



ARL-TR-9479 • JUNE 2022



In-situ Atmospheric Intelligence for Hybrid Power Grids: Volume 7 (Squad Energy and Power Scenario)

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In-situ Atmospheric Intelligence for Hybrid Power Grids: Volume 7 (Squad Energy and Power Scenario)

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) June 2022		2. REPORT TYPE Technical Report		3. DATES COVERED (From - To) October–November 2014	
4. TITLE AND SUBTITLE In-situ Atmospheric Intelligence for Hybrid Power Grids: Volume 7 (Squad Energy and Power Scenario)				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Robert S Jane, Gail T Vaucher, Morris S Berman, Corey M James, Michael D Cook, Michael S Lee, Michael S D'Arcy, Gordon G Parker, and Thomas K Price				5d. PROJECT NUMBER NaN	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) DEVCOM Army Research Laboratory ATTN: FCDD-RLS-CP Aberdeen Proving Ground, MD 21005-5066				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-9479	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES primary author's email: <robert.s.jane2.civ@army.mil> ORCIDs: Robert Jane, 0000-0001-6742-7306; Michael Lee, 0000-0002-0419-6069					
14. ABSTRACT The goal of this research was to better understand the implications of squad energy and power requirements/capabilities as they pertain to mission and atmospheric dependencies. The approach combined mathematical models of energy and power with relevant US Army events. The results found that including tactical resupply events with a conformable wearable photovoltaic (PV) array and a more unified conformable wearable battery reduced the unnecessary weight requirements imposed on the Soldier. As a consequence, the results imply that this enhancement can improve squad performance (mobility) and minimize Soldier cognitive burden while ensuring sufficient energy reserves. In the future, we plan to use the load requirements in combination with a power grid testbed to determine what PV requirements are needed to charge the nonstandard communication equipment batteries.					
15. SUBJECT TERMS US Army–relevant events, energy and power, E&P, squad E&P requirements/capabilities, tactical resupply, squad energy awareness, Energy Sciences, Network, Cyber, and Computational Sciences					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 151	19a. NAME OF RESPONSIBLE PERSON Robert S Jane
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) 845-983-7401

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1. Introduction

The thesis for the Artificial Intelligence for Hybridized Power Grid (AIHPG)¹⁻⁵ is that optimized tactical power distribution for an isolated grid is strengthened by analyzing and exploiting atmospheric intelligence. Optimal energy management of a hybridized power grid is a multivariate challenge, impacted by time, space, and the environment. By understanding these interactions, we can optimize our energy network's generation, distribution, storage, or transmission. Future military operations will rely on optimal hybridized tactical power, to include traditional generation and storage assets such as diesel generators and electrochemical batteries, as well as nontraditional generation such as solar, wind, and/or nuclear renewable resources. Optimal energy and power management will provide greater resiliency, adaptability, and flexibility, reducing warfighters' cognitive burden and maximizing military operations subject to mission effectiveness or mission efficiency.

This report presents a US Army-relevant scenario developed for use within the AIHPG testbed. The intent of this research effort was to develop a set of dynamic scenarios that could emulate the chaotic and dynamic operational environments related to future US Army squad energy and power requirements and capabilities. Incorrect operation or control of an energy network will degrade our warfighters' capabilities and reduce mission effectiveness and efficiency, leading to energy-constrained or contested operations. By developing more chaotic and dynamic load scenarios, operational knowledge can be developed that will provide added capabilities or functionalities for current and future warfighters.

The primary intent of this report is to document the work completed to develop the squad energy and power scenario. The remainder of this document is broken up into the following sections. Section 2 establishes the primary need to understand the individual Soldier's energy-and-power-based capabilities. Section 3 presents the event schedule, Section 4 the equipment list, and Section 5 a detailed description of the model components. Section 6 defines the squad energy and power scenarios, and Sections 7 and 8 present the results for the limited tactical resupply squad energy and power scenario and the tactical resupply squad energy and power scenario, respectively. Section 9 provides the conclusions and future work. The Appendix contains additional mathematical parameters used to define the model components as per Section 5.

2. Background

The energy and power requirements for an average US Army Soldier are higher than ever and expected to increase significantly for Multi-Domain Operations (MDO), which include multiple dissimilar semi-autonomous or autonomous ground, air, or sea vehicles. For this reason, the squad-based energy and power scenario was created.

The average Soldier will have a backpack weighing between 60 to 80 lb, filled with food, water, energy storage, and more importantly the ammunition and hardware required to complete their mission. Figures 1 and 2 show an approximate weight distribution for the average US Army infantry Soldier and communication officer outfitted for a 96-h mission. The maximum limit a Soldier would be required to carry is expected to be 80 lb. Weight greater than this will overburden a Soldier and reduce the Soldier's survivability, lethality, and mobility. The effectiveness of a squad or Soldier would be significantly diminished. Thus, it becomes important to understand their weight distributions as the weight of their equipment will impact the mission.



Fig. 1 An approximate weight distribution for an average US Army infantry Soldier is a minimum of 89.6 lb with 40.1 lb contained within a backpack

The average infantry rifleman is expected to carry a minimum of a 40.1-lb backpack for a 96-h mission. Conversely, a communications officer may have a 96-lb backpack. A substantial portion of the added weight is due to the energy storage requirements required to operate specialized communications and armament. For the totals shown within Fig. 2, the communications officer would not be responsible for carrying a 96-lb backpack. A squad is as fast as the slowest member. To avoid overburdened Soldiers, the weight would be redistributed to mitigate a reduction in the squad's effectiveness. This research effort focused on developing an US Army–relevant scenario in which the electrical energy implications that force individual squad members to carry copious amounts of energy storage devices could be better understood.



Fig. 2 An approximate weight distribution for an average US Army communications officer. The officer is expected to carry a minimum of 146.1 lb, where 96.6 lb would be contained within a backpack. Specialized communications equipment power requirements constitute a substantial portion of the added weight.

3. Event Schedule

There are two primary features for the squad energy and power model: a set of US Army–relevant events and an equipment list. The US Army–relevant events are used

to define an event schedule, which directly impacts energy generation, storage, dissipation, and the transmission of the model components. Eight different events were defined, including Rest and Recuperation (R&R), Guard Duty, Insertion/Extraction, Patrol, Patrol with Intermittent Contact, Patrol with Sustained Contact, Patrol Request Quick Response Force (QRF), and Tactical Resupply. Each of the eight events are listed in Table 1, along with their respective event identifier and number. Relevant events are assigned to each individual Soldier. The event in which each Soldier participated impacted energy usage as a function of the assigned electrical equipment each Soldier possessed. In this way, there was a tight coupling between the assigned events and assigned electrical equipment (i.e., any change to the assigned events leads to a change in the Soldiers' electrical energy usage).

Table 1 Squad energy and power event list

Event ID	Event names	Event no.
A	R&R	0
B	Guard Duty	1
C	Insertion Extraction	2
D	Patrol	3
E	Patrol Intermittent Contact	4
F	Patrol Sustained Contact	5
G	Patrol Requests QRF	6
H	Tactical Resupply	7

4. Equipment List

The second model feature is an equipment list, the set of representable government-furnished equipment (GFE) assigned to each individual Soldier. The component weight, energy generation, storage, dissipation, and transmission are subject to the previously defined events, which are aggregated together for each individual Soldier to form an event schedule. The event schedules are modeled such that the energy and power usage of a Soldier or squad can be analyzed. Thirteen different electrical components were included in the model: conformable wearable battery (CWB), conformable wearable photovoltaic (CWPV), night-vision goggles (NVGs), thermal-vision goggles (TVGs), flashlight, radio, portable radio communications (PRC), Toughbook, intra-squad radio (ISR), range finder, IR strobe, IR laser, and handheld global positioning satellite (GPS) device. In Table 2, the components

highlighted in red require nonstandard batteries (i.e., each of these components has their own battery model). An asterisk indicates an item that uses variable, pulsed-width signals to model power consumption as a function of an active event. Table 2 dictates which component is assigned to each squad member. The table contents assume that a squad is made up of eight Soldiers (i.e., Soldier A through Soldier H, where Soldier H is the communications officer).

Table 2 Squad energy and power equipment list

Component	Assigned individual
CWB	All
CWPV	All
NVGs	All
TVGs	Soldier B, Soldier C
Flashlight	All
Radio*	All
PRC*	Soldier H
Toughbook*	Soldier H
ISR*	Soldier H
Range finder*	Soldier B, Soldier C
IR strobe	All
IR laser	All
Handheld GPS*	Soldier H

5. Model Components

Each of the model components is now described in greater detail within the following subsections. Table 3 specifies which subsections or appendix subsections of this report have more information pertaining to each individual electrical model component. An asterisk indicates an item uses variable pulsed-width signals to model power consumption as a function of an active event. Again, the red text indicates which electrical components utilize nonstandard batteries, which requires the component to have a self-contained battery model.

Table 3 Squad energy and power content list

Component	Section	Appendix
CWB	5.1	A.1
CWPV	5.2	A.2
NVGs	5.3	A.3
TVGs	5.4	A.4
Flashlight	5.5	A.5
Radio*	5.6	A.6
PRC*	5.7	A.7
Toughbook*	5.8	A.8
ISR*	5.9	A.9
Range finder*	5.10	A.10
IR strobe	5.11	A.11
IR laser	5.12	A.12
Handheld GPS*	5.13	A.13

5.1 Conformable Wearable Battery

In an effort to reduce the Soldier's requirement to carry substantial amounts of dissimilar energy storage devices required to operate ancillary electrical equipment, US Army researchers are currently developing a CWB.⁶ Current versions of the CWB can provide sufficient energy for 24 h of continuous use, while the future CWB is expected to be able to provide sufficient energy for 72 h of continuous use. The discharge dynamics of our CWB are dictated by mission loads and charge dynamics are dictated by the CWPV and the Tactical Resupply event. The battery voltage is based on the lithium (Li)-ion battery model of Jane et al.⁷ and characteristic discharge curves for the CWB are provided in Fig. 3.

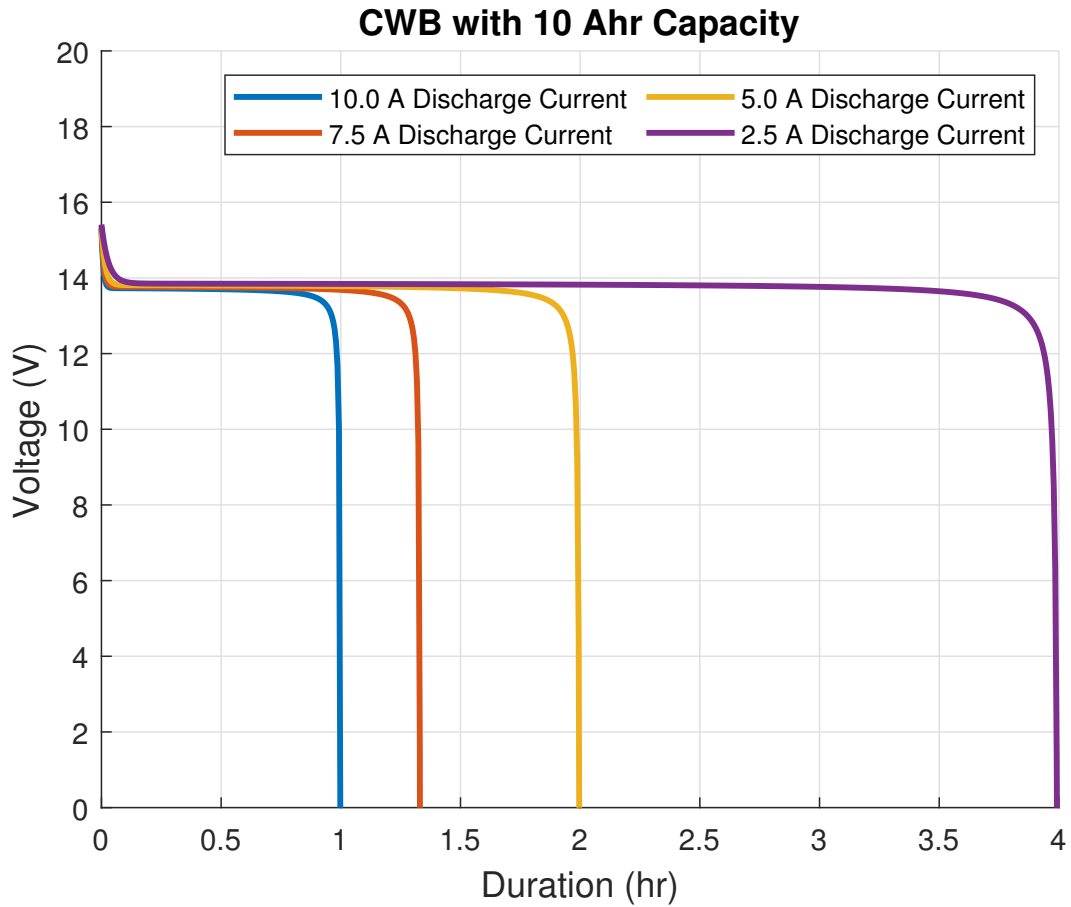


Fig. 3 Nonlinear discharge curve of the CWB

Any and all parameters required to define this component are defined in Section A.1.

5.2 Conformable Wearable Photovoltaic

In an effort to reduce the Soldier's dependency on carrying substantial amounts of dissimilar energy storage devices required to operate ancillary electrical equipment, US Army researchers are also developing a CWPV array.⁸ It is estimated that the CWPV of the future Soldier will be able to generate 18 W of power at standard test conditions (STC), where 10 W could be generated via a helmet-mounted PV and 8 W could be generated via a back-mounted PV.

Simscape's PV model was configured to achieve 18 W of power at STC, assuming the PV had a 12-V open circuit voltage and 2-A short circuit current. Multiple conditions were then simulated and used to construct a set of artificial neural networks,

which approximated the family of voltage-current (V-I) curves for the PV array, as shown in Figs. 4 and 5.

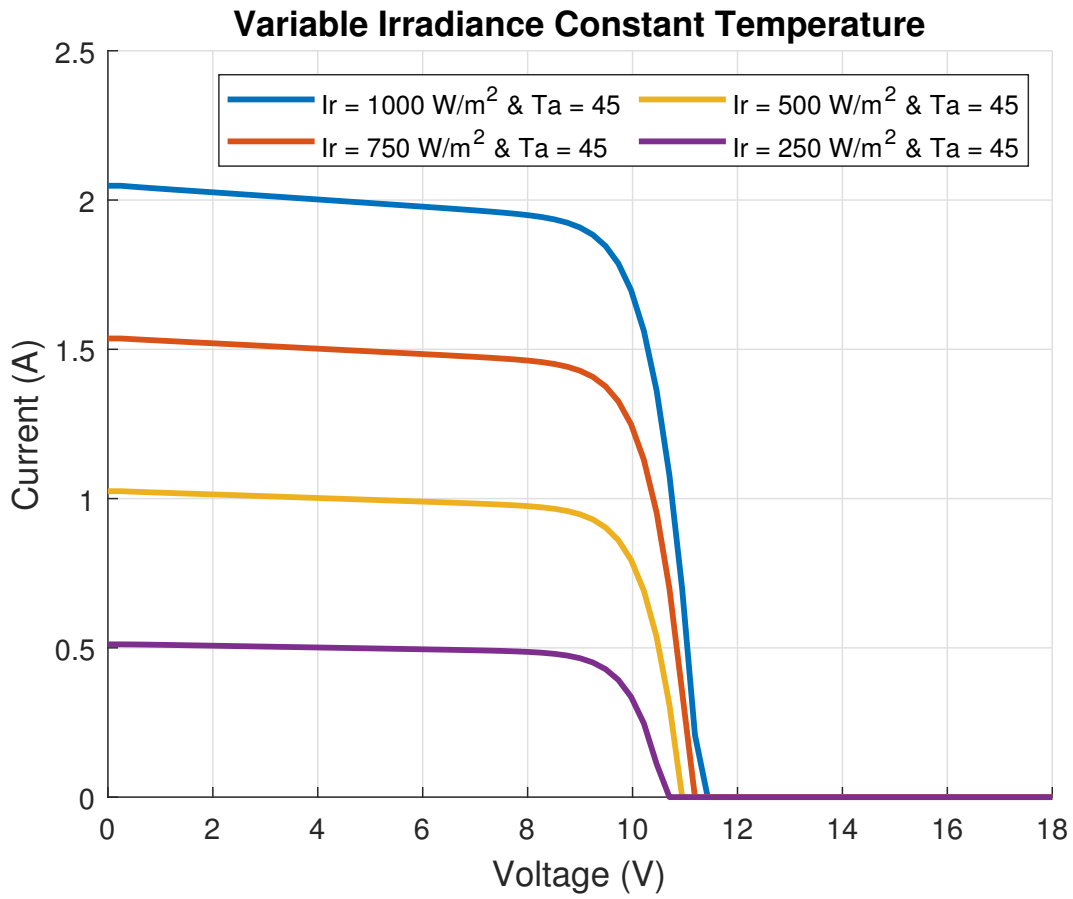


Fig. 4 Characteristic V-I curve for the CWPV assuming a constant ambient temperature (T_a) and a variable solar insulation (I_r)

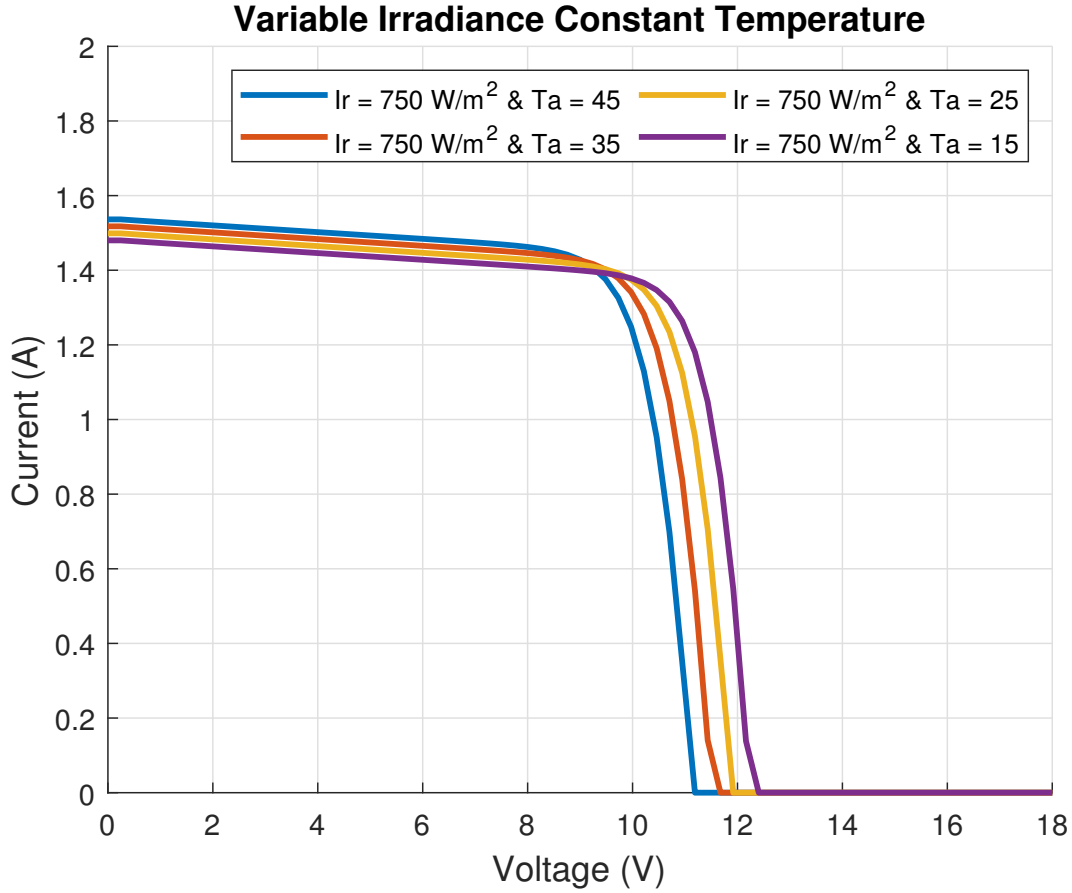


Fig. 5 Characteristic V-I curve for the CWPV assuming a variable ambient temperature (T_a) and a constant solar insulation (I_r)

Any and all parameters required to define this component are defined in Section A.2.

5.3 Night-Vision Goggles

NVGs⁹ are commonly assigned to Soldiers so that they can achieve greater awareness during early morning or late evening operations. As such, NVGs were modeled within this scenario. NVGs will consume the continuous discharge current if a Soldier is participating in Guard Duty, Insertion/Extraction, Patrol, Patrol with Intermittent Contact, Patrol with Sustained Contact, or Patrol Requests QRF and the sun is greatly obscured. For all other times, the discontinuous discharge current will slowly consume a small fraction of the total energy available from the CWB. The NVGs' continuous discharge current and discontinuous discharge current are shown in Fig. 6.

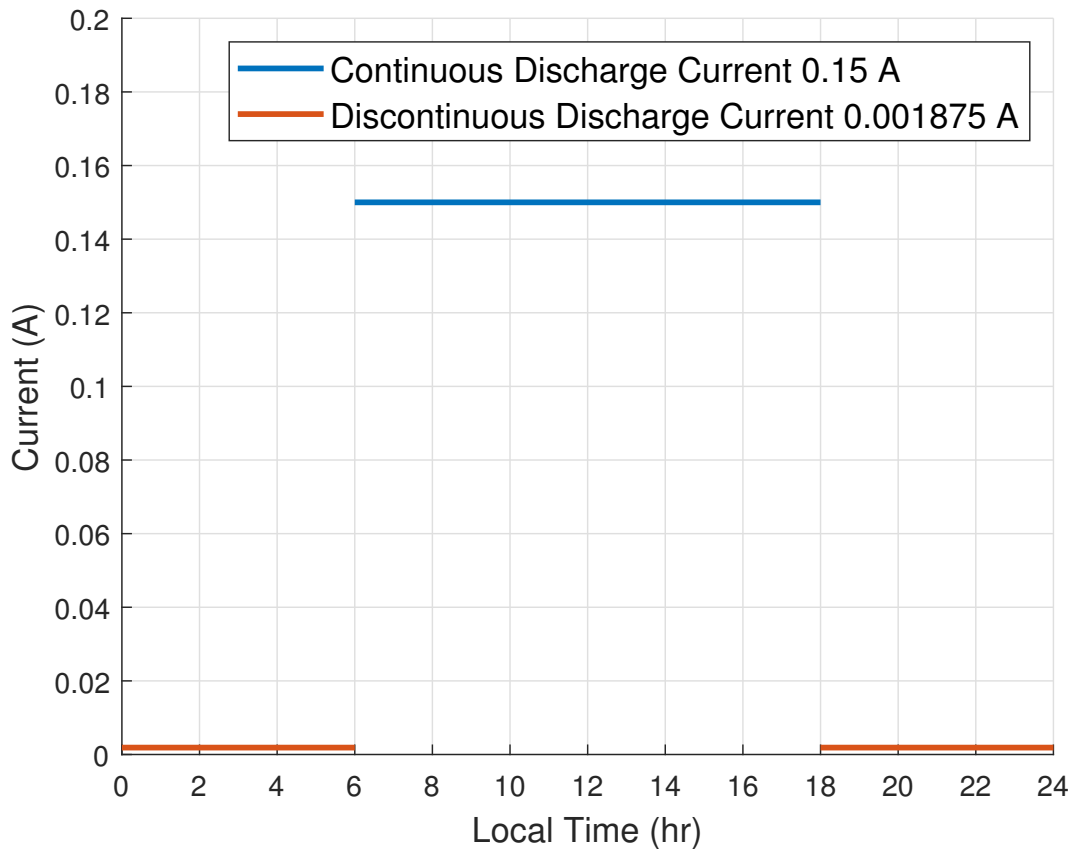


Fig. 6 NVG continuous and discontinuous discharge currents. NVGs are only used when the sun is greatly obscured.

Any and all parameters required to define this component are defined in Section A.3.

5.4 Thermal-Vision Goggles

TVGs⁹ are commonly assigned to Soldiers so they can achieve greater awareness during early morning or late evening operations. As such, TVGs were modeled within this scenario. TVGs will consume the continuous discharge current if a Soldier is participating in Guard Duty, Insertion/Extraction, Patrol, Patrol with Intermittent Contact, Patrol with Sustained Contact, or Patrol Requests QRF and the sun is greatly obscured. For all other times, the discontinuous discharge current will slowly consume a small fraction of the total energy available from the CWB. The TVG continuous discharge current and discontinuous discharge current are shown in Fig. 7.

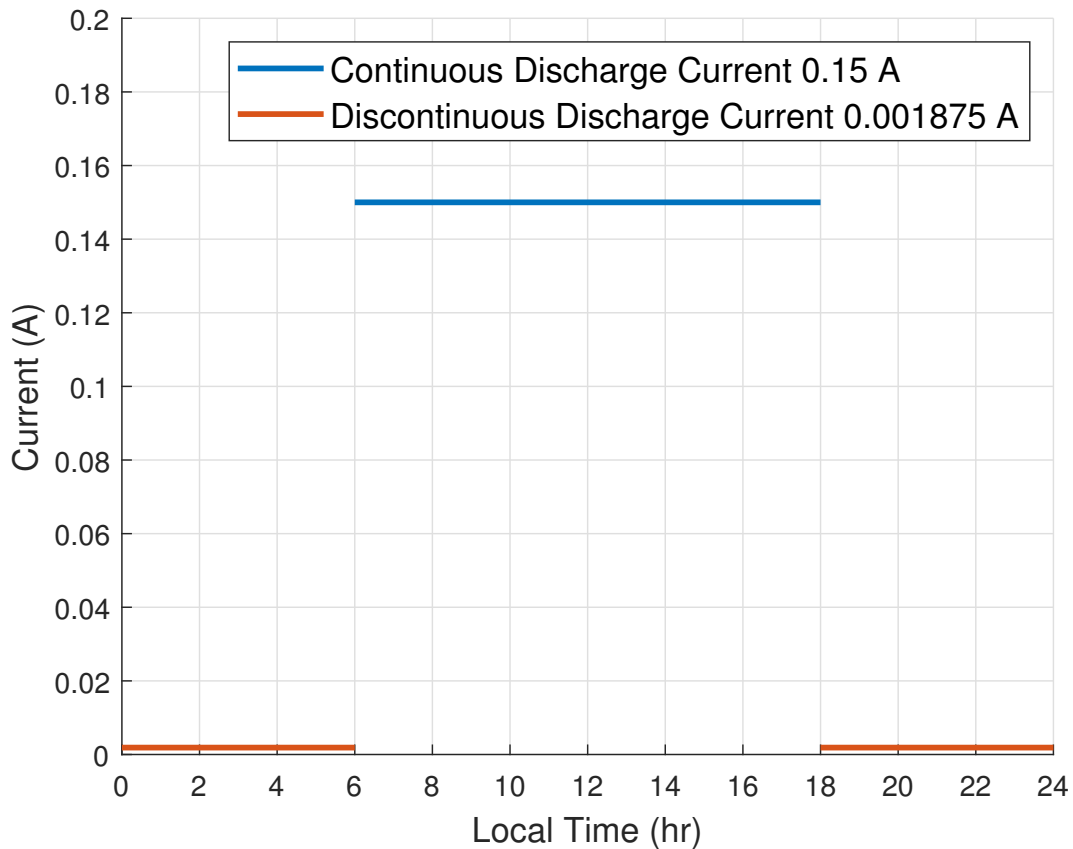


Fig. 7 TVG continuous and discontinuous discharge currents. TVGs are only used when the sun is greatly obscured.

Any and all parameters required to define this component are defined in Section A.4.

5.5 Flashlight

Flashlights¹⁰ are considered to be standard issue for all US military personnel, and as such flashlights were included within the scenario. Flashlights are vital pieces of electronics; however, because the device has a potential to give away the Soldiers' position, flashlights are rarely used. When used, it is because there are sufficient countermeasures in place that greatly obscure the Soldiers' position or there is a discernible need to use the device as function of mission directive. The flashlight will then consume the continuous discharge current only during the Patrol Requests QRF event. At all other times, the discontinuous discharge current will slowly consume a small fraction of the total energy available from the CWB. The flashlight's continuous discharge current and discontinuous discharge current are shown in Fig. 8.

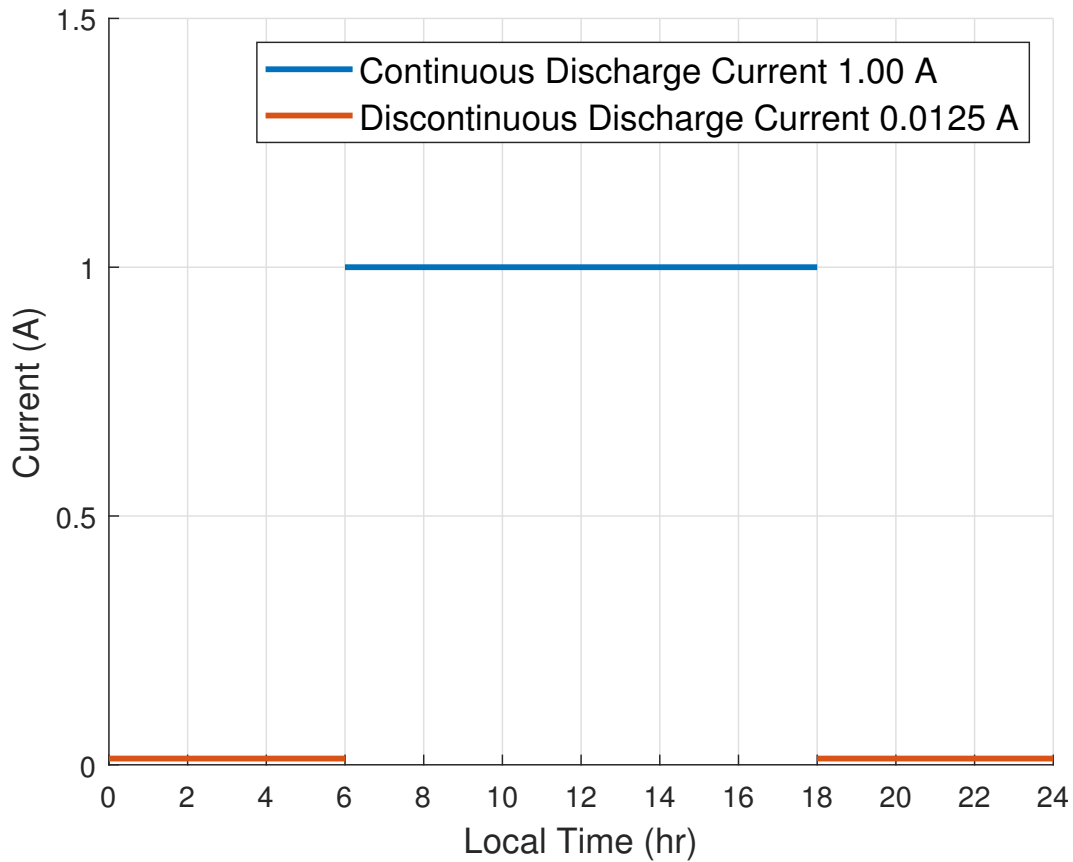


Fig. 8 The flashlight's continuous and discontinuous discharge currents. The flashlight is only used when the sun is greatly obscured.

Any and all parameters required to define this component are defined in Section A.5.

5.6 Radio

Because radios¹¹ are considered standard issue for all US military personnel, they were included within the scenario. Unlike the previous components, the radio is special for two reasons: 1) it requires the use of specialized battery packs, modeled using the same nonlinear battery model as the CWB, and 2) the operation of the radio changes as a function of the active event. A variable pulsed-width, fixed-amplitude signal was used to emulate power consumption. The on/off frequency of the pulsed signal is based on the event schedule; in this way, more chaotic or kinetic events can lead to more frequent discharge cycling of the radio. Recall that for the squad-based scenario, there are eight different events, each characterized by a different on/off frequency. The generic variable pulsed-width, fixed-amplitude

signal used to model the power consumption of the radio is provided in Fig. 9. The corresponding continuous and discontinuous discharge durations are then provided in Table 4.

