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METHOD FOR RETRIEVING A FIXED-WING AIRCRAFT WITHOUT A RUNWAY

This patent application is directly related to U.S. Provisional Patent Application 60/138,060, filed June 8, 1999, and to U.S. Patent Application 09/426,042, filed October 25, 1999, the contents of which are hereby incorporated by reference in their entirety and relied upon.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention addresses the problem of landing a small fixed-wing aircraft aboard a ship or in a space offering insufficient room for a runway, for example, on the roof of a building. The method involves the aircraft engaging a cable or cables held aloft by a kite, balloon, kite/balloon hybrid, aircraft, or mast. The aircraft is decelerated by the cable and then lowered to the deck.

2. Description of the Prior Art

Operation of small unmanned aircraft may call for retrieval where space is insufficient for a normal landing run, *e.g.*, aboard a boat. Current methods require the aircraft to fly into a net (*e.g.*, U.S. Patents 4,056,247; 4,143,840; 4,456,205; 4,979,701; 5,109,788) or to deploy a parachute (*e.g.*, U.S. Patents 3,980,259; 4,311,290). Net techniques have disadvantages including: (1) difficulty of precise targeting, especially when the approach is through the turbulent wake of a ship's superstructure or when the ship is rocking, with associated high



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risk of damage if the aircraft enters the net incorrectly; (2) significant risk of damage even when the net entry is correct; (3) hazard to staff and equipment aboard ship; (4) complexity and cost of the net and associated apparatus; and (5) requirement for a large deck space.

Parachute techniques have disadvantages including: (1) weight and complexity of equipment aboard the aircraft; and (2) difficulty of precise landing, and associated risk of damage.

3. Objects and Advantages

An object of the present invention is to improve upon current techniques in the following respects:

1. Easier targeting;
2. Less risk of damage to the aircraft if the target is missed;
3. Reduced hazard to staff and equipment on the surface;
4. Simpler apparatus, with lower cost and easier assembly and dismantling;
5. Smaller requirement for deck space, with associated feasibility of use even on small boats.

These improvements are realised through a combination of two distinct and novel concepts:

1. Use of a balloon, kite, crane, or mast to suspend the retrieval apparatus; and
2. Capture of the aircraft by a single cable having generally vertical orientation or, more precisely, whose orientation includes a significant component normal to a plane

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containing the aircraft's line of approach, and a line along the wing leading edge or other component of the aircraft intended to strike the cable.

Use of these concepts is particularly applicable to small aircraft, *i.e.*, weighing not more than a few tens of kilograms, since the size of the apparatus then becomes quite practical for routine use.

SUMMARY OF THE INVENTION

This invention calls for a kite, balloon, or mast to hold aloft one or more cables, the suspension force on each cable being sufficient also to support the aircraft to be retrieved. The aircraft flies into the cable such that contact is made on the wing leading edge or other spanwise surface. As the aircraft moves forward against the cable, the contact force causes the aircraft to decelerate and rotate toward the cable; the cable meanwhile moves spanwise on the aircraft until it encounters one of a number of hooks. Each hook has a spring catch or like mechanism such that the cable is captured upon engagement and will not subsequently be released until the aircraft is retrieved. After the cable is thus captured, the aircraft continues to decelerate until it no longer has flying speed. Retrieval can then be effected by sliding the aircraft along the cable, or by reeling the cable itself to the retrieval area.

More generally, the present invention is a method and an apparatus for capturing a flying object. The apparatus includes a linear fixture; a means for suspending the fixture across the path of the flying object; and means for capturing the flying object with the fixture.

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The method comprises suspending the linear fixture such that its orientation includes a component normal to the flying object's line of approach; directing the flying object to strike the fixture, which causes the flying object to rotate and decelerate, while the fixture slides along a surface of the flying object into a hook; capturing the fixture in the hook; and retrieving the flying object from the fixture.

In preferred embodiments of the apparatus and method, the linear fixture is a cable or pole; the means for suspending the linear fixture is selected from the group consisting of a kite, a balloon, a kite/balloon hybrid, an aircraft, a mast and a crane; and the means for capturing the flying object is at least one hook on a surface of the flying object. In another preferred embodiment, the hook further includes a cleat or latch.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will more fully be understood with reference to the attached drawings of example embodiments, in which:

FIG. 1 is a diagrammatic side view of an aircraft approaching a ship for retrieval by a kite and tether;

FIG. 2 is a diagrammatic side view of an alternative embodiment, in which the kite suspends a capture cable separate from the tether;

FIG. 3 is a diagrammatic side view of the same apparatus, showing retrieval of the aircraft onto the ship;

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- FIG. 4** is a diagrammatic isometric view of another embodiment, in which the capture cable is suspended by a mast rather than by a kite;
- FIG. 5** is a diagrammatic isometric view of the same apparatus, during deceleration of the aircraft;
- FIG. 6** is a diagrammatic isometric view of the same apparatus, during retrieval of the aircraft onto the ship;
- FIG. 7** is a diagrammatic plane view of the wing of the aircraft, including hooks for capturing the cable;
- FIG. 8** is a diagrammatic isometric view of a capture hook;
- FIG. 9** is a diagrammatic top view of an aircraft and kite tether during recovery;
- FIG. 10** is a diagrammatic side view of an aircraft and kite tether during recovery.

