

# Development and Implementation of a Hardware in-the-loop test bed for Unmanned Aerial Vehicle control algorithms

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## ABSTRACT

Successful prediction and management of battery life using prognostic algorithms through ground and flight tests is important for performance evaluation of electrical systems. This paper details the design of test beds suitable for replicating loading profiles that would be encountered in deployed electrical systems. The test bed data will be used to develop and validate prognostic algorithms for predicting battery discharge time and battery failure time. Online battery prognostic algorithms will enable health management strategies. The platform used for algorithm demonstration is the EDGE 540T electric unmanned aerial vehicle (UAV). The fully designed test beds developed and detailed in this paper can be used to conduct battery life tests by controlling current and recording voltage and temperature to develop a model that makes a prediction of end-of-charge and end-of-life of the system based on rapid state of health (SOH) assessment.

## 1. INTRODUCTION

In house prognostic testing of the EDGE 540T electric unmanned aerial vehicle (UAV) powertrain battery pack and Li-ion batteries are possible through the development and implementation of test beds that can simulate the loading profiles experienced by the UAV during flight. A test bed assembled using Li-ion batteries has been developed to evaluate and record battery characteristics when electrically loaded. A second test bed consisting of an EDGE UAV powertrain battery pack has been developed to simulate electrical loading profiles encountered during flight tests. This paper is organized as follows. Background information and motivation for the development of the Hardware-in-the-loop (HIL) test beds for the EDGE 540T electric UAV is given in section 2. The design cycles for each test bed is described in section 3. Conclusions are detailed in section 4.

## 2. BACKGROUND

Electric propulsion systems have become prevalent in everyday world applications for aircraft and ground vehicle deployment systems. Among the motivations is the need to address environmental concerns of emission and noise pollution and efforts to reduce mechanical parts and improve thrust response of deployment systems. Recent research developments in battery technology, increased market of battery powered ground vehicles and the need to include electric propulsion systems on aerial vehicles has led to interest in improving battery technology in these systems. Battery Health Management (BHM) techniques utilizing prognostic algorithms is critical in the

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development of systems that can increase the energy capacity of the batteries and estimation of the total storage capacity of the batteries and determination of the state of charge (SOC), remaining useful life (RUL) and predicting the end of life (EOL) of the electric systems. This research is aimed at designing and developing a framework for the testing of batteries to verify and validate prognostic algorithms that are useful in BHM strategies.

A test bed framework for Hardware-in-the-loop (HIL) testing is useful for in house testing and verification of battery prognostic algorithms utilizing more comprehensive and cheaper options compared to direct testing of the actual systems such as flight testing. HIL tests are methods that include some hardware components from the actual deployment systems. For this research, a Li-ion test bed has been designed to test prognostic algorithms for general battery characteristics which could be directed towards a separate rover research that uses these batteries in its propulsion system. Another test bed has been designed for the powertrain battery packs used on an electric EDGE 540 UAV for in-house recreation of dynamic loads, testing and verification of prognostic algorithms. HIL testing using in-house designed test beds has many advantages. The framework test bed is cheaper to design and test compared to an actual deployment system. Testing of the batteries can be carried out up until the actual lifetime of the batteries without compromising on the safety of the personnel or actual deployment system being tested. However, actual testing of the deployment systems for SOC and EOL of the electric propulsion systems is still necessary because HIL testing is limited in the actual accuracy simulation of the dynamic loads present during actual deployment of ground and flight systems.

### 3.DESIGN OF TEST BEDS

The sequence in developing and designing the test beds for the Li-ion battery cells and the EDGE 540T electric UAV are described in the sections below, which was the main focus of this research.

#### 3.1. Li-ion Battery cells test bed

A Li-ion battery test bed is designed and used in this research to generate, verify and validate general prognostic algorithms and characteristics of batteries. The test bed is designed to support 24 batteries connected in parallel to a computer and acquisition system to control current and record voltage and temperature. Thermocouples are connected to each battery cell to measure temperature independently for each cell. Each cell also is connected to a power and sense cable. All the cables run from the battery cell holders to the computer and processing unit. Figure 1 below shows the model of data and power transfer for the test bed.

