Power Budgeting Analysis for LSA-02 UAV Technology Demonstrator

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Abstract

This paper discusses the calculation of the LAS-02 UAV electrical power requirement as a technology demonstrator. To answer this issue, the method from ASTM F2490 Standard is used. By adopting that method, the condition of aircraft operation must be defined. Therefore, there are 2 aircraft conditions that will be investigated further. First, the LSA-02 aircraft will be fitted with EO/IR camera and supporting payload for conducting real-time surveillance system. The other condition is conducting the aerial photography mission to investigate the vegetation condition by equipping the aircraft with multispectral camera. The results show that the real-time mission will need bigger electrical power requirement comparing to aerial photography mission. To support the mission without sacrificing the other electrical equipment for functioning, the onboard power generator system inside LSA-02 aircraft should be upgraded, at least with 3.5 kVA capacity.

1. Introduction

National Institute of Aeronautics and Space of Indonesia has been begins developing the UAV technology demonstrator. One of the objectives of LSA-02 UAV technology demonstrator is to perform the automatic flight control functions and technologies. By default, the LSA-02 UAV is designed to perform several flight missions autonomously to comply with that objective. The scopes of the missions are including disaster mitigation surveillance, search and rescue, and Aerial photography. In order to carry out the flight mission successfully, the LSA-02 UAV demonstrator will be equipped with suitable payload, depending on the mission requirement. The payload is of many different types, it can be an imaging sensor, data transmitter, GPS and the other tools to support the mission. The additional payloads, e.g. sensors system, to the aircraft will affect the weight and available electricity onboard the aircraft. Therefore, further investigation is needed to ensure the additional sensor will not affect the aircraft performance which can jeopardize the aircraft safety. The paper will emphasize on investigation of the available electricity onboard the aircraft, when all aircraft payload is operate to conduct the mission. The result will ensure that the main avionics, primary flight instrument, and other system which give important information to pilot to perform the flight safely is still operable when conduct the flight missions which utilize the aircraft payloads. It is obvious that the additional payload will need electrical power from the aircraft power generator system, in order to operate normally.

In term of aircraft, The LSA-02 UAV demonstrator will use a typical high performance aircraft, with MTOW ≤ 2700 kg and use only single reciprocating engine. Right now, the aircraft type which plan to use for LSA-02 UAV technology demonstrator is still being investigated. But, the strongest candidate is Stemme S15 aircraft. It's a motorized glider aircraft which perform excellent aerodynamic performance in low subsonic flight regime. Due to the aircraft is powered only with single reciprocating engine (piston type, which turbocharger), the available electricity power is limited. This condition will reinforce the need to conduct electrical power budgeting analysis obviously. There are two types of flight missions which will be used to simulate the payload electrical load. First mission is border surveillance mission or SAR mission. Second mission is aerial photography to investigate the vegetation condition. Both of the mission is equipped with different type of payload and will be explained further in another chapter. The power budgeting analysis will be conducted according to ASTM F2490 standard, therefore the performed steps is strictly followed the ASTM F2490 standard. The analysis only investigates the maximum electrical demand or maximum load that will be work on aircraft electrical component and also the payload. This simplification is used because the power budgeting analysis conducted in this paper is only interested on the maximum electrical demand or maximum load that should be known during the flight to ensure the onboard aircraft power generation system is supplying enough electricity.

2. LSA-02 UAV Electrical System

The LSA-02 UAV electrical system is consists of two main components, the electric power supply system and the electrical component. The term “electrical system” as used in this paper means those parts of the aircraft that generate, distribute, and use electrical energy, including their support and attachments [1]. The aircraft electric power supply system is consisting of two main component, which are electric power generation system (EPGS) and electric power distribution system (EPDS) [2]. In the literature [3] stated that one of the electric power generation system in the civil aircraft used 28 VDC voltage. The voltage 28 VDC was the classical electrical power system from 1940s to 1950s. There were one or two DC batteries to support the essential loads during an emergency. The LSA-02 UAV electrical component is divided into two main component, the basic electrical component and payload component. It will be investigated further in this chapter, while the payload component will be investigated in chapter 3.

