Electrical Power Budgeting Analysis for LSA-02 UAV Technology Demonstrator

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Abstract. This paper addresses the calculation of the LSA-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 support 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 a 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 begun the development of UAV technology demonstrator. One of the objectives of LSA-02 UAV technology demonstrator is to realize the automatic flight control functions and technologies. By default, the LSA-02 UAV is intended to operate several flight missions autonomously to comply with that objective. The scopes of the missions are covering a monitoring for disaster mitigation, search and rescue, and aerial photography. In order to carry out the flight mission successfully, the LSA-02 UAV demonstrator will be outfitted with suitable payload, depending on the mission requirement. The payload comes from 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 availability of electrical power onboard the aircraft. Hence, further investigation is required to guarantee the additional sensor will not hit the aircraft performance that can jeopardize the aircraft safety. This paper will emphasize on the investigation of the availability of electrical power onboard the aircraft when all aircraft payload is engaged to conduct the mission. It is obvious that the additional payload needs electrical power from the aircraft power generator system, in order to operate normally. Hence, a calculation for electrical power requirement shall be made, and the result will ensure that the

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additional payload does not disturb the main avionics, primary flight instrument, and another system which give important information to the pilot to perform the flight safely.

In term of aircraft, The LSA-02 UAV demonstrator will use a typical high-performance aircraft, with MTOW ≤ 2700 kg and use the single reciprocating engine. Right now, the aircraft type which plans 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 deliver superior aerodynamic performance in low subsonic flight regime. Due to the aircraft is powered by a single reciprocating engine (piston type, with turbocharger), availability of electrical power is limited. This situation will strengthen the requirement to conduct electrical power budgeting analysis obviously. There are two types of flight missions that be used to simulate the electrical load. The first mission is border surveillance mission or SAR mission. The second mission is aerial photography to investigate the vegetation condition. Both of the mission is outfitted with a different type of payload and. The payload configuration is described further in another chapter. The power budgeting analysis is carried according to ASTM F2490 standard. Consequently, the performed steps are strictly obey the ASTM F2490 standard. The analysis only examines the maximum electrical demand or maximum electrical load on aircraft electrical component and also the payload. This simplification is used considering the power budgeting analysis conducted in this paper is only interested in the maximum electrical demand or maximum load that should be known during the flight and make a recommendation about the electrical capacity that shall be installed onboard the aircraft.

2. LSA-02 UAV Electrical System

The LSA-02 UAV electrical system 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 components, 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 systems in the civil aircraft used 28 VDC voltage. The voltage 28 VDC was the classical electrical power system from the 1940s to 1950s. There were one or two DC batteries to support the essential loads during an emergency. This configuration is commons to be installed into the aircraft at that time, even until today. Furthermore, The LSA-02 UAV electrical component is divided into two main component, the basic electrical component and payload component. The topic about the basic electrical component is investigated further in this chapter, while the payload component will be investigated in chapter 3.

2.1. Aircraft EPGS

The Stemme S15 EPGS adopt a 28Vdc system and one battery to maintain the flight operation. There are three EPGS inside The LSA-02 UAV [4] [5] [6], as shown in table 1 below. Based on the literature [4], the electrical system in the aircraft is designed to perform two types of operation, powered flight with the engine on and soaring flight without the engine on. This typical operation is mainly caused by the nature of Stemme S15 is a glider aircraft that capable to fly without the engine. Affected by this configuration, the electric power distribution system (EPDS) incorporates means to separately shut off the subsystems related to the engine. Even with the engine off, the aircraft is capable of continuing the flight with the essential electrical systems for flying is powered on by the battery only. The term of the essential electrical system consists of lighting, avionic, trim control and landing gear system.
### Table 1. Aircraft electric power generation system

| 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). |

2.2. Aircraft EPDS

In the literature [2], The EPDS represents the role of distribution, transition, control, protection and management of the electric power from the power generators buses to electrical equipment. In this paper, only the role of distribution the electric power from the power generator to the equipment is described. The distribution of electric power is profoundly linked to the electrical bus configuration onboard the aircraft. The electrical bus configuration of The LSA-02 UAV is explained in table 2 below.