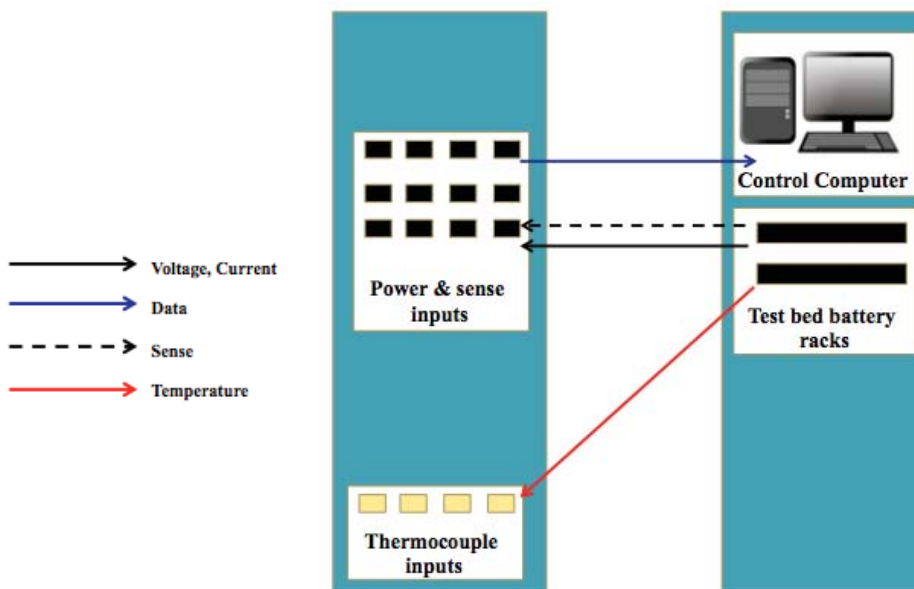


Fig.1 Model of Li-ion battery test bed and signal flow

The test bed consists of the processing unit on the left and the display computer and test bed battery rack on the right. 2 battery racks were designed in this research paper to complete the test bed. Each test bed rack consists of 12 Li-ion batteries (Fig. 2, pp. 3) independently connected to thermocouple, power and sense cables. The thermocouples are Nickel alloy T-type thermocouples suitable for temperature measurements of the batteries during loading. The thermocouples are electrically isolated from the power and sense circuits by disconnecting one half of the 2 terminal poles from the power circuit and redirecting current across the battery holder bypassing this terminal pole. The thermocouple is then attached to this isolated pole and is still in contact with the battery to pass temperature signals to the processing unit.



**Fig. 2: Li-ion battery cell**



**Fig. 3: Battery cell holder showing power, sense cables and isolated thermocouple wire**

The power cables are suitable to pass 4 Volts from the batteries to the processing unit. The racks are custom shelf drawers that we use to install the battery holders onto the rack which is then installed into the test bed shelf. The test bed battery rack is designed to pass voltage, current and temperature signals and fit as a drawer in the test bed shelf unit.



**Fig. 4: Assembled 12-battery test bed rack**

The cables on each test rack were assembled giving clearance between the shelf walls that could compromise the ease of movement of the drawer and protect the cables from the edges. The test rack drawer was designed to allow full drawing out the test racks to enable ease of installation batteries and checks of cable connections.

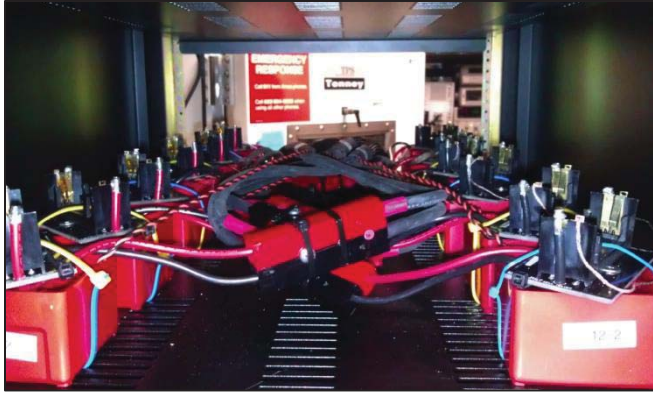


Fig. 5: Installed test bed rack, front view



Fig. 6: Installed test bed rack, rear view

Figure 7 below shows the segments of the test bed similar to the test bed model (Fig. 1 pp. 2) showing the passing of signals from the test bed racks to the processing unit inputs. Preliminary tests of the of the test bed was carried out by installing the batteries into each holder and confirming known battery voltages were passed from the cell holders to the processing unit and computer display. Temperature was also measured from the isolated poles of the cell holders to confirm temperature signals were detected, passed and displayed in the test bed. Cycling tests of the batteries to verify and validate prognostic algorithms can thus be carried out in further research.

