A Comprehensive Guide to Selecting and Testing Batteries for High-Altitude Balloon Missions

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Introduction

High-Altitude Balloon (HAB) missions in the stratosphere demand efficient energy systems and a deep understanding of challenging atmospheric conditions. To achieve mission success, trajectory prediction software is indispensable, aiding in landing estimation, flight path planning, and recovery preparation. Prominent tools such as the Cambridge University Spaceflight (CUSF) simulator, Balloon Trajectory Forecasts from the University of Wyoming, and Balloon Prediction rely on NOAA's Global Forecast System (GFS) model [1]–[6].

The CUSF simulator results are shown in Fig. 1.

Figure 1: CUSF trajectory simulation on Google Earth.

Integrating ISA and CUSF Trajectory Simulation

The International Standard Atmosphere (ISA) analysis is based on the equations from [7]. Relevant information is summarized in Table 1 and 2.

Table 1: Constants of ISA

Layer	z_0 [m]	T_0 [K]	λ_0 [K/m]	P_0 [Pa]
1	0	288.15	−0.0065	101,325.00
2	11,019	216.65	—	22,632.10
3	20,063	216.65	0.0010	5,474.89
4	32,162	228.65	0.0028	868.02
5	47,359	270.65	—	110.91

Table 2: Formulas of ISA

Layer	Temperature [K]	Pressure [Pa]
1	$T_0 + \lambda_0(z - z_0)$	$P_0 \left(\frac{T_0}{T}\right)^{g(z)\,M_{air}/(R\,\lambda_0)}$
2	T_0	$P_0\, e^{-g(z)\,M_{air}\cdot(z-z_0)/(R\,T)}$
3	$T_0 + \lambda_0(z - z_0)$	$P_0 \left(\frac{T_0}{T}\right)^{g(z)\,M_{air}/(R\,\lambda_0)}$
4	$T_0 + \lambda_0(z - z_0)$	$P_0 \left(\frac{T_0}{T}\right)^{g(z)\,M_{air}/(R\,\lambda_0)}$
5	T_0	$P_0\, e^{-g(z)\,M_{air}\cdot(z-z_0)/(R\,T)}$

In our simulations, an arbitrary location in Usulután, El Salvador, was chosen for testing. The analysis revealed extreme stratospheric conditions, with temperatures as low as 216.65 Kelvin and atmospheric pressure at 1.18% of standard (Fig. 2). A critical region near the tropopause, at approximately 11,000 meters.

