

CLAIMS

1. A method for autonomous safe emergency landing of a powered unmanned aerial vehicle (UAV) in the event of an engine failure, the method comprising the procedures of:

generating a landing approach trajectory, comprising:

- 5 a downwind leg, initiating at an initiation point of the trajectory;
- an upwind leg, terminating at a selected touchdown point; and
- a U-turn leg, joining between the downwind leg and the upwind leg;

directing the UAV to the initiation point to follow the downwind leg of the landing approach trajectory;

- 10 repeatedly determining a glide ratio of the UAV, based on current flight conditions of the UAV;

- repeatedly determining a current turning point along the downwind leg for landing the UAV at the selected touchdown point, the U-turn leg initiating at the current turning point, in which the determination of the current turning point is based on the determined glide ratio and is performed each time with respect to a precedingly determined turning point;
- 15 repeatedly determining a touchdown point corresponding to the current turning point, based on the determined glide ratio, in which the procedure of determining a current turning point is performed with respect to the discrepancy between: (i) the touchdown point that was precedingly determined in correspondence with the precedingly determined turning point, and (ii) the selected touchdown point; and

- 20 when the UAV arrives at the current turning point, directing the UAV to follow the U-turn leg and the upwind leg of the landing approach trajectory, for landing the UAV at the selected touchdown point.

- 25 2. A method according to Claim 1, in which the downwind leg extends along a downwind path, and the upwind leg extends along an upwind path that is substantially parallel to the downwind path, the upwind path extending along the runway on which the selected touchdown point is located.

3. A method according to Claim 1, further comprising the procedures of:

selecting a selected touchdown point, in which a determined prospective height of the UAV over the selected touchdown point is sufficient to enable the UAV to perform the safe emergency landing at the selected touchdown point, and in which the prospective height is determined based on the determined glide ratio; and

5 directing the UAV to glide towards the selected touchdown point, once the engine failure occurs.

4. A method according to Claim 3, in which the selected touchdown point is selected from a database comprising a collection of information relating to a plurality of touchdown points for emergency landing, the information comprising:

10 the direction of the runway on which the respective touchdown point is located; and the geographical location of the respective touchdown point.

5. A method according to Claim 1, further comprising the procedures of:

determining a prospective height of the UAV over the selected touchdown point, based on the determined glide ratio;

15 determining if gliding along a waiting trajectory is possible, based on whether the prospective height of the UAV exceeds a minimum height predefined to enable the safe emergency landing at the selected touchdown point; and

directing the UAV to glide along the waiting trajectory if determined to be possible.

6. A method according to Claim 5, further comprising the procedure of:

20 generating the waiting trajectory, comprising the sub-procedures of:

generating a waiting pattern, located over an area in proximity of the selected touchdown point;

determining a joining point along the waiting pattern;

25 determining an exit point along the waiting pattern from which the UAV can begin following the landing approach trajectory;

directing the UAV to join the waiting pattern at the joining point;

directing the UAV to glide along the waiting pattern; and

directing the UAV to exit the waiting pattern at the exit point.

7. A method according to Claim 6, in which the waiting pattern is circular.
8. A method according to Claim 6, in which the UAV is directed to exit the waiting pattern once the UAV descends below a predefined exit height that is of sufficient height for the UAV to perform the safe emergency landing at the selected touchdown point.
- 5 9. A method according to Claim 6, in which the waiting trajectory is tangential to the downwind leg of the landing approach trajectory, and in which an exit point of the waiting trajectory and an initiation point of the landing approach trajectory are determined to be located at the tangency point of the waiting trajectory and the downwind leg.
- 10 10. A method according to Claim 1, further comprising the procedure of continuously measuring the current flight conditions with sensors mounted onboard the UAV, in which the flight conditions are selected from the list consisting of:
 - location and navigation information of the UAV;
 - level of fuel onboard the UAV; and
 - atmospheric conditions in the vicinity of the UAV.
- 15 11. A method according to Claim 1, in which the procedure of repeatedly determining a glide ratio of the UAV comprises auto-learning the glide ratio by iteratively determining the glide ratio until convergence to a definite value, in which the auto-learning is at least partially empiric.
- 20 12. A method according to Claim 11, in which the auto-learning initiates once the UAV begins following the landing approach trajectory.
13. A method according to Claim 1, in which the UAV operates autonomously.
14. A method according to Claim 1, in which the U-turn leg is semi-circular.
15. A powered unmanned aerial vehicle (UAV) operable to perform an autonomous safe emergency landing in the event of an engine failure, the UAV comprising:
 - 25 a flight control system for controlling the flight of the UAV, the flight control system comprising a processing unit;
 - a safe emergency landing system coupled with the flight control system, the safe emergency landing system comprising a storage device readable by the processing unit

