing location, for example, in the case of power loss to the aircraft **110** or some other catastrophic anomaly detected immediately at the UAV **110** without the need to involve the operator **106**.

[0051] In one embodiment, the antenna **126** receives the burn signal **129** from the RF emitter **109** for the flight termination system **100** to activate the burn wires **122**A,B. More specifically, and with respect to FIG. **4**, the interface **128** receives the burn signal **129** from an output **154** of the antenna **126** and toggles a UAV backup battery **113** to pass current from an output **156** to the conducting burn wires **122**A,B, causing the wires **122**A,B to increase in temperature. The heat dissipated by each burn wire **122**A,B is a function of the particular burn wire's resistivity and thickness. In one embodiment, the burn wire **122**A,B is sufficiently heated by the electrical current generated by the backup battery **113** to burn the wire. In such embodiments, the current running through the wire may be approximately 2-3 Amps. In one embodiment, the burn wires **122**A,B are approximately 0.010 inches in diameter. In one embodiment, wires **122**A,B take 1-15 seconds to melt the string **120**, depending on the backup battery **113** voltage and the ambient temperature.

[0052] When the string **120** is severed, the door **114**, as shown in FIG. **3**, opens and the parachute **118**, as shown in FIG. **5**, deploys. In one embodiment, if the string **120** is not melted by the first burn wire **122**A of radio module **124**A, the operator **106** executes a command to transmit the RF burn signal **129** to radio module **124**B associated with the second burn wire **122**B to open the door. In another embodiment, the radio frequency burn signal **129** is sent from the RF emitter **109** to both of the radio modules **124**A,B, and both burn wires **122**A,B are activated simultaneously. That is, the operator **106** or the UAV **110** may determine, via various sensors, whether the deployment was successful and if not, initiate the second or backup means for deployment of the parachute **118**.

[0053] Embodiments of the system **100** provide for a redundant and independent system for safe landing of the UAV **110** in the case of power loss or other malfunction of the aircraft. The operator

106 transmits the burn signal **129** via the terrestrial RF emitter **109** to the antennae **126** of the radio modules **124**A,B. The interface **128** receives the burn signal **129** from an output **154** of the antenna **126** and toggles the UAV backup battery **113** to pass current from an output **156** to the conducting burn wires **122**A,B, causing the wires **122**A,B to increase in temperature. The burn wire **122**A,B, in turn, dissipates heat to melt the string **120** of the latching mechanism **116**, thereby causing the door **114** to open and deploy the off-center parachute **118**, allowing the UAV **110** to spiral down in a controlled and predictable manner to the landing area or a safe ditch site away from the landing area. If the first burn wire is unsuccessful, the operator **106** sends the burn signal **129** to an independent and redundant second burn wire of the radio module **124**B to ensure the off-center parachute **118** is released.

[0054] With respect to FIG. **6**, a flowchart of a method **200** for providing a redundant and independent flight termination system for safe landing of an unmanned aerial vehicle (UAV) in the case of power loss or other malfunction of the UAV is illustrated. An operator and/or a ground control station may transmit a burn signal via a terrestrial radio frequency (RF) emitter to at least one radio module of a latching mechanism of the UAV (step **202**). An interface of the at least one radio module receives the burn signal (step **204**). In some embodiments, the at least one radio module may include an antenna for receiving signals. The interface may toggle, via the interface, at least one backup battery of the UAV to pass current from the at least one backup battery to a conducting burn wire of the at least one radio module, causing the burn wire to increase in temperature (step **206**). The burn wire, in turn, dissipates heat to melt a string of the latching mechanism that holds a door of the UAV shut, thereby causing a door of the UAV to open (step **208**). The door may be released from the UAV by wind resistance, gravity, or the like once the latching mechanism is no longer holding the door in place. When the UAV door opens, an off-center parachute is deployed (step **210**). The off-center parachute allows the UAV to spiral down and land in a controlled and predictable manner to a landing area or a safe ditch site away from the landing area (step **210**). In some embodiments, if the first burn wire is unsuccessful, the operator and/or ground control station may send the burn signal to an independent and redundant second burn wire of a second radio module of the latching mechanism to ensure the off-center parachute is released. In another embodiment, the radio frequency burn signal may be sent from the RF emitter to both of the radio modules, and both burn wires are activated simultaneously. That is, the operator or the UAV may determine, via various sensors, whether the deployment was successful and if not, initiate the second or backup means for deployment of the parachute. In other embodiments, the second burn wire may receive current from the backup battery to melt the string if the first burn wire does not melt the string, cause the door to open, and deploy the parachute.