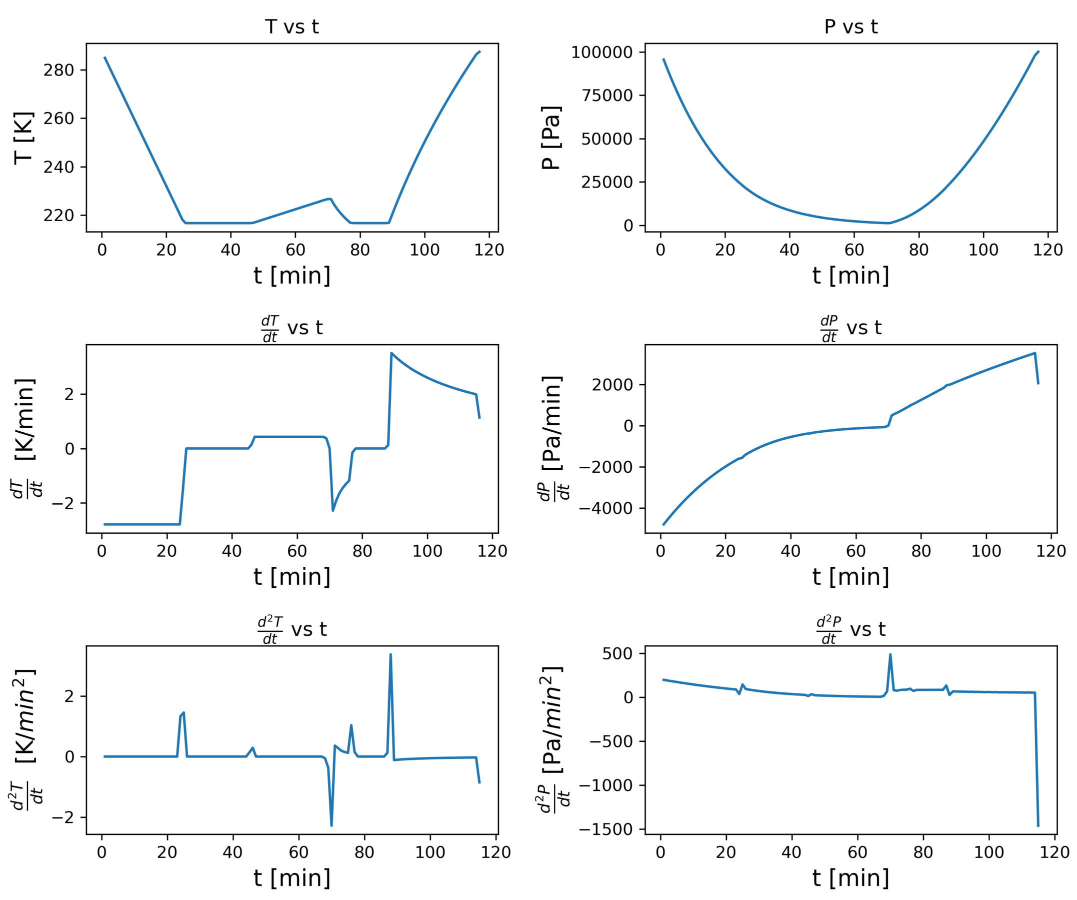

Figure 2: Simulated Atmospheric Variables for a 30 km HAB Mission.

Selecting COTS Batteries

The choice of Commercial Off-The-Shelf (COTS) Li-ion batteries for high-altitude balloon missions is crucial. While COTS batteries are cost-effective and readily available, the unique challenges of extreme altitudes require careful consideration. HAB missions demand reliable battery performance in harsh conditions. Low temperatures and pressures can impact battery performance, affecting ionic conductivity, internal resistance, and charge-transfer kinetics [8], [9]. Evaluating COTS Li-ion batteries is essential for mission success (Fig. 3).

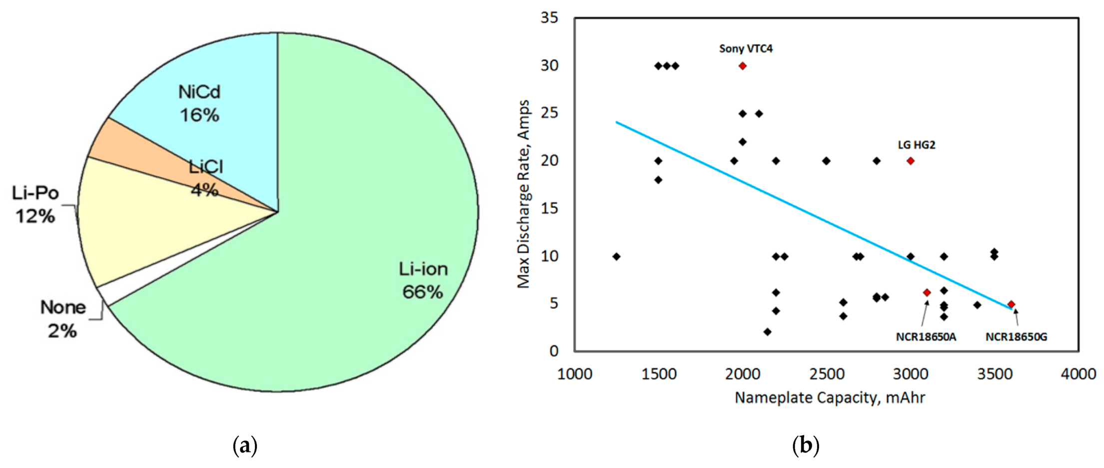

Figure 3: (a) Battery types used in pico- and nano-satellites[10]. (b) Summary of maximum discharge rate capabilities versus nameplate capacity of some representative COTS 18650 Li-ion cells [11].

Testing Procedure for 18650 Li-on Batteries

Our research presents a testing procedure to simulate balloon flight environmental conditions.Results are shown in Fig. 4.

