

AMENDED CLAIMS
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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:

5 generating a landing approach trajectory, comprising:

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

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

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

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

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

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

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

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

2. The method of claim 1, wherein said downwind leg extends along a downwind path, and said upwind leg extends along an upwind path that is substantially parallel to said downwind path, said upwind path
15 extending along the runway on which said selected touchdown point is located.

4. The method of claim 1, further comprising the procedures of:
selecting a selected touchdown point, wherein a determined
20 prospective height of said UAV over said selected touchdown point is sufficient to enable said UAV to perform said safe emergency landing

at said selected touchdown point, and wherein said prospective height is determined based on said determined glide ratio; and

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

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5. The method of claim 4, wherein said 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.

6. The method of claim 1, further comprising the procedures of:

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

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

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

7. The method of claim 6, further comprising the procedure of:

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

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

 determining a joining point along said waiting pattern;

10 determining an exit point along said waiting pattern wherefrom said UAV can begin following said landing approach trajectory;

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

15 directing said UAV to glide along said waiting pattern; and

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

8. The method of claim 7, wherein said waiting pattern is circular.

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9. The method of claim 7, wherein said UAV is directed to exit said waiting pattern once said UAV descends below a predefined exit height that is of sufficient height for said UAV to perform said safe emergency landing at said selected touchdown point.

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10. The method of claim 7, wherein said waiting trajectory is tangential to said downwind leg of said landing approach trajectory, and wherein an exit point of said waiting trajectory and an initiation point of said landing approach trajectory are determined to be located at the tangency point of said waiting trajectory and said downwind leg.

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11. The method of claim 1, further comprising the procedure of continuously measuring said current flight conditions with sensors mounted onboard said UAV, wherein said flight conditions are selected from the list consisting of:

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location and navigation information of said UAV;

level of fuel onboard said UAV; and

atmospheric conditions in the vicinity of said UAV.

20 12. The method of claim 1, wherein said procedure of repeatedly determining a glide ratio of said UAV comprises auto-learning the

glide ratio by iteratively determining said glide ratio until convergence to a definite value, wherein said auto-learning is at least partially empiric.

5 13. The method of claim 12, wherein said auto-learning initiates once said UAV begins following said landing approach trajectory.

14. The method of claim 1, wherein said UAV operates autonomously.

10 15. The method of claim 1, wherein said U-turn leg is semi-circular.

16. A powered unmanned aerial vehicle (UAV) operable to perform an autonomous safe emergency landing in the event of an engine failure, said UAV comprising:

15 a flight control system for controlling the flight of said UAV, said flight control system comprising a processing unit;

a safe emergency landing system coupled with said flight control system, said safe emergency landing system comprising a storage device readable by said processing unit of said flight control system, tangibly embodying a program of instructions executable by said
20 processing unit to perform method procedures for safe emergency

landing of said unmanned aerial vehicle in the event of an engine failure, the method procedures comprising:

generating a landing approach trajectory, comprising:

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

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

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

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

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

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

repeatedly determining a touchdown point corresponding to said current turning point, based on said determined glide ratio, wherein said 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) said selected touchdown point;

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

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

17. The UAV of claim 16, wherein said flight conditions are selected from the list consisting of:

location and navigation information of said UAV;

level of fuel onboard said UAV; and

atmospheric conditions in the vicinity of said UAV.

18. The UAV of claim 17, further comprising at least one sensor selected from the list consisting of:

a sensor for continuously providing said location and navigation information;

5 a sensor for continuously indicating said level of fuel,

a sensor for continuously providing said atmospheric information.

19. The UAV of claim 16, wherein said downwind leg extends along a downwind path, and said upwind leg extends along an upwind path that is substantially parallel to said downwind path, said upwind path extending along the runway on which said selected touchdown point is located.

20. The UAV of claim 16, wherein said safe emergency landing system is incorporated with said flight control system.

21. The UAV of claim 16, further comprising a database comprising a collection of touchdown points for emergency landing of said UAV, wherein said program of instructions of said safe emergency landing system is executable to further perform the method procedure of

selecting said selected touchdown point from said collection of
touchdown points, wherein a determined prospective height of said
UAV over said selected touchdown point is sufficient to enable said
UAV to perform said safe emergency landing at said selected
5 touchdown point, and wherein said prospective height is determined
based on said determined glide ratio.

22. The UAV of claim 16, wherein said program of instructions of said
emergency landing system is executable to further perform the
10 method procedures of:

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

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

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

23. The UAV of claim 22, wherein said program of instructions of said emergency landing system is executable to further perform the method procedures of:

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

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

determining a joining point along said waiting pattern; and

10 determining an exit point along said waiting pattern wherefrom said UAV can begin following said landing approach trajectory;

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

24. The UAV of claim 16, wherein said method procedure of repeatedly determining a glide ratio of said UAV comprises auto-learning the glide ratio by iteratively determining said glide ratio until convergence
20 to a definite value, wherein said auto-learning is at least partially empiric.

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

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

generating a landing approach trajectory, comprising:

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

an upwind leg, terminating at a selected touchdown point;

and

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

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

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

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

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

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

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

26. 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 said trajectory, said downwind leg extending along a downwind path;

an upwind leg, terminating at a selected touchdown point, said upwind leg extending along an upwind path that is substantially parallel to said downwind path, said upwind path
10 extending along the runway on which said selected touchdown point is located; and

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

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

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

repeatedly determining a current turning point along said downwind leg for landing said UAV at said selected touchdown point,
20 said U-turn leg initiating at said current turning point, wherein the

determination of said current turning point is based on the determined glide ratio; and

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

27. A powered unmanned aerial vehicle (UAV) operable to perform an autonomous safe emergency landing in the event of an engine failure, said UAV comprising:

a flight control system for controlling the flight of said UAV, said flight control system comprising a processing unit;

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

generating a landing approach trajectory, comprising:

a downwind leg, initiating at an initiation point of said trajectory, said downwind leg extending along a downwind path;

an upwind leg, terminating at a selected touchdown point, said upwind leg extending along an upwind path that is substantially parallel to said downwind path, said upwind path extending along the runway on which said selected touchdown point is located; and

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

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

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

repeatedly determining a current turning point along said downwind leg for landing said UAV at said selected touchdown point, said U-turn leg initiating at said current turning point, wherein the determination of said current turning point is based on the determined glide ratio;

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

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

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

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

generating a landing approach trajectory, comprising:

a downwind leg, initiating at an initiation point of said trajectory, said downwind leg extending along a downwind path;

an upwind leg, terminating at a selected touchdown point, said upwind leg extending along an upwind path that is

substantially parallel to said downwind path, said upwind path extending along the runway on which said selected touchdown point is located; and

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

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

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

repeatedly determining a current turning point along said downwind leg for landing said UAV at said selected touchdown point, said U-turn leg initiating at said current turning point, wherein the determination of said current turning point is based on said determined glide ratio;

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

when said UAV arrives at said current turning point, indicating to said flight control system to direct said UAV to follow said U-turn leg and

said upwind leg of said landing approach trajectory, for landing said UAV at said selected touchdown point.

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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;

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.

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 emergency landing of the UAV in the event of an engine failure, the system coupled with a

20 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.