2.1 Aircraft EPGS

The Stemme S15 EPGS is used 28Vdc and 1 DC batteries to support the flight operation. Based on the literature [4], the electrical system in the aircraft is designed to perform two types of operation, powered flight and soaring without engine on. This type of electrical system operation is mainly caused by the nature of Stemme S15 is a glider aircraft, which capable to fly without the engine. Affected by this configuration, the electric power distribution system (EPDS) includes means to separately shut off the electrical subsystems related to the engine. With engine off, the aircraft can continue the flight while the electrical system which essential for flight is powered by the battery only. The essential electrical system is consisting of lighting, avionic, trim control and landing gear system. There are three electric power generation systems (EPGS) inside Stemme S15 aircraft [4] [5] [6], as shown in table 1 below.

Table 1: aircraft electric power generation systems

Power Source	**Voltage [Vdc]**	**Rating [amp]**	**Electrical Power Allocation**
Battery (BAT)	24	19	To power up electrical system essential for flight
External Alternator (ALT)	28	90	Main power source of the electrical system and charges the battery when engine is running
Internal Engine Generator (GEN)	12	20	To powers the main fuel feeder pump, the fuel circulation pump, engine monitoring systems and the turbo-charged control unit (TCU). Capable to provide electrical power without a battery

2.2 Aircraft EPDS

In the literature **[2]**, The EPDS plays the role of distribution, transition, control, protection and management of the electric power from the power generators buses to equipment. In this paper, only the distribution of the electric power from power generator to the equipment is explained. The distribution of electric power is highly related to the bus configuration onboard the aircraft. The bus configuration of Stemme S15 is explained in table 2 below.

Table 2: aircraft electrical bus configuration

Bus Name	Power Source		Equipment
	Normal	**Soaring**	
Main	ALT	BAT	lighting, propeller variable pitch control, landing gear hydraulic pump, trim control actuator, payload, and avionic bus
Avionic	ALT	BAT	communication, GPS and navigation instrument, transponder, auto pilot and servo
Engine	ALT	-	Engine monitoring systems, cabin heating, main fuel feeder pump, the fuel circulation pump and the turbo-charged control unit (TCU)
Internal generator	GEN	-	

The main bus will get electrical power from the Battery if the engine is not running. When the engine is running, the alternator will provide the electrical power to the main bus, and also charge the battery. The avionic bus is connected to the main bus, and get same electrical power source as main bus. The engine bus is connected to the main bus via a master CB and the engine bus relay. The engine bus power source can be selected either come from alternator or battery. The engine bus supplies all subsystems necessary for engine operation and monitoring. It also powers the alternator field. The internal generator bus is need electricity from battery in the beginning to start the engine, after the engine and alternator is running, the electricity from battery is cut off, and the internal generator bus is powered by internal engine generator, independent from battery. In this paper, the investigation of power budgeting analysis only focused on main and avionic bus. The reason behind this is because during flight, all essential flight system, including mission payload is connected to the main bus. The engine and internal generator bus is distribute the electrical power to the less essential system, therefore not so important to investigated further.

2.3 LSA-02 Basic Electrical Equipment

The LSA-02 basic electrical equipment is all equipment connected to the main and avionic bus. The electrical equipment will be grouping into six main groups, which are lighting, avionic, autopilot, propeller variable pitch control (PVPC), landing gear, and trim control [4]. The electrical load needed and list of electrical component is shown in table 3 below.