### Table 2. Aircraft electrical bus configuration

| Bus Name                  | Power Source | Normal | Soaring | Equipment Connected to the Bus                                                                 |
|---------------------------|--------------|--------|---------|-----------------------------------------------------------------------------------------------|
| 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                |
| Internal generator engine | ALT          | -      |         | Engine monitoring systems, cabin heating, main fuel feeder pump, the fuel circulation pump and the turbo-charged control unit (TCU) |

The main bus will get electrical power from the Battery (BAT) if the engine is not running. When the engine is running, the alternator (ALT) will provide the electrical power to the main bus, and also charge the battery. The avionic bus connected to the main bus, and get same electrical power as the main bus. The engine bus is connected to the main bus via a master circuit breaker (CB) and the engine bus relay. The engine bus power source can be selected either come from alternator or battery. The engine bus distributes the electrical power to all subsystems which are necessary for engine operation and monitoring. The internal generator (GEN) bus needs electricity from a battery, in the beginning, to start the engine. After the engine and alternator are running, the electricity from the battery is cut off, and the internal generator bus is powered by internal engine generator, independently from the battery. In this paper, the investigation of power budgeting analysis only focused on a main and avionic bus. The reason behind this because during the flight, all flight system, including mission payload is connected to the main bus, not to the engine and internal generator bus. Hence, it is not so relevant to investigate the engine and internal generator bus further.

2.3. LSA-02 Basic Electrical Equipment

The LSA-02 basic electrical equipment defines as all equipment connected to the main and avionic bus. To expedite the investigation, the electrical equipment is arranged into six main groups, which are
lighting, avionic, autopilot, propeller variable pitch control (PVPC), landing gear, and trim control [4]. Table 3 presents the description of each group.

**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 mission requirement is a capability of LSA-02 to broadcast the surveillance result to the ground station in real time for day and night operation. By considering the requirement, it means when the LSA-02 start to detect the suspicious object, the result should be able to send directly to the ground station for further investigation. The capability of transmitting data in real-time is critical since the authorities require such data to determine what action should do next. To satisfy the requirement, the LSA-02 is simulated to be equipped with EO/IR sensors as the main imaging sensor and also the transmitter to forward the image/video data to the ground in real time. The concept of a 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 mission requirement is a capability of LSA-02 to provide the multispectral image. The multispectral image is an image which contains image data at specific frequencies across the electromagnetic spectrum, Blue-NIR (near infra-red) –MIR (middle infra-red), 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 not necessary to send in real time. To fulfill that requirement, the LSA-02 will be equipped with multispectral camera sensors as the 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 Methodology

The electrical load analysis methodology is adopted from literature [14]. The analysis is only conducted for DC load types because the LSA-02 aircraft is used DC as the main electrical system.

4.1. Assumption

The assumption applied during calculation states as follows:

1. Most severe electrical loading conditions and operational environment in which the aircraft will be expected to operate 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
4. The starting inrush power not considered.
5. Intermittent loads such as communications equipment (radios e.g. VHF/HF Communication) will be calculated at maximum power needed when active
6. Cyclic loads such as heaters, pumps etc. (duty cycle) are not included
7. Estimation of load current does not assume a voltage drop between the bus bar and load.

4.2. Aircraft Operation

The LSA-02 aircraft is simulated to perform a flight that accommodating both missions stated in chapter 3.1 and 3.2 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 6 below. The flight duration is adopted from [18]. The question arises, do the available electrical power generation as stated in table 1 is sufficient to accommodate the demands of electrical power along the flight duration as defined in table 6 below? Bear in mind that the onboard electrical power generation must generate sufficient electrical power at least for two hours in order to guarantee the aircraft is capable of performing the missions. The answers to this question can be obtained after conducting a DC loads analysis, described in chapter 5.
Table 6. Flight phase and 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 LSA-02 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 also charges 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 LSA-02 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. Electrical Power Calculations

The calculation is all based on literature [14] guideline. To estimate the aircraft total electrical current, the equation (1) below is used.

\[ I = n \times I_a \times t \]  

In equation (1), \( I \) 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 equation (2).

\[ P = n \times I_a \times V \]  

In equation (2), \( P \) represent maximum demand or maximum electrical 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 equation 3.

\[ t_{ec} = (Q_{batt} - I_{shed} - I_{land})/I_c \]  