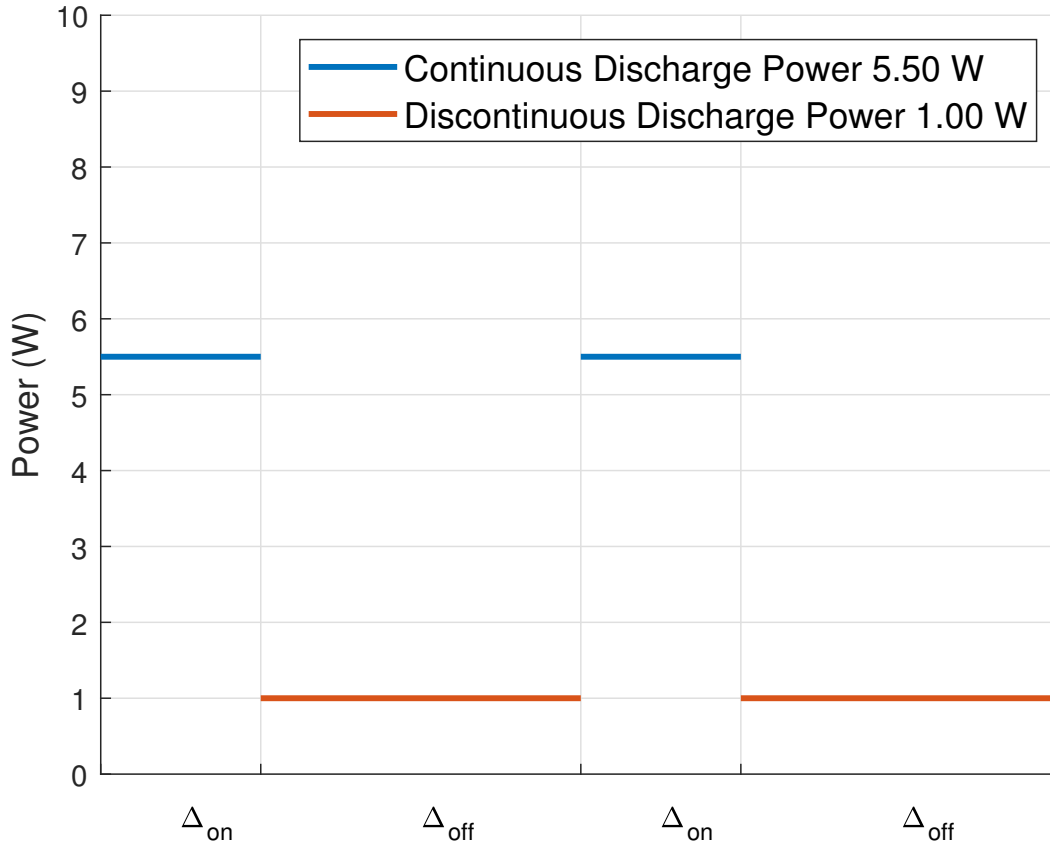


Fig. 9 Generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the radio. The variable on/off duration is governed by the continuous and discontinuous discharge delta Δ_{on} and Δ_{off} , respectively, as defined in Table 4.

Table 4 Continuous and discontinuous discharge durations of the radio

Event name	Continuous discharge duration	Discontinuous discharge duration
	(s)	(s)
R&R	15	3600
Guard Duty	15	2700
Insertion Extraction	15	600
Patrol	15	2700
Patrol Intermittent Contact	15	1800
Patrol Sustained Contact	15	900
Patrol Requests QRF	15	300
Tactical Resupply	15	60

Any and all parameters required to define this component are defined in Section A.6.

5.7 Portable Radio Communications

The PRC^{12,13} is considered standard issue for communication officers. Similar to the radio, the PRC is also special for two reasons: 1) it requires the use of specialized battery packs, modeled using the same nonlinear battery model as the CWB, and 2) the operation of the PRC changes as a function of the active event. A variable pulsed-width, fixed-amplitude signal was used to emulate power consumption. The on/off frequency of the pulsed signal is based on the event schedule, in this way, more chaotic or kinetic events can lead to more frequent discharge cycling of the PRC. Recall that for the squad-based scenario, there are eight different events, each characterized by a different on/off frequency. The generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the PRC is provided in Fig. 10. The corresponding continuous and discontinuous discharge durations are then provided in Table 5.

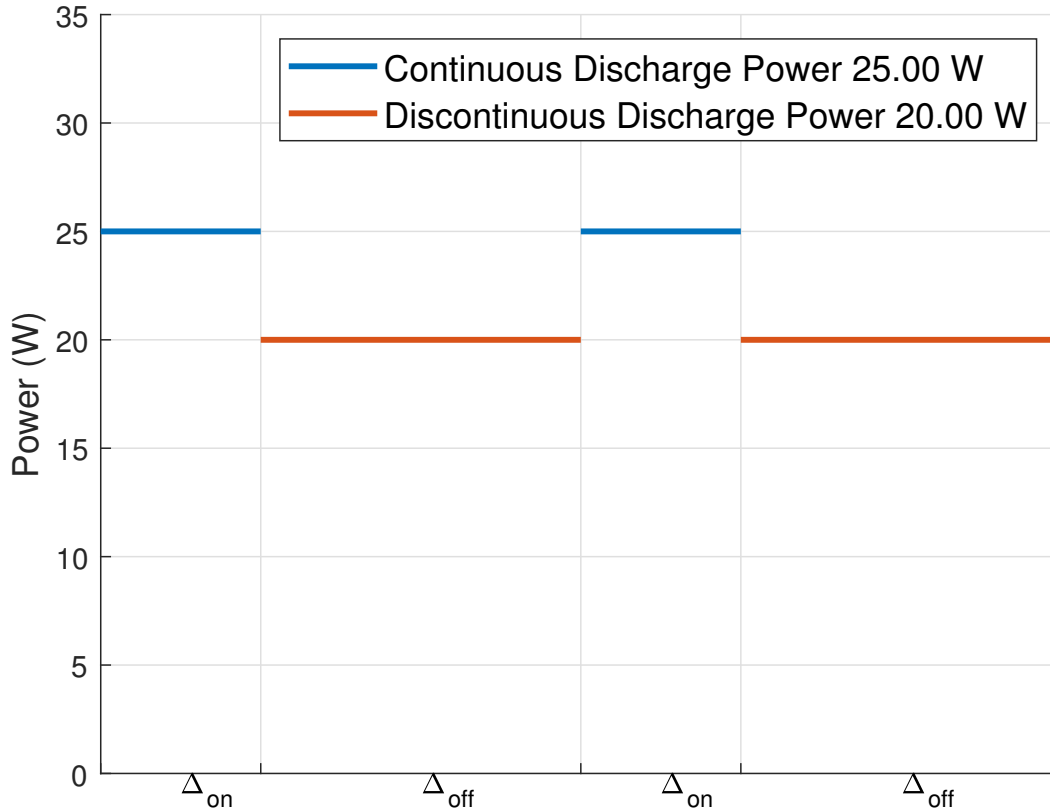


Fig. 10 Generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the PRC. The variable on/off duration is governed by the continuous and discontinuous discharge delta Δ_{on} and Δ_{off} , respectively, as defined in Table 5.

Table 5 Continuous and discontinuous discharge durations of the PRC

Event name	Continuous discharge duration	Discontinuous discharge duration
	(s)	(s)
R&R	15	3600
Guard Duty	15	2700
Insertion Extraction	15	600
Patrol	15	2700
Patrol Intermittent Contact	15	1800
Patrol Sustained Contact	15	600
Patrol Requests QRF	15	300
Tactical Resupply	15	60

Any and all parameters required to define this component are defined in Section A.7.

5.8 Toughbook

If a squad or Soldier is expected to complete a mission in which ordinary standard issue equipment is insufficient, a Toughbook¹⁴ may be assigned to the communications officer. Similar to both the radio and the PRC, the Toughbook is special for two reasons, 1) it requires the use of specialized battery packs, modeled using the same nonlinear battery model as the CWB, and 2) the operation of the Toughbook changes as a function of the active event. A variable pulsed-width, fixed-amplitude signal was used to emulate power consumption. The on/off frequency of the pulsed signal is based on the event schedule; in this way, more chaotic or kinetic events can lead to more frequent discharge cycling of the Toughbook. Recall that for the squad-based scenario, there are eight different events, each characterized by a different on/off frequency. The generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the Toughbook is provided in Fig. 11, the corresponding continuous and discontinuous discharge durations are then provided in Table 6.

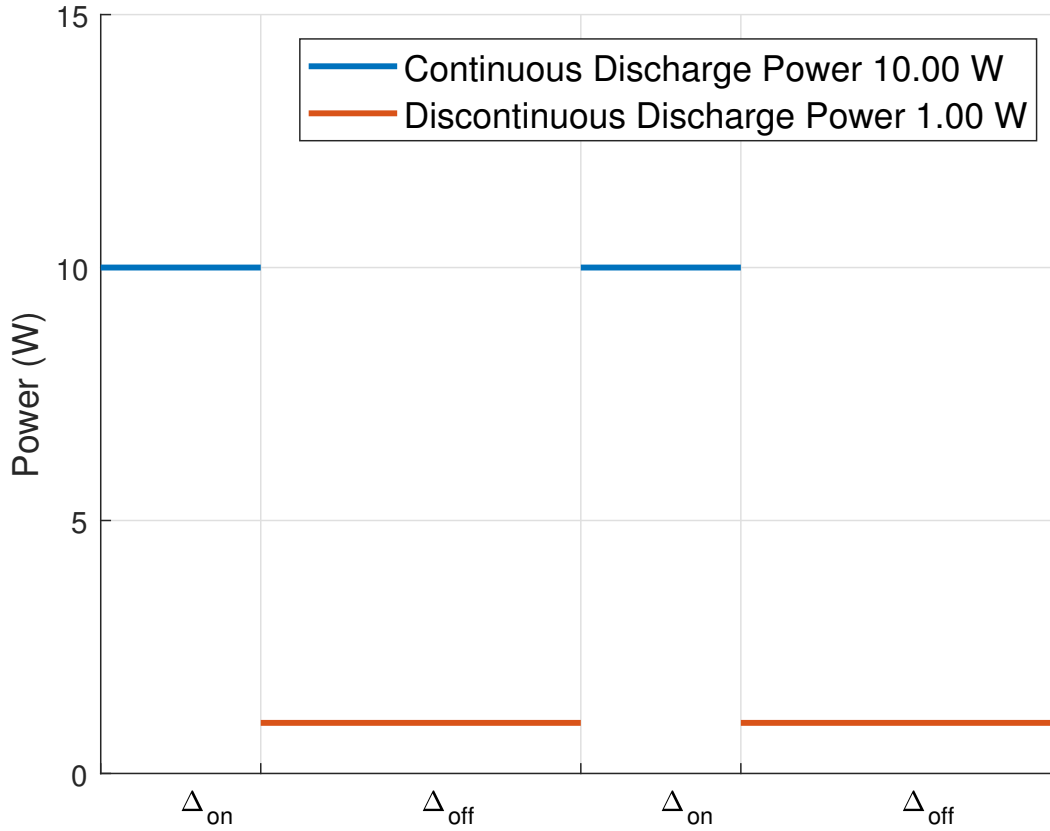


Fig. 11 Generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the Toughbook. The variable on/off duration is governed by the continuous and discontinuous discharge delta Δ_{on} and Δ_{off} , respectively, as defined in Table 6.

Table 6 Continuous and discontinuous discharge durations of the Toughbook

Event name	Continuous discharge duration	Discontinuous discharge duration
	(s)	(s)
R&R	300	3600
Guard Duty	300	3600
Insertion Extraction	300	∞
Patrol	300	3600
Patrol Intermittent Contact	300	∞
Patrol Sustained Contact	300	∞
Patrol Requests QRF	300	∞
Tactical Resupply	300	∞

Any and all parameters required to define this component are defined in Section A.8.

5.9 Intra-Squad Radio

If a squad or Soldier is expected to complete a mission in which ordinary standard issue communication equipment is insufficient, an ISR¹⁵ may be assigned to the communications officer. Similar to both the radio, PRC, and Toughbook, the ISR is special for two reasons: 1) it requires the use of specialized battery packs, modeled using the same nonlinear battery model as the CWB, and 2) the operation of the ISR changes as a function of the active event. A variable pulsed-width, fixed-amplitude signal was used to emulate power consumption. The on/off frequency of the pulsed signal is based on the event schedule; in this way, more chaotic or kinetic events can lead to more frequent discharge cycling of the ISR. Recall that for the squad-based scenario, there are eight different events, each event is characterized by a different on/off frequency. The generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the ISR is provided in Fig. 12, the corresponding continuous and discontinuous discharge durations are then provided in Table 7.

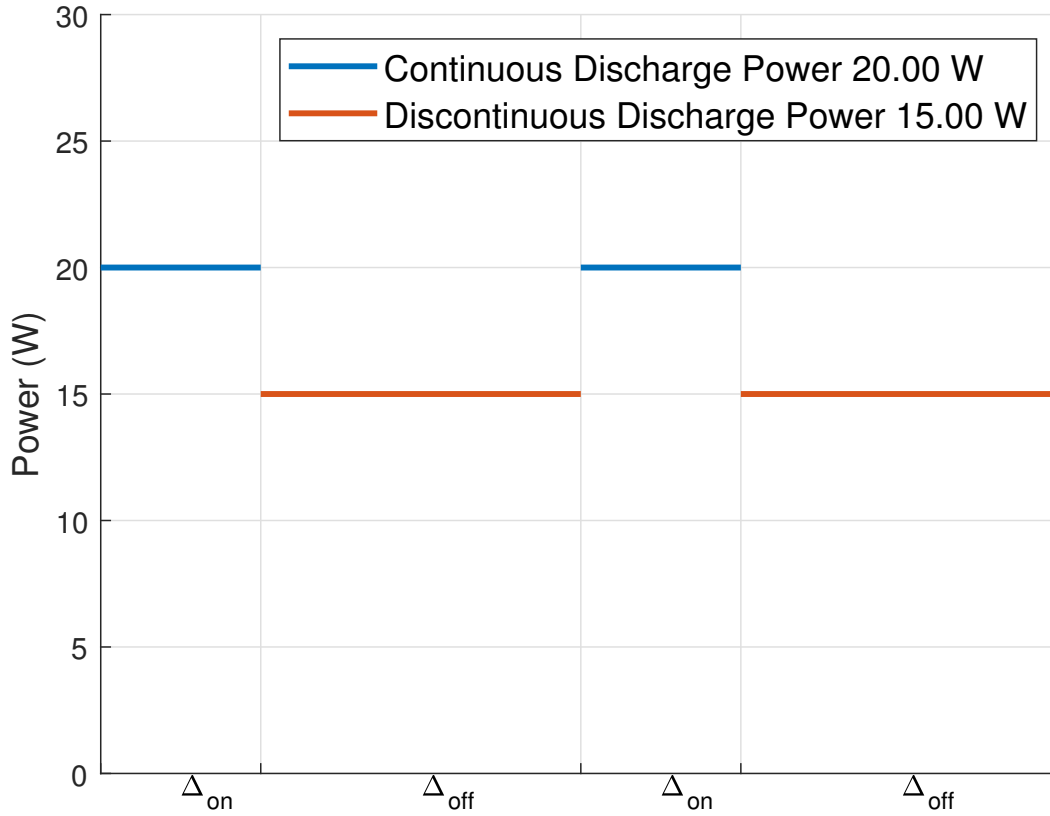


Fig. 12 Generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the ISR. The variable on/off duration is governed by the continuous and discontinuous discharge delta Δ_{on} and Δ_{off} , respectively, as defined in Table 7.

Table 7 Continuous and discontinuous discharge durations of the ISR

Event name	Continuous discharge duration	Discontinuous discharge duration
	(s)	(s)
R&R	300	3600
Guard Duty	300	2700
Insertion Extraction	300	600
Patrol	300	2700
Patrol Intermittent Contact	300	1800
Patrol Sustained Contact	300	600
Patrol Requests QRF	300	300
Tactical Resupply	300	60

Any and all parameters required to define this component are defined in Section A.9.

5.10 Range Finder

If a squad or Soldier is expected to complete a mission in which ordinary standard issue intelligence gathering equipment is insufficient, a range finder may be assigned. Similar to the radio, PRC, Toughbook, and ISR, the range finder is special in that the operation of the range finder changes as a function of the active event. A variable pulsed-width, fixed-amplitude signal was used to emulate power consumption. The on/off frequency of the pulsed signal is based on the event schedule; in this way, more chaotic or kinetic events can lead to more frequent discharge cycling of the range finder. Recall that for the squad-based scenario, there are eight different events, each characterized by a different on/off frequency. The generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the range finder is provided in Fig. 13, the corresponding continuous and discontinuous discharge durations are then provided in Table 8.

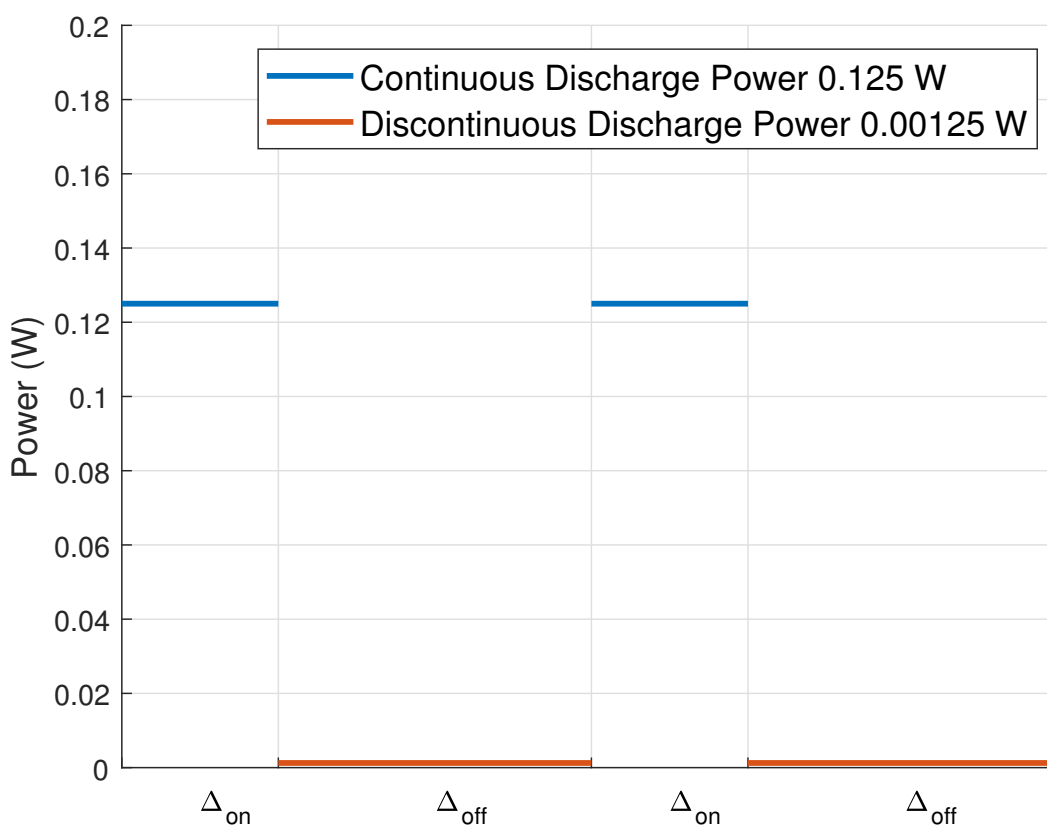


Fig. 13 Generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the range finder. The variable on/off duration is governed by the continuous and discontinuous discharge delta Δ_{on} and Δ_{off} , respectively, as defined in Table 8.

Table 8 Continuous and discontinuous discharge durations of the range finder

Event name	Continuous discharge duration	Discontinuous discharge duration
	(s)	(s)
R&R	300	3600
Guard Duty	300	3600
Insertion Extraction	300	∞
Patrol	300	3600
Patrol Intermittent Contact	300	∞
Patrol Sustained Contact	300	∞
Patrol Requests QRF	300	∞
Tactical Resupply	300	∞

Any and all parameters required to define this component are defined in Section A.10.

5.11 Infrared Strobe

IR strobes¹⁶ are considered to be standard issue for all US military personnel, as such IR strobes were included within the scenario. If the Soldier is participating in Guard Duty, Insertion/Extraction, Patrol, Patrol with Intermittent Contact, Patrol with Sustained Contact, or Patrol Requests QRF and the sun is greatly obscured, the IR strobe will consume the continuous discharge current. An IR strobe would normally use standard batteries, as such its discharge dynamics will impact the CWB. The IR strobe's continuous and discontinuous discharge currents are shown in Fig. 14.

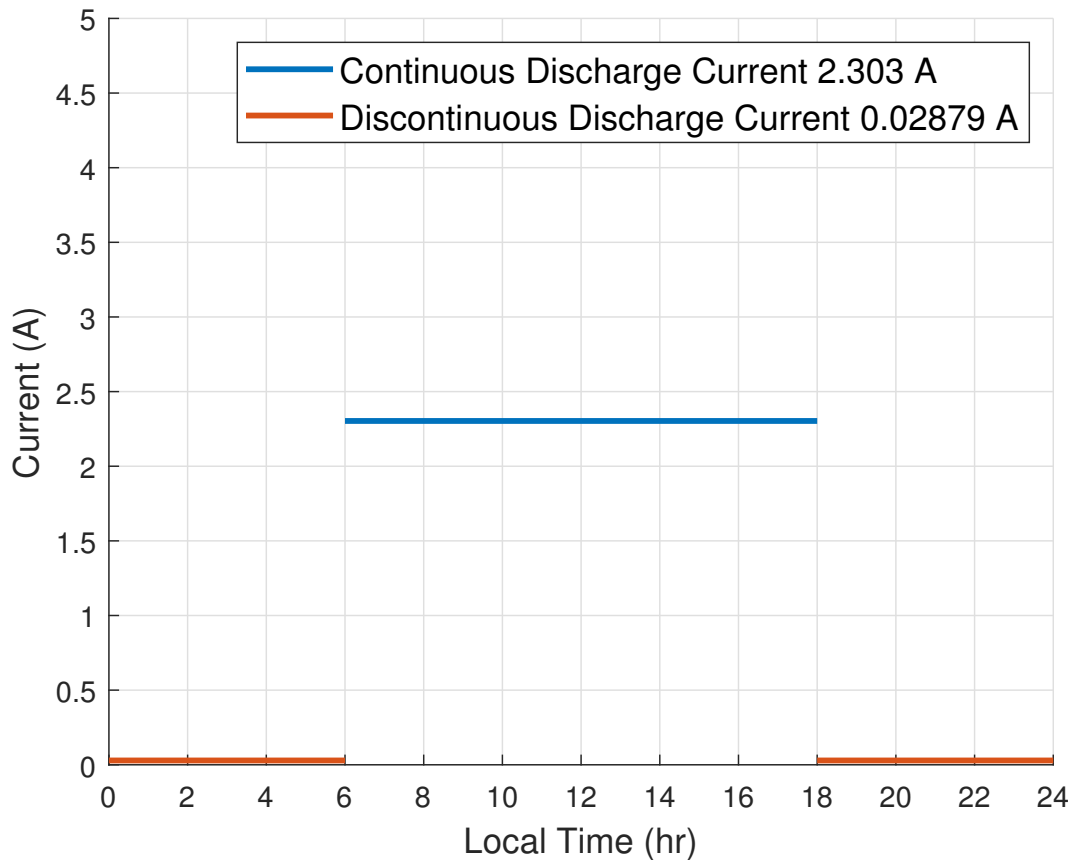


Fig. 14 IR strobe's continuous and discontinuous discharge currents. The IR strobe is only used when the sun is greatly obscured.

Any and all parameters required to define this component are defined in Section A.11.

5.12 Infrared Laser

IR lasers¹⁶ are considered to be standard issue for all US military personnel, as such IR lasers were included within the scenario. If the Soldier is participating in Guard Duty, Insertion/Extraction, Patrol, Patrol with Intermittent Contact, Patrol with Sustained Contact, or Patrol Requests QRF and the sun is greatly obscured, the IR laser will consume the continuous discharge current. An IR laser would normally use standard batteries, as such its discharge dynamics will impact the CWB. The IR laser's continuous and discontinuous discharge currents are shown in Fig. 15.

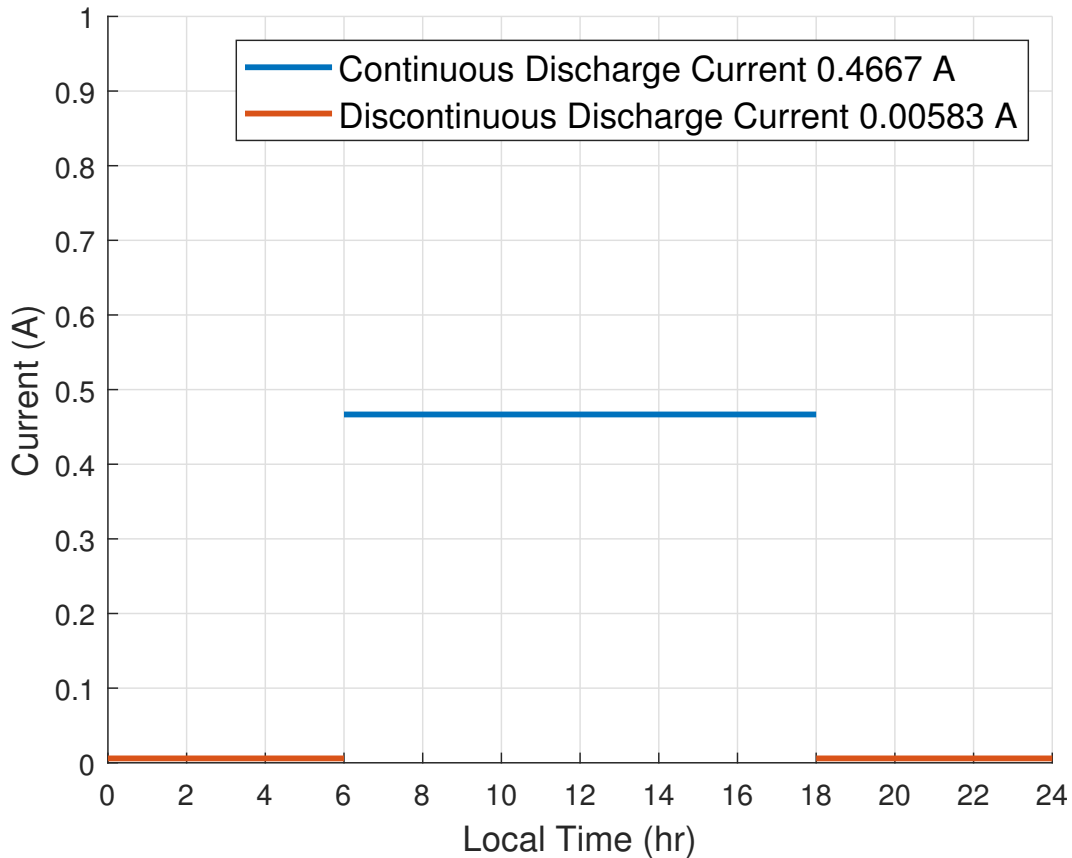


Fig. 15 IR laser’s continuous and discontinuous discharge currents. The IR laser is only used when the sun is greatly obscured.

Any and all parameters required to define this component are defined in Section A.12.

5.13 Handheld Global Positioning Satellite

GPS devices¹⁷ are considered to be standard issue for all US military personnel, as such GPSs were included within the scenario. Similar to both the radio, PRC, Toughbook, ISR, and range finder, the GPS is special in that the operation of the GPS changes as a function of the active event. A variable pulsed-width, fixed-amplitude signal was used to emulate power consumption. The on/off frequency of the pulsed signal is based on the event schedule, in this way, more chaotic or kinetic events can lead to more frequent discharge cycling of the component. Recall that for the squad-based scenario, there are eight different events, each event is characterized by a different on/off frequency. The generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the GPS device

is provided in Fig. 16, the corresponding continuous and discontinuous discharge durations are then provided in Table 9.

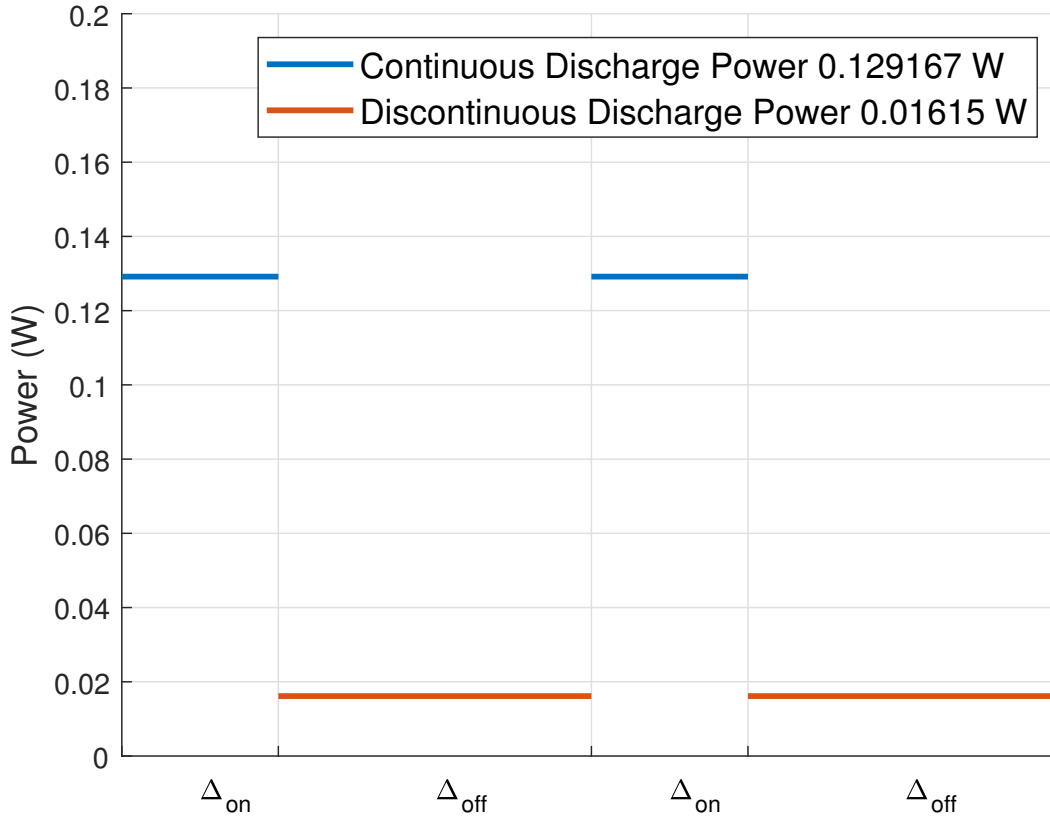


Fig. 16 Generic variable pulsed-width, fixed-amplitude signal used to model the power consumption of the range finder. The variable on/off duration is governed by the continuous and discontinuous discharge delta Δ_{on} and Δ_{off} , respectively, as defined in Table 9.

Table 9 Continuous and discontinuous discharge duration of the GPS

Event name	Continuous discharge duration	Discontinuous discharge duration
	(s)	(s)
R&R	300	3600
Guard Duty	300	3600
Insertion Extraction	300	∞
Patrol	300	3600
Patrol Intermittent Contact	300	∞
Patrol Sustained Contact	300	∞
Patrol Requests QRF	300	∞
Tactical Resupply	300	∞

Any and all parameters required to define this component are defined in Section A.13.

6. Scenarios

This report details two separate scenarios. The first scenario features a limited tactical resupply intelligence gathering mission. The mission lasts for a duration of 96 h. There are two squads, each squad has eight separate Soldiers. The Soldiers are inserted into the area of operation (AO) and progress through their mission by taking multiple objectives. Once all objectives have been completed, the squad of Soldiers is extracted; this concludes the scenario.

The second scenario features a tactical resupply intelligence gathering mission. The mission again lasts for a duration of 96 h. Again, there are two squads, and each squad comprises eight separate Soldiers. The Soldiers are inserted into the AO and progress through their mission by taking multiple objectives. Forty-eight hours into the 96-h mission, each Soldier will participate in a tactical resupply. During the tactical resupply, each Soldier recharges any and all electrical equipment within their possession. After the tactical resupply, the Soldiers continue to progress through their mission by taking all remaining objectives. Once all objectives have been completed, the squad of Soldiers is extracted; this concludes the scenario.

Both scenarios are explicitly defined within the following subsections.

6.1 Limited Tactical Resupply Scenario

The overarching theme of the mission scenario is for two squads of eight Soldiers each to conduct an intelligence gathering mission over a 96-h period. The scenario begins with both squads being deployed via a helicopter to their common insertion point, after which they are required to take objectives A through D. Upon completion of objective D, the squads are extracted via helicopters.

The first phase of the scenario is illustrated in Fig. 17. Here, the squads are airlifted into the insertion point, presumed to occur at $T + 0$ h. Over the next 24-h period, the squads move from the insertion point to objective A and gather any relevant intelligence. During the early morning or late evening hours, the squads are stationary. During this time, the bulk of the squads participate in the R&R event. Those not participating in the R&R event were on 2- to 3-h shifts of guard duty or roaming patrols to ensure the bulk of the squad is protected. During the daylight

hours, both squads are displaced and conduct targeted patrols. This event allows the squad members to move toward taking objective A, as shown in Fig. 18. This event is presumed to be completed by $T + 24$ h.



Fig. 17 Phase I of the squad-based scenario, the squads of Soldiers are airlifted into the AO



Fig. 18 Phase II of the squad-based scenario, the squads of Soldiers move from the insertion point to objective A over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering

Over the next 24-h period, the squads move from the objective A to objective B, repeating the previously stated event cycling. This movement allows the squads to take objective B, as shown in Fig. 19, and is presumed to be completed by $T + 48$ h.