Table 3: aircraft basic electrical equipment

Electrical Equipment Group	Voltage [Vdc]	Max Current [amp]	Electrical Component List
Lighting	28	4.18	Interior lights, navigation + strobe lights, position lights, landing lights
Avionic	28	9.01	VHF communication, audio panel/intercom, transponder, GPS/Navigation, EFIS, CDI, variometer, altitude digitizer
Autopilot	24	6.29	Master control, control surface actuator
PVPC	28	1.5	Electrical motor
Landing gear	24	12.5	Hydraulic pump
Trim control	24	2.25	Actuator

3. Payload Configuration

3.1 SAR and Disaster Mitigation Mission

The requirement for this mission is capability of LSA-02 to provide surveillance result to the ground station in real time for day and night operation. It means, when the LSA-02 start to detect the suspicious object, the result should be transmitted directly to the ground station for further investigation. The real-time capability for transmitting data is important because the authorities need that data to decide what should to do next. To fulfill that requirement, the LSA-02 will be equipped with EO/IR sensors as main imaging sensor and also the transmitter to transmit the image/ video data to the ground and work in real time mode. The concept of real-time data transmitter for aircraft is adopted from literature [7], and the payload configuration for this mission and the specification is described in table 4 below [8] [9] [10] [11] [12].

Table 4: payload configuration and electrical specification for SAR and disaster mitigation mission

Component	**Voltage [Vdc]**	**Max Current [amp]**
High Power Transmitter	28	12.5
Downlink Control Panel	28	0.1
Aircraft Transmit Antenna	28	1
GPS Steerable Antenna System	28	5.5
EO/IR Camera	28	32.14
Camera Hand Controller Unit (HCU)	28	0.18

3.2 Aerial Photography Mission

The requirement for this mission is capability of LSA-02 to provide multispectral image. The multispectral image is an image which contain image data at specific frequencies across the electromagnetic spectrum, Blue-NIR-MIR, where the blue channel uses visible blue, green uses NIR (so vegetation stays green), and MIR is shown as red. Such images allow seeing the water depth, vegetation coverage, soil moisture content, and presence of fires, all in a single image. The image data then will be saved into onboard storage system inside the aircraft and no need to transmit in real time. To fulfill that requirement, the LSA-02 will be equipped with multispectral camera sensors as main imaging sensor, a GPS to geotagging the image and also the data storage facility. The payload configuration for this mission and the specification is described in table 5 below **[13]**.

Table 5: payload configuration and electrical specification for aerial photography

Component	**Voltage [Vdc]**	**Max Current [amp]**
Multispectral Camera Arrays	12	1.65
Data storage	12	2
GPS	12	0.02
Laptop	19.5	2.3

4. Load Analysis

The electrical load analysis methodology is adopted from literature [14] . The analysis is only conducted for DC load types, because the Stemme S15 aircraft is use DC as main electrical system.

4.1 Assumption

The assumption which applied during calculation is stated as follows.

1. Most severe electrical loading conditions and operational environment in which the aircraft will be expected to operate are assumed to be during the day and in clear conditions
2. Momentary/intermittent loads, such as electrically operated valves, which open and close in a few seconds are not included in the calculations.
3. No Motor load demands analysis for steady-state operation and do not include starting inrush power.
4. Intermittent loads such as communications equipment (radios e.g. VHF/HF Communication) will be calculated at maximum power needed when active.
5. Cyclic loads such as heaters, pumps etc. (duty cycle) is not included
6. Estimation of load current, does not assume a voltage drop between bus bar and load

4.2 Condition of Aircraft Operation

The LSA-02 aircraft is simulated to perform a flight to accommodate both mission stated above. The aircraft will be simulated to fly at altitude 504 m, and cruising speed at 180 km/s. The LSA-02 will be conducting the cruise (while cruising, the aircraft is performing the mission) for 2 hours. The detail of flight duration for each flight phase is described in table below.

Table 6: flight duration

Flight Phase	Duration [s]
Engine Start + Taxiing	600
Take-off and Climb	168
Cruise	7200
Descent + Landing	632

4.3 Condition of Power Source

From the literature [14], there are three condition of power source, which are normal, abnormal, and emergency. The normal operating condition is defined as all available electrical power system is functioning properly. In the Stemme S15 aircraft, the normal operating condition is defined if the engine is running, the alternator also running and generates electrical power to the main, avionic and engine bus. The alternator is charging the battery in normal condition. The abnormal power operation is occur when a malfunction or failure in the electric system has taken place and the protective devices of the system are operating to remove the malfunction or the failure from the remainder of the system before the limits of abnormal operation are exceeded. This operating condition is not investigated in this paper. The last operating condition is the emergency electrical power operation. In the Stemme S15 aircraft, the emergency electrical power operation is same with soaring flight operation, where the engine is and alternator is not running and the aircraft electrical system is mainly powered by battery. When the aircraft is in emergency electrical power operation, the aircraft payload will not be operated and all available electrical power will be used for the essential system.

