SUMMARY

[0003a] According to an aspect, the present disclosure refers to a method of controlling an electric aircraft that comprises a plurality of actuators that includes a plurality of electric propulsion units, the method comprising: receiving desired force and moment commands for the electric aircraft; determining control commands for the plurality of actuators based on the desired force and moment commands by solving an optimization problem that comprises a noise minimization term for minimizing noise generated by the electric propulsion units; and controlling the plurality of actuators according to the determined control commands to meet the force and moment commands for the electric aircraft, wherein at least a portion of the plurality of electric propulsion units are tiltable, and controlling the plurality of actuators according to the determined control commands comprises at least one of tilting the electric propulsion units and adjusting an attitude of the electric aircraft to minimize edgewise flight time.

[0003b] According to an aspect, the present disclosure refers to a system for controlling an electric aircraft that comprises a plurality of actuators that includes a plurality of electric propulsion units, the system comprising: one or more processors, memory, and one or more programs stored in the memory for execution by the one or more processors to cause the system to perform the method of the above aspect.

[0003c] According to an aspect, the present disclosure refers to an electric aircraft comprising: a plurality of actuators that includes a plurality of electric propulsion units; and the system of the above aspect for controlling the electric aircraft via the plurality of actuators.

[0004] According to some examples, systems and methods for control allocation in an electric VTOL aircraft include accounting for rotor acoustics in controlling the actuators of the aircraft. According to various examples, the control allocation includes solving an optimization objective function that includes meeting force and moment commands as a primary objective and modulating rotor acoustics as a secondary objective. In some examples, rotor acoustics are modulated by minimizing edgewise flight, varying the rotor speeds across the set of rotors, and/or minimizing propeller tip speed.

[0005] According to some examples, systems and methods for control allocation include accounting for battery pack charge in controlling actuators of the aircraft.

In some examples, an electric VTOL aircraft includes a plurality of battery packs that are electrically isolated from one another and power one or more electric propulsion units. The control allocation can include solving an optimization objective function that includes meeting force and moment commands as a primary objective and balancing energy usage of the battery packs as a secondary objective. In some examples, electric propulsion units energized by battery packs with greater charge are preferentially utilized.

[0006] According to various examples, a method of controlling an electric aircraft that comprises a plurality of actuators that includes a plurality of electric propulsion units includes: receiving force and moment commands for the electric aircraft; determining control commands for the plurality of actuators based on the desired force and moment commands by solving an optimization problem that comprises a noise minimization term for minimizing noise generated by the electric propulsion units; and controlling the plurality of actuators according to the determined control commands to meet the force and moment commands for the electric aircraft.

[0007] In any of these examples, controlling the plurality of actuators according to the determined control commands may include operating at least a first electric propulsion unit of a plurality of electric propulsion units at a different speed than at least a second electric propulsion unit of the plurality of electric propulsion units to spread frequencies of the plurality of electric propulsion units across a wider frequency band.

[0008] In any of these examples, electric propulsion units closer to a fuselage of the aircraft may be operated at lower speeds than electric propulsion units further from the fuselage to reduce noise at the fuselage.

[0009] In any of these examples, electric propulsion units may be operated at different speeds during straight-ahead flight.

[0010] In any of these examples, at least a portion of the plurality of electric propulsion units may be tiltable, and controlling the plurality of actuators according to the determined control commands may include at least one of tilting the electric propulsion units and adjusting an attitude of the aircraft to minimize edgewise flight time.

[0011] In any of these examples, controlling the plurality of actuators according to the determined control commands may include setting a pitch of the blades of at least one electric propulsion unit to minimize a speed of the at least one electric propulsion unit.

[0012] In any of these examples, the electric aircraft may be a vertical take-off and landing aircraft.

[0013] In any of these examples, the electric aircraft may be manned.

[0014] In any of these examples, the electric aircraft may include multiple electric propulsion units on either side of a fuselage of the aircraft.

[0015] According to various examples, a system for controlling an electric aircraft that includes a plurality of actuators that includes a plurality of electric propulsion units, includes one or more processors, memory, and one or more programs stored in the memory for execution by the one or more processors for: receiving desired force and moment commands for the electric aircraft; determining control commands for the plurality of actuators based on the desired force and moment commands by solving an optimization problem that comprises a noise minimization term for minimizing noise generated by the electric propulsion units; and controlling the plurality of actuators according to the determined control commands to meet the desired force and moment commands of the electric aircraft.

[0016] According to various examples, a method of controlling an electric aircraft that includes a plurality of actuators that includes a plurality of electric propulsion units and a plurality of battery packs that power the plurality of electric propulsion units includes: receiving desired force and moment commands for the electric aircraft; monitoring energy states of the plurality of battery packs, wherein at least a first battery pack of the plurality of battery packs is electrically isolated from at least a second battery pack of the plurality of battery packs; determining control commands for the plurality of actuators based on the desired force and moment commands by solving an optimization problem that comprises an energy balance term for balancing energy draw of the electric propulsion units according to the monitored energy state of the plurality of battery packs; and controlling the plurality of actuators according to the determined control commands to meet the desired force and moment commands of the electric aircraft.

