Contents

Acronyms **1**

Notations **2**

1 Introduction **3**
1.1 Statement of the Problem . . . 3
1.2 Objetives . . . 7
1.2.1 Main Objective . . . 7
1.2.2 Specific Objectives . . . 7
1.3 Hypotheses . . . 7
1.4 Overview of this Thesis . . . 8
1.4.1 Thesis Outline . . . 8
1.4.2 Main Contributions . . . 9

2 State of the Art **12**
2.1 Introduction . . . 12
2.2 UAV Definition and Applications . . . 12
2.3 Battery Health Management for Electric UAVs . . . 14
2.3.1 BHM for Rotary-wing UAVs . . . 25
2.3.2 Considerations on the Performance of Rotary-wing UAVs . . . 26
2.4 SOC Estimation and Prognosis Methods for Batteries . . . 29
2.4.1 Direct Measurement . . . 29
2.4.2 Book-keeping Estimation . . . 30
2.4.3 Adaptive Systems . . . 30
2.5 A Particle-filtering-based Prognosis Scheme for non-linear Dynamic Systems 36
2.5.1 Particle Filter . . . 36
2.5.2 Particle-filtering-based Prognostic . . . 38
2.5.3 Probability of Failure in PF-based Prognostic Algorithms . . . 38
2.6 Summary . . . 40

3 Prognostics Framework for BHM Systems in Small-size Electric Multirotors **42**
3.1 Introduction . . . 42
3.2 State-Space Model For State-Of-Charge Estimation In Batteries . . . 46
3.3 Outer Feedback Correction Loop . . . 47
3.4 Approximate Power Consumption Model for Rotary-wing Aircraft . . . 52
3.5 Definition of Probability of Failure as Risk Mitigation Method . . . 55

3.6 Summary . . . 58

4 Case Study: Delivery Missions **60**
4.1 Introduction . . . 60
4.2 Missions Description . . . 60
4.3 Performance Indicators . . . 62
4.4 Simplified Battery Model Along with the Novel OFCL During Estimation Stage . . . 63
4.5 Power Consumption Model as Future Inputs in Prediction Stage . . . 73
4.6 Mitigating the Risk . . . 79
4.7 Summary . . . 83

5 Concluding Remarks and Future Research **84**
5.1 Future work . . . 85

Appendix **88**

A Rotary-Wing Aerodynamics: Momentum Theory **88**
A.1 Induced Velocity and Thrust in Axial Translation . . . 90
A.1.1 Vertical Climb and Hovering . . . 90
A.1.2 Vertical Descent . . . 91
A.2 Power in Axial Translation . . . 91
A.2.1 Ideal Power in Climb and Hovering . . . 91
A.2.2 Ideal Power in Descent . . . 92
A.3 Induced Velocity and Thrust in Nonaxial Translation . . . 93
A.4 Power in Nonaxial Translation . . . 94

B Causes of Battery Degradation and Failures **95**
B.1 Electrical Abuse . . . 95
B.1.1 Overcharge . . . 95
B.1.2 Over-Discharge . . . 96
B.1.3 External Short Circuit . . . 96
B.2 Thermal Abuse . . . 96
B.3 Mechanical Abuse . . . 97

C Dissemination of the Results **98**
C.1 Journal and Conference Papers . . . 98
C.2 Presentations at Symposiums . . . 98
C.3 Doctoral Internships . . . 98

Bibliography **99**