4.4 Calculations

The calculation is all based on literature [14] guideline. To estimate the aircraft total electrical current, the general equation below is used.

$$I = n \times I_a \times t \tag{1}$$

Where I represent total electrical current during a period of operating time (Amp-Min), n is number of electrical component operating simultaneously, I_a represent electrical current per unit (Amps), and t is operating time (min). The estimation of maximum demand or maximum load is calculated by following equation.

$$P = n \times I_a \times V \tag{2}$$

Where P represent maximum demand or maximum load (Volt-Amps, VA or kVA), and V is supply voltage (volts). The calculation of flight duration in cruise phase during emergency power source condition is estimated by using following equation.

$$t_{ec} = (Q_{batt} - Ished - Iland)/I_c \tag{3}$$

Where t_{ec} represent flight duration of cruise flight during emergency (Min), Q_{batt} is battery capacity (Amp-Min), $Ished$ represent electrical current consumption during a cruise pre-load shedding period (Amp-Min), $Iland$ represent electrical current consumption during a landing period (Amp-Min), and I_c is represent minimum electrical current during cruise necessary to maintain flight after the generator/alternator failed (Amps). The total flight duration during emergency power condition then can be calculated as follows.

$$t_{e-flt} = t_{ec} + t_{pls} + t_{ldg} \tag{4}$$

Where t_{e-flt} represent total flight duration during emergency power condition (Min), t_{pls} is cruise pre-load shedding period (Min), and t_{ldg} is landing period (Min).

5. DC Loads Analysis

The electrical load analysis is performed for whole duration of flight. The first step of electrical load analysis is described the operating time for each electrical component, which is described in table 3, 4, and 5 during normal condition of power source. The maximum operating time for each flight phase should not exceed the flight time stated on table 6. The recapitulation of component operating time is shown in table 7 below.

Table 7: electrical component operating time during normal operation

Component	**Operating Time [s]**			
	Engine Start + Taxiing	**Take-off and Climb**	**Cruise**	**Descent + Landing**
Navigation + Strobe Lights	0	168	7200	632
Position Lights	0	168	7200	632
Landing Lights	0	0	0	300
VHF COMM	600	168	7200	632
Audio Panel/Intercom	600	168	7200	632

XPDR (Transponder)	600	168	7200	632
GPS/NAV	600	168	7200	632
EFIS/Artificial Horizon	600	168	7200	632
Course Deviation Indicator	600	168	7200	632
Variometer	0	0	0	632
Altitude Digitizer	600	168	7200	632
Autopilot master control and servo	0	0	7200	0
Propeller Variable Pitch Control	0	300	300	0
Landing Gear (Hydraulic Pump)	0	90	0	90
Trim Control (actuator)	0	0	300	0
Mission payload	0	0	7200	0

By utilizing equation 1, the total current and maximum electrical load during normal operation flight can be obtained. The result of total electrical current during flight then divided into each flight phase to identify which flight phase consume more electrical current. Figure 1 below show the electrical current consumption during flight period for basic aircraft electrical equipment. The electrical current consumption is writes in percentage for each flight phase.