of the flight control system, tangibly embodying a program of instructions executable by the processing unit to perform method procedures for safe emergency landing of the unmanned aerial vehicle in the event of an engine failure, the method procedures comprising:

5 generating a landing approach trajectory, comprising:

a downwind leg, initiating at an initiation point of the trajectory;

an upwind leg, terminating at a selected touchdown point; and

a U-turn leg, joining between the downwind leg and the upwind leg;

10 providing the landing approach trajectory to the flight control system, for directing the UAV to the initiation point to follow the downwind leg;

repeatedly determining a glide ratio of the UAV, based on current flight conditions of the UAV;

15 repeatedly determining a current turning point along the downwind leg for landing the UAV at the selected touchdown point, the U-turn leg initiating at the current turning point, in which the determination of the current turning point is based on the determined glide ratio and is performed each time with respect to a precedingly determined turning point;

20 repeatedly determining a touchdown point corresponding to the current turning point, based on the determined glide ratio, in which the procedure of determining a current turning point is performed with respect to the discrepancy between: (i) the touchdown point that was precedingly determined in correspondence with the precedingly determined turning point, and (ii) the selected touchdown point;

repeatedly providing the current turning point to the flight control system, for directing the UAV to glide towards the current turning point; and

25 when the UAV arrives at the current turning point, indicating to the flight control system to direct the UAV to follow the U-turn leg and the upwind leg of the landing approach trajectory, for landing the UAV at the selected touchdown point.

16. An UAV according to Claim 15, in which the flight conditions are selected from the list consisting of:

location and navigation information of the UAV;

level of fuel onboard the UAV; and

atmospheric conditions in the vicinity of the UAV.

17. An UAV according to Claim 16, further comprising at least one sensor selected from the
5 list consisting of:

a sensor for continuously providing the location and navigation information;

a sensor for continuously indicating the level of fuel;

a sensor for continuously providing the atmospheric information.

18. An UAV according to Claim 15, in which the downwind leg extends along a downwind
10 path, and the upwind leg extends along an upwind path that is substantially parallel to the
downwind path, the upwind path extending along the runway on which the selected
touchdown point is located.

19. An UAV according to Claim 15, in which the safe emergency landing system is
incorporated with the flight control system.

15 20. An UAV according to Claim 15, further comprising a database comprising a collection
of touchdown points for emergency landing of the UAV, in which the program of instructions
of the safe emergency landing system is executable to further perform the method procedure
of selecting the selected touchdown point from the collection of touchdown points, in which a
determined prospective height of the UAV over the selected touchdown point is sufficient to
20 enable the UAV to perform the safe emergency landing at the selected touchdown point, and
in which the prospective height is determined based on the determined glide ratio.

21. An UAV according to Claim 15, in which the program of instructions of the emergency
landing system is executable to further perform the method procedures of:

25 determining a prospective height of the UAV over the selected touchdown point, based
on the determined glide ratio;

determining if gliding along a waiting trajectory is possible, based on whether the
prospective height of the UAV exceeds a minimum height predefined to enable the safe
emergency landing at the selected touchdown point; and

indicating to the flight control system to direct the UAV to glide along the waiting trajectory if determined to be possible.

22. An UAV according to Claim 21, in which the program of instructions of the emergency landing system is executable to further perform the method procedures of:

5 generating the waiting trajectory, comprising the sub-procedures of:

generating a waiting pattern, located over an area in proximity of the selected touchdown point;

determining a joining point along the waiting pattern; and

determining an exit point along the waiting pattern from which the UAV can begin

10 following the landing approach trajectory;

providing the generated waiting trajectory to the flight control system for directing the UAV to join the waiting pattern at the joining point, to glide along the waiting pattern, and to exit the waiting pattern at the exit point.