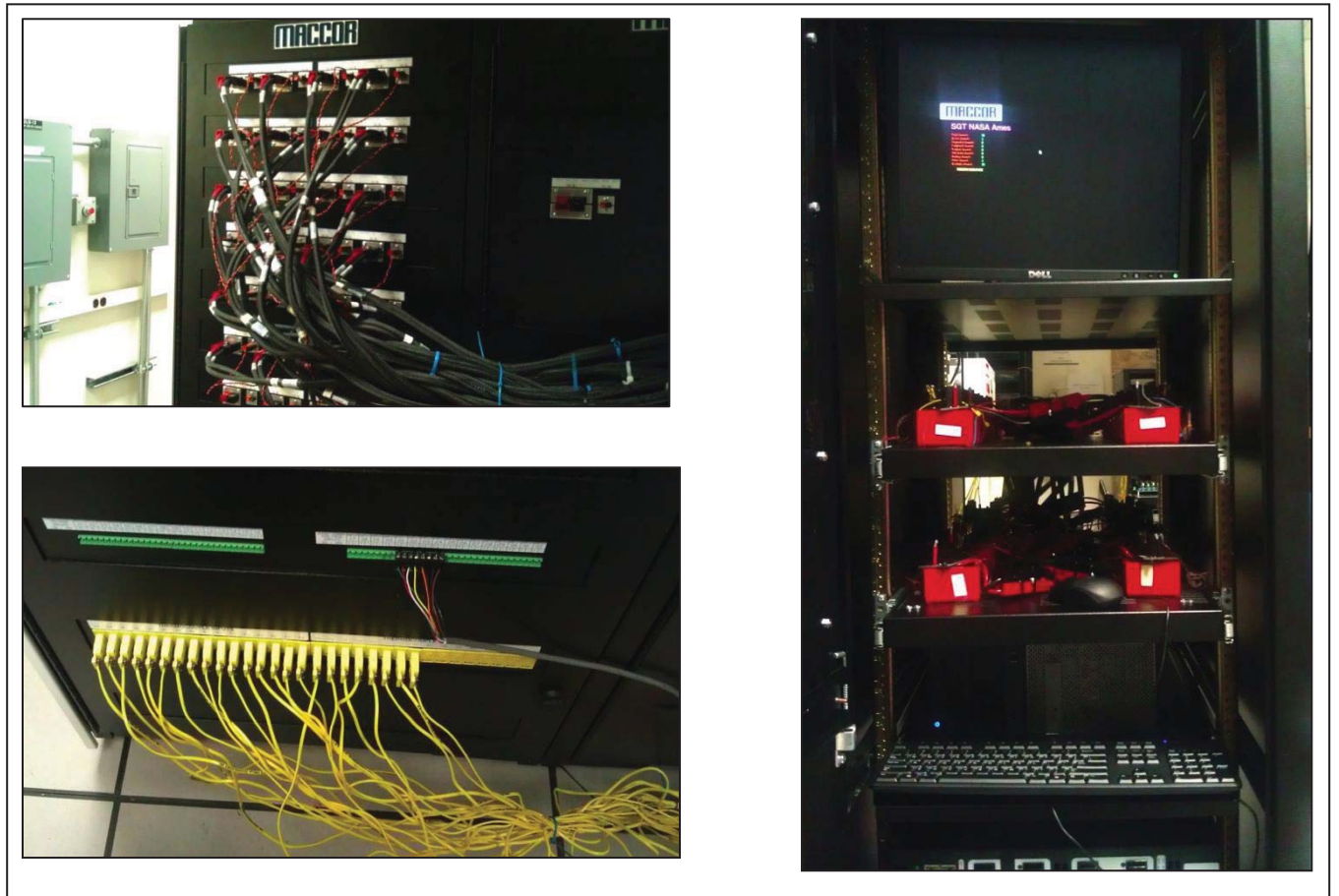


Fig. 7: Li-ion test bed

### 3.2. Powertrain battery pack test bed

A Powertrain battery pack test bed has been designed to replicate the dynamic loads present during flight of a prototype electric EDGE 540T unmanned aerial vehicle (UAV), which is used as our aircraft platform. In house testing of the test bed can lead to development, verification and validation of prognostic algorithms for battery health management (BHM) strategies to predict state of charge, remaining useful life and end of life of the battery packs used on the EDGE UAV during flight. The EDGE 540T is a commercial-off-the-shelf aircraft with electric propulsion and is controlled remotely by an operator on ground (Fig. 8 pp. 5). It is a 33% scale model of the actual Zirko EDGE 540T airplane.