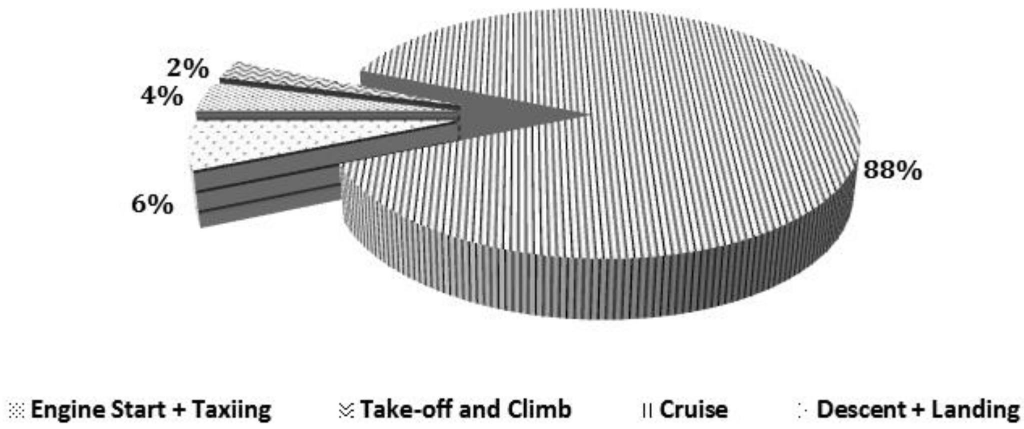

Figure 1: percentage of electrical current utilization during normal operation flight for basic electrical equipment

From figure 1, when aircraft is in cruise phase, it will utilize 88% electrical current consumption of total consumption for whole flight operation. This calculation is make sense, because the cruise flight phase is occupied almost 83% of flight time. The investigation is continued to identify the basic aircraft electrical equipment which consume most of electrical current during the cruise phase. The result is shown in figure 2 below.

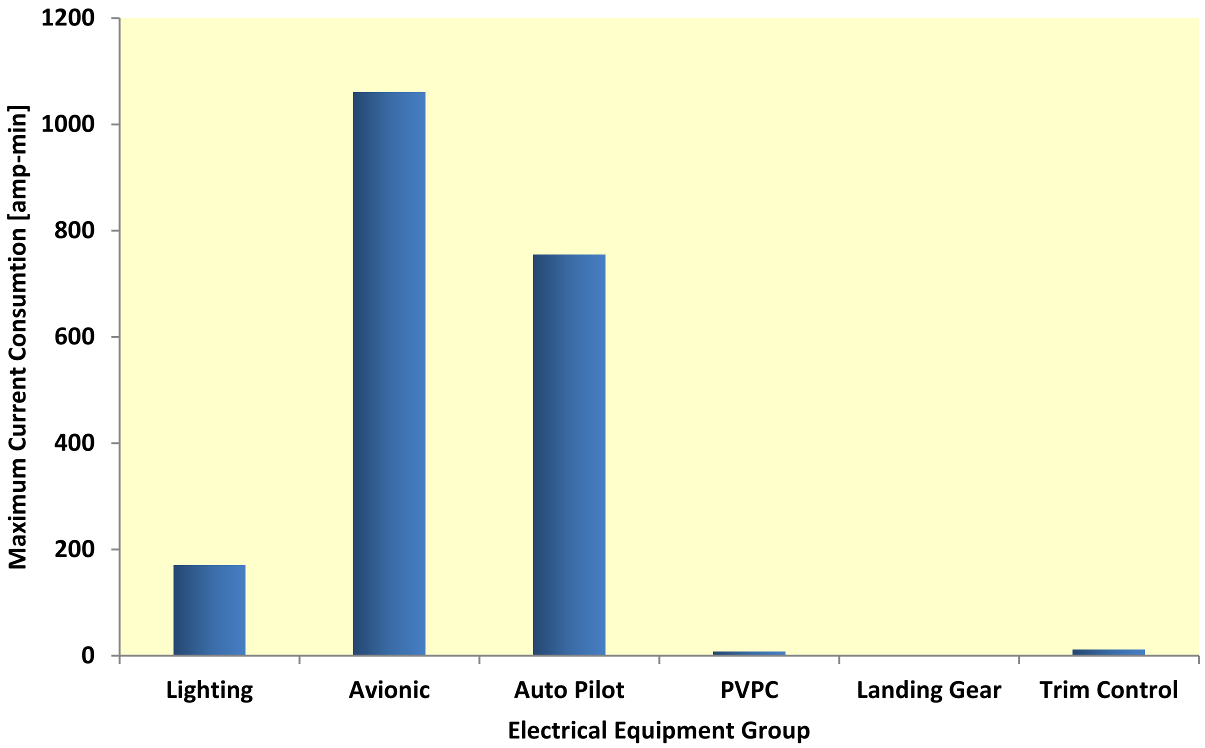

Figure 2: total maximum current for each basic electrical equipment group during cruise