[0055] In another embodiment, the RF burn signal may be transmitted to a flight control computer (FCC) onboard the UAV. The FCC **107** may be in communication with either or both of the radio modules to direct the burn signal to the burn wires. In another embodiment, the FCC onboard the UAV may determine that an emergency landing is needed and thereby executes a command to deploy the off-center parachute for a controlled descent and predictable crash landing location, for example, in the case of power loss to the UAV or some other catastrophic anomaly detected immediately at the UAV without the need to involve the operator.

[0056] FIG. **7** depicts a high-level flowchart of a method **700** embodiment for a flight termination system of an unmanned aerial vehicle, according to one embodiment. The method **300** may include checking for a triggering event of an unmanned aerial vehicle (UAV) (step **302**). The triggering event may be a loss in power of the UAV, a loss of control of one or more electric motors of the UAV, a loss in communication between the ground control station and the UAV, or the like. If there is no triggering event, the method **700** may continue to check for a triggering event. The triggering event may be determined by an operator of the ground control system, a processor of the ground control system, a processor of the UAV, or the like. If there is a triggering event, the ground control system and/or operator may transmit a first burn signal to a first radio module (step **304**). The UAV may contain two or more redundant radio modules. Current passes from a backup battery to a first conducting burn wire of the first radio module (step **306**). The first radio module may send a signal and/or activate a switch to allow power to flow from a backup battery to a first conducting burn wire. The first conducting burn wire may cause a string of a latching mechanism to burn and separate. The string of the latching mechanism may hold a door in place during operation of the UAV. When the string is separated, the door can open and a parachute located in the UAV can deploy (step **308**).

[0057] If the door does not open and the parachute does not deploy (step **308**), this may indicate a problem with the first radio module, backup battery, and/or first conducting burn wire. The ground control system and/or operator may then transmit a second burn signal to a second radio module (step **310**). In some embodiments, the second radio module may be identical to the first radio module. Current passes from a backup battery to a second conducting burn wire of the second radio module (step **312**). The second radio module may send a signal and/or activate a switch to allow power to flow from a backup battery to a second conducting burn wire. The second conducting burn wire may cause a string of a latching mechanism to burn and separate.

[0058] Once the door opens and the parachute is deployed, the UAV spirals down to the ground in a controlled and predictable manner (step **314**). Optionally, power may be restored to the UAV, one or more motors of the UAV, and/or one or more control systems of the UAV, which may allow for steering control of the UAV if the triggering event ends (step **316**). The ground control system and/or the operator may control the UAV to halt the spiral and land the UAV at a desired location.

[0059] FIG. **8** is a high-level block diagram **500** showing a computing system comprising a computer system useful for implementing an embodiment of the system and process, disclosed herein. Embodiments of the system may be implemented in different computing environments. The computer system includes one or more processors **502**, and can further include an electronic display device **504** (e.g., for displaying graphics, text, and other data), a main memory **506** (e.g., random access memory (RAM)), storage device **508**, a removable storage device **510** (e.g., removable storage drive, a removable memory module, a magnetic tape drive, an optical disk drive, a computer readable medium having stored therein computer software and/or data), user interface device **511** (e.g., keyboard, touch screen, keypad, pointing device), and a communication interface **512** (e.g., modem, a network interface (such as an Ethernet card), a communications port, or a PCM CIA slot and card). The communication interface **512** allows software and data to be transferred between the computer system and external devices. The system further includes a communications infrastructure **514** (e.g., a communications bus, cross-over bar, or network) to which the aforementioned devices/modules are connected as shown.

[0060] Information transferred via communications interface **514** may be in the form of signals such as electronic, electromagnetic, optical, or other signals capable of being received by communications interface **514**, via a communication link **516** that carries signals and may be implemented using wire or cable, fiber optics, a phone line, a cellular/mobile phone link, an radio frequency (RF) link, and/or other communication channels. Computer program instructions representing the block diagram and/or flowcharts herein may be loaded onto a computer, programmable data processing apparatus, or processing devices to cause a series of operations performed thereon to produce a computer implemented process.

[0061] Embodiments have been described with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments. Each block of such illustrations/diagrams, or combinations thereof, can be implemented by computer program instructions. The computer program instructions when provided to a processor produce a machine, such that the instructions, which execute via the processor, create means for implementing the functions/operations specified in the flowchart and/or block diagram. Each block in the flowchart/block diagrams may represent a hardware and/or software module or logic, implementing embodiments. In alternative implementations, the functions noted in the blocks may occur out of the order noted in the figures, concurrently, etc.