23. An UAV according to Claim 15, in which the method procedure of repeatedly
15 determining a glide ratio of the UAV comprises auto-learning the glide ratio by iteratively determining the glide ratio until convergence to a definite value, in which the auto-learning is at least partially empiric.

24. A system for mounting on a powered unmanned aerial vehicle (UAV) to allow safe
20 emergency landing of the UAV in the event of an engine failure, the system coupled with a flight control system of the UAV, the system comprising:

a storage device readable by a processing unit of the flight control system, tangibly embodying a program of instructions executable by the processing unit to perform method procedures comprising:

generating a landing approach trajectory, comprising:

25 a downwind leg, initiating at an initiation point of the trajectory;

an upwind leg, terminating at a selected touchdown point; and

a U-turn leg, joining between the downwind leg and the upwind leg;

providing the landing approach trajectory to the flight control system, for directing the UAV to the initiation point to follow the downwind leg;

repeatedly determining a glide ratio of the UAV, based on current flight conditions of the UAV;

5 repeatedly determining a current turning point along the downwind leg for landing the UAV at the selected touchdown point, the U-turn leg initiating at the current turning point, in which the determination of the current turning point is based on the determined glide ratio and is performed each time with respect to a precedingly determined turning point;

10 repeatedly determining a touchdown point corresponding to the current turning point, based on the determined glide ratio, in which the procedure of determining a current turning point is performed with respect to the discrepancy between: (i) the touchdown point that was precedingly determined in correspondence with the precedingly determined turning point, and (ii) the selected touchdown point;

15 repeatedly providing the current turning point to the flight control system, for directing the UAV to glide towards the current turning point; and
when the UAV arrives at the current turning point, indicating to the flight control system to direct the UAV to follow the U-turn leg and the upwind leg of the landing approach trajectory, for landing the UAV at the selected touchdown point.

CLAIMS

1. A method for autonomous safe emergency landing of a powered unmanned aerial vehicle (UAV) in the event of an engine failure, the method comprising the procedures of:

generating a landing approach trajectory, comprising:

5 a downwind leg, initiating at an initiation point of the trajectory, the downwind leg directed toward a first direction of a runway;

an upwind leg, extending along the runway and terminating at a selected touchdown point located on the runway, the upwind leg being substantially parallel to the downwind leg and directed toward a second direction of the runway
10 opposite to the first direction; and

a U-turn leg, joining between the downwind leg and the upwind leg;

directing the UAV to the initiation point to follow the downwind leg of the landing approach trajectory;

15 repeatedly determining a glide ratio of the UAV, based on current flight conditions of the UAV;

repeatedly determining a current turning point along the downwind leg for landing the UAV at the selected touchdown point, the U-turn leg initiating at the current turning point, in which the determination of the current turning point is based on the determined glide ratio and is performed each time with respect to a precedingly determined turning
20 point;

repeatedly determining a touchdown point corresponding to the current turning point, based on the determined glide ratio, in which the procedure of determining a current turning point is performed with respect to the discrepancy between: (i) the touchdown point that was precedingly determined in correspondence with the precedingly
25 determined turning point, and (ii) the selected touchdown point; and

when the UAV arrives at the current turning point, directing the UAV to follow the U-turn leg and the upwind leg of the landing approach trajectory, for landing the UAV at the selected touchdown point.

2. A method according to Claim 1, further comprising the procedures of:

selecting a selected touchdown point, in which a determined prospective height of the UAV over the selected touchdown point is sufficient to enable the UAV to perform the safe emergency landing at the selected touchdown point, and in which the prospective height is determined based on the determined glide ratio; and

5 directing the UAV to glide towards the selected touchdown point, once the engine failure occurs.

3. A method according to Claim 2, in which the selected touchdown point is selected from a database comprising a collection of information relating to a plurality of touchdown points for emergency landing, the information comprising:

10 the direction of the runway on which the respective touchdown point is located; and
the geographical location of the respective touchdown point.