In figure 2, the avionic and autopilot electrical equipment group consume around 1000 amp-min and 800 amp-min during cruise flight. The high consumption of electrical current for both equipment groups is due to the component inside that group is need more electrical current to operate normally, for example the servo motor in autopilot group and the VHF comm, transponder, and GPS/NAV in avionic group. The next analysis is focused on investigation of maximum electrical load during flight. The maximum electrical load during flight is calculated by using equation 2. The next investigation is to identify in which flight phase the maximum electrical load is occurs, as shown in figure 3 below.

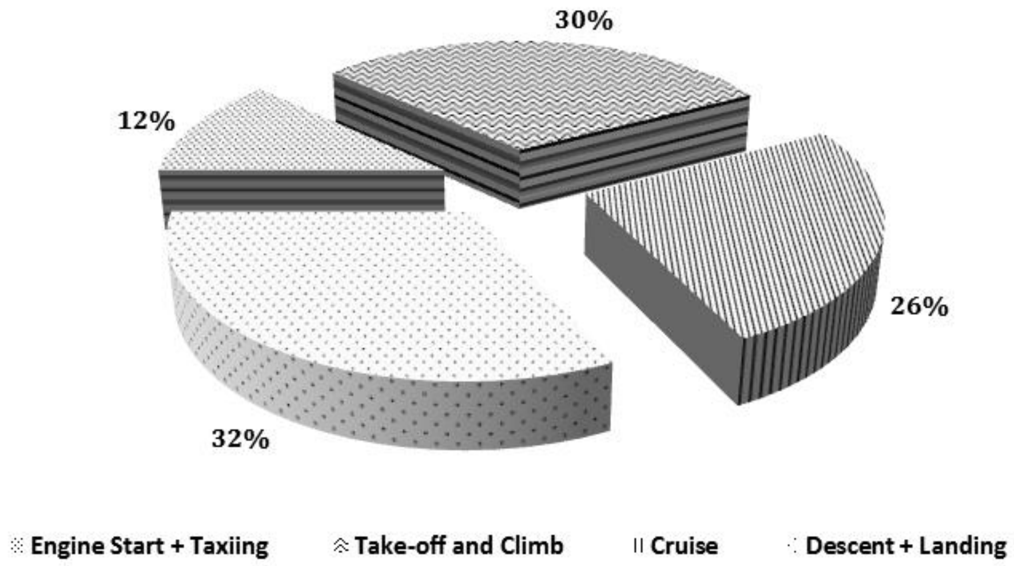

Figure 3: percentage of maximum electrical load during normal operation flight for basic electrical equipment

In figure 3, the maximum electrical load is identified during descent + landing phase, which occupied 32%, and also during take-off + climb which occupied 30% of total basic aircraft electrical load. As shown in figure 4, the maximum electrical load for both flight phases is due to landing gear usage. The landing gear is need hydraulic pump to retract or extend the landing gear strut. The hydraulic pump need maximum 12.5 amp at 24 Vdc for 90 second at normal operation. Although the hydraulic pump operation need big electrical current, but the short duration of operation times makes the electrical current consumption is only 18.75 amp-min. Compared to almost 1000 amp-min for avionic electrical component during cruise phase, the landing gear hydraulic pump electrical current consumption is 53 times lower.