Fig. 8: EDGE 540T electric UAV

The propellers are driven by 2 brushless DC motors each powered by a series connection of Lithium polymer powertrain battery packs. Each of the battery packs consist of 5 series connections of two 4.2 Volts, 3.9 Amperes Lithium polymer pouch cells wired in parallel. The batteries have been assembled into a test board along with power, sense and data acquisition signals (Fig. 9, pp. 5).

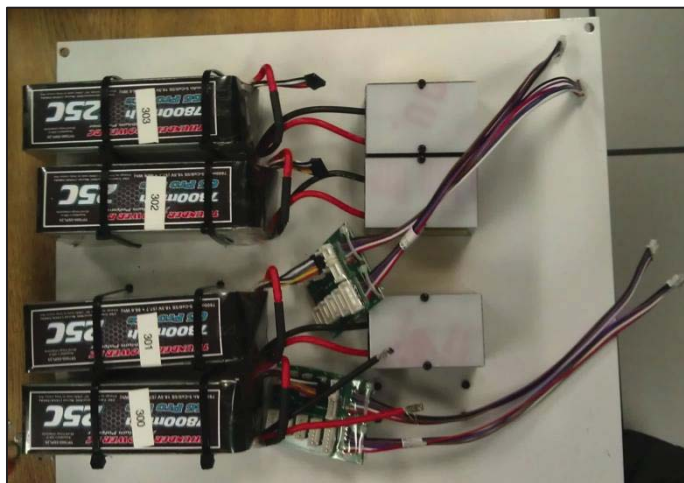


Fig. 9: Powertrain Battery cell test board

The fully designed test bed is small, portable and fits into a 1X1 square foot box. The box has been designed to pass power, sense, ribbon and data acquisition cables through the battery test board to the computer and processing unit that is used to control and record the signals that enable prognostic algorithm validation and verification. With the current research progress, current can be controlled while recording voltages using data acquisition software to test battery health management strategies.

The UAV rotor torque loading effect on battery life is an additional factor that can be tested in future research. However, in-lab experiments of the UAV test bed would be difficult to perform using an actual UAV rotor coupled to its motor. Future work could involve designing a loading system that can simulate the torque generated by the rotor on the motor and link it to the test bed for further tests.

#### 4. CONCLUSIONS

Test beds have been designed suitable for replicating loading profiles that would be encountered in deployed electrical systems. The test beds are useful for research involving prediction and management of battery life which is important for performance evaluation of electrical systems. The test bed research data will be used to develop and validate prognostic algorithms for predicting battery discharge time and battery failure time. Online battery prognostic algorithms will enable health management strategies. The platform used for algorithm demonstration is the EDGE 540T electric unmanned aerial vehicle (UAV) in this research, which is a suitable model of aircraft electrical propulsion system. The fully designed test beds are used to conduct battery life tests by controlling current and recording voltage and temperature to develop models that make predictions of end-of-charge and end-of-life of the systems based on rapid state of health (SOH) assessment. This research can lead to improvement in battery technology and battery health management of electric propulsion systems in ground and air vehicles.

#### ACKNOWLEDGMENTS

E. Nyangweso thanks Motivating Undergraduates in Science and Technology (MUST) and the Hispanic College Fund (HCF) for providing financial and professional development support through the summer internships, symposiums and college scholarships.

E. Nyangweso also thanks the NASA Ames - Intelligent Systems Division, Diagnostics and Prognostics branch and the Office of Education for providing a fulfilling academic and professional development summer internship.

#### NOMENCLATURE

<i>BHM</i>	=	Battery Health Management
<i>EOL</i>	=	End of Life
<i>HIL</i>	=	Hardware in the loop
<i>RUL</i>	=	Remaining Useful Life
<i>SOC</i>	=	State of Charge
<i>SOH</i>	=	State of Health
<i>UAV</i>	=	Unmanned Aerial Vehicle

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## BIOGRAPHIES



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**Brian Bole** graduated from the FSU-FAMU School of Engineering in 2008 with a B.S. in Electrical and Computer Engineering and a B.S. in Applied Math. Brian received M.S. degree in Electrical Engineering from the Georgia Institute of Technology in 2011, and he is currently pursuing Ph.D. Brian's research interests include: analysis of stochastic processes, risk analysis, and optimization of stochastic systems. Brian is currently investigating the use of risk management and stochastic optimization techniques for optimal adaptation of active component load allocations in robotic and aviation applications. In a previous project, Brian worked with the Georgia Tech EcoCar team to develop an energy management controller for optimizing the fuel economy of a charge sustaining hybrid electric vehicle.