Fig. 19 Phase III of the squad-based scenario, the squads of Soldiers move from the objective A over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering to take objective B

Over the next 24-h period, the squads move from the objective B to objective C, again repeating the previously stated event cycling, allowing the squads to take objective C, as shown in Fig. 20; and is presumed to be completed by $T + 72$ h.



Fig. 20 Phase IV of the squad-based scenario, the squads of Soldiers move from the objective B over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering to take objective C

For the final 24-h period, the squads move from objective C to objective D, again repeating the previously stated event cycling. Sometime within the late evening or early morning after achieving objective D, the squads are airlifted out of the AO, concluding the scenario; this set of events is shown in Fig. 21.



Fig. 21 Phase V of the squad-based scenario, the squads of Soldiers move from the objective C over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering to take objective D. Sometime in the late event or early morning after 96 h have passed, the Soldiers are extracted from the AO, concluding the squad-based scenario.

6.2 Tactical Resupply Scenario

The overarching theme of the mission scenario is for two squads of eight Soldiers each to conduct an intelligence gathering mission over the 96-h period. The scenario begins with both squads being deployed via a helicopter to their common insertion point, after which they are required to take objectives A through D. Upon completion of objective D, the squads are extracted via helicopters. Unlike the previous scenario, this scenario includes a tactical resupply event; such an event is designed to minimize the amount of energy storage requirements a Soldier is expected to carry.

The first phase of the scenario is illustrated in Fig. 22. Here, the squads are airlifted into the insertion point, presumed to occur at $T + 0$ h. Over the next 24-h period the squads move from the insertion point to objective A and gather any relevant intelligence. During the early morning or late evening hours, the squads are stationary. During this time, the bulk of the squads participate in the R&R event. Those not participating in the R&R event are on 2- to 3-h shifts of guard duty or roaming patrols to ensure the bulk of the squad was protected. During the daylight hours,

both squads are displaced and conduct targeted patrols. This event allows the squad members to move toward taking objective A, as shown in Fig. 23. This event is presumed to be completed by $T + 24$ h.



Fig. 22 Phase I of the squad-based scenario, the squads of Soldiers are airlifted into the AO



Fig. 23 Phase II of the squad-based scenario, the squads of Soldiers move from the insertion point to objective A over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering

Over the next 24-h period, the squads move from the objective A to objective B, repeating the previously stated event cycling. This movement allows the squads to take objective B, as shown in Fig. 24, and is presumed to be completed by $T + 48$ h.



Fig. 24 Phase III of the squad-based scenario, the squads of Soldiers move from the objective A over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering to take objective B

Roughly 48 h into the 96-h mission, according to the defined event schedule, the Soldiers participate in a tactical resupply. During the Tactical Resupply event, any and all battery storage associated with the individual squad members is charged. Note: This action significantly contributes to minimizing the amount of weight each individual Soldier is required to carry by reducing battery storage requirements.

Over the next 24-h period, the squads move from the objective B to objective C, again repeating the previously stated event cycling, allowing the squads to take objective C, as shown in Fig. 25; and is presumed to be completed by $T + 72$ h.



Fig. 25 Phase IV of the squad-based scenario, the squads of Soldiers move from the objective B over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering to take objective C

For the final 24-h period, the squads moved from objective C to objective D, again repeating the previously stated event cycling. Sometime within the late evening or early morning after achieving objective D, the squads are airlifted out of the AO, concluding the scenario; this set of events is shown in Fig. 26.

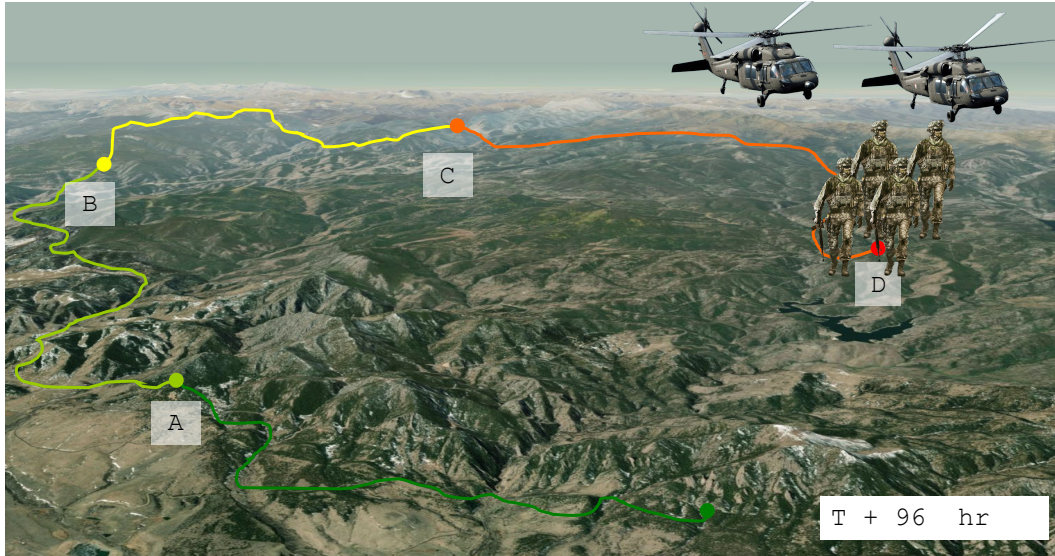


Fig. 26 Phase V of the squad-based scenario, the squads of Soldiers move from the objective C over the next 24-h period by conducting targeted patrols and any relevant intelligence gathering to take objective D. Sometime in the late event or early morning after 96 h have passed, the Soldiers are extracted from the AO, concluding the squad-based scenario.

7. Limited Tactical Resupply Results

A Simulink model was constructed using parameters defined in the Appendix and the individual Soldier event schedule, as defined within the `squad_event_configuration_without_tactical_resupply.xls` file. The simulation duration was predefined as a 96-h period. The scenario included two separate squads. Each squad had eight individual Soldiers, and each Soldier had a different number of components. This section is divided into three subsections: two of the three sections display the individual results for each squad (Sections 7.1 and 7.2, respectively) and the last section summarized the individual results for the aggregate unit (Section 7.3). Table 10 specifies which subsections of this report contain results specific to each Soldier.

Table 10 Limited tactical resupply results

Squad designation	Soldier designation	Section
A	A	7.1.1
	B	7.1.2
	C	7.1.3
	D	7.1.4
	E	7.1.5
	F	7.1.6
	G	7.1.7
	H	7.1.8
B	A	7.2.1
	B	7.2.2
	C	7.2.3
	D	7.2.4
	E	7.2.5
	F	7.2.6
	G	7.2.7
	H	7.2.8

7.1 Squad A Results

Squad A consists of eight separate Soldiers, Soldier A through Soldier H. Soldier H is defined as the squad's communications officer. To help arrange the multitude of results, this section is broken into subsections, one for each Soldier. Each subsection has a different number of graphs, starting with three foundational figures: 1) the Soldier-specific event schedule, 2) charging and discharging currents for the CWB,

and 3) the individual Soldier's CWB state of charge (SOC). The third figure contains two curves: the first is the individual Soldier's CWB SOC and the second is the aggregate squad's SOC.

Additional figures are included for each Soldier who is assigned additional components requiring nonstandard batteries: 1) the charging and discharging currents for the component's nonstandard battery and 2) the nonstandard battery's SOC and battery usage metric, for example, how many batteries are required for the duration of the mission. Since many of the Soldiers have been assigned the same components, many of the results are repetitive. To minimize repetitive text, a summary of the results is provided in Section 7.3. Table 11 specifies which subsections of this report contain results specific to each Soldier within Squad A.

Table 11 Squad A limited tactical resupply results

Squad designation	Soldier designation	Section
A	A	7.1.1
	B	7.1.2
	C	7.1.3
	D	7.1.4
	E	7.1.5
	F	7.1.6
	G	7.1.7
	H	7.1.8

7.1.1 Squad A–Soldier A Results

Squad A–Soldier A carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. Additionally, the CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 27 through 28.

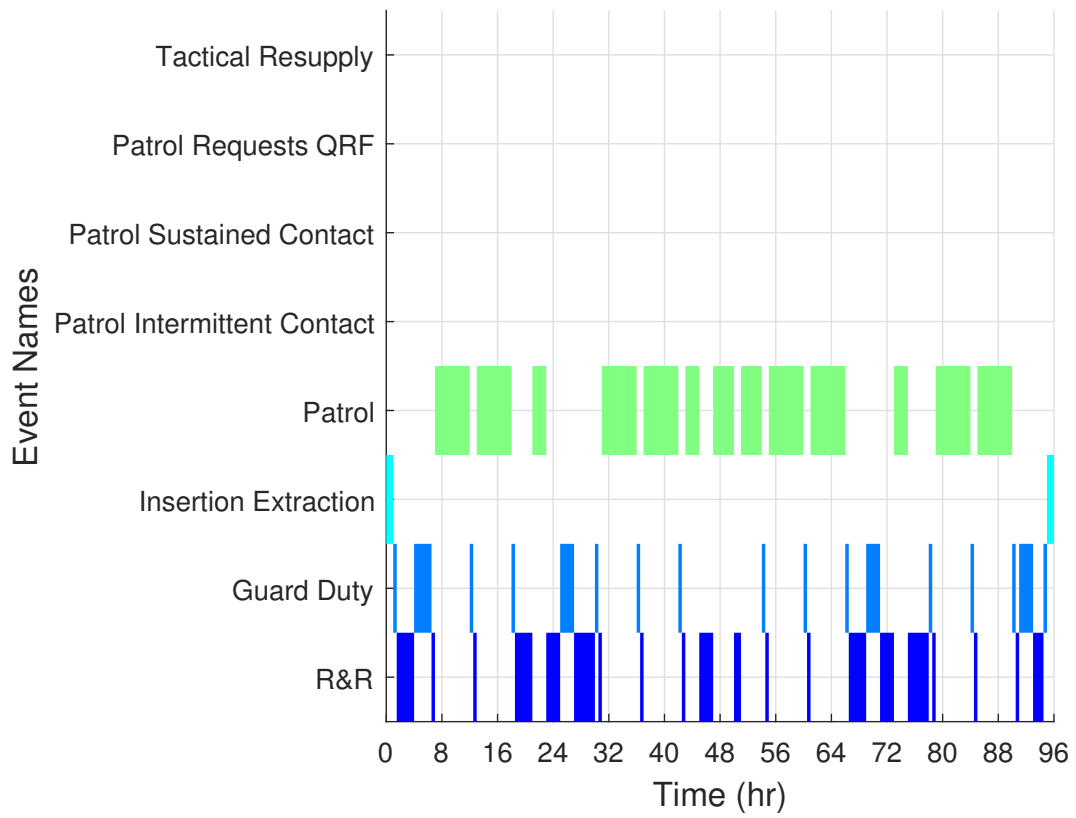
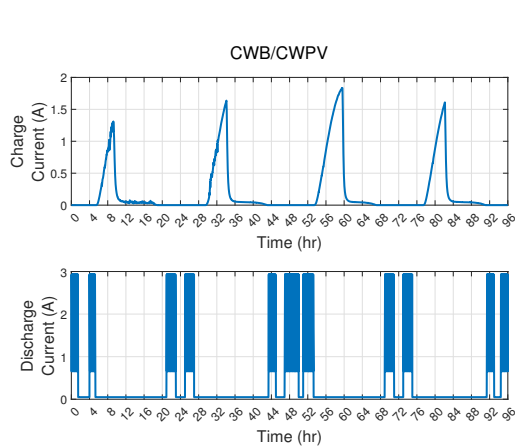
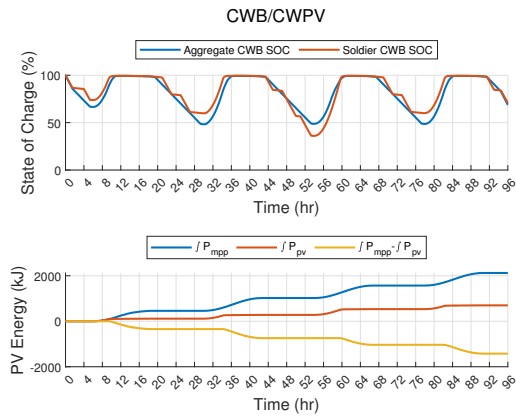


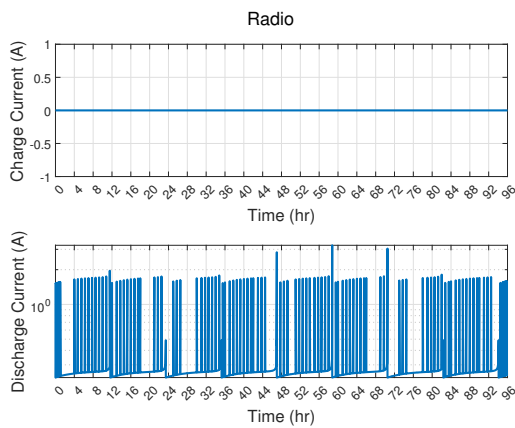
Fig. 27 Squad A-Soldier A's event schedule



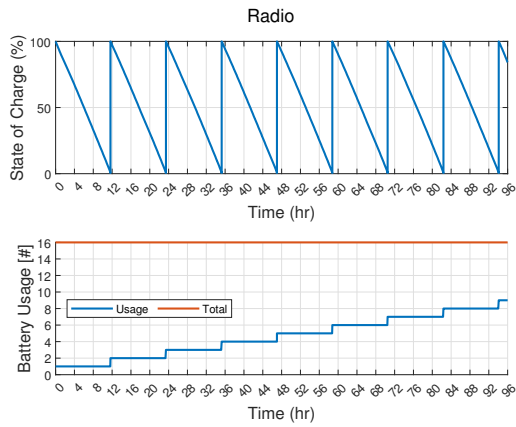
(a) Squad A-Soldier A's CWB charging and discharging currents



(b) Squad A-Soldier A's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier A's radio charging and discharging currents



(d) Squad A-Soldier A's radio SOC when compared to the radio's battery usage metric

Fig. 28 Electrical components assigned to Squad A-Soldier A

7.1.2 Squad A-Soldier B Results

Squad A-Soldier B carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. The NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 29 through 30.

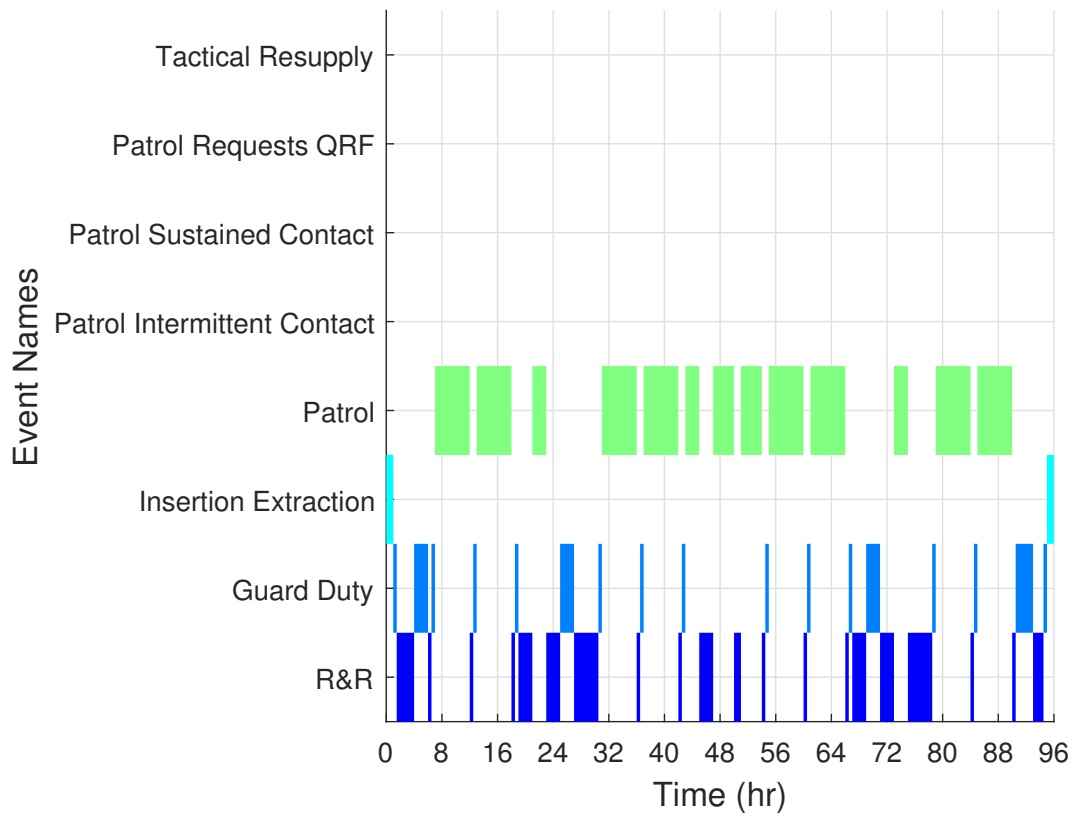


Fig. 29 Squad A-Soldier B's event schedule

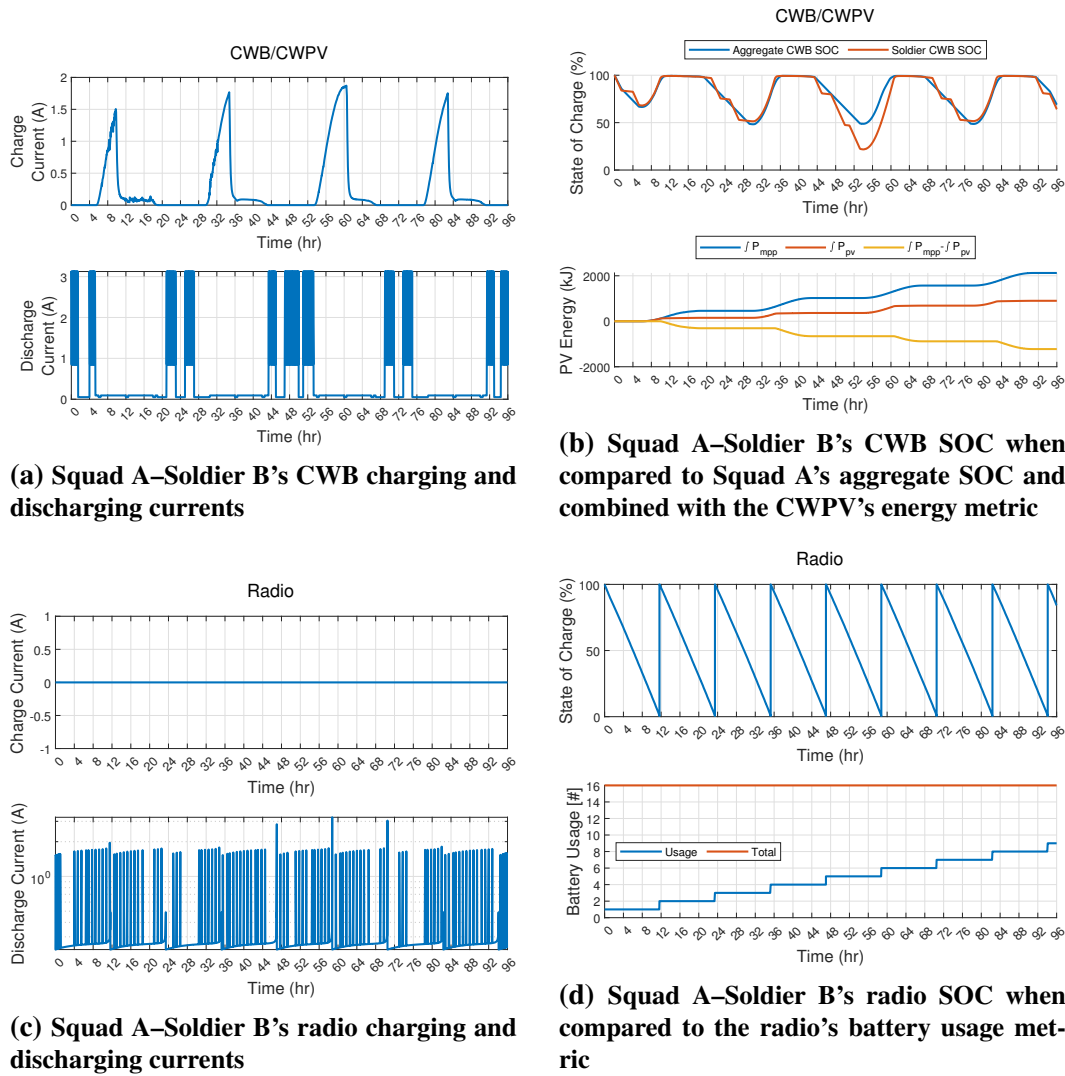


Fig. 30 Electrical components assigned to Squad A–Soldier B

7.1.3 Squad A–Soldier C Results

Squad A–Soldier C carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 31 through 32.



Fig. 31 Squad A-Soldier C's event schedule

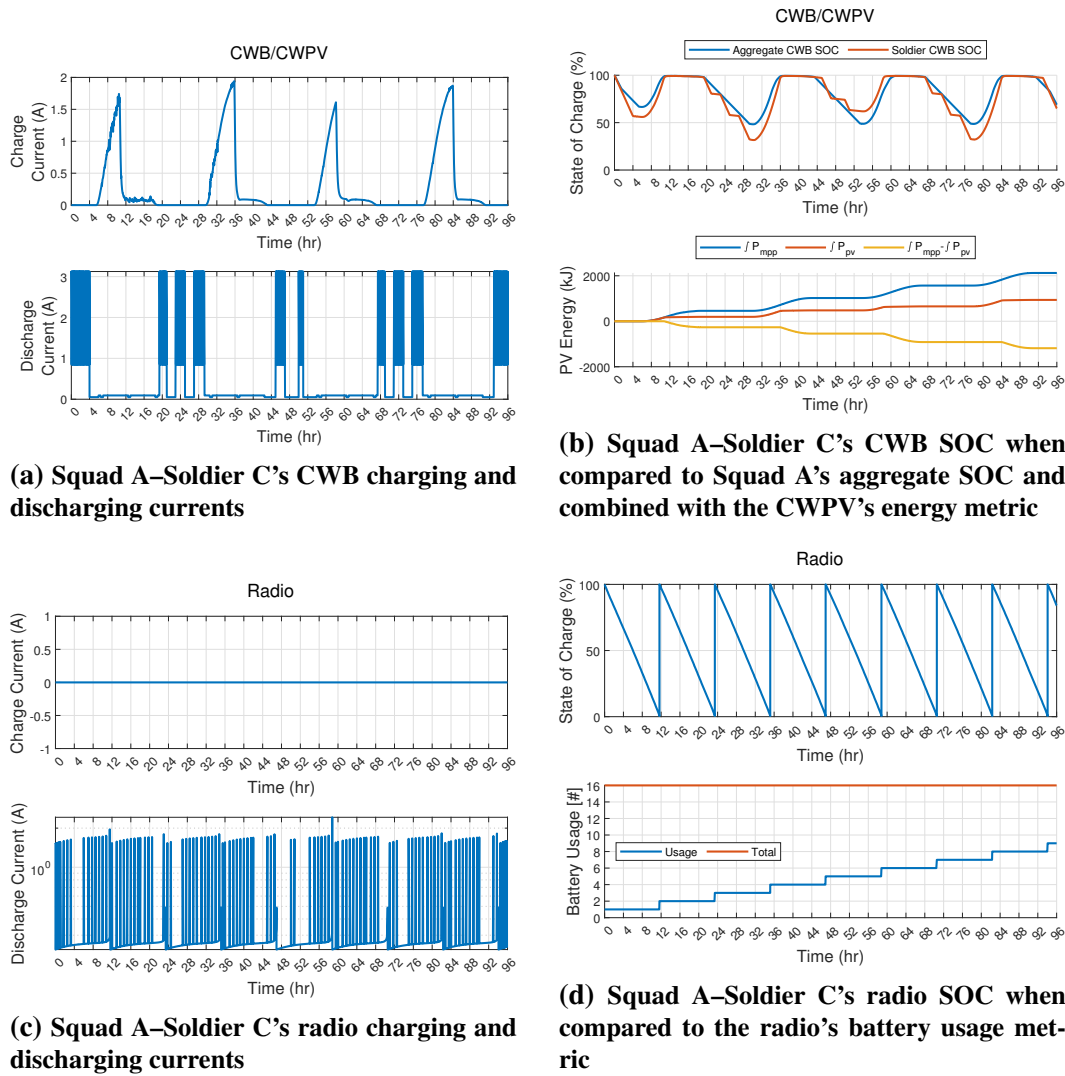


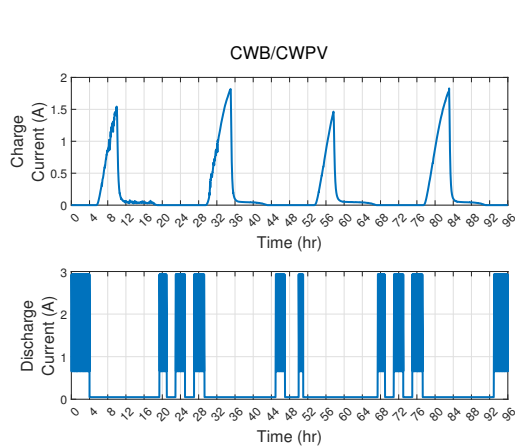
Fig. 32 Electrical components assigned to Squad A–Soldier C

7.1.4 Squad A–Soldier D Results

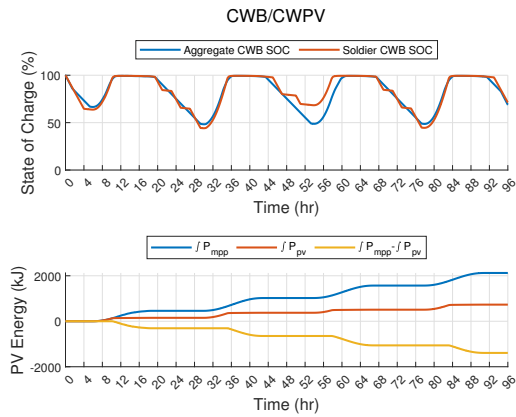
Squad A–Soldier D carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 33 through 34.



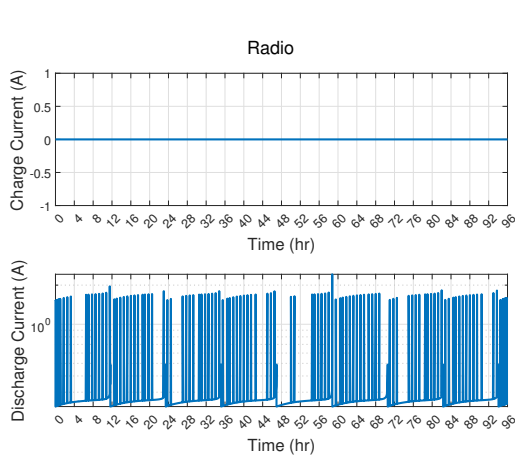
Fig. 33 Squad A-Soldier D's event schedule



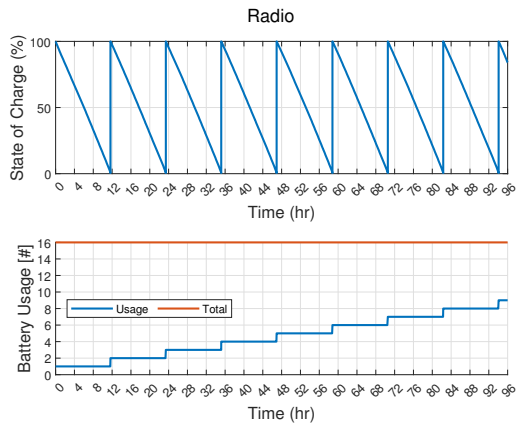
(a) Squad A-Soldier D's CWB charging and discharging currents



(b) Squad A-Soldier D's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier D's radio charging and discharging currents



(d) Squad A-Soldier D's radio SOC when compared to the radio's battery usage metric

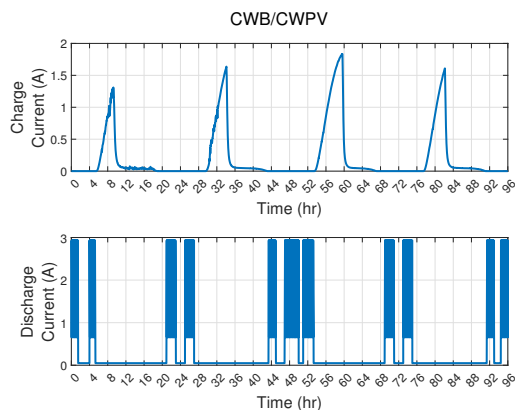
Fig. 34 Electrical components assigned to Squad A-Soldier D

7.1.5 Squad A-Soldier E Results

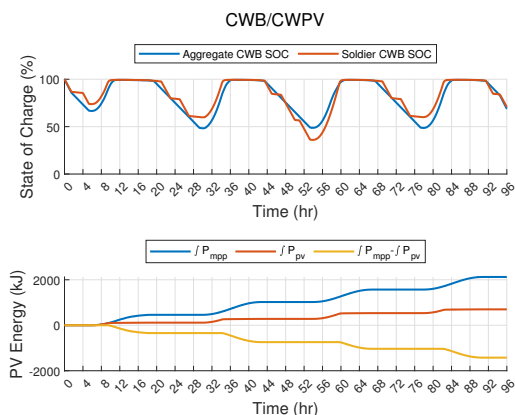
Squad A-Soldier E carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 35 through 36.



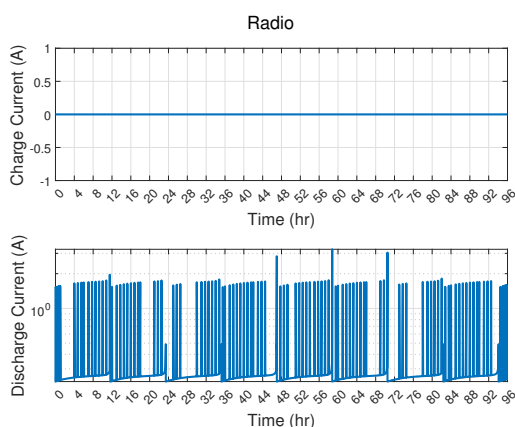
Fig. 35 Squad A-Soldier E's event schedule



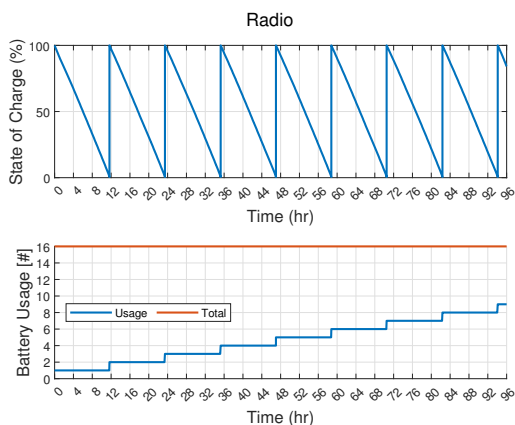
(a) Squad A-Soldier E's CWB charging and discharging currents



(b) Squad A-Soldier E's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier E's radio charging and discharging currents



(d) Squad A-Soldier E's radio SOC when compared to the radio's battery usage metric

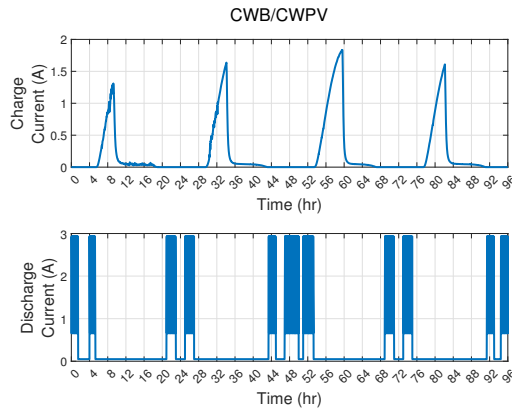
Fig. 36 Electrical components assigned to Squad A-Soldier E

7.1.6 Squad A-Soldier F Results

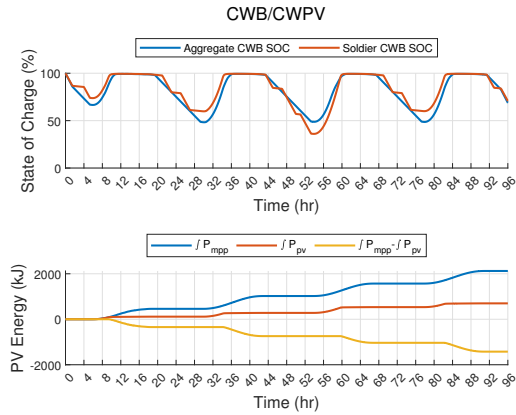
Squad A-Soldier F carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 37 through 38.