[0062] Computer programs (i.e., computer control logic) are stored in main memory and/or secondary memory. Computer programs may also be received via a communications interface **512**. Such computer programs, when executed, enable the computer system to perform the features of the embodiments as discussed herein. In particular, the computer programs, when executed, enable the processor and/or multi-core processor to perform the features of the computer system. Such computer programs represent controllers of the computer system.

[0063] FIG. **9** shows a block diagram of an example system **600** in which an embodiment may be implemented. The system **600** includes one or more client devices **601** such as consumer electronics devices, connected to one or more server computing systems **630**. A server **630** includes a bus **602** or other communication mechanism for communicating information, and a processor (CPU) **604** coupled with the bus **602** for processing information. The server **630** also includes a main memory **606**, such as a random access memory (RAM) or other dynamic storage device, coupled to the bus **602** for storing information and instructions to be executed by the processor **604**. The main memory **606** also may be used for storing temporary variables or other intermediate information during execution or instructions to be executed by the processor **604**. The server computer system **630** further includes a read only memory (ROM) **608** or other static storage device coupled to the bus **602** for storing static information and instructions for the processor **604**. A storage device **610**, such as a magnetic disk or optical disk, is provided and coupled to the bus **602** for storing information and instructions. The bus **602** may contain, for example, thirty-two address lines for addressing video memory or main memory **606**. The bus **602** can also include, for example, a 32-bit data bus for transferring data between and among the components, such as the CPU **604**, the main memory **606**, video memory and the storage **610**. Alternatively, multiplex data/address lines may be used instead of separate data and address lines.

[0064] The server **630** may be coupled via the bus **602** to a display **612** for displaying information to a computer user. An input device **614**, including alphanumeric and other keys, is coupled to the bus **602** for communicating information and command selections to the processor **604**. Another type or user input device comprises cursor control **616**, such as a mouse, a trackball, or cursor direction keys for communicating direction information and command selections to the processor **604** and for controlling cursor movement on the display **612**.

[0065] According to one embodiment, the functions are performed by the processor **604** executing one or more sequences of one or more instructions contained in the main memory **606**. Such instructions may be read into the main memory **606** from another computer-readable medium, such as the storage device **610**. Execution of the sequences of instructions contained in the main memory **606** causes the processor **604** to perform the process steps described herein. One or more processors in a multi-processing arrangement may also be employed to execute the sequences of instructions contained in the main memory **606**. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement the embodiments. Thus, embodiments are not limited to any specific combination of hardware circuitry and software.

[0066] The terms “computer program medium,” “computer usable medium,” “computer readable medium”, and “computer program product,” are used to generally refer to media such as main memory, secondary memory, removable storage drive, a hard disk installed in hard disk drive, and signals. These computer program products are means for providing software to the computer system. The computer readable medium allows the computer system to read data, instructions, messages or message packets, and other computer readable information from the computer readable medium. The computer readable medium, for example, may include non-volatile memory, such as a floppy disk, ROM, flash memory, disk drive memory, a CD-ROM, and other permanent storage. It is useful, for example, for transporting information, such as data and computer instructions, between computer systems. Furthermore, the computer readable medium may comprise computer readable information in a transitory state medium such as a network link and/or a network interface, including a wired network or a wireless network that allow a computer to read such computer readable information. Computer programs (also called computer control logic) are stored in main memory and/or secondary memory. Computer programs may also be received via a communications interface. Such computer programs, when executed, enable the computer system to perform the features of the embodiments as discussed herein. In particular, the computer programs, when executed, enable the processor multi-core processor to perform the features of the computer system. Accordingly, such computer programs represent controllers of the computer system.

[0067] Generally, the term “computer-readable medium” as used herein refers to any medium that participated in providing instructions to the processor **604** for execution. Such a medium may take many forms, including but not limited to, non-volatile media, volatile media, and transmission media. Non-volatile media includes, for example, optical or magnetic disks, such as the storage device **610**. Volatile media includes dynamic memory, such as the main memory **606**. Transmission media includes coaxial cables, copper wire and fiber optics, including the wires that comprise the bus **602**. Transmission media can also take the form of acoustic or light waves, such as those generated during radio wave and infrared data communications.

[0068] Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, or any other magnetic medium, a CD-ROM, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, a RAM, a PROM, an EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave as described hereinafter, or any other medium from which a computer can read.