4. A method according to any preceding claim, further comprising the procedures of:

determining a prospective height of the UAV over the selected touchdown point, based on the determined glide ratio;

15 determining if gliding along a waiting trajectory is possible, based on whether the prospective height of the UAV exceeds a minimum height predefined to enable the safe emergency landing at the selected touchdown point; and

directing the UAV to glide along the waiting trajectory if determined to be possible.

5. A method according to Claim 4, further comprising the procedure of:

20 generating the waiting trajectory, comprising the sub-procedures of:

generating a waiting pattern, located over an area in proximity of the selected touchdown point;

determining a joining point along the waiting pattern;

determining an exit point along the waiting pattern from which the UAV can begin
25 following the landing approach trajectory;

directing the UAV to join the waiting pattern at the joining point;

directing the UAV to glide along the waiting pattern; and

directing the UAV to exit the waiting pattern at the exit point.

6. A method according to Claim 5, in which the waiting pattern is circular.
7. A method according to Claim 5 or 6, in which the UAV is directed to exit the waiting pattern once the UAV descends below a predefined exit height that is of sufficient height for the UAV to perform the safe emergency landing at the selected touchdown point.
- 5 8. A method according to Claim 5, 6 or 7, in which the waiting trajectory is tangential to the downwind leg of the landing approach trajectory, and in which an exit point of the waiting trajectory and an initiation point of the landing approach trajectory are determined to be located at the tangency point of the waiting trajectory and the downwind leg.
9. A method according to any preceding claim, further comprising the procedure of
- 10 continuously measuring the current flight conditions with sensors mounted onboard the UAV, in which the flight conditions are selected from the list consisting of:
 - location and navigation information of the UAV;
 - level of fuel onboard the UAV; and
 - atmospheric conditions in the vicinity of the UAV.
- 15 10. A method according to any preceding claim, in which the procedure of repeatedly determining a glide ratio of the UAV comprises auto-learning the glide ratio by iteratively determining the glide ratio until convergence to a definite value, in which the auto-learning is at least partially empiric.
11. A method according to Claim 10, in which the auto-learning initiates once the UAV
- 20 begins following the landing approach trajectory.
12. A method according to any preceding claim, in which the UAV operates autonomously.
13. A method according to any preceding claim, in which the U-turn leg is semi-circular.
14. A powered unmanned aerial vehicle (UAV) operable to perform an autonomous safe emergency landing in the event of an engine failure, the UAV comprising:
 - 25 a flight control system for controlling the flight of the UAV, the flight control system comprising a processing unit;
 - a safe emergency landing system coupled with the flight control system, the safe emergency landing system comprising a storage device readable by the processing unit

of the flight control system, tangibly embodying a program of instructions executable by the processing unit to perform method procedures for safe emergency landing of the unmanned aerial vehicle in the event of an engine failure, the method procedures comprising:

5 generating a landing approach trajectory, comprising:

a downwind leg, initiating at an initiation point of the trajectory, the downwind leg directed toward a first direction of a runway;

10 an upwind leg, extending along the runway and terminating at a selected touchdown point located on the runway, the upwind leg being substantially parallel to the downwind leg and directed toward a second direction of the runway opposite to the first direction; and

a U-turn leg, joining between the downwind leg and the upwind leg;

providing the landing approach trajectory to the flight control system, for directing the UAV to the initiation point to follow the downwind leg;

15 repeatedly determining a glide ratio of the UAV, based on current flight conditions of the UAV;

20 repeatedly determining a current turning point along the downwind leg for landing the UAV at the selected touchdown point, the U-turn leg initiating at the current turning point, in which the determination of the current turning point is based on the determined glide ratio and is performed each time with respect to a precedingly determined turning point;

25 repeatedly determining a touchdown point corresponding to the current turning point, based on the determined glide ratio, in which the procedure of determining a current turning point is performed with respect to the discrepancy between: (i) the touchdown point that was precedingly determined in correspondence with the precedingly determined turning point, and (ii) the selected touchdown point;

repeatedly providing the current turning point to the flight control system, for directing the UAV to glide towards the current turning point; and

when the UAV arrives at the current turning point, indicating to the flight control system to direct the UAV to follow the U-turn leg and the upwind leg of the landing approach trajectory, for landing the UAV at the selected touchdown point.