DETAILED DESCRIPTION OF THE INVENTION

The present invention reveals a method and an apparatus for capturing a flying object. The invention will more fully be described with reference to the following drawings.

FIG. 1 shows a side view of a kite 1 anchored by its tether 2 to a boat 3, the tether 2 optionally being fitted with stops 4 at intervals along its length to prevent the aircraft 5 from sliding freely to the bottom of the tether 2 during capture. The aircraft 5 is brought aboard the boat 3 by lowering the kite 1.

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FIG. 2 shows a variation on the concept in which the kite 1 suspends a second cable 6 tensioned by a weight 7 (or alternatively by a sea anchor). This arrangement has the advantage that whereas the lift force generated by the kite 1, and therefore the tension in its tether 2, must be greater than the weight of the aircraft 5, in the second cable 6 the tension can be smaller. The decelerating force on the aircraft 5 scales approximately with the ratio of cable tension to cable length. Hence if the apparatus is sized for a predetermined maximum deceleration, the possibility of making the tension in the second cable 6 relatively low allows the kite tether 2 to be made shorter in the embodiment of **FIG. 2** than in that of **FIG. 1**.

A second advantage of the embodiment of **FIG. 2** is that after capture the aircraft 5 can be brought aboard the boat 3 without lowering the kite, for example by reeling in a drawstring 10 to eliminate slack from the capture cable 6, and then, as shown in **FIG. 3**, by spooling the capture cable 6 around a pulley 8 attached to the kite 1.

FIG. 4 shows a mast 9 suspending a capture cable 10 over the side of a ship 11. A spreader pole 12 holds the capture cable 10 in the desired position at deck level. The cable 10 slides through a guide on the spreader pole 12 into the water 13, where the weight and drag of a sea anchor, or simply a length of cable underwater, maintain cable tension. The aircraft 14 approaches off the side of the ship 11, and strikes the cable 10 on the fuselage or the leading edge of the wing. In either case, the cable 10 moves outward along the wing leading edge, causing the aircraft 14 to yaw toward the cable 10, and the cable 10 to slide into a hook on the wing. Several such cables may be suspended in order to maximize the probability of

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capture, with the cables spaced outward from the ship at intervals comparable to the wing span of the aircraft 14.

FIG. 5 shows the aircraft 14 during deceleration, with its wing tip 15 hooked to the capture cable 10. The capture cable is made compliant, for example, by elastic cord or a constant-tension winch, in order to limit deceleration and dissipate the energy of the aircraft.

Additional dissipation is provided by aerodynamic drag on the aircraft and cable, and by the drag of the cable 10 through the water 13.

FIG. 6 shows retrieval of the aircraft 14 onto the ship 11. The spreader pole 12 is rotated alongside, and the aircraft 14 pulled aboard ship while the cable 10 is lowered from the mast 9.

FIG. 7 shows the upper surface of a wing 16 designed to intercept a capture cable 17. Any number of capture hooks could be placed along the wing leading edge 18. In this embodiment only two such hooks 19 are installed at the wing tips.

FIG. 8 shows the wingtip hook 19 in more detail. Many different designs could be used for the hook. Its essential function is to capture the cable 17 as it moves spanwise, and to prevent subsequent escape. Thus in this case, after making contact with the wing 16, the capture cable 17 slides outward along the leading edge 18 and strikes a gate 21 in the hook 19. The hook is spring-loaded into the forward position 19, but the cable 17 pulls the hook 19 around a hinge line 20. As the cable 17 continues spanwise it pushes through the gate 21 into a

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tapered slot 22 in the hook 19. The tapered slot 22 clamps the cable 23 in the manner of a jam cleat. Meanwhile the gate 24 springs back to the closed position so that the cable cannot escape.

FIGS. 9 and 10 shows stages in an example of capture by a kite tether. At first contact, the aircraft 25 strikes the capture cable 26 at a point near the wing root 27. The aircraft in this example has a pusher propellor 28, and an inverted-vee tail 29 mounted on twin tailbooms 30. After contact, the aircraft begins to yaw, roll, and descend, while the cable slides outward along the wing leading edge, the aircraft and cable reaching the positions marked 31 and 32, respectively, at the moment of capture in a hook at the wing tip. The yaw and roll then increase, and for most of the subsequent deceleration the attitude of the aircraft is comparable to that in position 33. At low speed, the aircraft drops below the cable 34, until finally it is left dangling. The aircraft can then be retrieved.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but on the contrary is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. Thus, it is to be understood that variations can be made without departing from the novel aspects of this invention as defined in the claims. All patents and articles cited herein are hereby incorporated by reference in their entirety and relied upon.