[0069] Various forms of computer readable media may be involved in carrying one or more sequences of one or more instructions to the processor **604** for execution. For example, the instructions may initially be carried on a magnetic disk of a remote computer. The remote computer can load the instructions into its dynamic memory and send the instructions over a telephone line using a modem. A modem local to the server **630** can receive the data on the telephone line and use an infrared transmitter to convert the data to an infrared signal. An infrared detector coupled to the bus **602** can receive the data carried in the infrared signal and place the data on the bus **602**. The bus **602** carries the data to the main memory **606**, from which the processor **604** retrieves and executes the instructions. The instructions received from the main memory **606** may optionally be stored on the storage device **610** either before or after execution by the processor **604**.

[0070] The server **630** also includes a communication interface **618** coupled to the bus **602**. The communication interface **618** provides a two-way data communication coupling to a network link **620** that is connected to the world wide packet data communication network now commonly referred to as the Internet **628**. The Internet **628** uses electrical, electromagnetic or optical signals that carry digital data streams. The signals through the various networks and the signals on the network link **620** and through the communication interface **618**, which carry the digital data to and from the server **630**, are exemplary forms or carrier waves transporting the information.

[0071] In another embodiment of the server **630**, interface **618** is connected to a network **622** via a communication link **620**. For example, the communication interface **618** may be an integrated services digital network (ISDN) card or a modem to provide a data communication connection to a corresponding type of telephone line, which can comprise part of the network link **620**. As another example, the communication interface **618** may be a local area network (LAN) card to provide a data communication connection to a compatible LAN. Wireless links may also be implemented. In any such implementation, the communication interface **618** sends and receives electrical electromagnetic or optical signals that carry digital data streams representing various types of information.

[0072] The network link **620** typically provides data communication through one or more networks to other data devices. For example, the network link **620** may provide a connection through the local network **622** to a host computer **624** or to data equipment operated by an Internet Service Provider (ISP). The ISP in turn provides data communication services through the Internet **628**. The local network **622** and the Internet **628** both use electrical, electromagnetic or optical signals that carry digital data streams. The signals through the various networks and the signals on the network link **620** and through the communication interface **618**, which carry the digital data to and from the server **630**, are exemplary forms or carrier waves transporting the information.

[0073] The server **630** can send/receive messages and data, including e-mail, program code, through the network, the network link **620** and the communication interface **618**. Further, the communication interface **618** can comprise a USB/Tuner and the network link **620** may be an antenna or cable for connecting the server **630** to a cable provider, satellite provider or other terrestrial transmission system for receiving messages, data and program code from another source.

[0074] The example versions of the embodiments described herein may be implemented as logical operations in a distributed processing system such as the system **600** including the servers **630**. The logical operations of the embodiments may be implemented as a sequence of steps executing in the server **630**, and as interconnected machine modules within the system **600**. The implementation is a matter of choice and can depend on performance of the system **600** implementing the embodiments. As such, the logical operations constituting said example versions of the embodiments are referred to for e.g., as operations, steps or modules.

[0075] Similar to a server **630** described above, a client device **601** can include a processor, memory, storage device, display, input device and communication interface (e.g., e-mail interface) for connecting the client device to the Internet **628**, the ISP, or LAN **622**, for communication with the servers **630**.

[0076] The system **600** can further include computers (e.g., personal computers, computing nodes) **605** operating in the same manner as client devices **601**, where a user can utilize one or more computers **605** to manage data in the server **630**.

[0077] Referring now to FIG. **10**, illustrative cloud computing environment **50** is depicted. As shown, cloud computing environment **50** comprises one or more cloud computing nodes **10** with which local computing devices used by cloud consumers, such as, for example, personal digital assistant (PDA), smartphone, smart watch, set-top box, video game system, tablet, mobile computing device, or cellular telephone **54**A, desktop computer **54**B, laptop computer **54**C, and/or automobile computer system **54**N may communicate. Nodes **10** may communicate with one another. They may be grouped (not shown) physically or virtually, in one or more networks, such as Private, Community, Public, or Hybrid clouds as described hereinabove, or a combination thereof. This allows cloud computing environment **50** to offer infrastructure, platforms and/or software as services for which a cloud consumer does not need to maintain resources on a local computing device. It is understood that the types of computing devices **54**A-N shown in FIG. **10** are intended to be illustrative only and that computing nodes **10** and cloud computing environment **50** can communicate with any type of computerized device over any type of network and/or network addressable connection (e.g., using a web browser).