Where \( t_{ec} \) represent flight duration of cruise flight during emergency (Min), \( Q_{batt} \) is battery capacity (Amp-Min), \( I_{shed} \) represent electrical current consumption during a cruise pre-load shedding period (Amp-Min), \( I_{land} \) 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 by using equation 4 below.

\[ t_{e-flt} = t_{ec} + t_{pls} + t_{ldg} \]
In equation (4), the $t_{e-flt}$ 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 Load Analysis

The electrical load analysis is performed for flight duration which is described in table 6. The first step of electrical load analysis is described the operating time for each electrical component, described in table 3, 4, and 5 during normal operation. The payload electrical component in table 4 and 5 is grouping into mission payload component. The recapitulation of component operating time is shown in table 7 below.

| Component                     | Operating Time [s] |
|-------------------------------|--------------------|
|                              | Engine Start +     | Take-off and 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  | 0                  | 0                  | 7200               | 0                 |
| servo                         |                     |                    |                    |                   |
| Propeller Variable Pitch      | 0                  | 300                | 300                | 0                 |
| Control                       |                     |                    |                    |                   |
| 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 needs a lot of electrical current consumption. Figure (1) below shows the electrical current consumption during flight period for basic aircraft electrical equipment. The electrical current consumption is written in percentage for each flight phase.
From figure (1) it utilizes 88% electrical current consumption of total consumption in cruise phase. This calculation makes sense because the cruise phase is occupied almost 83% of flight time. The investigation is continued to identify the basic aircraft electrical equipment which consumes most of electrical current during the cruise phase. The result is shown in figure (2) below.

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

![Figure 3. Percentage of maximum electrical load during normal operation flight for basic electrical equipment.](image)

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 the operation of a landing gear. The landing gear operation needs hydraulic pump to retract or extend the landing gear strut. The hydraulic pump will need maximum 12.5 amps at 24 Vdc for 90 seconds to operate normally. Although the hydraulic pump operation needs big electrical current, but the in short duration of operation times makes the electrical current consumption is only 18.75 amp-min. compared to almost 1000 amp-min for the avionic electrical component during cruise phase, the landing gear hydraulic pump is 53 times lower.
The combination of maximum electrical loads for basic aircraft electrical equipment and the mission payload must be investigated to ensure the available electrical power generation is sufficient during flight. The mission one is described as SAR and Disaster Mitigation Mission, where the payloads configuration refers to the table (4). While mission two is described as Aerial Photography Mission where the payloads configuration refers to the table (5). The maximum load for both payload configurations is shown in figure (5) below.
From the figure (5) above, the mission 1 payload configuration demand approximately 15 times more electrical loads comparing to the mission 2. The entire electrical load required to handle mission 1 is about 3.5 kVA. However, the current aircraft alternator is only proficient to providing 2.5 kVA of electricity. From this result confirms that the current aircraft alternator is not adequate to provide electrical power necessarily to powering the mission 1 payload. In the other hand, the current aircraft alternator is sufficient to power up mission 2 payloads.

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

| Component   | Current | Remark                                                                 |
|-------------|---------|------------------------------------------------------------------------|
| Q\( \text{batt} \) at 75% [amp-mins] | 855     | Assumption of 75% capacity is obtained from literature [14]             |
| I\( \text{shed} \) [amp-mins]    | 360     | Electrical load: mission 1 payload, avionic, all light except interior and landing light, trim control, and PVPC |
| I\( \text{land} \) [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 \( t_{ec} = 27.4 \text{ min} \). The total flight duration is \( t_{e-fit} = 37.4 \text{ min} \) during the emergency power operation with 19ah battery capacity rating.

6. Conclusion
The electrical load and power source capacity analysis for LSA-02 UAV confirmed that the current alternator is adequate to power up the basic aircraft electrical equipment and also conducting aerial photography mission. However, it becomes insufficient if the LSA-02 UAV must performing SAR and disaster mitigation mission. To support those missions, an upgrade for an alternator capacity to at least 3.5 kVA rating is necessary. The onboard battery also sufficient to power up all critical flight instruments in case of emergency power condition for 37.4 min flight duration. This result then will be used as starting point to conduct further analysis of EPGS requirement when sophisticated autopilot equipment is needed to be installed in LSA-02 aircraft.

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