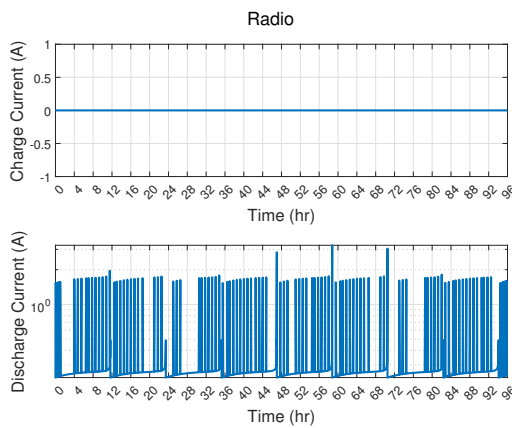
Fig. 37 Squad A-Soldier F's event schedule



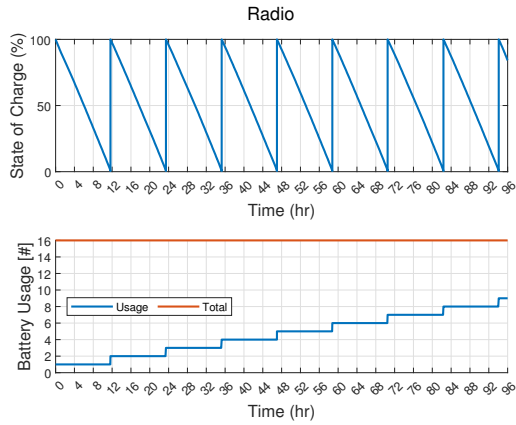
(a) Squad A-Soldier F's CWB charging and discharging currents



(b) Squad A-Soldier F's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier F's radio charging and discharging currents



(d) Squad A-Soldier F's radio SOC when compared to the radio's battery usage metric

Fig. 38 Electrical components assigned to Squad A-Soldier F

7.1.7 Squad A-Soldier G Results

Squad A-Soldier G carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 39 through 40.



Fig. 39 Squad A–Soldier G’s event schedule

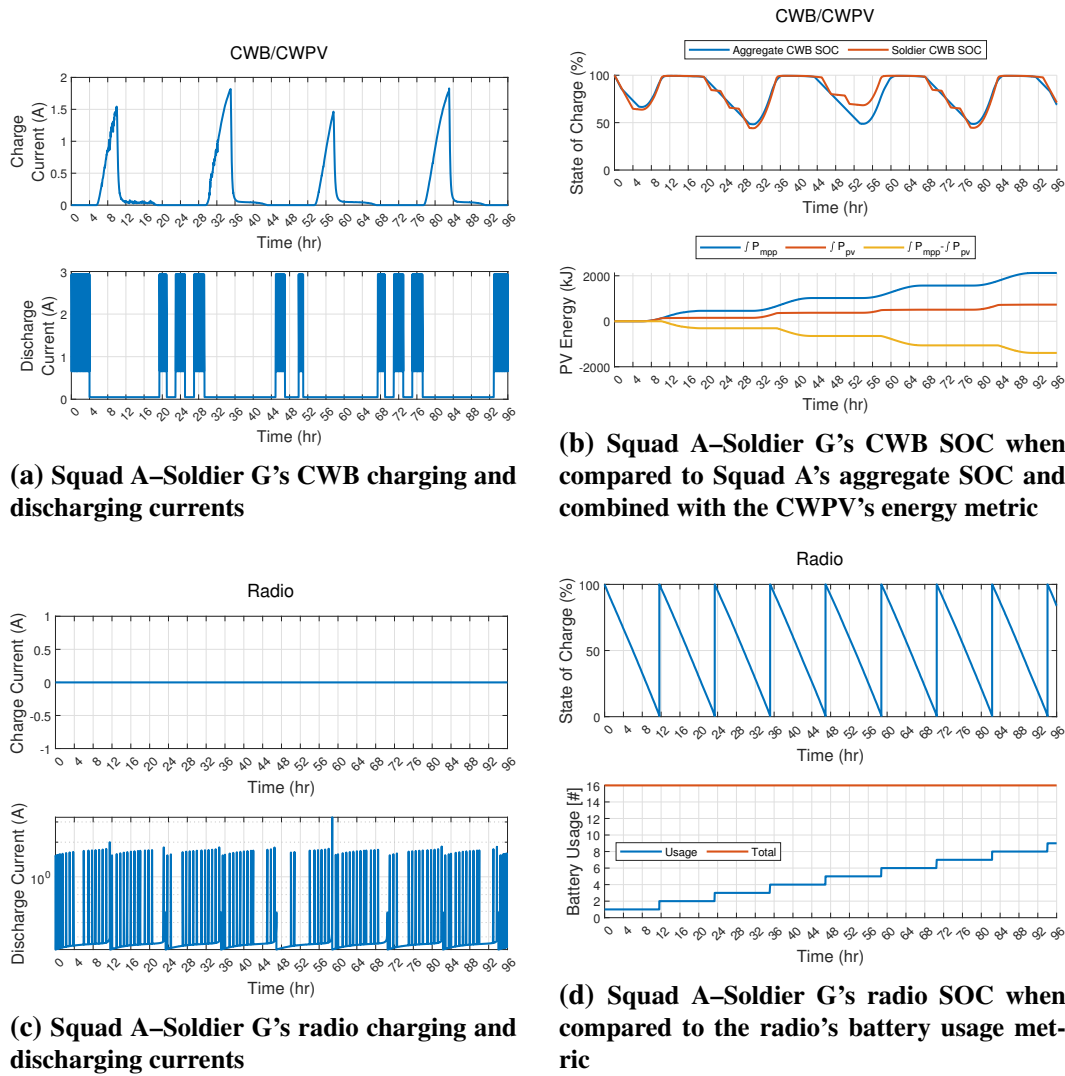


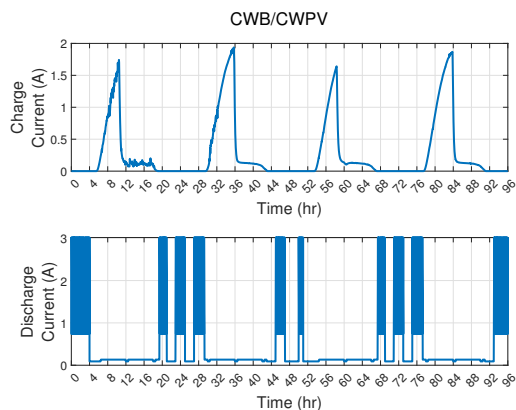
Fig. 40 Electrical components assigned to Squad A–Soldier G

7.1.8 Squad A–Soldier H Results

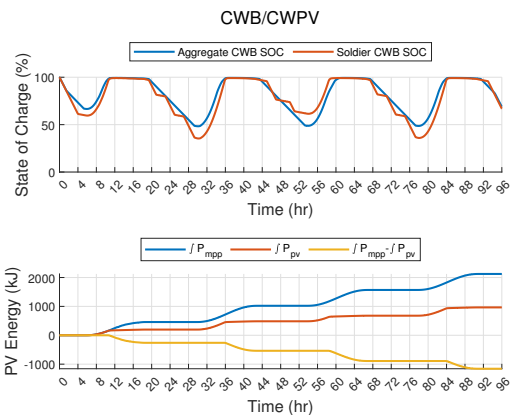
Squad A–Soldier H carries a CWB, CWPV, NVGs, flashlight, radio, PRC, Toughbook, ISR, GPS, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio, PRC, Toughbook, and ISR all of which use a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 41 through 43.



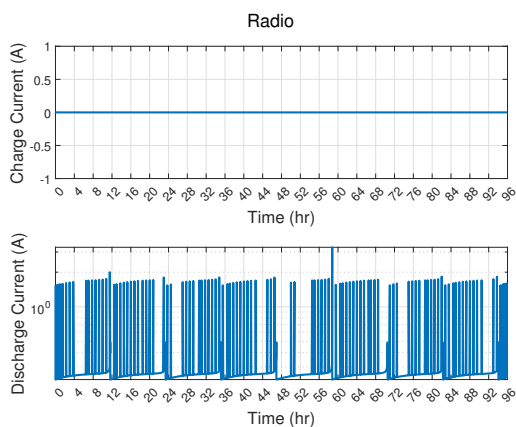
Fig. 41 Squad A–Soldier H’s event schedule



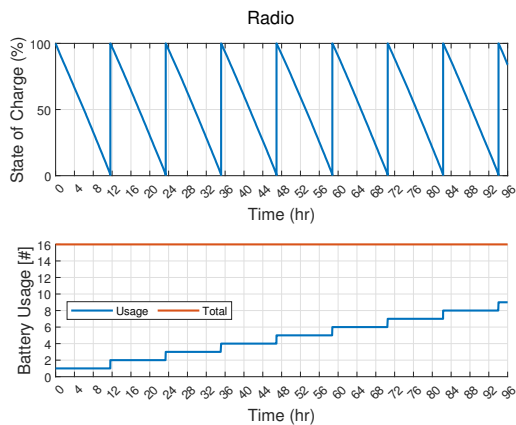
(a) Squad A–Soldier H’s CWB charging and discharging currents



(b) Squad A–Soldier H’s CWB SOC when compared to Squad A’s aggregate SOC and combined with the CWPV’s energy metric

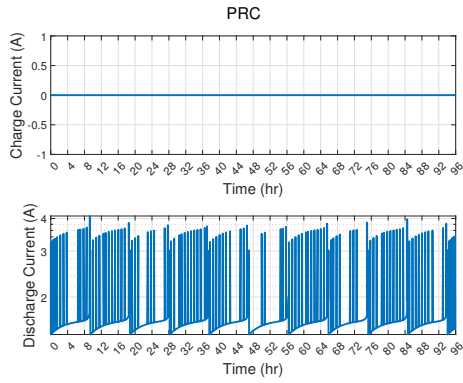


(c) Squad A–Soldier H’s radio charging and discharging currents

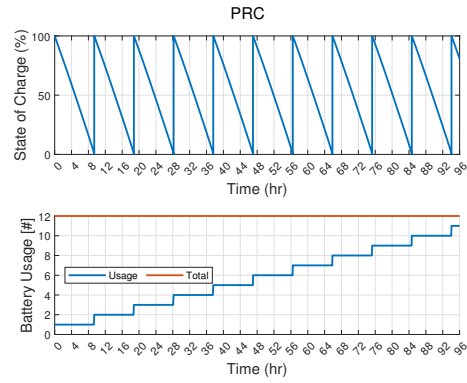


(d) Squad A–Soldier H’s radio SOC when compared to the radio’s battery usage metric

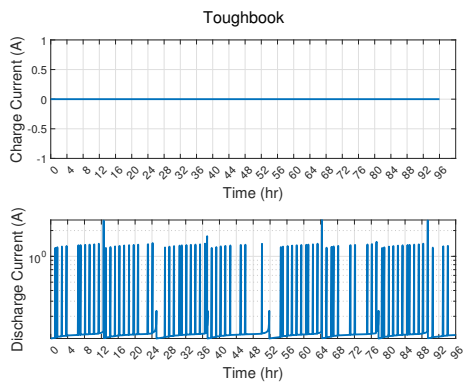
Fig. 42 Electrical components assigned to Squad A–Soldier H (part 1)



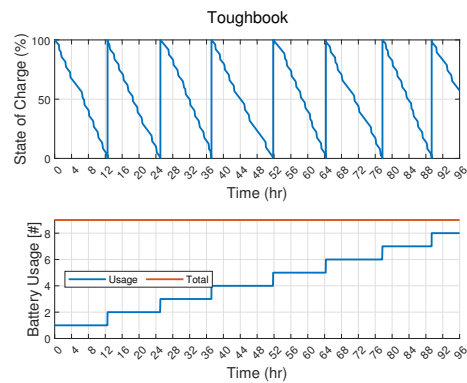
(a) Squad A–Soldier H’s PRC charging and discharging currents



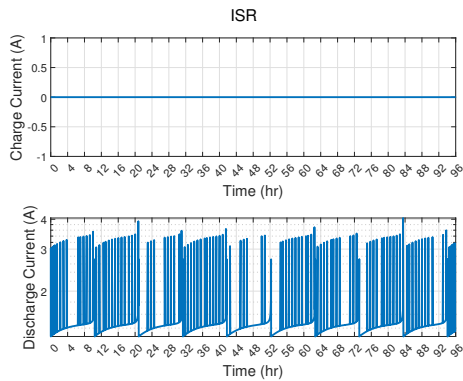
(b) Squad A–Soldier H’s PRC SOC compared to its battery usage metric



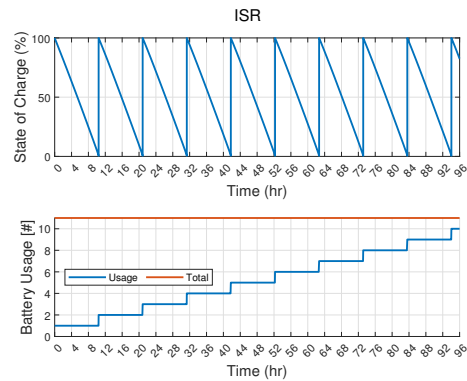
(c) Squad A–Soldier H’s Toughbook charging and discharging currents



(d) Squad A–Soldier H’s Toughbook SOC compared to its battery usage



(e) Squad A–Soldier H’s ISR charging and discharging currents



(f) Squad A–Soldier H’s ISR SOC compared to its battery usage metric

Fig. 43 Electrical components assigned to Squad A–Soldier H (part 2)

7.2 Squad B Results

Squad B consists of eight separate Soldiers, Soldier A through Soldier H. Soldier H is defined as the squad's communications officer. To help arrange the multitude of the results, this section is broken into subsections, one for each Soldier. Each subsection has a different number of graphs, starting with three foundational figures: 1) the Soldier specific event schedule, 2) charging and discharging currents for the CWB, and 3) the individual Soldier's CWB SOC. The third figure contains two curves: the first is the individual Soldier's CWB SOC and the second is the aggregate squad's SOC.

Additional figures are included for each Soldier that is assigned additional components requiring nonstandard batteries: 1) the charging and discharging currents for the components nonstandard battery and 2) the nonstandard battery's SOC and battery usage metric, for example, how many batteries are required for the duration of the mission. Since many of the Soldiers have been assigned the same components, many of the results are repetitive. To minimize repetitive text, a summary of the results is provided in Section 7.3. Table 12 specifies which subsections of this report contain results specific to each Soldier within Squad B.

Table 12 Squad B limited tactical resupply results

Squad designation	Soldier designation	Section
B	A	Section 7.2.1
	B	Section 7.2.2
	C	Section 7.2.3
	D	Section 7.2.4
	E	Section 7.2.5
	F	Section 7.2.6
	G	Section 7.2.7
	H	Section 7.2.8

7.2.1 Squad B–Soldier A Results

Squad B–Soldier A carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. Additionally, the CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 44 through 45.

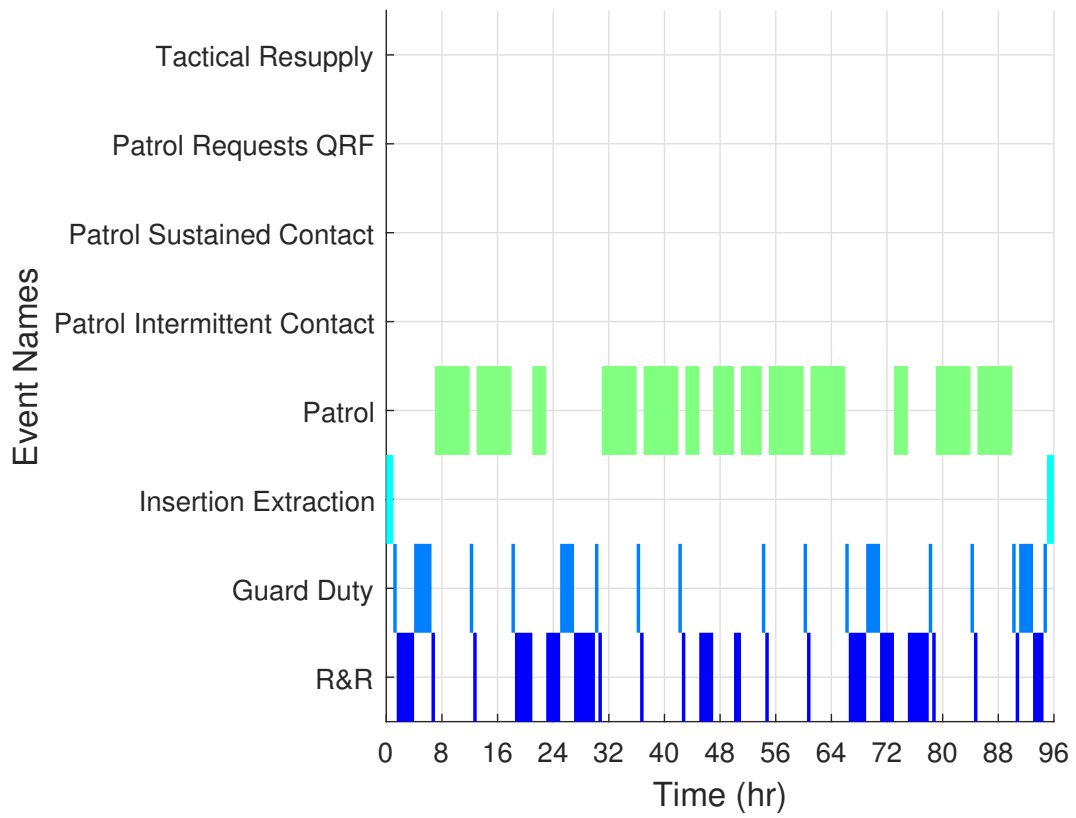
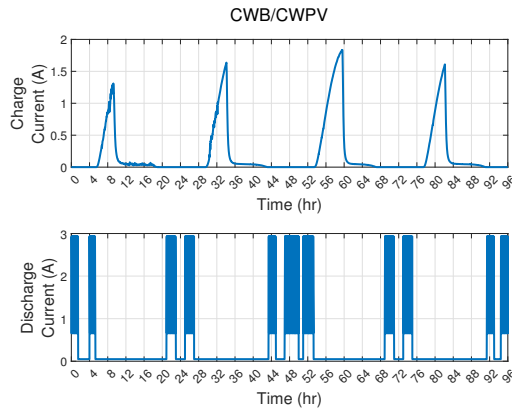
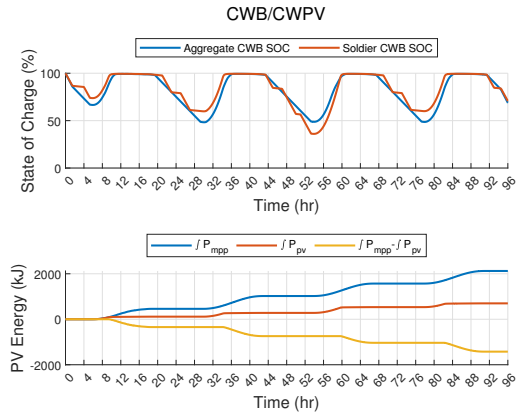


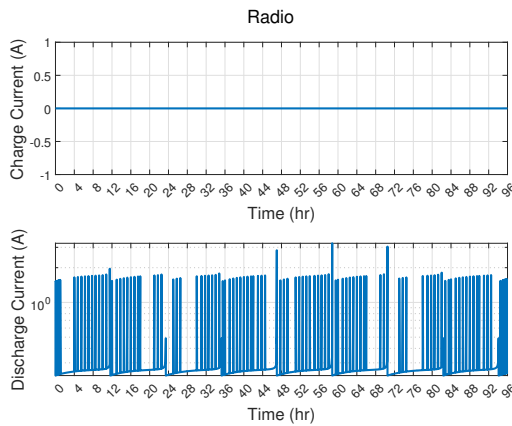
Fig. 44 Squad B-Soldier A's event schedule



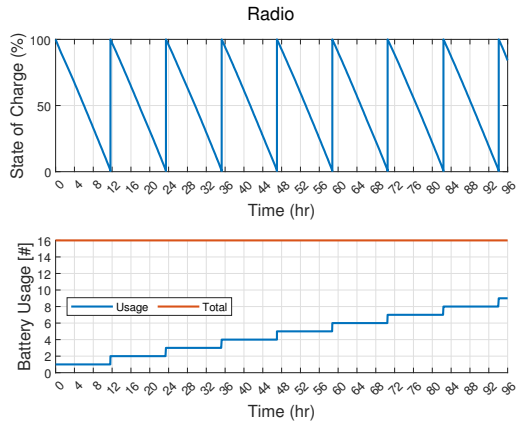
(a) Squad B-Soldier A's CWB charging and discharging currents



(b) Squad B-Soldier A's CWB SOC when compared to Squad B's aggregate SOC and combined with the CWPV's energy metric



(c) Squad B-Soldier A's radio charging and discharging currents



(d) Squad B-Soldier A's radio SOC when compared to the radio's battery usage metric

Fig. 45 Electrical components assigned to Squad B-Soldier A

7.2.2 Squad B-Soldier B Results

Squad B-Soldier B carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. The NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 46 through 47.

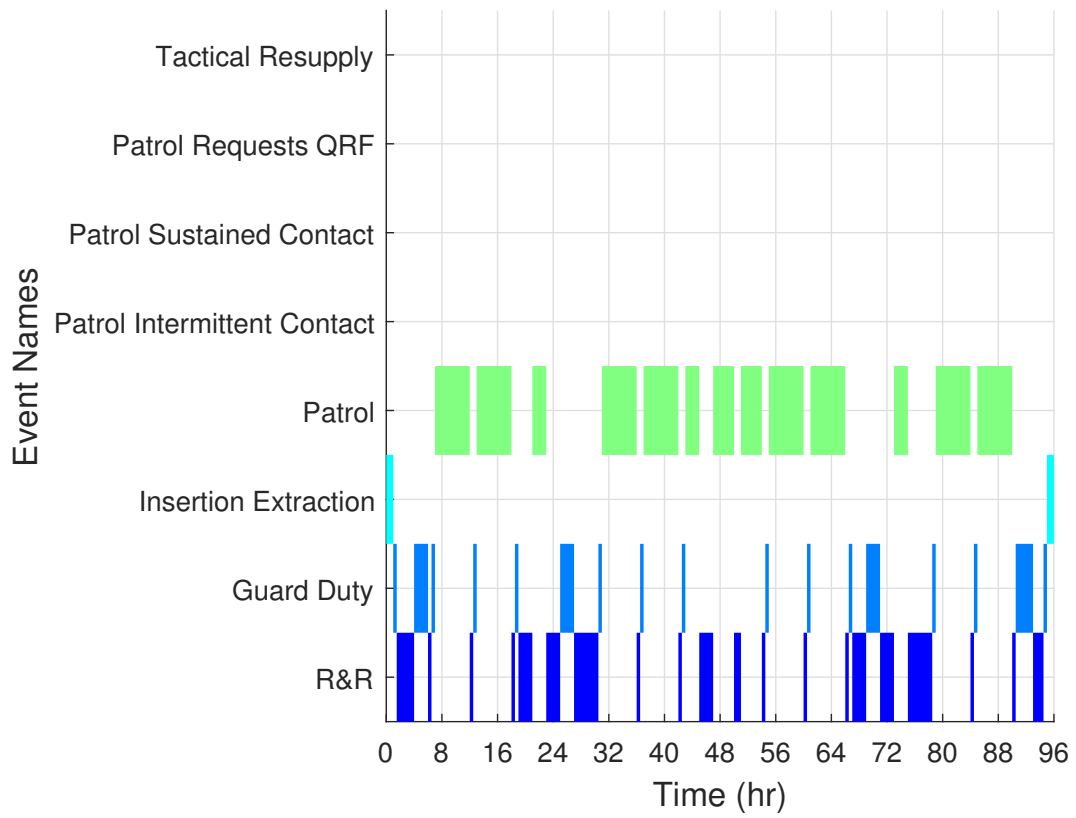


Fig. 46 Squad B-Soldier B's event schedule

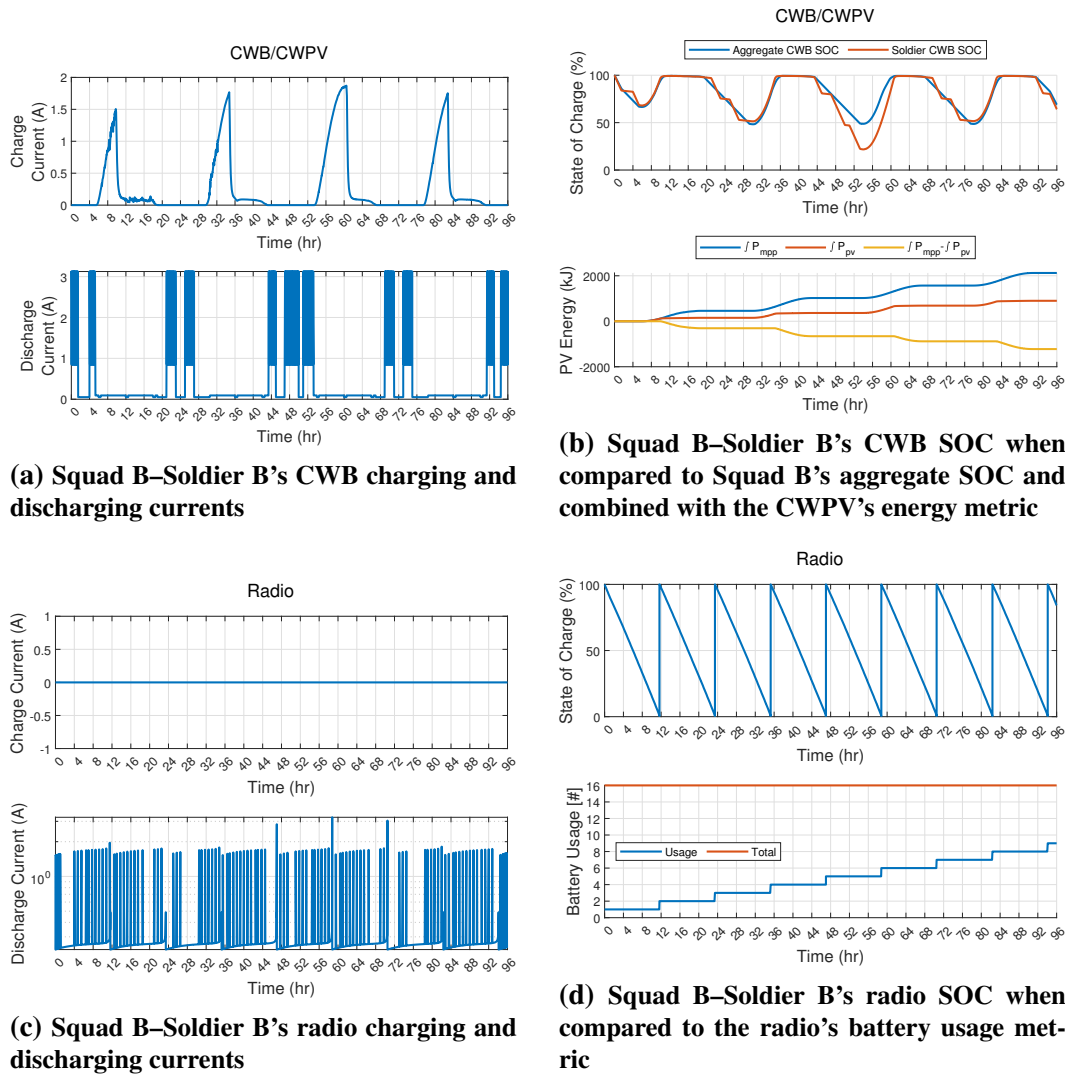


Fig. 47 Electrical components assigned to Squad B–Soldier B

7.2.3 Squad B–Soldier C Results

Squad B–Soldier C carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. The NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 48 through 49.



Fig. 48 Squad B-Soldier C's event schedule

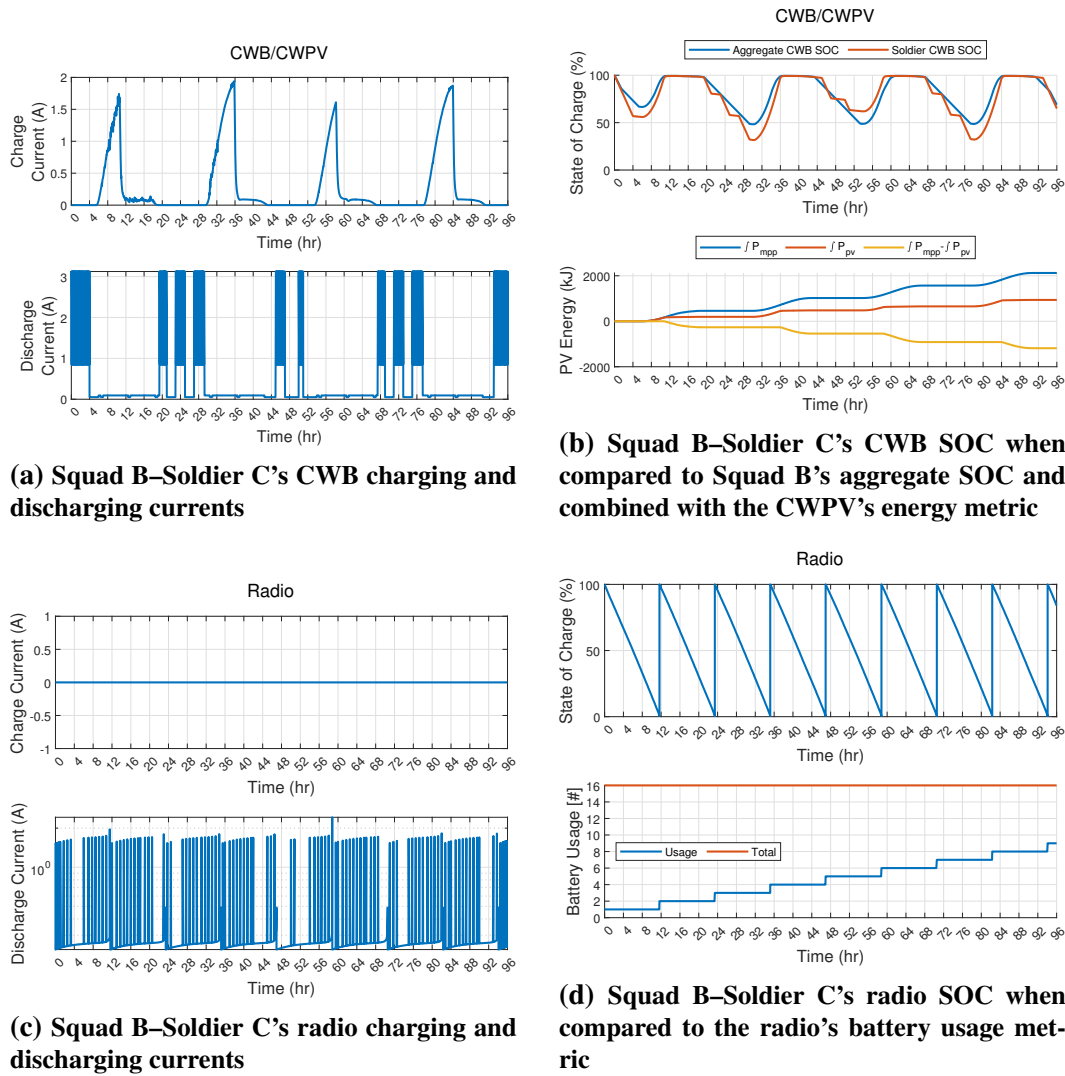


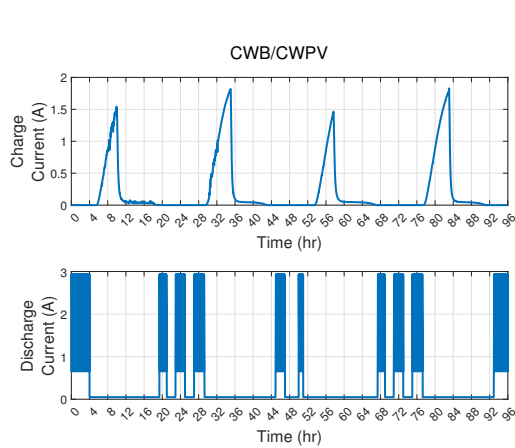
Fig. 49 Electrical components assigned to Squad B–Soldier C

7.2.4 Squad B–Soldier D Results

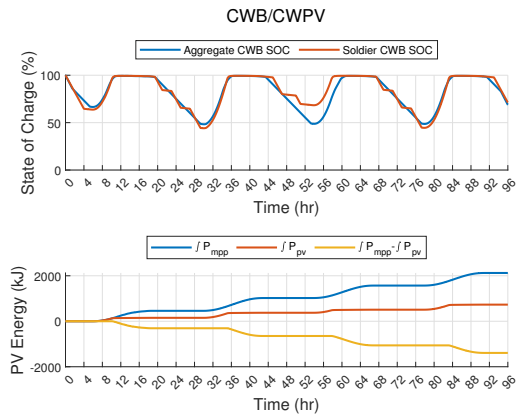
Squad B–Soldier D carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 50 through 51.