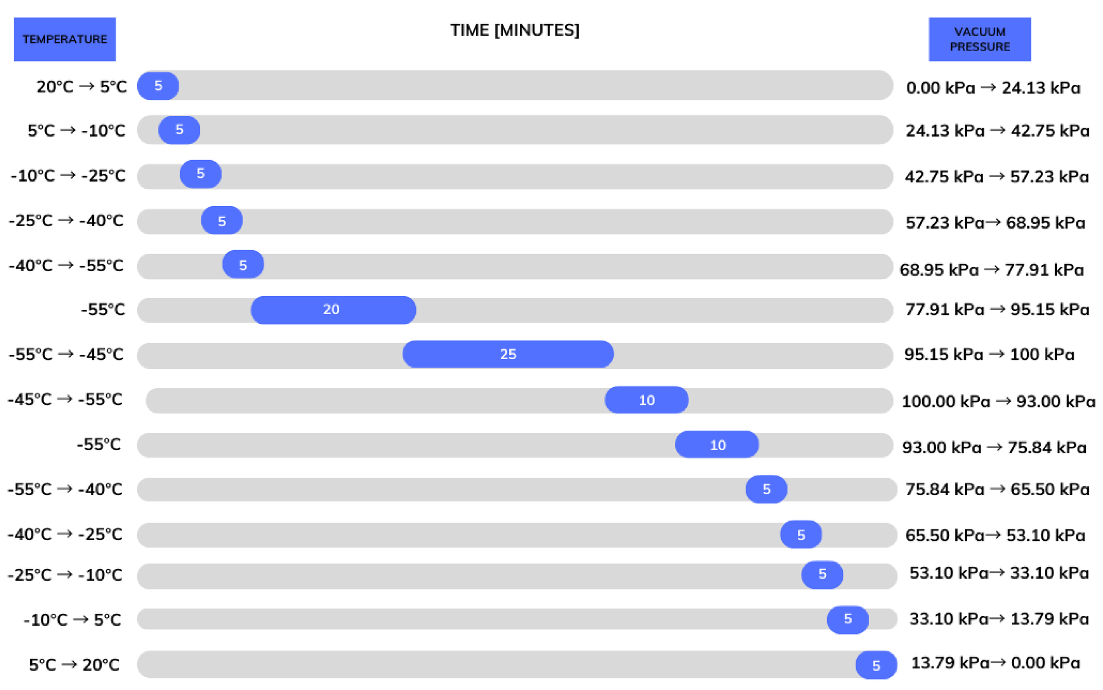

Figure 4: Timeline diagram for temperature and pressure transitions.

For COTS 18650 Li-ion batteries performance assessment and fundamental electrical parameter determination, we designed a functional diagram inspired by prior works [12], [13]. See Fig. 5.

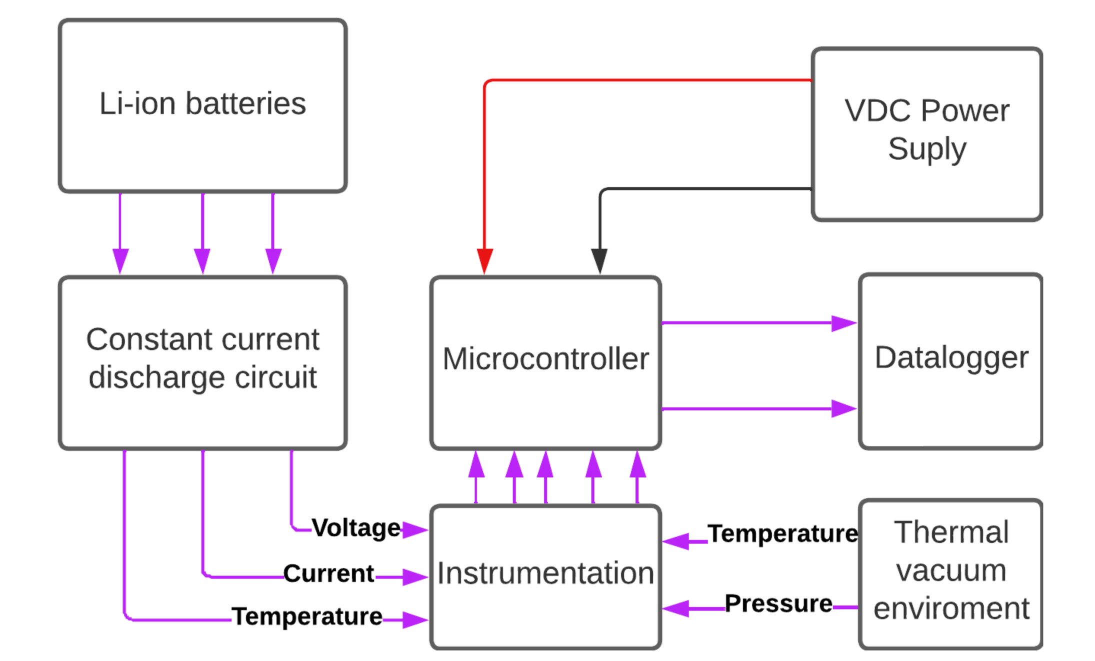

Figure 5: Functional Diagram for thermal vacuum battery tests. Purple wires represent data, black is ground, and red is +VCC.

Conclusion

The comprehensive testing procedure for COTS batteries provides valuable insights into HAB mission environmental variables. By following this paper's process and applying the resulting procedure based on specific location and time conditions, more accurate testing results can be obtained for specific missions. The study identifies exceptional COTS Li-ion battery models as promising candidates for HAB missions. Additionally, the proposed functional diagram for battery testing serves as a foundational framework for future designing of instrumentation circuits.

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