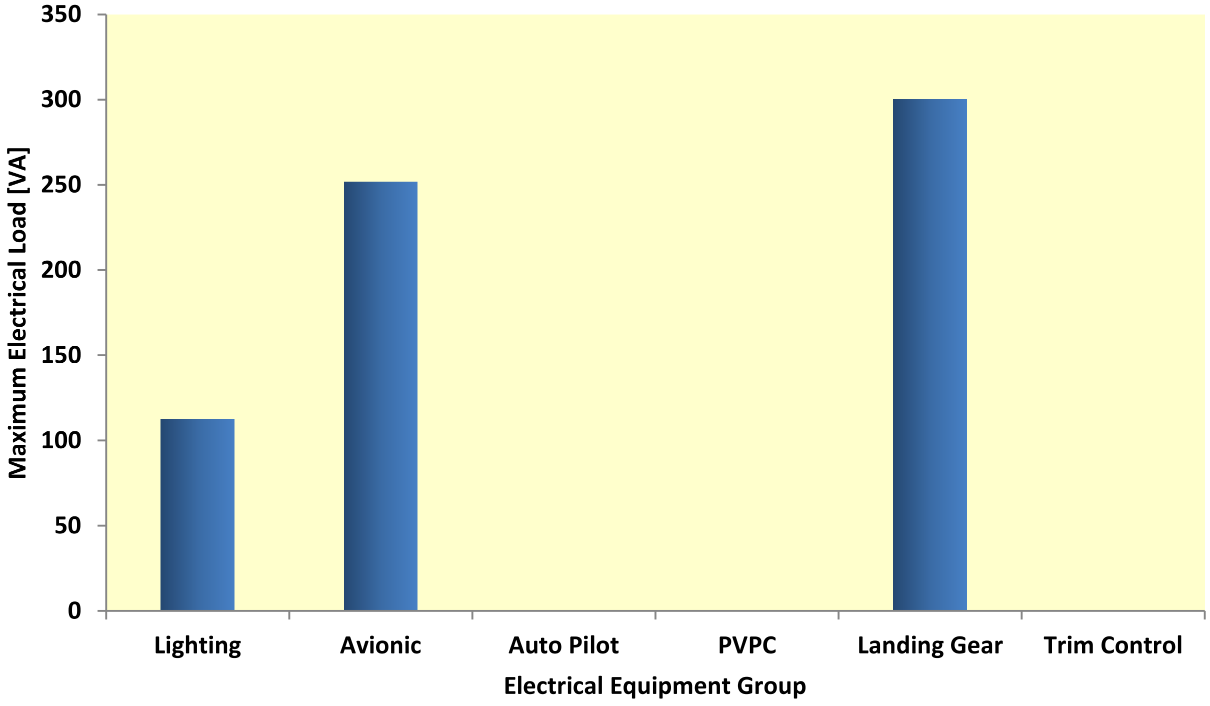

Figure 4: total maximum electrical load for each basic electrical equipment group during descent + landing

The combination between maximum electrical loads for basic aircraft electrical equipment and the mission payload should be investigated to ensure the electrical power generation is sufficient during flight. The mission 1 is described as SAR and Disaster Mitigation Mission, where the payloads configuration is refers to table 4. While mission 2 is describes as Aerial Photography Mission where the payloads configuration is refers to table 5. The maximum load for both payload configurations is shown in figure 5 below.