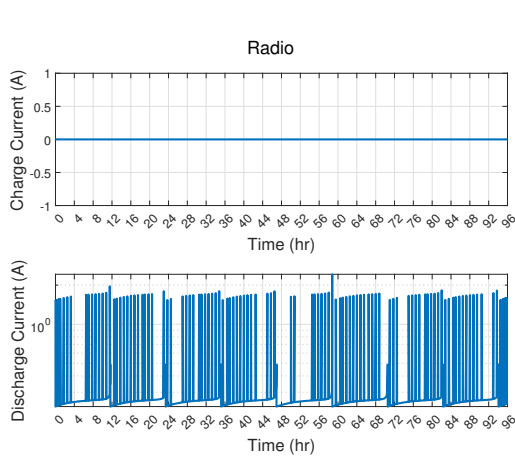
Fig. 50 Squad B-Soldier D's event schedule



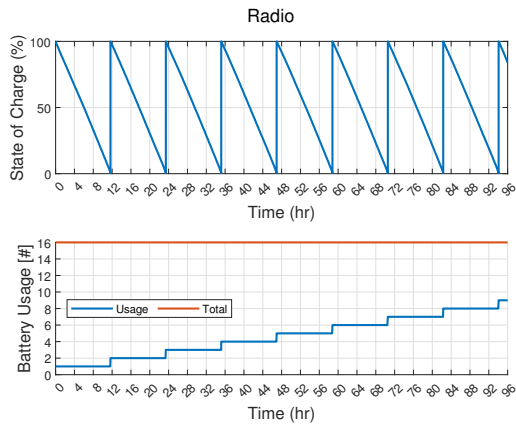
(a) Squad B–Soldier D's CWB charging and discharging currents



(b) Squad B–Soldier D's CWB SOC when compared to Squad B's aggregate SOC and combined with the CWPV's energy metric



(c) Squad B–Soldier D's radio charging and discharging currents



(d) Squad B–Soldier D's radio SOC when compared to the radio's battery usage metric

Fig. 51 Electrical components assigned to Squad B–Soldier D

7.2.5 Squad B–Soldier E Results

Squad B–Soldier E carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 52 through 53.



Fig. 52 Squad B-Soldier E's event schedule

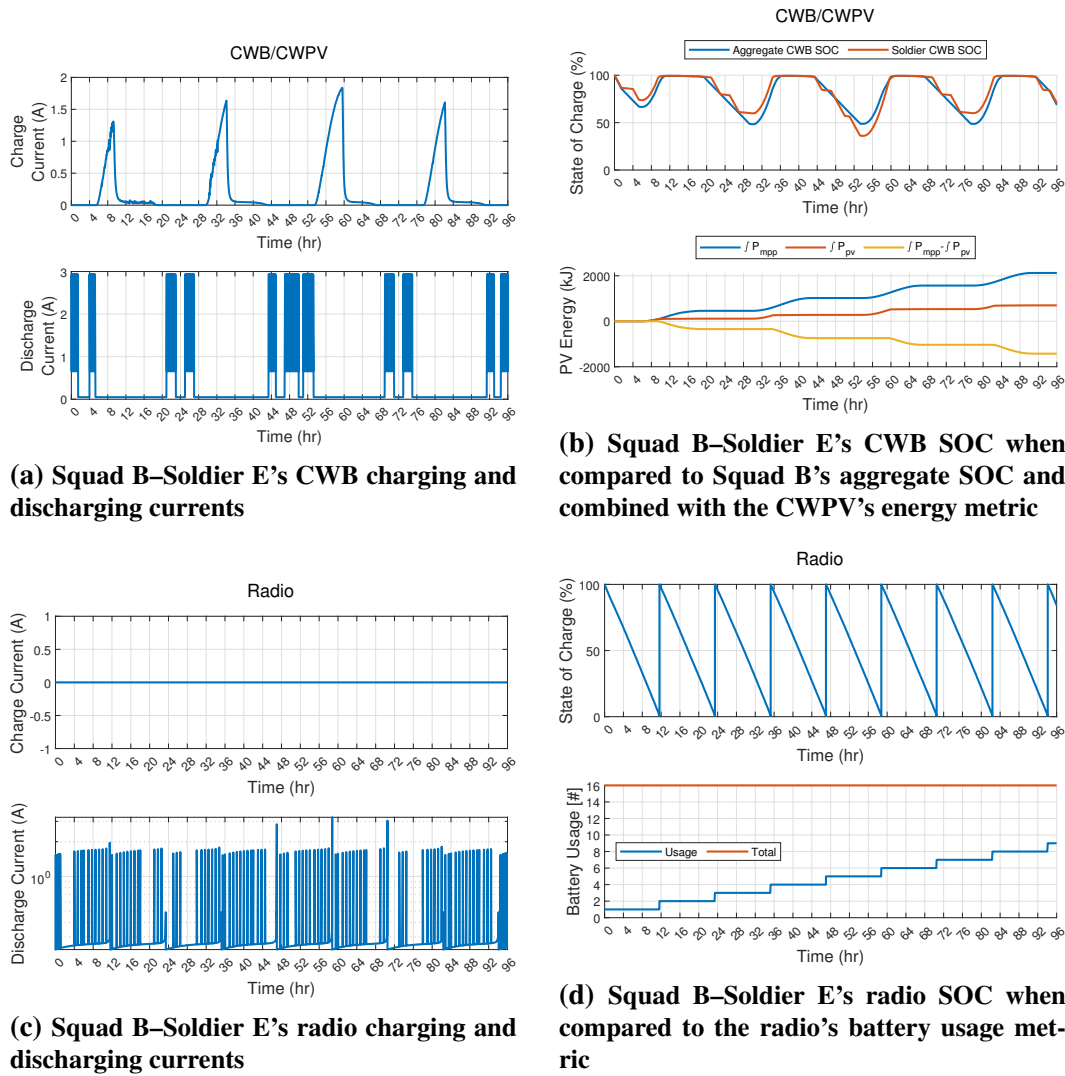


Fig. 53 Electrical components assigned to Squad B–Soldier E

7.2.6 Squad B–Soldier F Results

Squad B–Soldier F carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 54 through 55.



Fig. 54 Squad B-Soldier F's event schedule

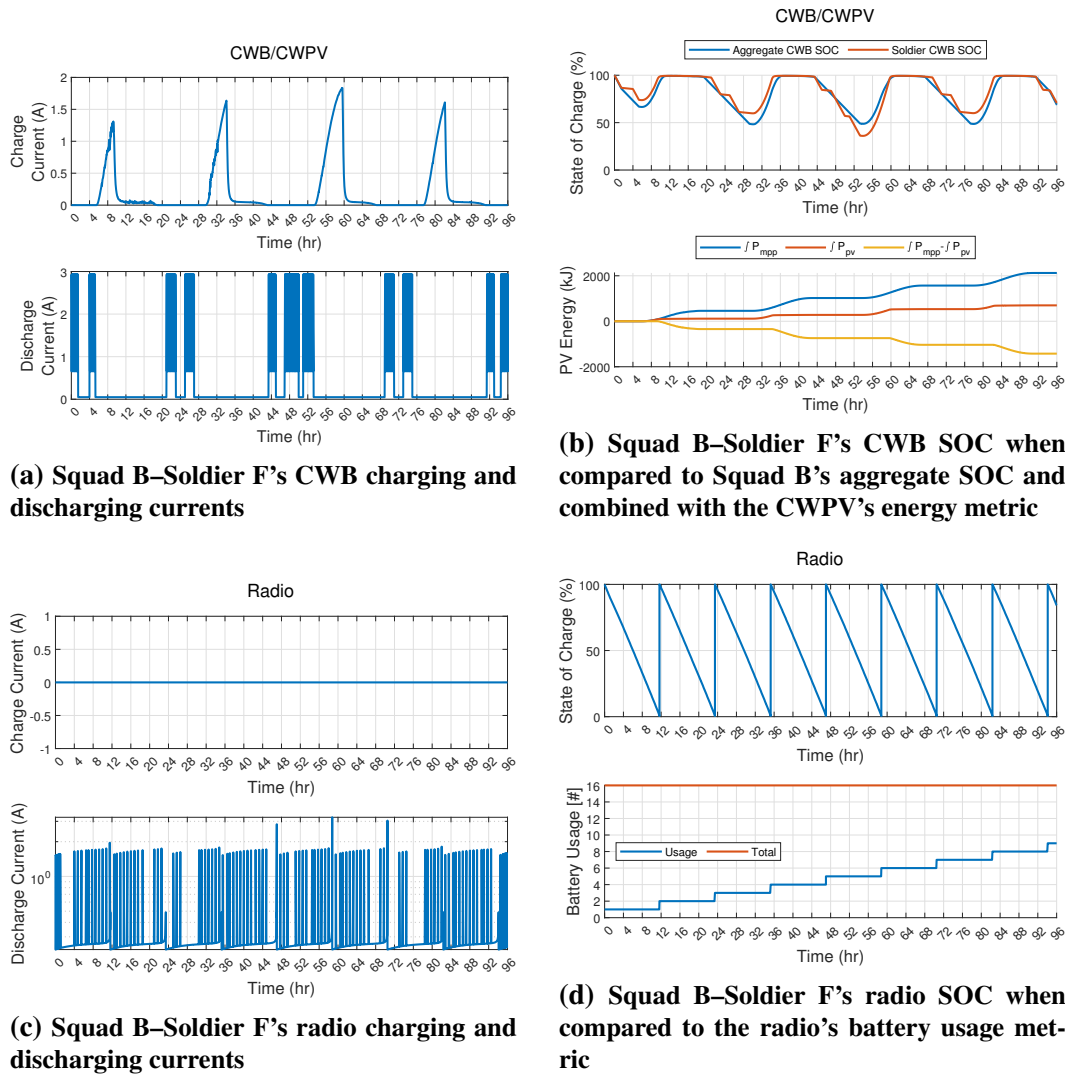


Fig. 55 Electrical components assigned to Squad B–Soldier F

7.2.7 Squad B–Soldier G Results

Squad B–Soldier G carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and an IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 56 through 57.



Fig. 56 Squad B–Soldier G’s event schedule

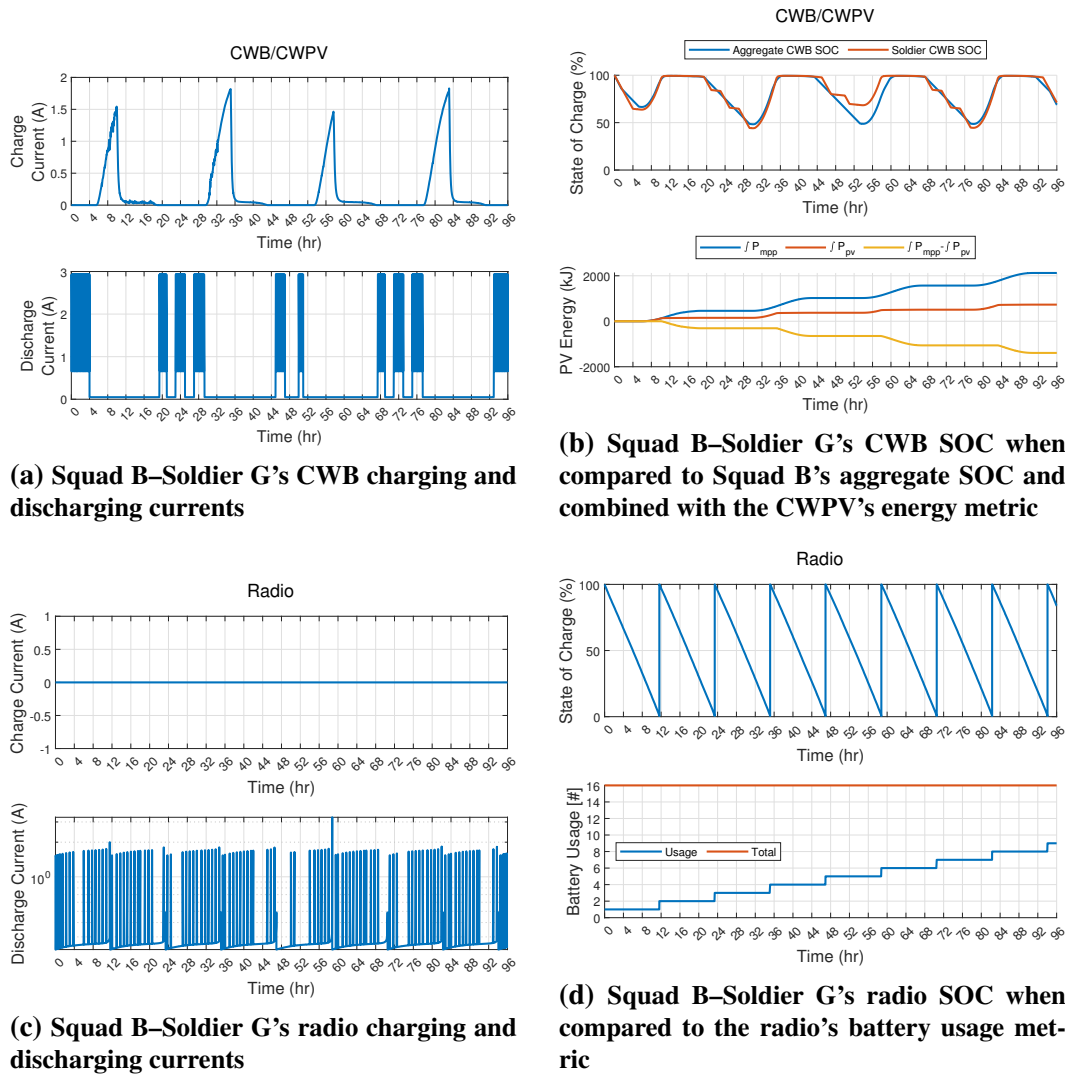


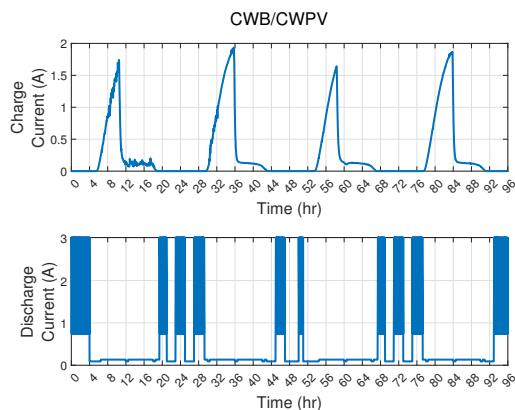
Fig. 57 Electrical components assigned to Squad B–Soldier G

7.2.8 Squad B–Soldier H Results

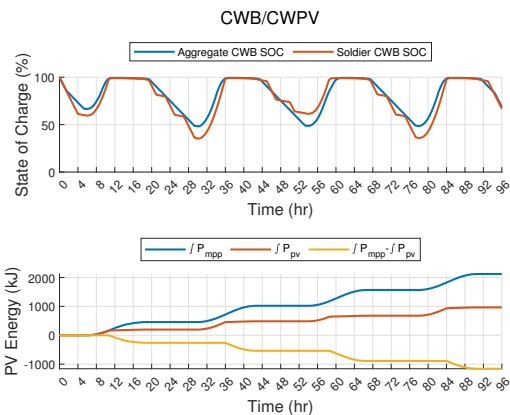
Squad B–Soldier H carries a CWB, CWPV, NVGs, flashlight, radio, PRC, Toughbook, ISR, GPS, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio, PRC, Toughbook, and ISR all of which use a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 58 through 60.



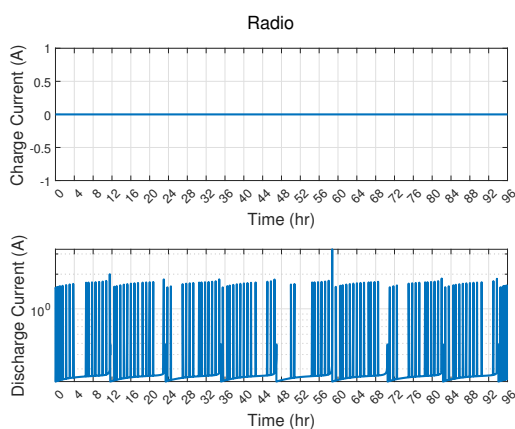
Fig. 58 Squad B–Soldier H’s event schedule



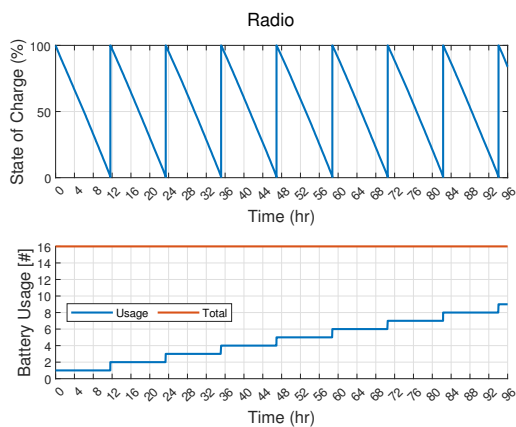
(a) Squad B–Soldier H’s CWB charging and discharging currents



(b) Squad B–Soldier H’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric

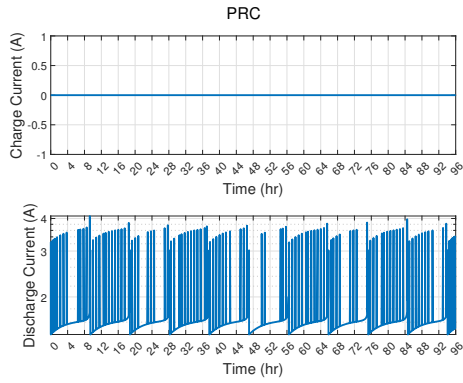


(c) Squad B–Soldier H’s radio charging and discharging currents

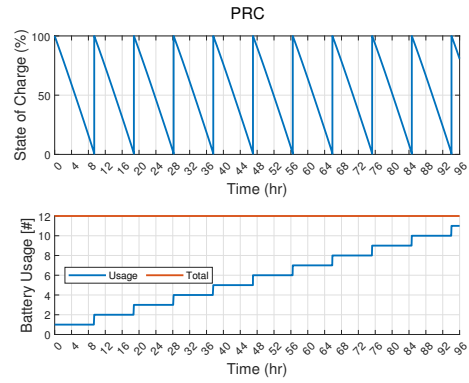


(d) Squad B–Soldier H’s radio SOC when compared to the radio’s battery usage metric

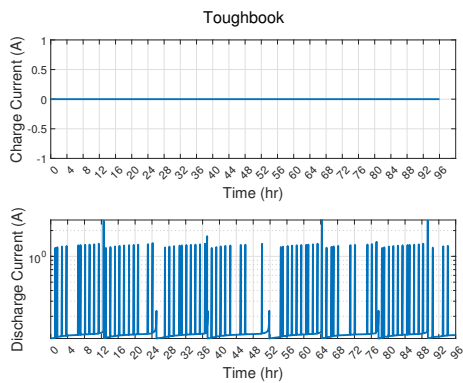
Fig. 59 Electrical components assigned to Squad B–Soldier H(part 1)



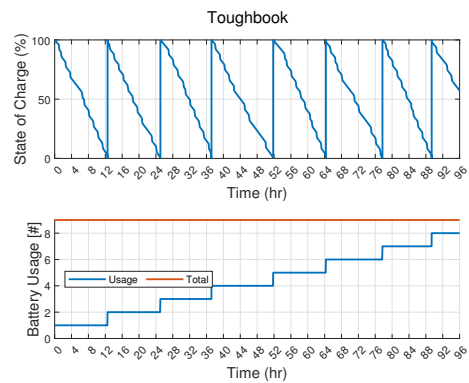
(a) Squad B–Soldier H’s PRC charging and discharging currents



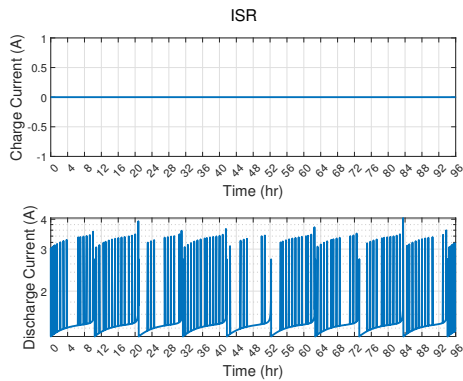
(b) Squad B–Soldier H’s PRC SOC compared to its battery usage metric



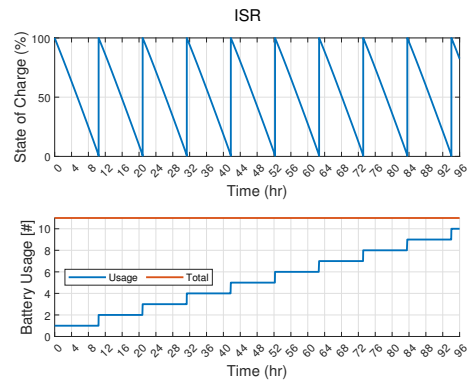
(c) Squad B–Soldier H’s Toughbook charging and discharging currents



(d) Squad B–Soldier H’s Toughbook SOC compared to its battery usage



(e) Squad B–Soldier H’s ISR charging and discharging currents



(f) Squad B–Soldier H’s ISR SOC compared to its battery usage metric

Fig. 60 Electrical components assigned to Squad B–Soldier H(part 2)

7.3 Summary of Squad A and Squad B Results

The results of the squad scenario that does not include a tactical resupply, are contained within Sections 7.1 through 7.2. Analysis of any of the PV energy trajectories or the Soldiers' battery SOC would indicate that energy is being wasted. There is sufficient energy being generated by the PV array such that the Soldiers' CWB SOC can be sufficiently charged. After the CWB has been charged, however, there is no available energy storage space to fully utilize the energy generation capabilities of the PV array. This surplus represents an area of improvement in that the rejected energy could be recaptured and used to charge additional components that use nonstandard batteries. However, these nonstandard batteries tend to have large amp-hour capacities, and as such, a PV array that generates 18 W of power at 2 A will be hard pressed to sufficiently charge the nonstandard batteries within a timely manner.

For these cases, every squad member was assigned a radio. Based on the radio-specific figures associated with each Soldier, on average, the Soldiers' radios fully discharge a total of eight times, which indicates that each Soldier would require nine radio batteries. Each radio battery was estimated to weigh 0.41 lb. This means that each Soldier would have to carry 3.69 lb of radio batteries.

Both Squad A–Soldier H and Squad B–Soldier H were determined to be a communications officer, as a result this Soldier also possessed a PRC, Toughbook, and ISR. Based on the results provided in Sections 7.1.8 and 7.2.8, each PRC will fully discharge a total of 10 times, each Toughbook will fully discharge a total of 7 times, and each ISR will fully discharge a total of 9 times. This would indicate that the communications officer must bring 11 PRC batteries, 8 Toughbook batteries, and 10 ISR batteries. This would indicate, at minimum, the communications officer must carry 24.31 lb of PRC batteries (2.21 lb), 14 lb of Toughbook batteries (1.75 lb), and 10 lb of ISR batteries (1 lb), equating to 48.31 lb of miscellaneous nonstandard batteries to operate the PRC, Toughbook, and ISR. If one includes their radio batteries, the communications officer is required to bring 52 lb of batteries to operate all the specialized communications equipment.

Note: Given the parameters set within the simulation, the radio batteries will last about 12 h, the PRC batteries will last between 8 and 9 h, the Toughbook batteries will last 12 h, and the ISR batteries will last between 9 and 10 h. If the parameters

used to define the batteries and/or alternative communications equipment are defined, the weight that a Soldier may be required to carry could increase or decrease. A summary of results is provided in Tables 13 and 14.

Table 13 Squad A summary of results

Squad	Soldier	Battery type	Weight (lb)	Quantity (#)	Weight (lb)	Duration (h)
A	A	Radio	0.41	9	3.69	12
	B	Radio	0.41	9	3.69	12
	C	Radio	0.41	9	3.69	12
	D	Radio	0.41	9	3.69	12
	E	Radio	0.41	9	3.69	12
	F	Radio	0.41	9	3.69	12
	G	Radio	0.41	9	3.69	12
	H	Radio	0.41	9	3.69	12
		PRC	2.21	11	24.31	8–9
		Toughbook	1.75	8	14.00	12
		ISR	1.00	10	10.00	9–10

Table 14 Squad B summary of results

Squad	Soldier	Battery type	Weight (lb)	Quantity (#)	Weight (lb)	Duration (h)
A	A	Radio	0.41	9	3.69	12
	B	Radio	0.41	9	3.69	12
	C	Radio	0.41	9	3.69	12
	D	Radio	0.41	9	3.69	12
	E	Radio	0.41	9	3.69	12
	F	Radio	0.41	9	3.69	12
	G	Radio	0.41	9	3.69	12
	H	Radio	0.41	9	3.69	12
		PRC	2.21	11	24.31	8–9
		Toughbook	1.75	8	9.75	12
		ISR	1.00	10	10.00	9–10

8. Tactical Resupply Results

A Simulink model was constructed using parameters defined in the Appendix and the individual Soldier event schedule as defined within the `squad_event_configuration_tactical_resupply.xls` file. The simulation duration was pre-defined as a 96-h period. The scenarios included two separate squads. Each squad had eight individual Soldiers, and each Soldier had a different number of components.

Exactly 48 h into the simulation each Soldier participated in a tactical resupply. During this event, each Soldier recharged any and all electrical equipment. The result section is divided into three subsections: two of the three sections display the individual results for each squad (Sections 8.1 and 8.2, respectively) and the last section summarized the individual results for the aggregate unit (Section 8.3). Table 15 specifies which subsections of this report contain results specific to each Soldier.

Table 15 Limited tactical resupply results

Squad designation	Soldier designation	Section
A	A	8.1.1
	B	8.1.2
	C	8.1.3
	D	8.1.4
	E	8.1.5
	F	8.1.6
	G	8.1.7
	H	8.1.8
B	A	8.2.1
	B	8.2.2
	C	8.2.3
	D	8.2.4
	E	8.2.5
	F	8.2.6
	G	8.2.7
	H	8.2.8

8.1 Squad A Results

Squad A consists of eight separate Soldiers, Soldier A through Soldier H. Soldier H is defined as the squad's communications officer. To help arrange the multitude

of the results, this section is broken into subsections, one for each Soldier. Each subsection has a different number of graphs, starting with three foundational figures: 1) the Soldier specific event schedule, 2) charging and discharging currents for the CWB, and 3) the individual Soldier's CWB SOC. The third figure contains two curves: the first is the individual Soldier's CWB SOC and the second is the aggregate squad's SOC.

Additional figures are included for each Soldier that is assigned additional components requiring nonstandard batteries: 1) the charging and discharging currents for the components nonstandard battery and 2) the nonstandard battery's SOC and battery usage metric, for example, how many batteries are required for the duration of the mission. Since many of the Soldiers have been assigned the same components, many of the results are repetitive. To minimize repetitive text, a summary of the results is provided in Section 8.3. Table 16 specifies which subsections of this report contain results specific to each Soldier within Squad A.

Table 16 Squad A limited tactical resupply results

Squad designation	Soldier designation	Section
A	A	8.1.1
	B	8.1.2
	C	8.1.3
	D	8.1.4
	E	8.1.5
	F	8.1.6
	G	8.1.7
	H	8.1.8

8.1.1 Squad A–Soldier A Results

Squad A–Soldier A carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. Additionally, the CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 61 through 62.

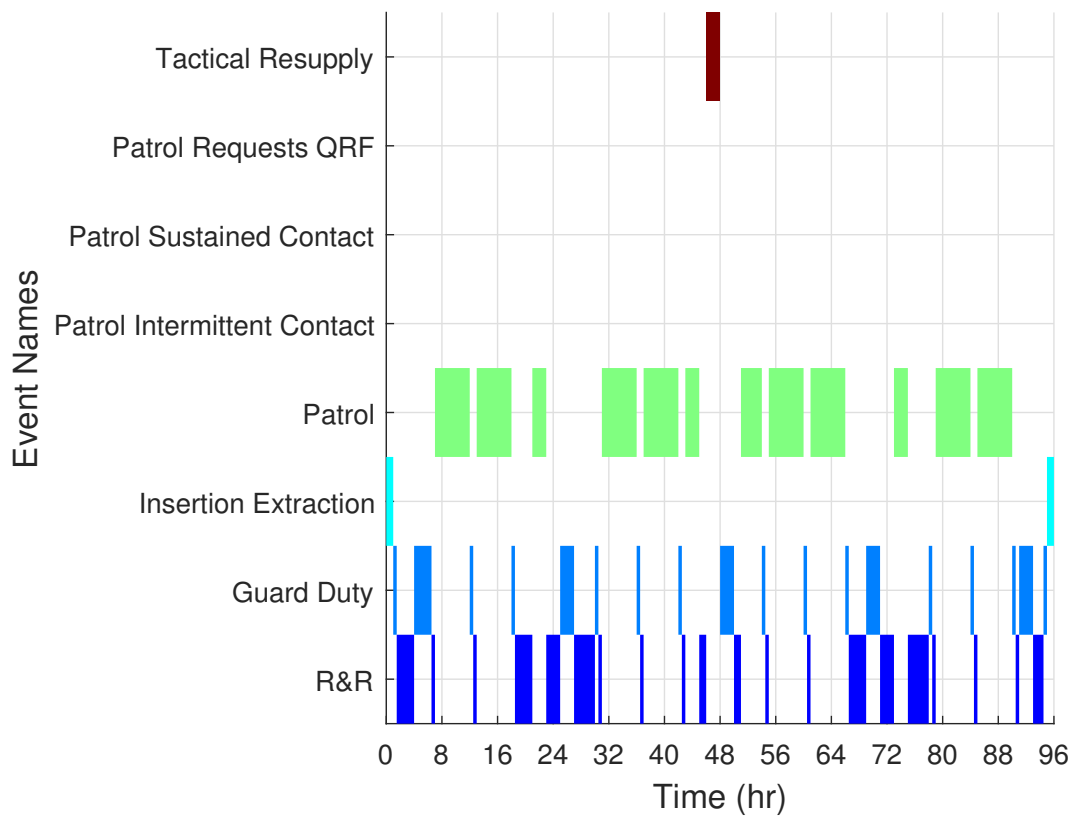
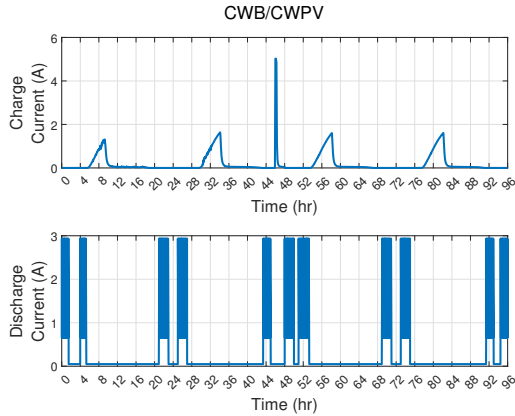
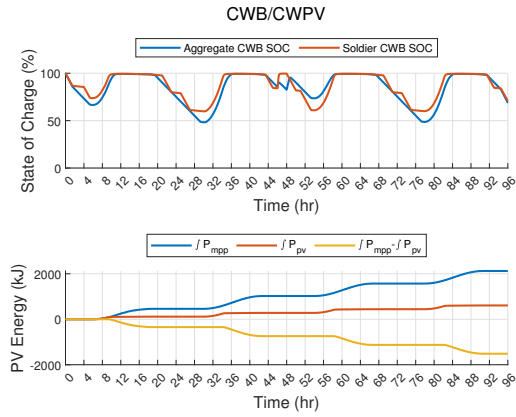


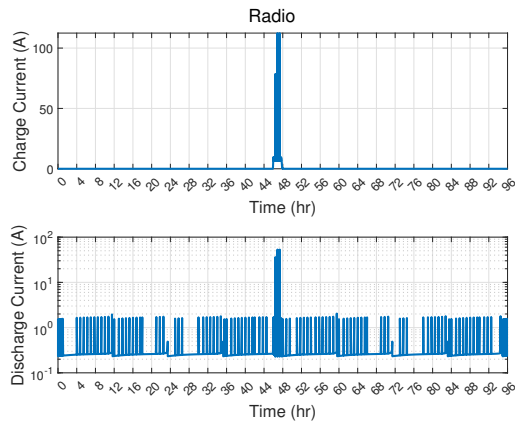
Fig. 61 Squad A-Soldier A's event schedule



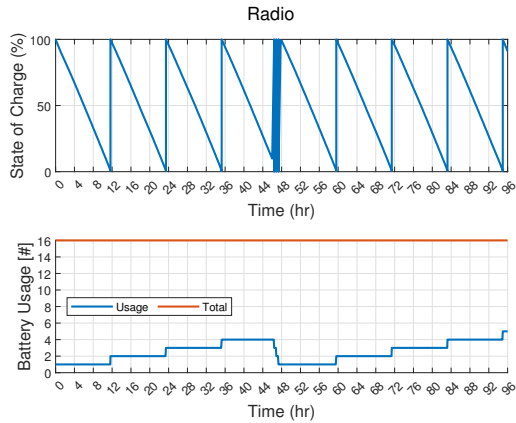
(a) Squad A–Soldier A’s CWB charging and discharging currents



(b) Squad A–Soldier A’s CWB SOC when compared to Squad A’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad A–Soldier A’s radio charging and discharging currents



(d) Squad A–Soldier A’s radio SOC when compared to the radio’s battery usage metric

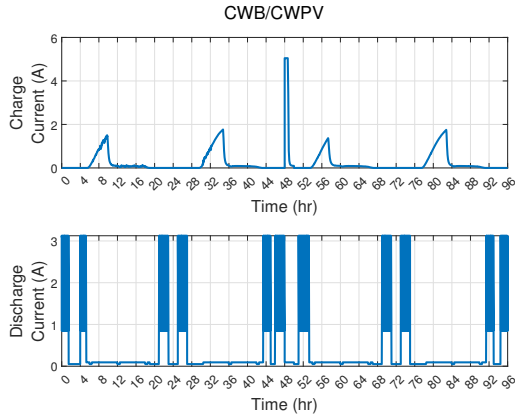
Fig. 62 Electrical components assigned to Squad A–Soldier A

8.1.2 Squad A–Soldier B Results

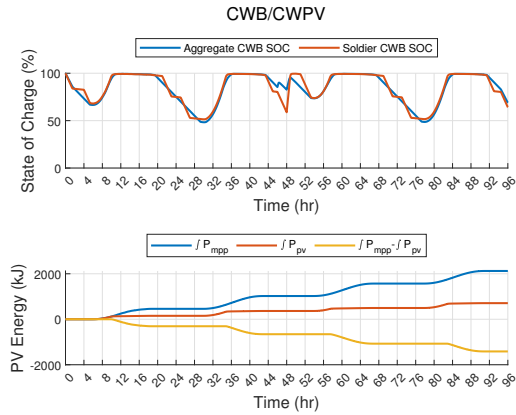
Squad A–Soldier B carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. The NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 63 through 64.