[0078] It is contemplated that various combinations and/or sub-combinations of the specific features and aspects of the above embodiments may be made and still fall within the scope of the invention. Accordingly, it should be understood that various features and aspects of the disclosed embodiments may be combined with or substituted for one another in order to form varying modes of the disclosed invention. Further, it is intended that the scope of the present invention herein disclosed by way of examples should not be limited by the particular disclosed embodiments described above.

Claims

1. A system, comprising: at least two radio modules in communication with at least one of: a ground control station (GCS) and a flight control computer (FCC) of an unmanned aerial vehicle (UAV); and at least two burn wires in contact with a portion of a string configured to secure a door of the UAV, wherein each burn wire of the at least two burn wires is attached to a respective radio module of the at least two radio modules; a first panel configured to attach to a portion of the UAV; and a second panel configured to attach to a portion of the UAV distal from the first latch; wherein the string is configured to be connected between the first panel and the second panel; and wherein at least one of the at least two radio modules are configured to receive a burn signal from at least one of: the GCS and the FCC, wherein current from a backup battery passes to a corresponding burn wire of the at least two burn wires based on receiving the burn signal, wherein the corresponding burn wire is attached to the radio module that is configured to receive the burn signal.
2. The system of claim 1, wherein the string is configured to secure the door of the UAV shut.
3. The system of claim 2, wherein each burn wire is configured to melt the portion of the string in contact with each burn wire causing the connection between the first panel and the second panel to be broken.
4. The system of claim 3, wherein the door of the UAV is separated from a rest of the UAV when the connection between the first panel and the second panel is broken.
5. The system of claim 1, further comprising: a parachute disposed in the UAV, wherein the parachute is configured to be deployed when the door of the UAV is separated from the UAV.
6. The system of claim 5, wherein the parachute is disposed off-center of the UAV.
7. The system of claim 6, wherein deploying the parachute causes a drag force on a first side of the UAV, wherein the drag force slows down the first side of the UAV more than a second opposite side of the UAV inducing a torque on the UAV which results in a rotation of the UAV.
8. The system of claim 7, wherein the drag force combined with the induced torque causes the UAV to exit a current flight pattern and spiral down towards the ground.
9. The system of claim 1, wherein the at least two radio modules comprise: a first radio module; and a second radio module.
10. The system of claim 7, wherein the first radio module comprises: an antenna; and an interface configured to receive the burn signal from the antenna, wherein the interface toggles the backup battery to pass current to a first burn wire of the at least two burn wires.
11. The system of claim 1, wherein the ground control station is in communication with a terrestrial GPS receiver, a terrestrial RF emitter, a terrestrial RF receiver, and a visual band emitter.
12. The system of claim 1, wherein the string is made of a combustible material.
13. The system of claim 1, wherein the at least two burn wires are made of nichrome (NiCr).
14. The system of claim 1, wherein the FCC of the UAV determines that an emergency landing of the UAV is needed, and wherein the FCC of the UAV generates the burn signal in response to the determination that the emergency landing of the UAV is needed.
15. A method comprising: receiving a burn signal at an interface of a radio module of two or more radio modules from at least one of: a ground control station (GCS) and a flight control computer (FCC) of an unmanned aerial vehicle (UAV); toggling, via the interface, at least one backup battery to pass current from the at least one backup battery to a conducting burn wire attached to the radio module of two or more radio modules, wherein the conducting burn wire is attached to a portion of a string; and melting, by the conducting burn wire, the portion of the string, wherein the string is connected between a first panel and a second panel.
16. The method of claim 15, wherein the string is made of a combustible material, and wherein the conducting burn wire is made of nichrome (NiCr).
17. The method of claim 15, wherein the first panel is configured to attach to the door of the UAV, wherein the second panel is configured to attach to a portion of the UAV distal from the first panel.

18. The method of claim 17, further comprising: separating the door of the UAV from a rest of the UAV when the connection between the first latch and the second latch is broken.

19. The method of claim 16, further comprising: deploying an off-center parachute when the door of the UAV separates from the UAV, wherein deploying the parachute causes a drag force on a first side of the UAV, wherein the drag force slows down the first side of the UAV more than a second opposite side of the UAV inducing a torque on the UAV which results in a rotation of the UAV, and wherein the drag force combined with the induced torque causes the UAV to exit a current flight pattern and spiral down towards the ground.

20. The method of claim 19, further comprising: determining, by the FCC of the UAV, that an emergency landing of the UAV is needed; and generating, by the FCC of the UAV, the burn signal in response to the determination that the emergency landing of the UAV is needed.