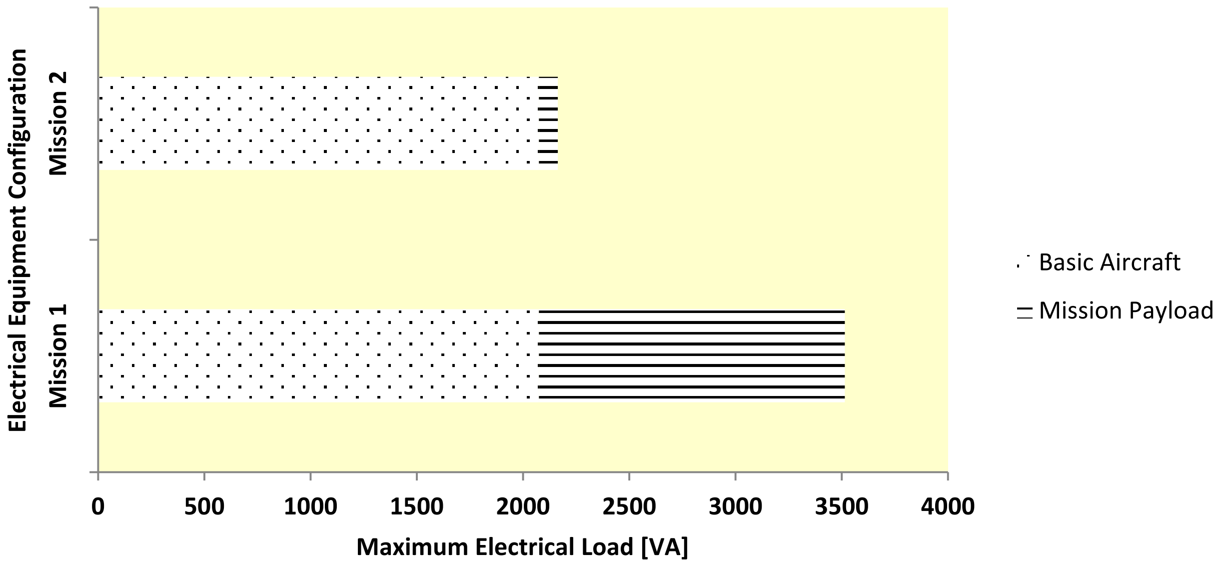

Figure 5: maximum electrical load for mission 1 and mission 2 electrical payloads

From the figure 5 above, payload configuration for mission 1 is need almost 1.5 electrical load comparing to the mission 2. The total electrical load to conduct mission 1 is around 3.5 kVA. The result show that the onboard aircraft alternator is not sufficient to power up mission 1 payload configuration, while just enough to power up mission 2 payload configuration.

The emergency operation of power source is conducted based on mission 1 payload configuration. The aircraft main power generation is assumed to be failed during conducting mission 1. The calculation of total flight time that supported by onboard battery is started by calculation of pre-load shed cruise electrical consumption. It's assumed that pilot will need 5 minute $(t_{pls} = 5\, min)$ to shed essential loads following the low voltage warning [14]. After that, the minimum cruise electrical load for essential flight system or flight instrument must be calculated. Last, the electrical consumption required during the landing approach must be calculated. Its will be assumed that the landing approach will need 5 minute $\left(t_{ldg} = 5\, min\right)$ [14]. The recapitulation of electrical current during the emergency flight is shown in table 8 below.

Table 8: electrical current during the emergency power operation

Component	Current	Remark
Q_{batt} at 75% **[amp-mins]**	855	Assumption of 75% capacity is obtained from literature [14]
$Ished$ **[amp-mins]**	360	Electrical load : mission 1 payload, avionic, all light except interior and landing light, trim control, and PVPC
$Iland$ **[amp-mins]**	104	Electrical load : avionic, all light except interior, and landing gear hydraulic pump
I_c **[amp]**	14.3	Electrical load : avionic, all light except interior and landing light, trim control, and PVPC

By utilizing equation 3 and 4 in chapter 4.4, the cruise flight duration during the emergency power operation $t_{ec} = 27.4\, min$. The total flight duration is $t_{e-flt} = 37.4\, min$ during the emergency power operation with 19ah battery capacity rating.

5. Conclusion

The electrical load and power source capacity analysis for LSA-02 UAV showed that the onboard EPGS is sufficient to power up the basic aircraft electrical equipment and also conducting aerial photography mission. The onboard EPGS is become insufficient if the LSA-02 UAV must performing SAR and disaster mitigation mission. To support SAR and disaster mitigation mission, an upgrade for alternator to at least 3.5 kVA rating is mandatory. The onboard battery also sufficient to power up all critical flight instruments in case of emergency power condition for 37.4 min. This result then can be used for further analysis of EPGS in case of installment of sophisticated autopilot equipment to make the LSA-02 UAV fly autonomously without onboard pilot.

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