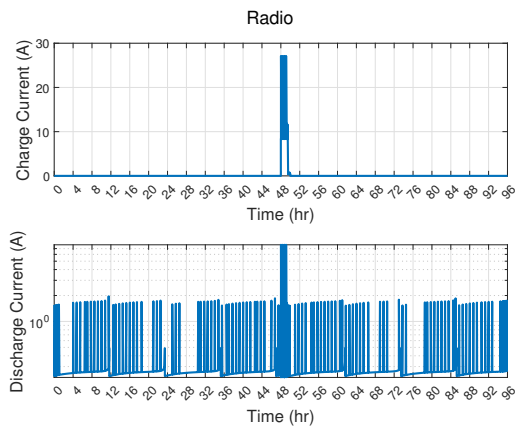
Fig. 63 Squad A-Soldier B's event schedule



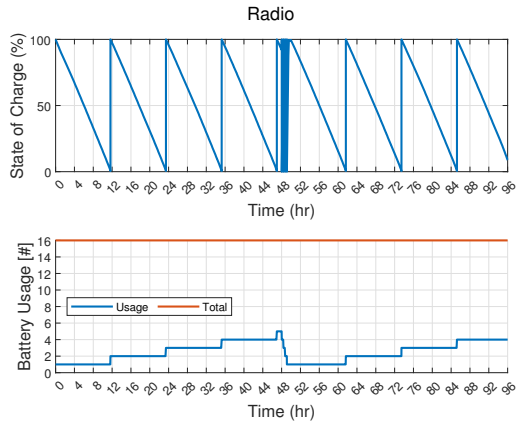
(a) Squad A-Soldier B's CWB charging and discharging currents



(b) Squad A-Soldier B's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier B's radio charging and discharging currents



(d) Squad A-Soldier B's radio SOC when compared to the radio's battery usage metric

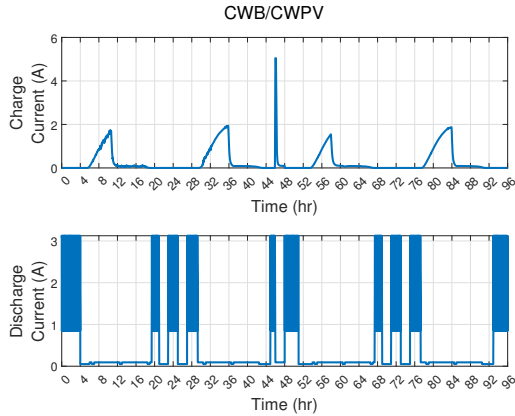
Fig. 64 Electrical components assigned to Squad A-Soldier B

8.1.3 Squad A-Soldier C Results

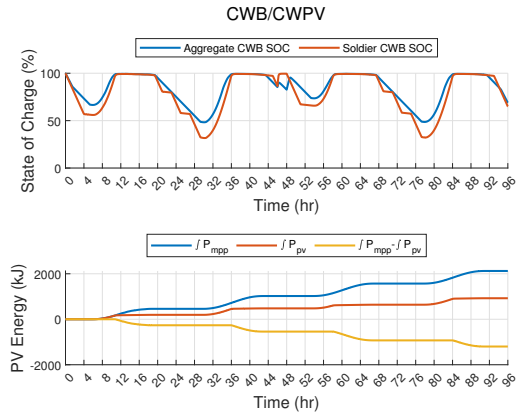
Squad A-Soldier C carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. The NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 65 through 66.



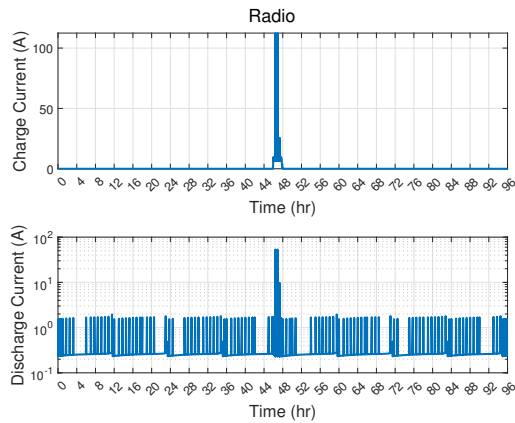
Fig. 65 Squad A-Soldier C's event schedule



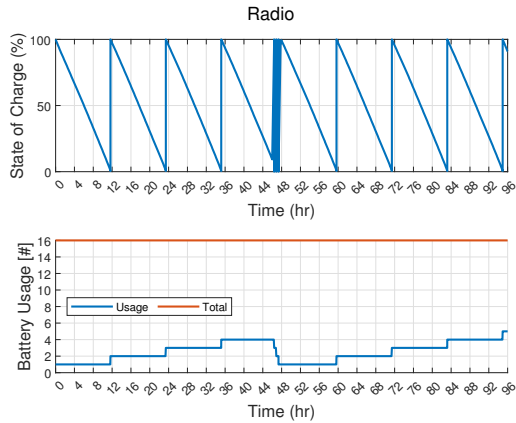
(a) Squad A-Soldier C's CWB charging and discharging currents



(b) Squad A-Soldier C's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier C's radio charging and discharging currents



(d) Squad A-Soldier C's radio SOC when compared to the radio's battery usage metric

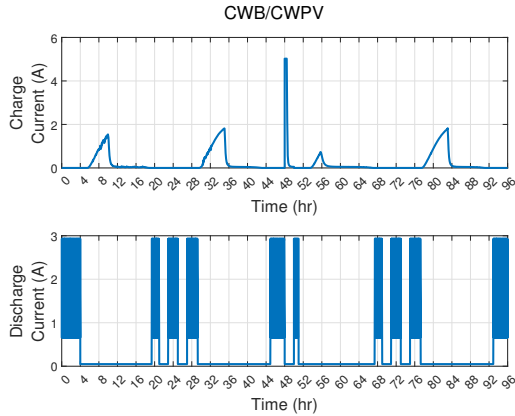
Fig. 66 Electrical components assigned to Squad A-Soldier C

8.1.4 Squad A-Soldier D Results

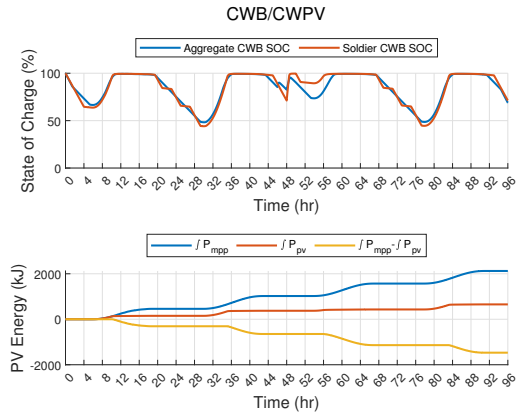
Squad A-Soldier D carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 67 through 68.



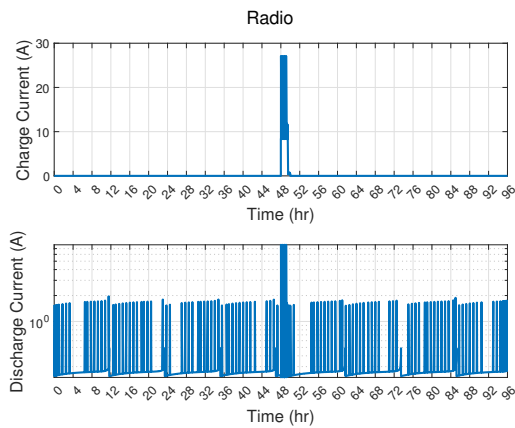
Fig. 67 Squad A-Soldier D's event schedule



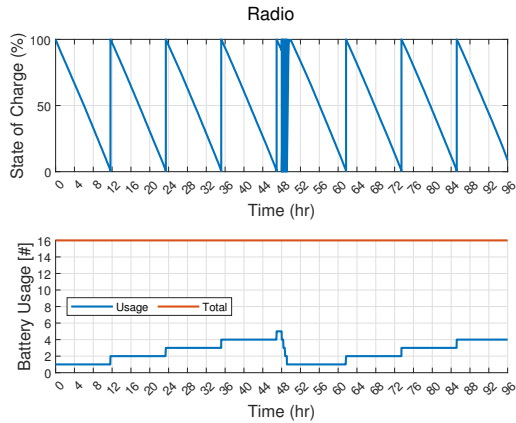
(a) Squad A–Soldier D’s CWB charging and discharging currents



(b) Squad A–Soldier D’s CWB SOC when compared to Squad A’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad A–Soldier D’s radio charging and discharging currents



(d) Squad A–Soldier D’s radio SOC when compared to the radio’s battery usage metric

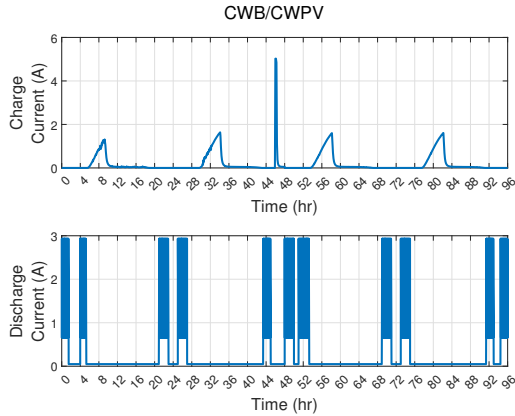
Fig. 68 Electrical components assigned to Squad A–Soldier D

8.1.5 Squad A–Soldier E Results

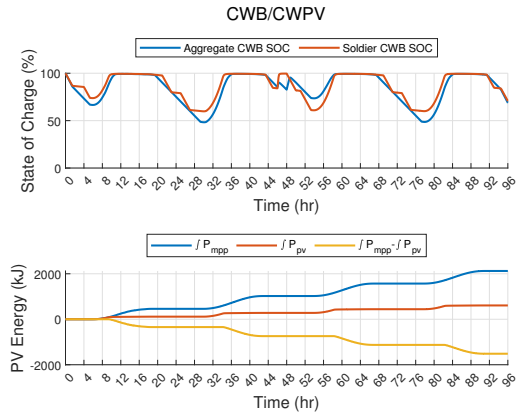
Squad A–Soldier E carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 69 through 70.



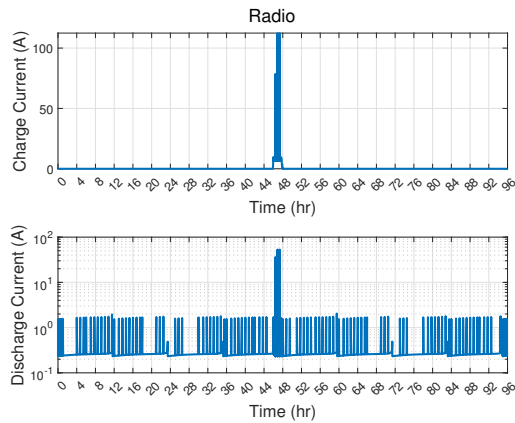
Fig. 69 Squad A-Soldier E's event schedule



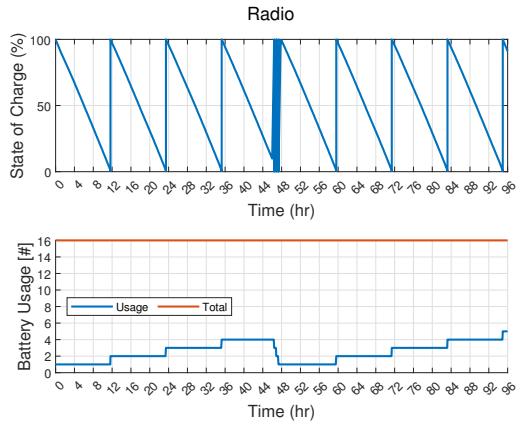
(a) Squad A-Soldier E's CWB charging and discharging currents



(b) Squad A-Soldier E's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier E's radio charging and discharging currents



(d) Squad A-Soldier E's radio SOC when compared to the radio's battery usage metric

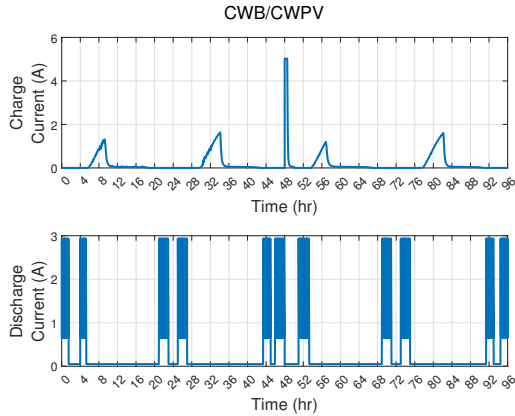
Fig. 70 Electrical components assigned to Squad A-Soldier E

8.1.6 Squad A-Soldier F Results

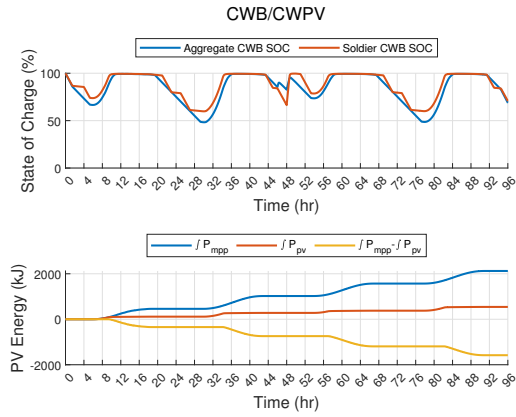
Squad A-Soldier F carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 71 through 72.



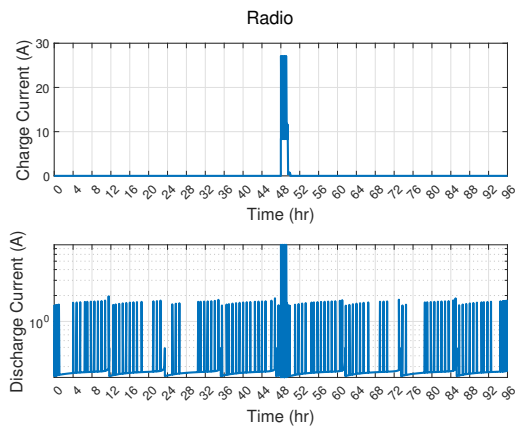
Fig. 71 Squad A-Soldier F's event schedule



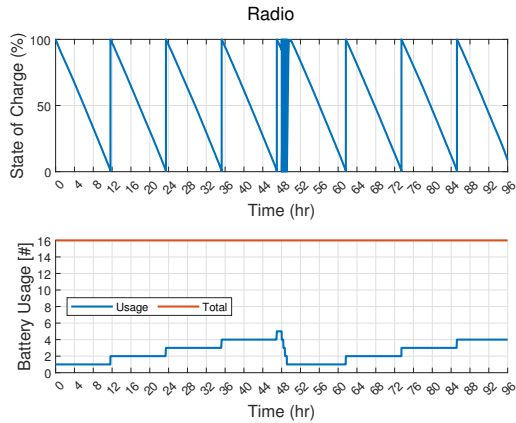
(a) Squad A–Soldier F’s CWB charging and discharging currents



(b) Squad A–Soldier F’s CWB SOC when compared to Squad A’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad A–Soldier F’s radio charging and discharging currents



(d) Squad A–Soldier F’s radio SOC when compared to the radio’s battery usage metric

Fig. 72 Electrical components assigned to Squad A–Soldier F

8.1.7 Squad A–Soldier G Results

Squad A–Soldier G carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 73 through 74.

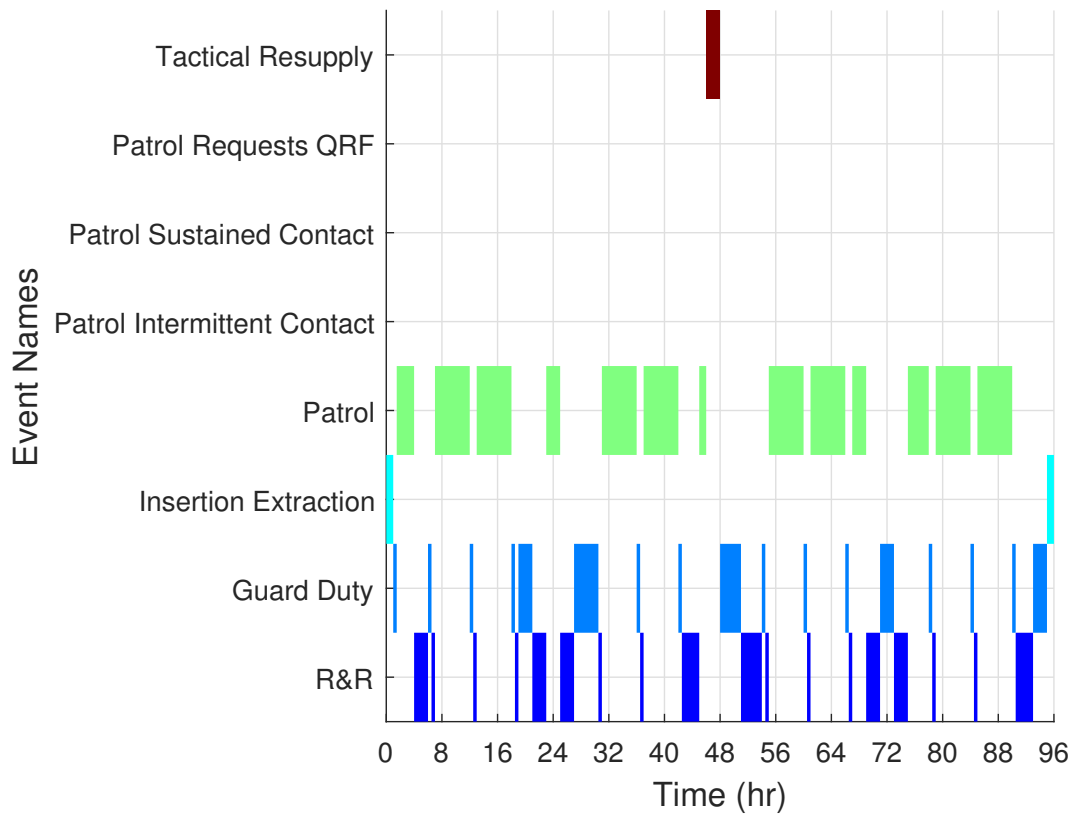
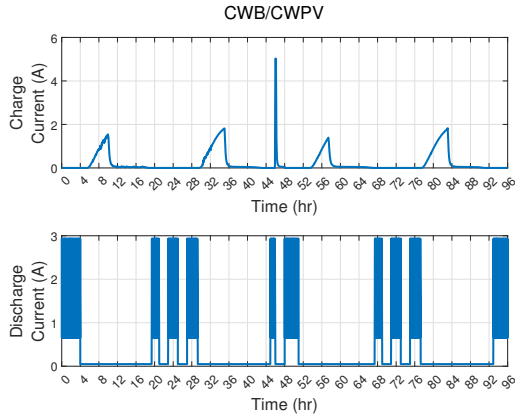
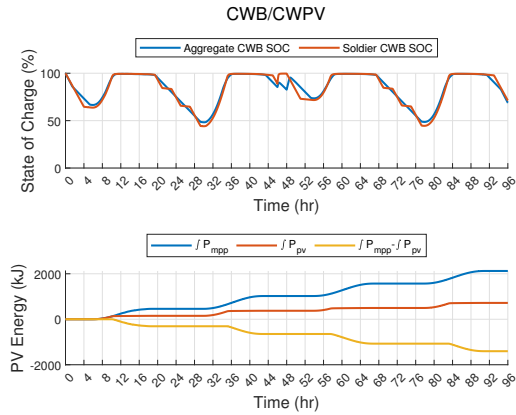


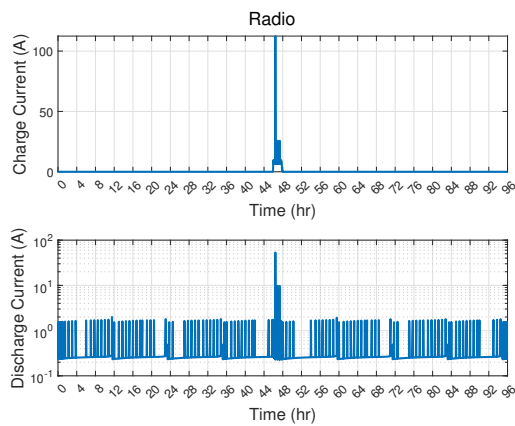
Fig. 73 Squad A-Soldier G's event schedule



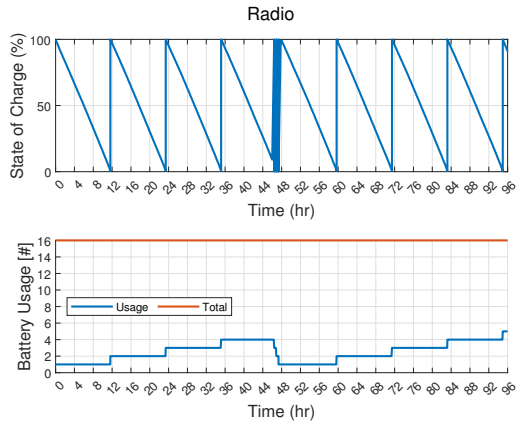
(a) Squad A-Soldier G's CWB charging and discharging currents



(b) Squad A-Soldier G's CWB SOC when compared to Squad A's aggregate SOC and combined with the CWPV's energy metric



(c) Squad A-Soldier G's radio charging and discharging currents



(d) Squad A-Soldier G's radio SOC when compared to the radio's battery usage metric

Fig. 74 Electrical components assigned to Squad A-Soldier G

8.1.8 Squad A-Soldier H Results

Squad A-Soldier H carries a CWB, CWPV, NVGs, flashlight, radio, PRC, Toughbook, ISR, GPS, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio, PRC, Toughbook, and ISR all of which use a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 75 through 77.

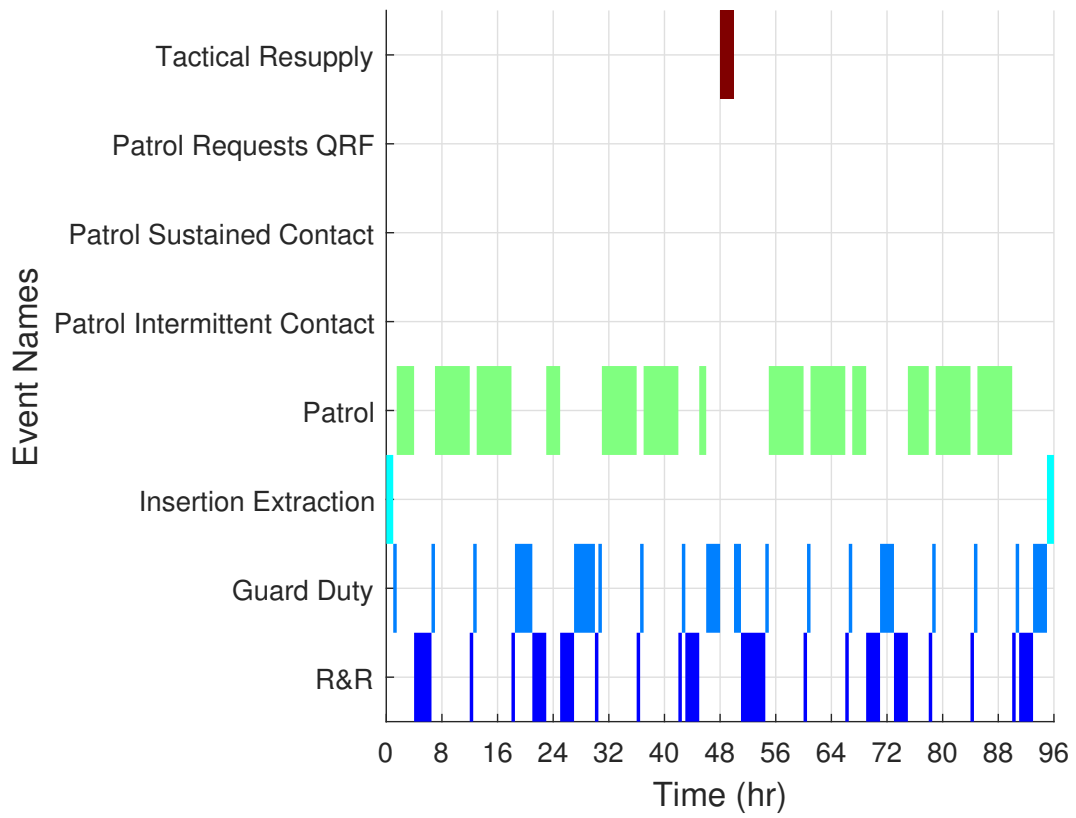
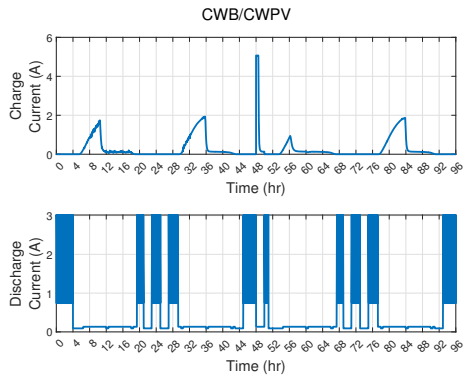
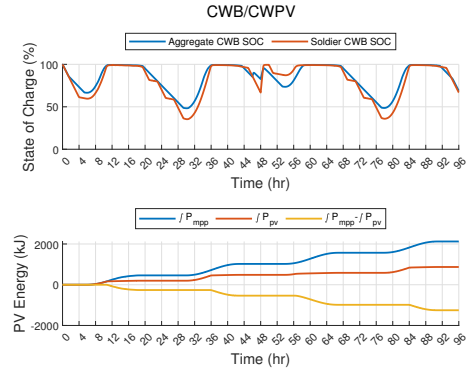


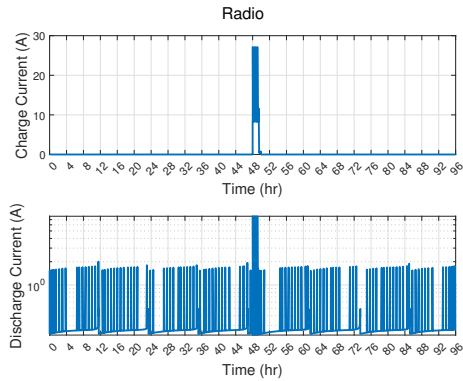
Fig. 75 Squad A–Soldier H’s event schedule



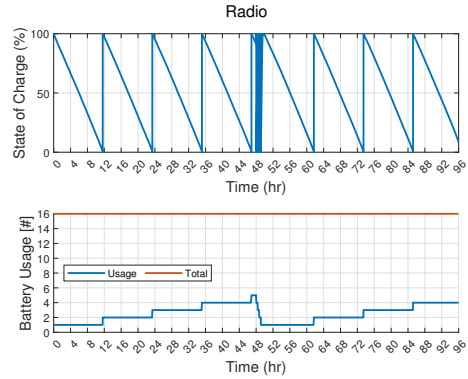
(a) Squad A–Soldier H’s CWB charging and discharging currents



(b) Squad A–Soldier H’s CWB SOC when compared to Squad A’s aggregate SOC and combined with the CWPV’s energy metric

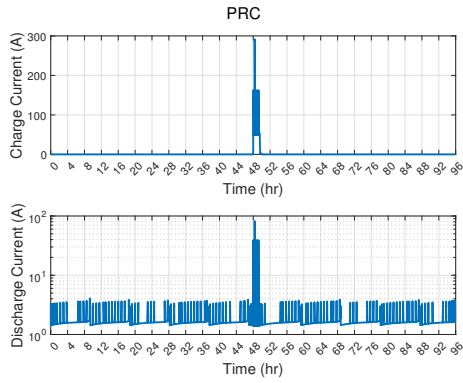


(c) Squad A–Soldier H’s radio charging and discharging currents

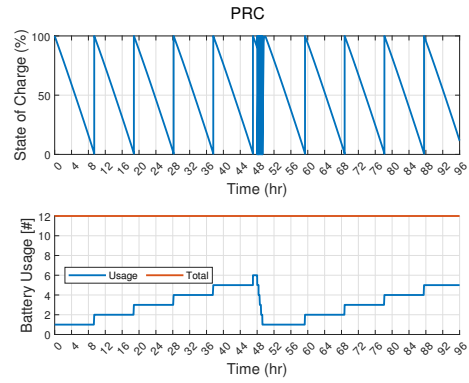


(d) Squad A–Soldier H’s radio SOC when compared to the radio’s battery usage metric

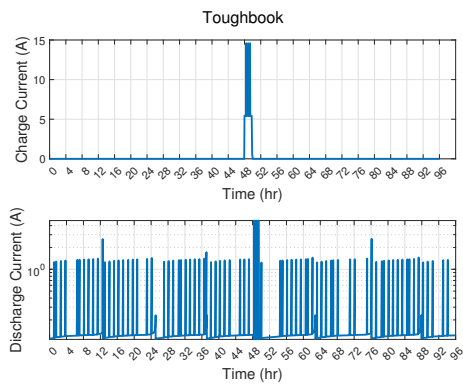
Fig. 76 Electrical components assigned to Squad A–Soldier H (part 1)



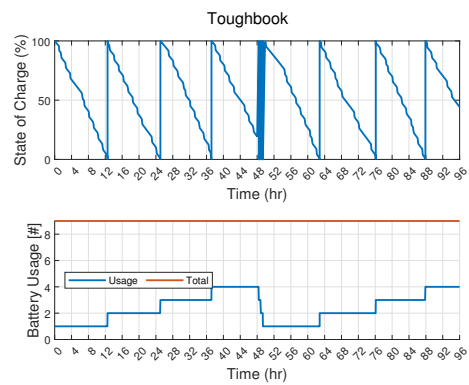
(a) Squad A–Soldier H’s PRC charging and discharging currents



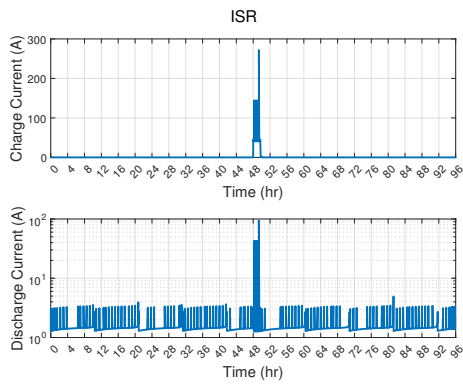
(b) Squad A–Soldier H’s PRC SOC compared to its battery usage



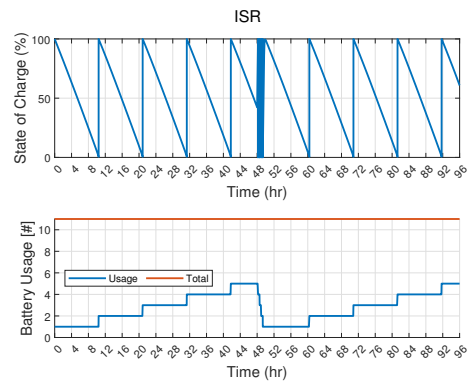
(c) Squad A–Soldier H’s Toughbook charging and discharging currents



(d) Squad A–Soldier H’s Toughbook SOC compared to its battery usage



(e) Squad A–Soldier H’s ISR charging and discharging currents



(f) Squad A–Soldier H’s ISR SOC compared to its battery usage

Fig. 77 Electrical components assigned to Squad A–Soldier H (part 2)

8.2 Squad B Results

Squad B consists of eight separate Soldiers, Soldier A through Soldier H. Soldier H is defined as the squad's communications officer. To help arrange the multitude of the results, this section is broken into subsections, one for each Soldier. Each subsection has a different number of graphs, starting with three foundational figures: 1) the Soldier-specific event schedule, 2) charging and discharging currents for the CWB, and 3) the individual Soldier's CWB SOC. The third figure contains two curves: the first is the individual Soldier's CWB SOC and the second is the aggregate squad's SOC.