15. An UAV according to Claim 14, in which the flight conditions are selected from the list
5 consisting of:

location and navigation information of the UAV;

level of fuel onboard the UAV; and

atmospheric conditions in the vicinity of the UAV.

16. An UAV according to Claim 15, further comprising at least one sensor selected from the
10 list consisting of:

a sensor for continuously providing the location and navigation information;

a sensor for continuously indicating the level of fuel;

a sensor for continuously providing the atmospheric information.

17. An UAV according to any of Claims 14 to 16, in which the safe emergency landing
15 system is incorporated with the flight control system.

18. An UAV according to any of Claims 14 to 17, further comprising a database comprising
a collection of touchdown points for emergency landing of the UAV, in which the program of
instructions of the safe emergency landing system is executable to further perform the method
procedure of selecting the selected touchdown point from the collection of touchdown points,
20 in which a determined prospective height of the UAV over the selected touchdown point is
sufficient to enable the UAV to perform the safe emergency landing at the selected touchdown
point, and in which the prospective height is determined based on the determined glide ratio.

19. An UAV according to any of Claims 14 to 18, in which the program of instructions of
the emergency landing system is executable to further perform the method procedures of:

25 determining a prospective height of the UAV over the selected touchdown point, based
on the determined glide ratio;

determining if gliding along a waiting trajectory is possible, based on whether the prospective height of the UAV exceeds a minimum height predefined to enable the safe emergency landing at the selected touchdown point; and

indicating to the flight control system to direct the UAV to glide along the waiting trajectory if determined to be possible.

20. An UAV according to Claim 19, in which the program of instructions of the emergency landing system is executable to further perform the method procedures of:

generating the waiting trajectory, comprising the sub-procedures of:

generating a waiting pattern, located over an area in proximity of the selected touchdown point;

determining a joining point along the waiting pattern; and

determining an exit point along the waiting pattern from which the UAV can begin following the landing approach trajectory;

providing the generated waiting trajectory to the flight control system for directing the UAV to join the waiting pattern at the joining point, to glide along the waiting pattern, and to exit the waiting pattern at the exit point.

21. An UAV according to any of Claims 14 to 20, in which the method procedure of repeatedly determining a glide ratio of the UAV comprises auto-learning the glide ratio by iteratively determining the glide ratio until convergence to a definite value, in which the auto-learning is at least partially empiric.

22. A system for mounting on a powered unmanned aerial vehicle (UAV) to allow safe emergency landing of the UAV in the event of an engine failure, the system coupled with a flight control system of the UAV, the system comprising:

a storage device readable by a processing unit of the flight control system, tangibly embodying a program of instructions executable by the processing unit to perform method procedures comprising:

generating a landing approach trajectory, comprising:

a downwind leg, initiating at an initiation point of the trajectory, the downwind leg directed toward a first direction of a runway;

an upwind leg, extending along the runway and terminating at a selected touchdown point located on the runway, the upwind leg being substantially parallel to the downwind leg and directed toward a second direction of the runway opposite to the first direction; and

5 a U-turn leg, joining between the downwind leg and the upwind leg;

providing the landing approach trajectory to the flight control system, for directing the UAV to the initiation point to follow the downwind leg;

repeatedly determining a glide ratio of the UAV, based on current flight conditions of the UAV;

10 repeatedly determining a current turning point along the downwind leg for landing the UAV at the selected touchdown point, the U-turn leg initiating at the current turning point, in which the determination of the current turning point is based on the determined glide ratio and is performed each time with respect to a precedingly determined turning point;

15 repeatedly determining a touchdown point corresponding to the current turning point, based on the determined glide ratio, in which the procedure of determining a current turning point is performed with respect to the discrepancy between: (i) the touchdown point that was precedingly determined in correspondence with the precedingly determined turning point, and (ii) the selected touchdown point;

20 repeatedly providing the current turning point to the flight control system, for directing the UAV to glide towards the current turning point; and

when the UAV arrives at the current turning point, indicating to the flight control system to direct the UAV to follow the U-turn leg and the upwind leg of the landing approach trajectory, for landing the UAV at the selected touchdown point.

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