[0017] In any of these examples, the first battery pack may have a lower remaining energy than the second battery pack, and a first electric propulsion unit powered by the first battery pack may operate at a lower power than a second electric propulsion unit powered by the second battery pack.

[0018] In any of these examples, the first battery pack and the second battery pack may have the same energy capacity.

[0019] In any of these examples, the first electric propulsion unit and the second electric propulsion unit may have the same power rating.

[0020] In any of these examples, the energy balance term may include a set of preferred operating states for the plurality of electric propulsion units, and preferred operating states for electric propulsion units powered by battery packs having lower remaining energy may be lower than preferred operating states for electric propulsion units powered by battery packs having higher remaining energy.

[0021] In any of these examples, the energy balance term may include a set of penalties for deviating from preferred operating states and a penalty associated with an electric propulsion unit connected to a lower energy battery pack may be higher than a penalty associated with an electric propulsion unit connected to a higher energy battery pack.

[0022] In any of these examples, the optimization problem may include a noise minimization term for minimizing noise generated by the electric propulsion units.

[0023] In any of these examples, the electric aircraft may be a vertical take-off and landing aircraft.

[0024] In any of these examples, the electric aircraft may be manned.

[0025] In any of these examples, the electric aircraft may include multiple electric propulsion units on either side of a fuselage of the aircraft.

[0026] According to various examples, a system for controlling an electric aircraft that includes a plurality of actuators that includes a plurality of electric propulsion units, includes one or more processors, memory, and one or more programs stored in the memory for execution by the one or more processors for: receiving desired force and moment commands for the electric aircraft; monitoring energy states of the plurality of battery packs, wherein at least a first battery pack of the plurality of battery packs is electrically isolated from at least a second battery pack of the plurality of battery packs; determining control commands for the plurality of actuators based on the desired force and moment commands by solving an optimization problem that comprises an energy balance term for balancing energy draw of the electric propulsion units according to the monitored energy state of the plurality

CLAIMS

1. A method of controlling an electric aircraft that comprises a plurality of actuators that includes a plurality of electric propulsion units, the method comprising:

receiving desired force and moment commands for the electric aircraft;

determining control commands for the plurality of actuators based on the desired force and moment commands by solving an optimization problem that comprises a noise minimization term for minimizing noise generated by the electric propulsion units; and

controlling the plurality of actuators according to the determined control commands to meet the force and moment commands for the electric aircraft,

wherein at least a portion of the plurality of electric propulsion units are tiltable, and controlling the plurality of actuators according to the determined control commands comprises at least one of tilting the electric propulsion units and adjusting an attitude of the electric aircraft to minimize edgewise flight time.

2. The method of claim 1, wherein controlling the plurality of actuators according to the determined control commands comprises operating at least a first electric propulsion unit of a plurality of electric propulsion units at a different speed than at least a second electric propulsion unit of the plurality of electric propulsion units to spread frequencies of the plurality of electric propulsion units across a wider frequency band.

3. The method of claim 2, wherein electric propulsion units closer to a fuselage of the electric aircraft are operated at lower speeds than electric propulsion units further from the fuselage to reduce noise at the fuselage.

4. The method of claim 2 or claim 3, wherein electric propulsion units are operated at different speeds during straight-ahead flight.

5. The method of any one of the preceding claims, wherein controlling the plurality of actuators according to the determined control commands comprises setting a pitch of blades of at least one electric propulsion unit to minimize a speed of the at least one electric propulsion unit.

6. The method of any one of the preceding claims, wherein the electric aircraft is a vertical take-off and landing aircraft.

7. The method of any one of the preceding claims, wherein the electric aircraft is manned.

8. The method of any one of the preceding claims, wherein the electric aircraft comprises multiple electric propulsion units on either side of a fuselage of the electric aircraft.

9. A system for controlling an electric aircraft that comprises a plurality of actuators that includes a plurality of electric propulsion units, the system comprising: one or more processors, memory, and one or more programs stored in the memory for execution by the one or more processors to cause the system to perform the method of any one of the preceding claims.

10. An electric aircraft comprising:

a plurality of actuators that includes a plurality of electric propulsion units; and

the system of claim 9 for controlling the electric aircraft via the plurality of actuators.

11. The electric aircraft of claim 10, wherein at least a portion of the plurality of electric propulsion units are tiltable.

12. The electric aircraft of claim 10 or 11, wherein the electric aircraft is a vertical take-off and landing aircraft.

13. The electric aircraft of any one of claims 10-12, wherein the electric aircraft is manned.

14. The electric aircraft of any one of claims 10-13, comprising multiple electric propulsion units on either side of a fuselage of the electric aircraft.