CLAIMS

1. An apparatus for capturing a flying object having a spanwise lifting surface with a capture device and flying along a flight path, the apparatus comprising:
a generally linear, curvilinear or linear and curvilinear fixture positionable in the flight path of the flying object, at least a portion of the fixture being inclined at an angle relative to the spanwise lifting surface to intersect the spanwise lifting surface, the fixture having an engaging surface positioned to engage the capture device of the flying object to releasably secure the flying object to the fixture; and
a support structure coupled to the fixture and positioned to support the fixture in the flight path.
2. The apparatus of claim 1, wherein the fixture includes a cable or pole.
3. The apparatus of claim 1, wherein the support structure includes at least one of a kite, a balloon, a kite/balloon hybrid, an aircraft, a mast and a crane.
4. The apparatus of claim 1, further comprising the flying object and the capture device, and wherein the capture device includes at least one hook on the spanwise lifting surface of the flying object.
5. The apparatus of claim 4, wherein each hook includes at least one of a cleat and a latch.
6. The apparatus of claim 1, wherein the fixture includes at least one of a cable and a pole, and wherein the support structure includes at least one of a kite, a balloon, a kite/balloon hybrid, an aircraft, a mast and a crane, and wherein the apparatus further comprises the flying object and the capture device, the capture device including at least one hook on the spanwise lifting surface of the flying object.
7. The apparatus of claim 6, wherein each hook further includes at least one of a cleat and a latch.

8. A method for capturing a flying object, comprising:
allowing a spanwise lifting surface of a flying object to strike a generally linear, curvilinear or linear and curvilinear fixture positioned at an angle relative to the spanwise lifting surface while imparting a decelerating force to the flying object;
releasably engaging the fixture with a capture device on the flying object;
and
retrieving the flying object.
9. The method of claim 8, further comprising selecting the fixture to include at least one of a cable and a pole.
10. The method of claim 8, further comprising suspending the fixture from at least one of a kite, a balloon, a kite/balloon hybrid, an aircraft, a mast and a crane.
11. The method of claim 8, wherein releasably engaging the fixture with a capture device includes engaging the fixture with at least one hook on a surface of the flying object.
12. The method of claim 8, further comprising positioning a generally linear or curvilinear fixture includes suspending a cable or pole from at least one of a kite, a balloon, a kite/balloon hybrid, an aircraft, a mast and a crane, and wherein releasably engaging the fixture with a capture device of the flying object includes engaging the fixture with at least one hook on the spanwise lifting surface of the flying object.
13. The method of claim 12, further comprising selecting each hook to include a cleat or latch.
14. The method of claim 8, further comprising orienting the fixture at an angle approximately normal to the spanwise lifting surface.

15. The apparatus of claim 1 wherein the support structure includes a kite.
16. The apparatus of claim 1 wherein the support structure includes a balloon.
17. The apparatus of claim 1 wherein the support structure includes a kite/balloon hybrid.
18. The apparatus of claim 1 wherein the support structure includes an aircraft.
19. The apparatus of claim 1 wherein the support structure includes a mast.
20. The apparatus of claim 1 wherein the support structure includes a crane.
21. The apparatus of claim 1, further comprising the flying object, and wherein the spanwise lifting surface of the flying object has a swept leading edge.
22. The apparatus of claim 1, further comprising the flying object, and wherein the spanwise lifting surface of the flying object has an aft swept leading edge.
23. The apparatus of claim 1, further comprising the flying object, and wherein the capture device is positioned at least proximate to an outboard tip of the spanwise lifting surface.
24. The apparatus of claim 1, further comprising the flying object, and wherein the flying object has a swept aerodynamic center.
25. The method of claim 8 wherein positioning the fixture includes positioning a kite.
26. The method of claim 8 wherein positioning the fixture includes positioning a balloon.

27. The method of claim 8 wherein positioning the fixture includes positioning a kite/balloon hybrid.

28. The method of claim 8 wherein positioning the fixture includes positioning an aircraft.

29. The method of claim 8 wherein positioning the fixture includes positioning a mast.

30. The method of claim 8 wherein positioning the fixture includes positioning a crane.

31. The method of claim 8 wherein releasably engaging the fixture includes releasably engaging the fixture with a capture device positioned toward an outboard edge of the spanwise lifting surface.

32. The method of claim 8 wherein allowing the spanwise lifting surface of the flying object to strike the fixture includes allowing a swept spanwise lifting surface of the flying object to strike the fixture.

33. The method of claim 32 wherein allowing a swept portion of a spanwise lifting surface to strike a fixture includes allowing an aft swept portion of a spanwise lifting surface to strike a fixture.

34. The method of claim 32 wherein allowing a swept portion of a spanwise lifting surface to strike a fixture includes allowing a spanwise surface having a swept aerodynamic center to strike a fixture.

35. The method of claim 8, further comprising positioning the fixture in the flight path of the flying object.

36. The method of claim 8, further comprising sliding at least one of the spanwise lifting surface and the fixture relative to the other while the fixture contacts the spanwise lifting surface.