Additional figures are included for each Soldier that is assigned additional components requiring nonstandard batteries: 1) the charging and discharging currents for the components nonstandard battery and 2) the nonstandard battery's SOC and battery usage metric, for example, how many batteries are required for the duration of the mission. Since many of the Soldiers have been assigned the same components, many of the results are repetitive. To minimize repetitive text, a summary of the results is provided in Section 8.3. Table 17 specifies which subsections of this report contain results specific to each Soldier within Squad B.

Table 17 Squad B limited tactical resupply results

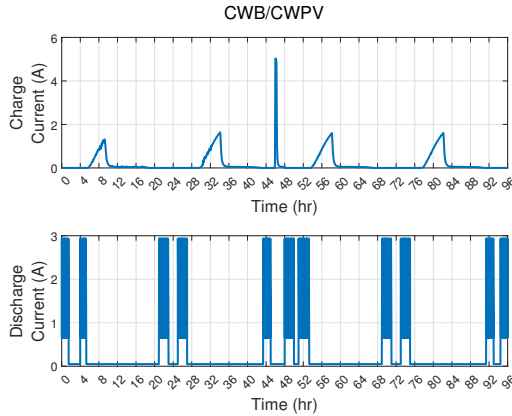
Squad designation	Soldier designation	Section
B	A	8.2.1
	B	8.2.2
	C	8.2.3
	D	8.2.4
	E	8.2.5
	F	8.2.6
	G	8.2.7
	H	8.2.8

8.2.1 Squad B–Soldier A Results

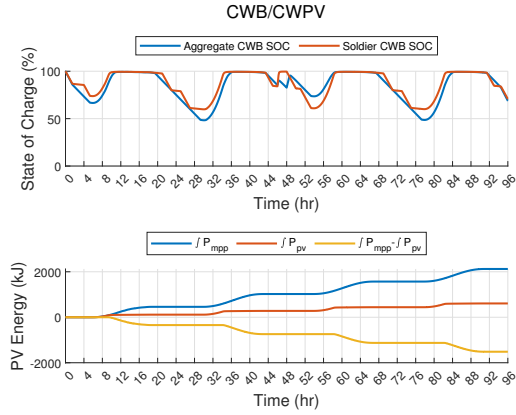
Squad B–Soldier A carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. Additionally, the CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 78 through 79.



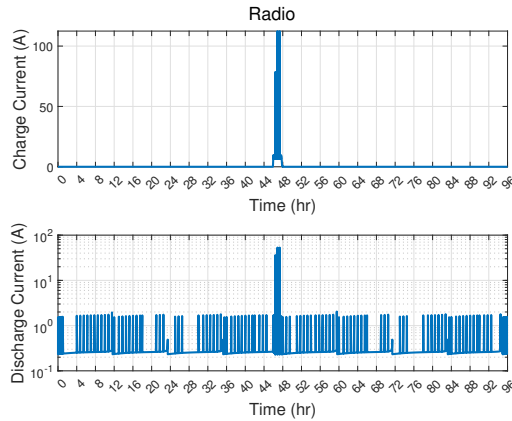
Fig. 78 Squad B-Soldier A's event schedule



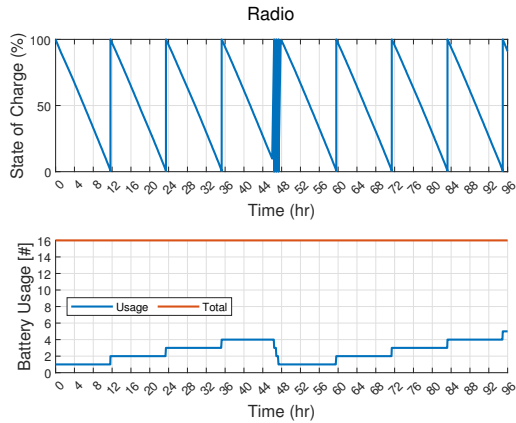
(a) Squad B–Soldier A’s CWB charging and discharging currents



(b) Squad B–Soldier A’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad B–Soldier A’s radio charging and discharging currents



(d) Squad B–Soldier A’s radio SOC when compared to the radio’s battery usage metric

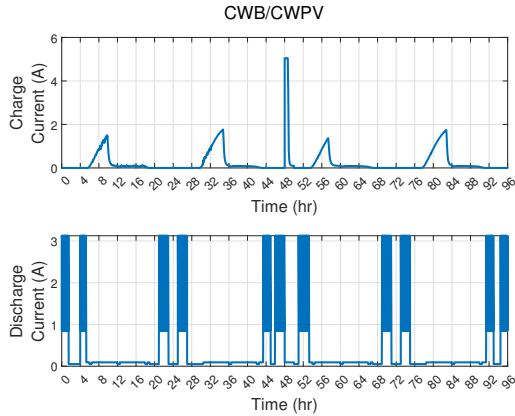
Fig. 79 Electrical components assigned to Squad B–Soldier A

8.2.2 Squad B–Soldier B Results

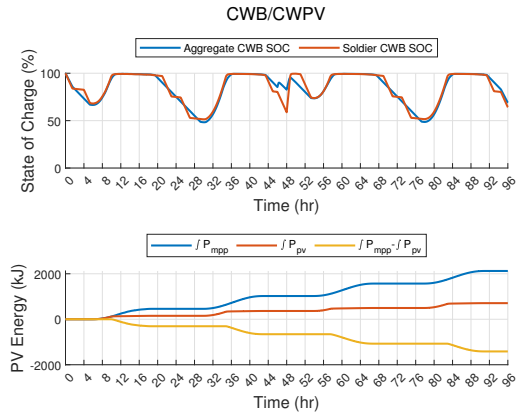
Squad B–Soldier B carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. The NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 80 through 81.



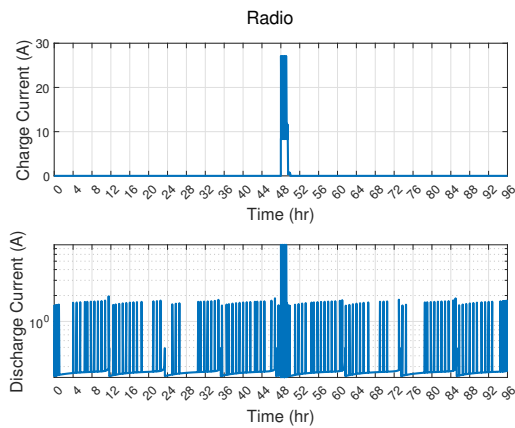
Fig. 80 Squad B-Soldier B's event schedule



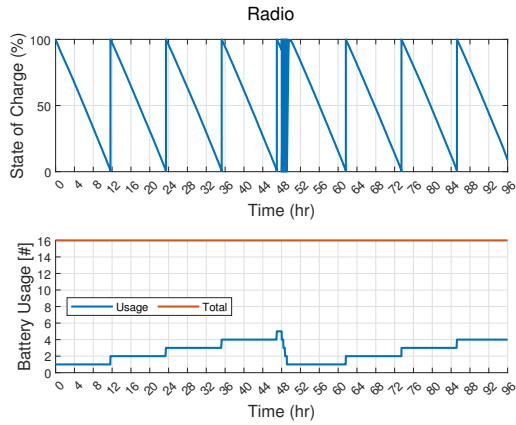
(a) Squad B–Soldier B’s CWB charging and discharging currents



(b) Squad B–Soldier B’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad B–Soldier B’s radio charging and discharging currents



(d) Squad B–Soldier B’s radio SOC when compared to the radio’s battery usage metric

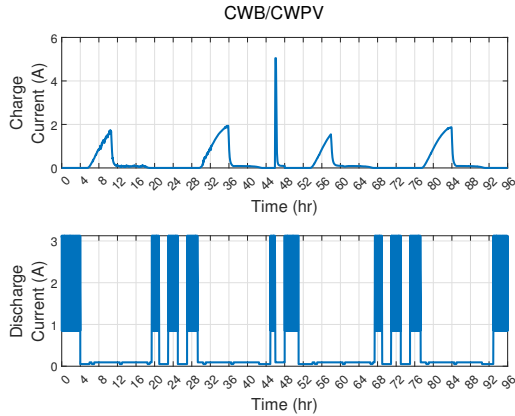
Fig. 81 Electrical components assigned to Squad B–Soldier B

8.2.3 Squad B–Soldier C Results

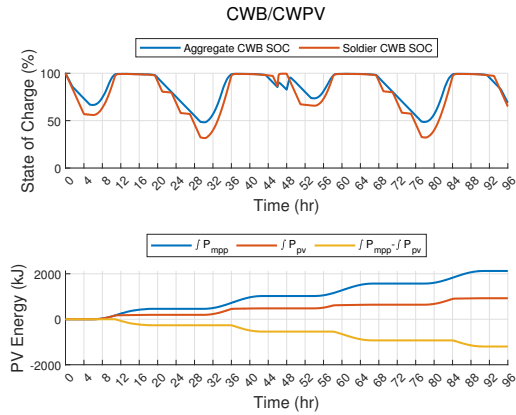
Squad B–Soldier C carries a CWB, CWPV, NVGs, TVGs, range finder, flashlight, radio, IR strobe, and IR laser. The NVGs, TVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 82 through 83.



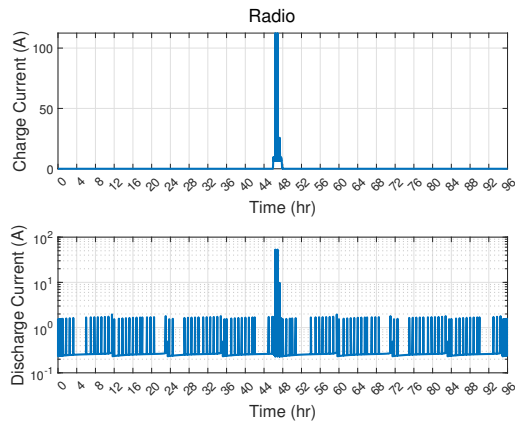
Fig. 82 Squad B-Soldier C's event schedule



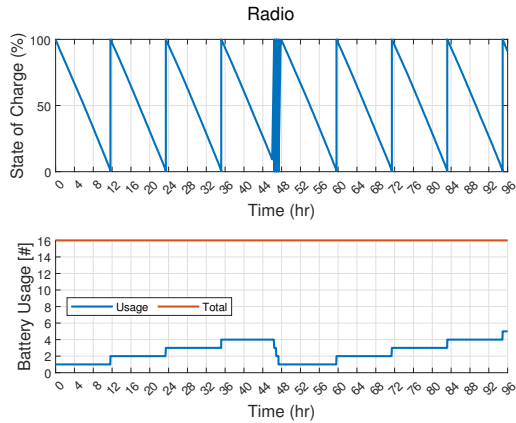
(a) Squad B-Soldier C's CWB charging and discharging currents



(b) Squad B-Soldier C's CWB SOC when compared to Squad B's aggregate SOC and combined with the CWPV's energy metric



(c) Squad B-Soldier C's radio charging and discharging currents



(d) Squad B-Soldier C's radio SOC when compared to the radio's battery usage metric

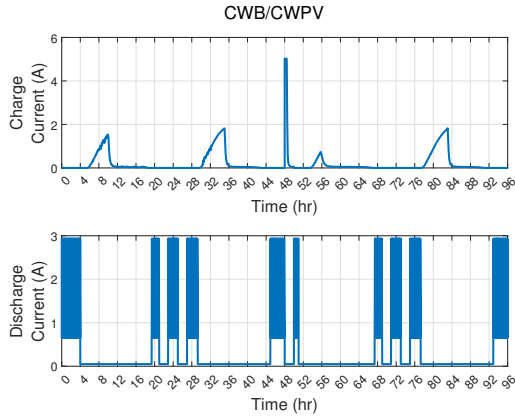
Fig. 83 Electrical components assigned to Squad B-Soldier C

8.2.4 Squad B-Soldier D Results

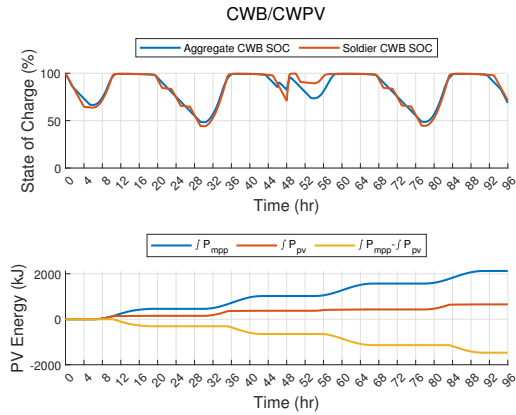
Squad B-Soldier D carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 84 through 85.



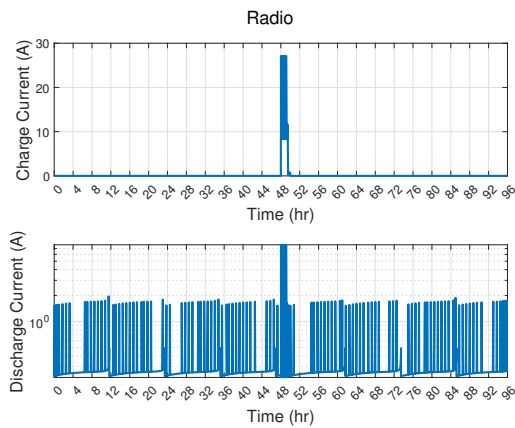
Fig. 84 Squad B-Soldier D's event schedule



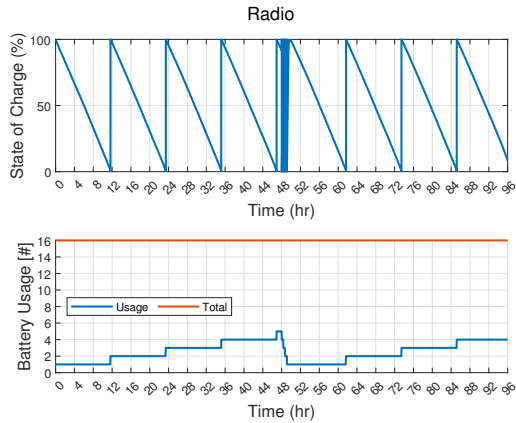
(a) Squad B–Soldier D’s CWB charging and discharging currents



(b) Squad B–Soldier D’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad B–Soldier D’s radio charging and discharging currents



(d) Squad B–Soldier D’s radio SOC when compared to the radio’s battery usage metric

Fig. 85 Electrical components assigned to Squad B–Soldier D

8.2.5 Squad B–Soldier E Results

Squad B–Soldier E carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 86 through 87.

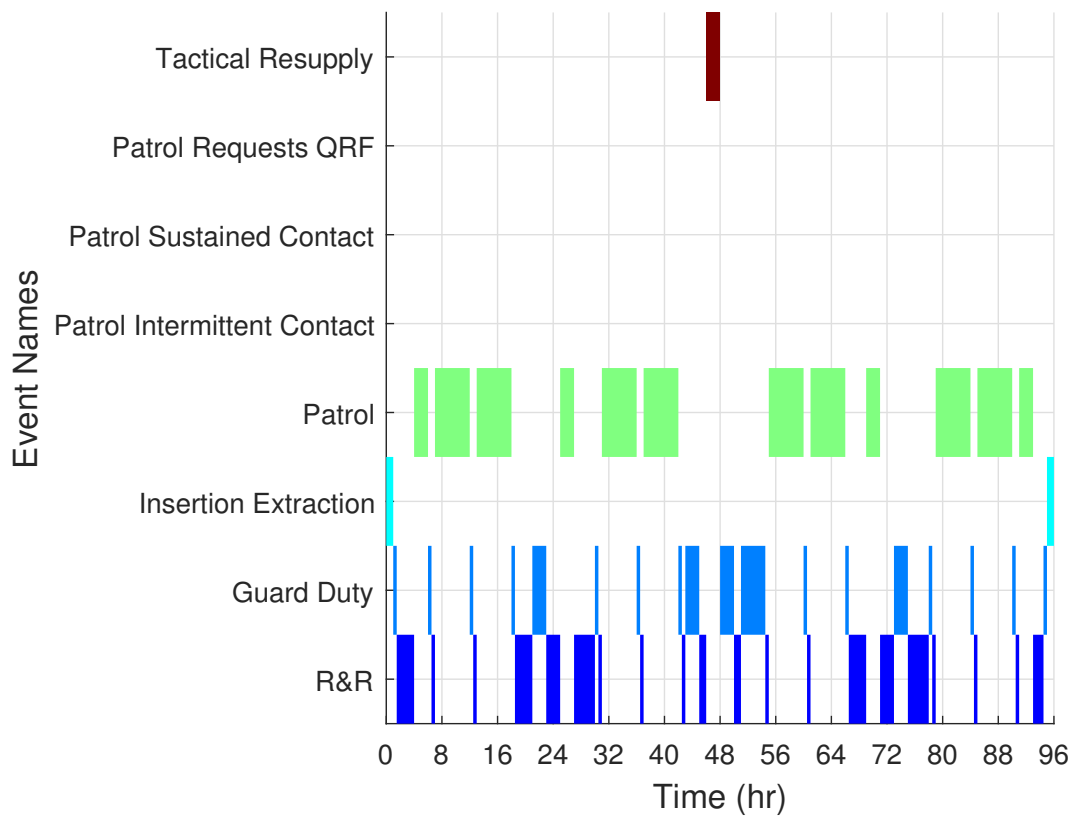
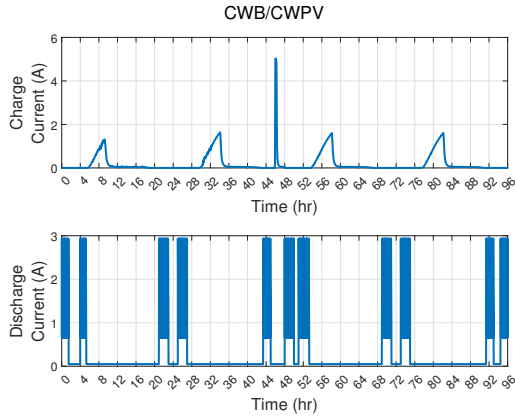
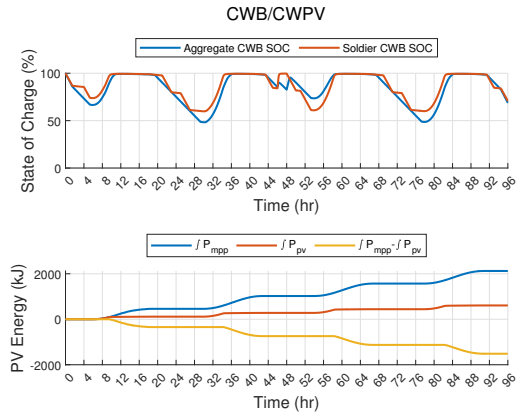


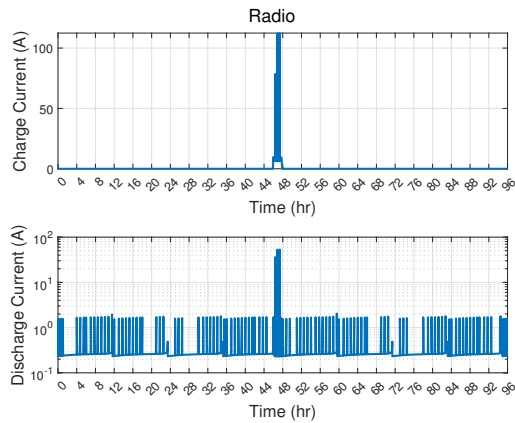
Fig. 86 Squad B-Soldier E's event schedule



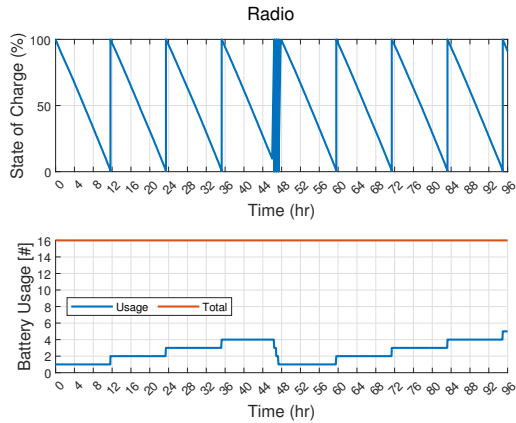
(a) Squad B–Soldier E’s CWB charging and discharging currents



(b) Squad B–Soldier E’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad B–Soldier E’s radio charging and discharging currents



(d) Squad B–Soldier E’s radio SOC when compared to the radio’s battery usage metric

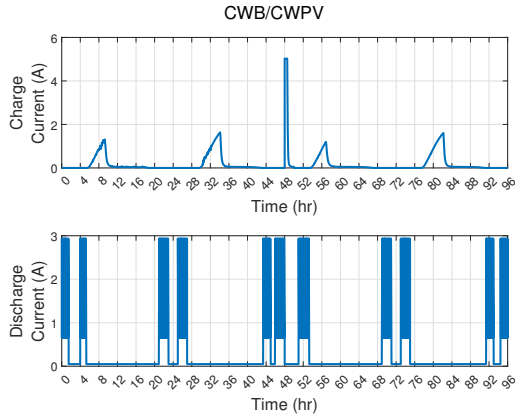
Fig. 87 Electrical components assigned to Squad B–Soldier E

8.2.6 Squad B–Soldier F Results

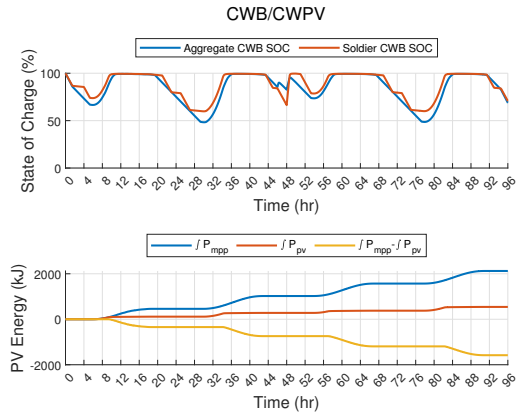
Squad B–Soldier F carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 88 through 89.



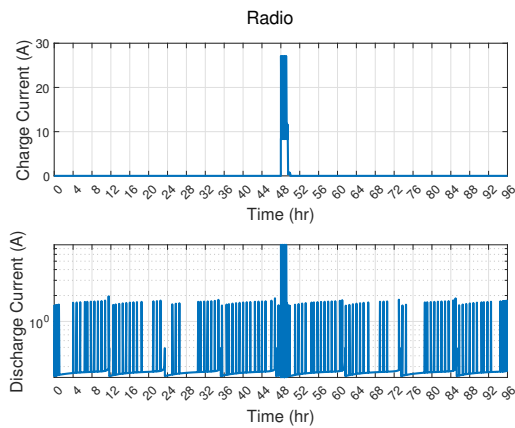
Fig. 88 Squad B-Soldier F's event schedule



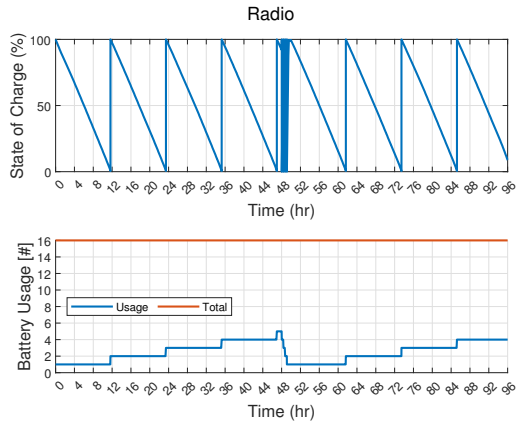
(a) Squad B–Soldier F’s CWB charging and discharging currents



(b) Squad B–Soldier F’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad B–Soldier F’s radio charging and discharging currents



(d) Squad B–Soldier F’s radio SOC when compared to the radio’s battery usage metric

Fig. 89 Electrical components assigned to Squad B–Soldier F

8.2.7 Squad B–Soldier G Results

Squad B–Soldier G carries a CWB, CWPV, NVGs, flashlight, radio, IR strobe, and IR laser. Recall the NVGs, range finder, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio that uses a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 90 through 91.

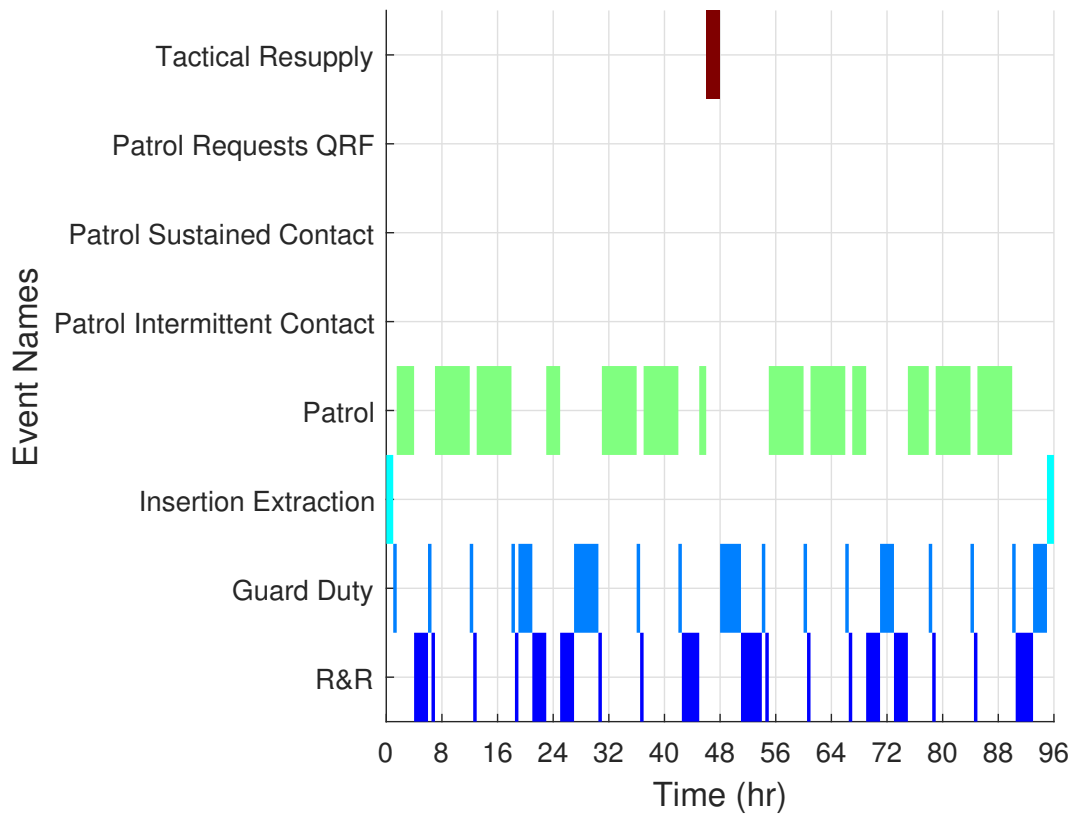
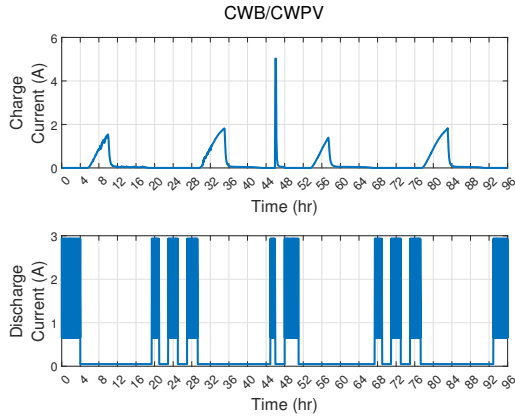
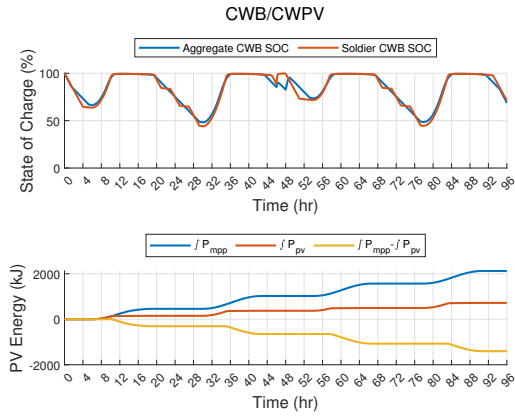


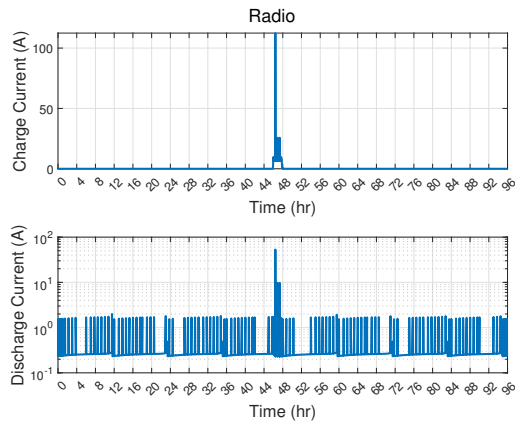
Fig. 90 Squad B-Soldier G's event schedule



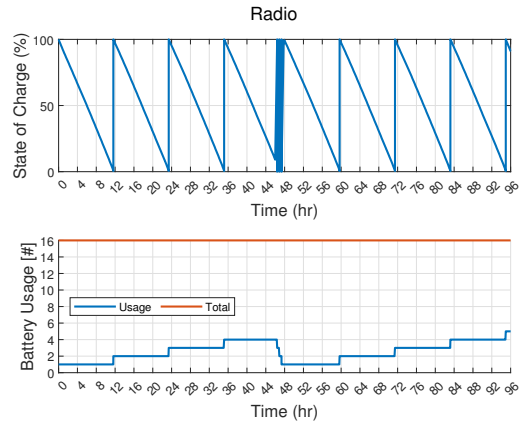
(a) Squad B–Soldier G’s CWB charging and discharging currents



(b) Squad B–Soldier G’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric



(c) Squad B–Soldier G’s radio charging and discharging currents



(d) Squad B–Soldier G’s radio SOC when compared to the radio’s battery usage metric

Fig. 91 Electrical components assigned to Squad B–Soldier G

8.2.8 Squad B–Soldier H Results

Squad B–Soldier H carries a CWB, CWPV, NVGs, flashlight, radio, PRC, Toughbook, ISR, GPS, IR strobe, and IR laser. The NVGs, flashlight, IR strobe, and IR laser all act as a parasitic load associated with the CWB. The CWPV is used to charge the CWB. The Soldier also possesses a radio, PRC, Toughbook, and ISR all of which use a separate nonstandard battery. The results for this particular Soldier are provided in Figs. 92 through 94.

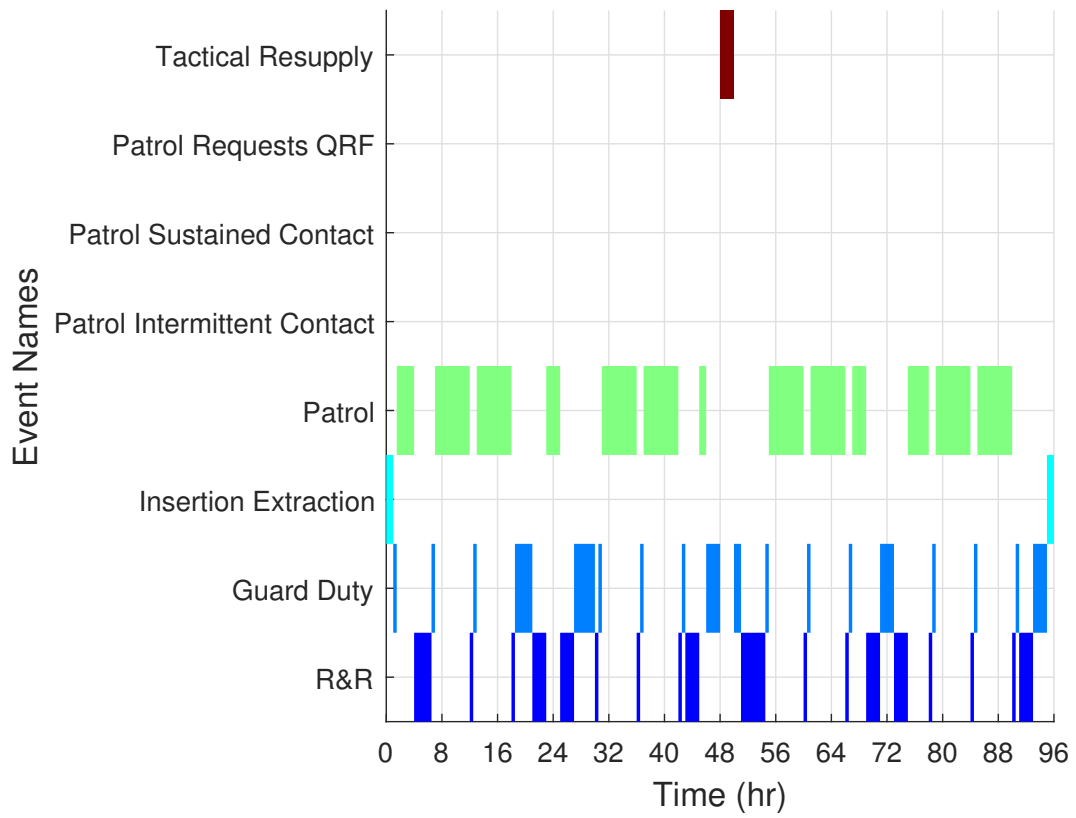
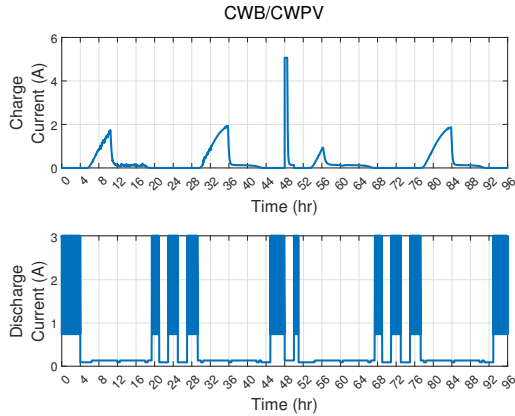
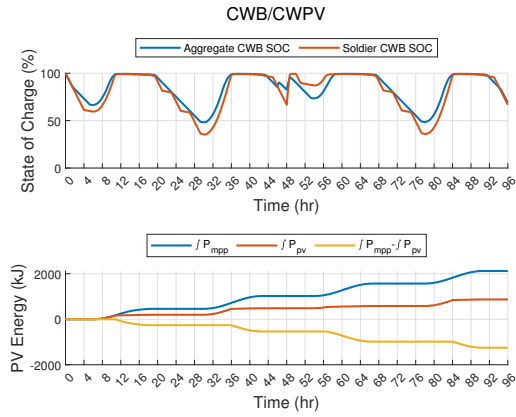


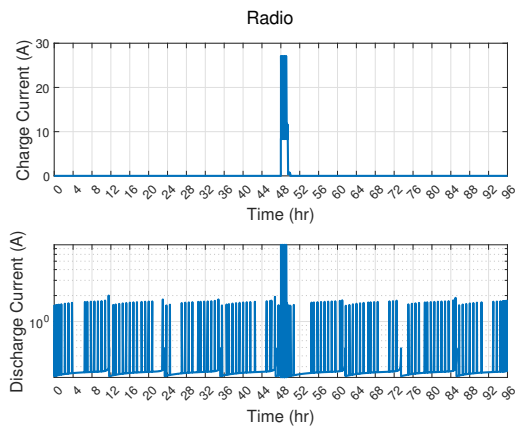
Fig. 92 Squad B-Soldier H's event schedule



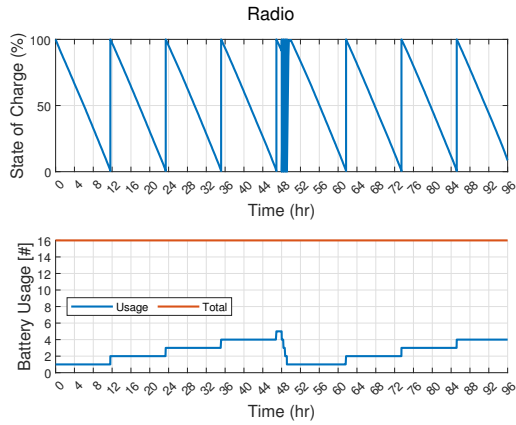
(a) Squad B–Soldier H’s CWB charging and discharging currents



(b) Squad B–Soldier H’s CWB SOC when compared to Squad B’s aggregate SOC and combined with the CWPV’s energy metric

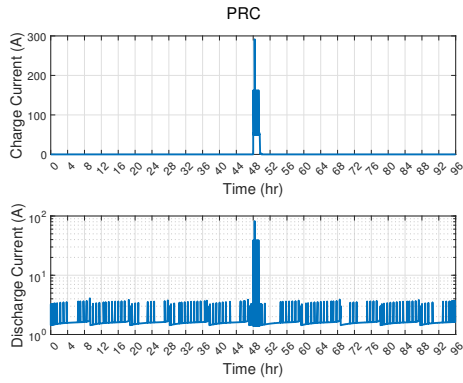


(c) Squad B–Soldier H’s radio charging and discharging currents

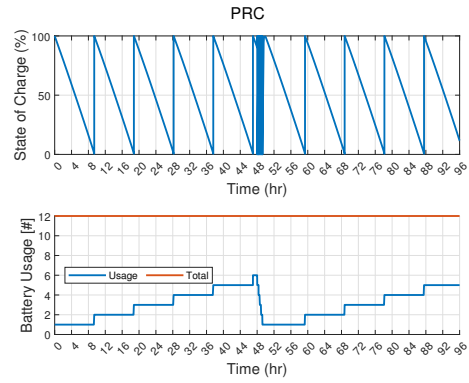


(d) Squad B–Soldier H’s radio SOC when compared to the radio’s battery usage metric

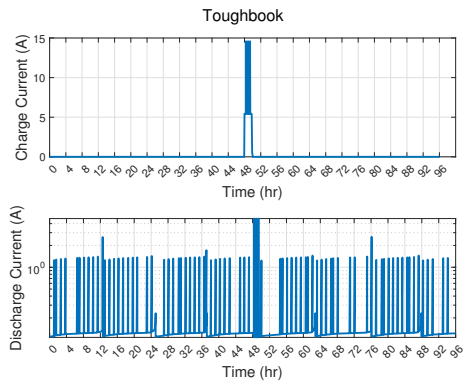
Fig. 93 Electrical components assigned to Squad B–Soldier H (part 1)



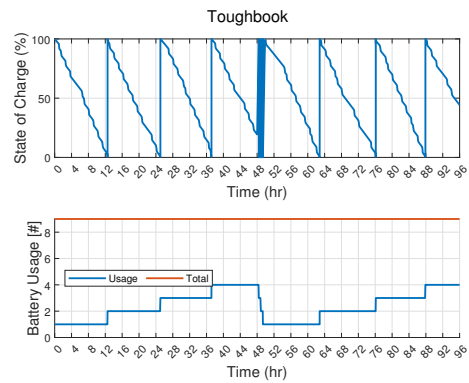
(a) Squad B–Soldier H’s PRC charging and discharging currents



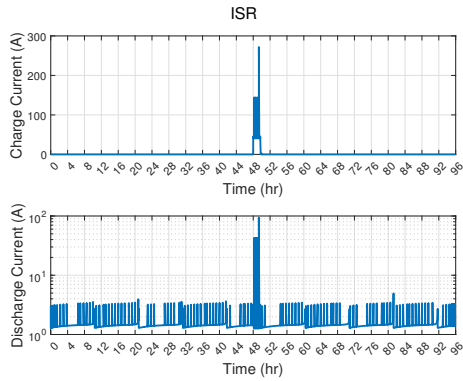
(b) Squad B–Soldier H’s PRC SOC compared to its battery usage metric



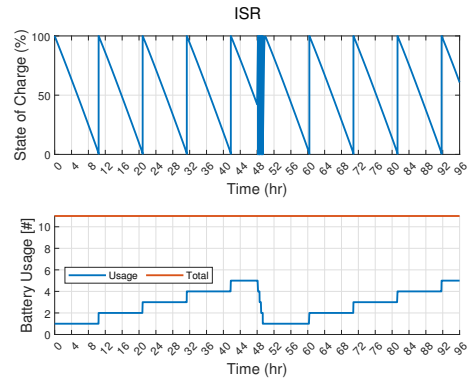
(c) Squad B–Soldier H’s Toughbook charging and discharging currents



(d) Squad B–Soldier H’s Toughbook SOC compared to its battery usage



(e) Squad B–Soldier H’s ISR charging and discharging currents



(f) Squad B–Soldier H’s ISR SOC compared to its battery usage metric

Fig. 94 Electrical components assigned to Squad B–Soldier H (part 2)

8.3 Summary of Squad A and Squad B Results

The results of the squad scenario that included a tactical resupply are contained within Sections 8.1 through 8.2. Analysis of any of the PV energy trajectories or the Soldiers' battery SOC would indicate that energy is being wasted. There is sufficient energy being generated by the PV array such that the Soldiers' CWB SOC can be sufficiently charged. After the CWB has been charged, however, there is no available energy storage space to fully utilize the energy generation capabilities of the PV array. This surplus represents an area of improvement in that the rejected energy could be recaptured and used to charge additional components that use nonstandard batteries. However, these nonstandard batteries tend to have large amp-hour capacities, and as such, a PV array that generates 18 W of power at 2 A will be hard pressed to sufficiently charge the nonstandard batteries within a timely manner.

For these cases, every squad member was assigned a radio. Based on the radio-specific figures associated with each Soldier, on average, the Soldiers' radios fully discharge a total of four times, which indicates that each Soldier would require five radio batteries. Each radio battery was estimated to weigh 0.41 lb. This means that each Soldier would have to carry 2.05 lb of radio batteries.

Both Squad A–Soldier H and Squad B–Soldier H were determined to be a communications officer, as a result this Soldier also possessed a PRC, Toughbook, and ISR. Based on the results provided in Sections 8.1.8 and 8.2.8, each PRC will fully discharge a total of five times, each Toughbook will fully discharge a total of three times, and each ISR will fully discharge a total of four times. This would indicate that the communications officer must bring six PRC batteries, four Toughbook batteries, and five ISR batteries. This would indicate at minimum the communications officer must possess 13.26 lb of PRC batteries (2.21 lb), 7 lb of Toughbook batteries (1.75 lb), and 5 lb of ISR batteries (1 lb), equating to 25.26 lb of miscellaneous nonstandard batteries to operate the PRC, Toughbook, and ISR. If one includes their radio batteries, the communications officer is required to bring 27.31 lb of batteries to operate all the specialized communications equipment.

Note: Given the parameters set within the simulation, the radio batteries will last about 12 h, the PRC batteries will last between 8 and 9 h, the Toughbook batteries will last 12 h, and the ISR batteries will last between 9 and 10 h. If the parameters

used to define the batteries and/or alternative communications equipment are defined, the weight that a Soldier may be required to carry could increase or decrease. A summary of results is provided in Tables 18 and 19.

Table 18 Squad A summary of results

Squad	Soldier	Battery type	Weight (lb)	Quantity (#)	Weight (lb)	Duration (h)
A	A	Radio	0.41	5	2.05	12
	B	Radio	0.41	5	2.05	12
	C	Radio	0.41	5	2.05	12
	D	Radio	0.41	5	2.05	12
	E	Radio	0.41	5	2.05	12
	F	Radio	0.41	5	2.05	12
	G	Radio	0.41	5	2.05	12
	H	Radio	0.41	5	2.05	12
		PRC	2.21	6	13.26	8–9
		Toughbook	1.75	4	7.00	12
		ISR	1.00	5	5.00	9–10

Table 19 Squad A summary of results

Squad	Soldier	Battery type	Weight (lb)	Quantity (#)	Weight (lb)	Duration (h)
A	A	Radio	0.41	5	2.05	12
	B	Radio	0.41	5	2.05	12
	C	Radio	0.41	5	2.05	12
	D	Radio	0.41	5	2.05	12
	E	Radio	0.41	5	2.05	12
	F	Radio	0.41	5	2.05	12
	G	Radio	0.41	5	2.05	12
	H	Radio	0.41	5	2.05	12
		PRC	2.21	6	13.26	8–9
		Toughbook	1.75	4	7.00	12
		ISR	1.00	5	5.00	9–10

9. Conclusions and Future Work

The energy and power capabilities for the warfighter are higher than ever and expected to increase with the development and deployment of small semiautonomous and autonomous aerial, ground, and surface vehicles. Such vehicles will aid the warfighters, bolstering security, mobility, and lethality of operations. With the inclusion of such devices, Soldier cognitive burdens are expected to increase, this will then impact performance of military operations. Further, the Soldiers are likely to possess a considerable number of specialized batteries. This requirement forces the Soldiers to carry large sums of electrical equipment that have the potential to overburden a Soldier and limit the squad's effectiveness and mobility. It is for this reason we sought to develop the squad energy and power scenario. The intent of the scenario was to link US Army-relevant event scenarios and atmospheric conditions directly to the energy and power requirements and capabilities of the individual Soldier or aggregate squad.

In this report, MATLAB/*Simulink* was used to model and simulate two US Army-relevant squad event scenarios. The first scenario included that of a limited tactical resupply intelligence gathering mission. The second scenario included an intelligence gathering mission that included a tactical resupply. The mission duration for each scenario was that of 96 h. The intent of these scenarios was to understand the energy and power capabilities/requirements for each individual Soldier and understand the implications for requiring substantial amounts of electrical energy storage. We observed that with inclusion of a tactical resupply event within a 96-h mission, each ordinary infantry Soldier could reduce their weight by 1.64 lb. Conversely, an ordinary communications officer could reduce their weight by as much as 21 lb. The reduction in weight is a direct result of the tactical resupply and the ability to generate power using the CWPV. With improvements to the CWPV, we expect greater energy generation capabilities, which can further reduce the dependency on carrying multiple sets of batteries to operate specialized electrical equipment. Further, inclusion of tactical resupply events to be facilitated by full- or medium-sized autonomous vehicles or predeployed energy storage depot can reduce squad weight requirements. Such benefits can increase the mobility and lethality of the Soldier, leading to improved mission efficiency and effectiveness of military operations.

We expect to continue this work in some capacity to include the inclusion of artificial intelligence and machine learning algorithms to generated predictive capabilities. Such capabilities could link the dissimilar US Army–relevant events to the specific performance of the individual Soldier or squad in combination with the atmospherics. Atmospherics can significantly impact performance of electrical devices, and this will directly impact the performance of military operations. Future work will include development of a similar set of US Army–relevant events focused on a more standard, stationary energy, network-based operation of a forward operating base or combat outpost. We also intend to use the defined scenarios within our AIHPG testbed^{1–5} as a representable load that can be combined with an optimization routine to harmonize dissimilar energy and power capabilities of the energy network. Such capabilities will lead to the development of energy awareness, a capability that is required to operate effectively and efficiently subject to the MDO battlespace.

10. References

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2. Vaucher G, Berman M, Parker G, Lee M, D'Arcy S, Jane R, Price T. In-situ atmospheric intelligence for hybrid power grids: Volume 2 (automated data flow tests). DEVCOM Army Research Laboratory (US); 2020 Sep. Report No.: ARL-TR-9060.
3. Vaucher G, Lee MS, Goodman H. In-situ atmospheric intelligence for hybrid power grids: Volume 3 (analysis of whole sky image compression). DEVCOM Army Research Laboratory (US); 2021 Dec. Report No.: ARL-TR-9360.
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Appendix. Squad Energy and Power Model Parameters

This appendix contains additional information regarding the squad-based energy and power scenario. Specifically, it defines all parameters as defined within the Excel document that was used to model the various electrical components as defined within the squad-based energy and power scenario. Table A-1 specifies which subsections of this report or appendix have more information pertaining to each individual electrical model component. Components highlighted in red required non-standard batteries (i.e., each of these components had their own battery model). An asterisk indicates an item that used variable, pulsed-width signals to model power consumption as a function of an active event.

Table A-1 Squad-based scenario content list

Component	Section	Appendix
Conformable wearable battery (CWB)	5.1	A.1
Conformable wearable photovoltaic (CWPV)	5.2	A.2
Night-vision goggles (NVGs)	5.3	A.3
Thermal-vision goggles (TVGs)	5.4	A.4
Flashlight	5.5	A.5
Radio*	5.6	A.6
Portable Radio Communications (PRC)*	5.7	A.7
Toughbook*	5.8	A.8
Intra-squad radio (ISR)*	5.9	A.9
Range finder*	5.10	A.10
IR strobe	5.11	A.11
IR laser	5.12	A.12
Handheld global positioning satellite (GPS)*	5.13	A.13

A.1 Conformable Wearable Battery Parameters

The parameters used to model the CWB are provided in Tables A-2 through A-6. Parameters as defined within the subsequent are ultimately imported into MATLAB/Simulink, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-2 Parameters required to model the CWB (part 1)

Duration	Weight	No. of batteries	Nominal voltage
(h)	(lbf)	(#)	(V)
24	2.6	1	12

Table A-3 Parameters required to model the CWB (part 2)

Amp-hour capacity	Chemical composition	Efficiency	Resistance
(ahr)	(nd)	(%)	(ohm)
10	Li-ion	0.9975	0.016042781

Table A-4 Parameters required to model the CWB (part 3)

Fully charged voltage	Rated discharge	Nominal amp-hour capacity	Exponential voltage
(V)	(ahr)	(ahr)	(V)
13.92	2	9.35	12.36

Table A-5 Parameters required to model the CWB (part 4)

Exponential amp-hour capacity	Initial amp-hour capacity	Exponential zone voltage drop	Exponential zone amp-hour capacity
(ahr)	(ahr)	(V)	(ahr)
8.5	10	1.56	0.352941176

Table A-6 Parameters required to model the CWB (part 5)

Polarization voltage	Voltage constant
(V)	(V)
0.029026688	12.42111225

A.2 Conformable Wearable Photovoltaic Array Parameters

The parameters used to model the CWPV array are provided in Table A-7. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*,

both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-7 Parameters required to model the CWPV

Short-circuit current	Open-circuit voltage
(A)	(V)
2	12

A.3 Night-Vision Goggles Parameters

The parameters used to model the NVGs are provided in Tables A-8 through A-10. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-8 Parameters required to model the NVGs (part 1)

Duration	Component weight	Battery weight	Configuration
(h)	(lbf)	(lbf)	
30	1.6875	0.05	Parallel

Table A-9 Parameters required to model the NVGs (part 2)

Total no. of batteries	Rated voltage	Rated amp-hour capacity	Nominal voltage
(#)	(V)	(ahr)	(V)
3	3	1.5	3

Table A-10 Parameters required to model the NVGs (part 3)

Amp hour capacity	Continuous discharge current	Discontinuous discharge current
(ahr)	(A)	(A)
4.5	0.15	0.001875

A.4 Thermal-Vision Goggles Parameters

The parameters used to model the TVGs are provided in Tables A-11 through A-13. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-11 Parameters required to model the TVGs (part 1)

Duration	Component weight	Battery weight	Configuration
(h)	(lbf)	(lbf)	
30	1.6875	0.05	Parallel

Table A-12 Parameters required to model the TVGs (part 2)

Total no. of batteries	Rated voltage	Rated amp-hour capacity	Nominal voltage
(#)	(V)	(ahr)	(V)
3	3	1.5	3

Table A-13 Parameters required to model the TVGs (part 3)

Amp hour capacity	Continuous discharge current	Discontinuous discharge current
(ahr)	(A)	(A)
4.5	0.15	0.001875

A.5 Flashlights Parameters

The parameters used to model the flashlight are provided in Tables A-14 through A-16. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-14 Parameters required to model the flashlight (part 1)

Duration	Component weight	Battery weight	Configuration
(h)	(lbf)	(lbf)	
1.5	1	0.05	Parallel

Table A-15 Parameters required to model the flashlight (part 2)

Total no. of batteries	Rated voltage	Rated amp-hour capacity	Nominal voltage
(#)	(V)	(ahr)	(V)
1	3	1.5	3

Table A-16 Parameters required to model the flashlight (part 3)

Amp hour capacity	Continuous discharge current	Discontinuous discharge current
(ahr)	(A)	(A)
1.5	1	0.0125

A.6 Radio Parameters

The parameters used to model the radio are provided in Tables A-17 through A-25. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-17 Parameters required to model the radio (part 1)

Duration	Average power consumption	Nominal voltage	Estimated amp-hour capacity
(h)	(W)	(V)	(ahr)
96	1,900	3.7	49.2972973

Table A-18 Parameters required to model the radio (part 2)

Total no. of batteries	Component weight	Battery weight	Discontinuous use average power consumption	Continuous use average power consumption
(#)	(lbf)	(lbf)	(W)	(W)
16	0.68	0.40625	1	5.5

Table A-19 Parameters required to model the radio (part 3)

Discontinuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
3600	2700	600	2700	1800	900	300	60

Table A-20 Parameters required to model the radio (part 4)

Continuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
15	15	15	15	15	15	15	15

Table A-21 Parameters required to model the radio (part 5)

Average pulsed power (W)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
1.019	1.025	1.110	1.025	1.037	1.074	1.214	1.900

Table A-22 Parameters required to model the radio (part 6)

Amp-hour capacity (ahr)	Chemical composition	Efficiency (%)	Resistance (ohm)
3.1	Li-Ion	0.9975	0.015956529

Table A-23 Parameters required to model the radio (part 7)

Fully charged voltage (V)	Rated discharge (ahr)	Nominal amp-hour capacity (ahr)	Exponential voltage (V)
4.292	0.62	2.8985	3.811

Table A-24 Parameters required to model the radio (part 8)

Exponential amp-hour capacity (ahr)	Initial amp-hour capacity (ahr)	Exponential zone voltage drop (V)	Exponential zone amp-hour capacity (ahr)
2.635	3.1	0.481	1.138519924

Table A-25 Parameters required to model the radio (part 9)

Polarization voltage (V)	Voltage constant (V)
0.008949895	3.829842944

A.7 Portable Radio Communications Parameters

The parameters used to model the PRC are provided in Tables A-26 through A-34. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-26 Parameters required to model the PRC (part 1)

Duration (h)	Average power consumption (W)	Nominal voltage (V)	Estimated amp-hour capacity (ahr)
96	21.000	12	168

Table A-27 Parameters required to model the PRC (part 2)

Total no. of batteries	Component weight	Battery weight	Discontinuous use average power consumption	Continuous use average power consumption
(#)	(lbf)	(lbf)	(W)	(W)
12	2.79375	2.20625	20	25

Table A-28 Parameters required to model the PRC (part 3)

Discontinuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
3600	2700	600	2700	1800	600	300	60

Table A-29 Parameters required to model the PRC (part 4)

Continuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
15	15	15	15	15	15	15	15

Table A-30 Parameters required to model the PRC (part 5)

Average pulsed power (W)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
20.021	20.028	20.122	20.028	20.041	20.122	20.238	21.000

Table A-31 Parameters required to model the PRC (part 6)

Amp-hour capacity	Chemical composition	Efficiency	Resistance
(ahr)		(%)	(ohm)
15	Li-Ion	0.9975	0.010695187

Table A-32 Parameters required to model the PRC (part 7)

Fully charged voltage (V)	Rated discharge (ahr)	Nominal amp-hour capacity (ahr)	Exponential voltage (V)
13.92	3	14.025	12.36

Table A-33 Parameters required to model the PRC (part 8)

Exponential amp-hour capacity (ahr)	Initial amp-hour capacity (ahr)	Exponential zone voltage drop (V)	Exponential zone amp-hour capacity (ahr)
12.75	15	1.56	0.235294118

Table A-34 Parameters required to model the PRC (part 9)

Polarization voltage (V)	Voltage constant (V)
0.029026688	12.42111225

A.8 Toughbook Parameters

The parameters used to model the Toughbook are provided in Tables A-35 through A-43. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-35 Parameters required to model the Toughbook (part 1)

Duration (h)	Average power consumption (W)	Nominal voltage (V)	Estimated amp-hour capacity (ahr)
96	1.692	7.8	20.82840237

Table A-36 Parameters required to model the Toughbook (part 2)

Total no. of batteries	Component weight	Battery weight	Discontinuous use average power consumption	Continuous use average power consumption
(#)	(lbf)	(lbf)	(W)	(W)
9	2.130070547	1.75	1	10

Table A-37 Parameters required to model the Toughbook (part 3)

Discontinuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
3600	3600	∞	3600	∞	∞	∞	∞

Table A-38 Parameters required to model the Toughbook (part 4)

Continuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
300	300	0	300	0	0	0	0

Table A-39 Parameters required to model the Toughbook (part 5)

Average pulsed power (W)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
1.692	1.692	0.000	1.692	0.000	0.000	0.000	0.000

Table A-40 Parameters required to model the Toughbook (part 6)

Amp-hour capacity	Chemical composition	Efficiency	Resistance
(ahr)		(%)	(ohm)
2.6	Li-Ion	0.9975	0.040106952

Table A-41 Parameters required to model the Toughbook (part 7)

Fully charged voltage (V)	Rated discharge (ahr)	Nominal amp-hour capacity (ahr)	Exponential voltage (V)
9.048	0.52	2.431	8.034

Table A-42 Parameters required to model the Toughbook (part 8)

Exponential amp-hour capacity (ahr)	Initial amp-hour capacity (ahr)	Exponential zone voltage drop (V)	Exponential zone amp-hour capacity (ahr)
2.21	2.6	1.014	1.357466063

Table A-43 Parameters required to model the Toughbook (part 9)

Polarization voltage (V)	Voltage constant (V)
0.018867347	8.073722962

A.9 Intra-Squad Radio Parameters

The parameters used to model the ISR are provided in Tables A-44 through A-52. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-44 Parameters required to model the ISR (part 1)

Duration (h)	Average power consumption (W)	Nominal voltage (V)	Estimated amp-hour capacity (ahr)
96	16.000	10	153.6

Table A-45 Parameters required to model the ISR (part 2)

Total no. of batteries	Component weight	Battery weight	Discontinuous use average power consumption	Continuous use average power consumption
(#)	(lbf)	(lbf)	(W)	(W)
11	1.41	1	15	20

Table A-46 Parameters required to model the ISR (part 3)

Discontinuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
3600	2700	600	2700	1800	600	300	

Table A-47 Parameters required to model the ISR (part 4)

Continuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
15	15	15	15	15	15	15	15

Table A-48 Parameters required to model the ISR (part 5)

Average pulsed power (W)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
15.021	15.028	15.122	15.028	15.041	15.122	15.238	16.000

Table A-49 Parameters required to model the ISR (part 6)

Amp-hour capacity	Chemical composition	Efficiency	Resistance
(ahr)		(%)	(ohm)
15	Li-Ion	0.9975	0.008912656

Table A-50 Parameters required to model the ISR (part 7)

Fully charged voltage (V)	Rated discharge (ahr)	Nominal amp-hour capacity (ahr)	Exponential voltage (V)
11.6	3	14.025	10.3

Table A-51 Parameters required to model the ISR (part 8)

Exponential amp-hour capacity (ahr)	Initial amp-hour capacity (ahr)	Exponential zone voltage drop (V)	Exponential zone amp-hour capacity (ahr)
12.75	15	1.3	0.235294118

Table A-52 Parameters required to model the ISR (part 9)

Polarization voltage (V)	Voltage constant (V)
0.024188907	10.35092687

A.10 Range Finder Parameters

The parameters used to model the range finder are provided in Tables A-53 through A-58. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-53 Parameters required to model the range finder (part 1)

Duration (h)	Component weight (lbf)	Battery weight (lbf)	Configuration	Total no. of batteries (#)
96	2	0.05	Parallel	2

Table A-54 Parameters required to model the range finder (part 2)

Rated voltage (V)	Rated amp-hour capacity (ahr)	Nominal voltage (V)	Amp-hour capacity (ahr)
3	1.5	3	3

Table A-55 Parameters required to model the range finder (part 3)

Discontinuous use average power consumption (W)	Continuous use average power consumption (W)	Discontinuous use average current consumption (A)	Continuous use average current consumption (A)
0.00125	0.125	0.000416667	0.041666667

Table A-56 Parameters required to model the range finder (part 4)

Discontinuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
3600	3600	∞	3600	∞	∞	∞	∞

Table A-57 Parameters required to model the range finder (part 5)

Continuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
30	30	0	30	0	0	0	0

Table A-58 Parameters required to model the range finder (part 6)

Average pulsed power (W)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
3.000	3.000	0.000	3.000	0.000	0.000	0.000	0.000

A.11 IR Strobe Parameters

The parameters used to model the IR strobe are provided in Tables A-59 through A-61. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-59 Parameters required to model the IR strobe (part 1)

Duration	Component weight	Battery weight	Configuration	Total no. of batteries
(h)	(lbf)	(lbf)		(#)
100	0.25	0.05	Series	3

Table A-60 Parameters required to model the IR strobe (part 2)

Rated voltage	Rated amp-hour capacity	Nominal voltage	Amp-hour capacity
(V)	(ahr)	(V)	(ahr)
1.5	8.1	4.5	8.1

Table A-61 Parameters required to model the IR strobe (part 3)

Continuous discharge current	Discontinuous discharge current
(A)	(A)
2.303222222	0.028790278

A.12 IR Laser Parameters

The parameters used to model the IR laser are provided in Tables A-62 through A-64. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-62 Parameters required to model the IR laser (part 1)

Duration	Component weight	Battery weight	Configuration	Total no. of batteries
(h)	(lbf)	(lbf)		(#)
3	0.25	0.05	Series	1

Table A-63 Parameters required to model the IR laser (part 2)

Rated voltage	Rated amp-hour capacity	Nominal voltage	Amp-hour capacity
(V)	(ahr)	(V)	(ahr)
3	1.4	3	1.4

Table A-64 Parameters required to model the IR laser (part 3)

Continuous discharge current	Discontinuous discharge current
(A)	(A)
0.466666667	0.005833333

A.13 Handheld Global Positioning Satellite Parameters

The parameters used to model the handheld GPS are provided in Tables A-65 through A-70. Parameters as defined within the subsequent are ultimately imported into MATLAB/*Simulink*, both of which support 64-bit numeric quantities. Precision as dictated by individual table values are primarily dictated by any calculations that are made within the subsequent Microsoft Excel documents as referenced in Sections A.14 and A.15.

Table A-65 Parameters required to model the handheld GPS (part 1)

Duration	Component weight	Battery weight	Configuration	Total no. of batteries
(h)	(lbf)	(lbf)		(#)
24	1	0.05	Series	3

Table A-66 Parameters required to model the handheld GPS (part 2)

Rated voltage	Rated amp-hour capacity	Nominal voltage	Amp-hour capacity
(V)	(ahr)	(V)	(ahr)
3.8	3.1	11.4	3.1

Table A-67 Parameters required to model the handheld GPS (part 3)

Discontinuous use average power consumption	Continuous use average power consumption	Discontinuous use average current consumption	Continuous use average current consumption
(W)	(W)	(A)	(A)
0.016145833	0.129166667	0.005208333	0.041666667

Table A-68 Parameters required to model the handheld GPS (part 4)

Discontinuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
3600	3600	∞	3600	∞	∞	∞	∞

Table A-69 Parameters required to model the handheld GPS (part 5)

Continuous use average power duration (s)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
300	300	0	300	0	0	0	0

Table A-70 Parameters required to model the handheld GPS (part 6)

Average pulsed power (W)							
Event A	Event B	Event C	Event D	Event E	Event F	Event G	Event H
10.762	10.762	0.000	10.762	0.000	0.000	0.000	0.000

A.14 Limited Tactical Resupply Parameters

Any and all parameters for the limited tactical resupply based squad-based energy and power scenario are provided in the sheets of the Excel document `squad_event_configuration_limited_tactical_resupply.xlsx`.

A.15 Tactical Resupply Parameters

Any and all parameters for the tactical resupply based squad-based energy and power scenario are provided in the sheets of the Excel document `squad_event_configuration_tactical_resupply.xlsx`.

List of Symbols, Abbreviations, and Acronyms

AIHPG	Artificial Intelligence for Hybridized Power Grid
AO	area of operation
CWB	conformable wearable battery
CWPV	conformable wearable photovoltaic
GFE	government-furnished equipment
GPS	global positioning satellite
IR	infrared
ISR	intra-squad radio
Li	lithium
MDO	Multi-Domain Operations
NVGs	night-vision goggles
QRF	Quick Response Force
PRC	portable radio communications
PV	photovoltaic
R&R	Rest and Relaxation
SOC	state of charge
STC	standard test conditions
TVGs	thermal-vision goggles
V-I	voltage-current

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