# Advisory Circular
# AC21-11 & AC91-23

**Revision 1**
**10 December 2019**

## Electrical Load Analysis

### General

Civil Aviation Authority advisory circulars (ACs) contain guidance and information about standards, practices, and procedures that the Director has found to be an acceptable means of compliance with the associated rules and legislation.

Consideration will be given to other methods of compliance that may be presented to the Director. When new standards, practices, or procedures are found to be acceptable they will be added to the appropriate AC.

### Purpose

This AC describes an acceptable means of compliance with standards for the preparation of an electrical load analysis (ELA).

### Related Rules

This AC relates specifically to Civil Aviation Rules Part 91*General Operating and Flight Rules* and Part 21 *Certification of Products and Parts*.

### Change Notice

Revision 1 provides clarity around the expected content of an ELA, its place within the aircraft records, and its intended purpose.

### Cancellation Notice

This AC cancels AC21-11 & AC91-23 Revision 0 dated 2 August 2016.

### Version History

History Log

| Revision No. | Effective Date | Summary of Changes |
|---|---|---|
| 0 | 02 August 2016 | This was the initial issue of this AC. |
| 1 | 10 December 2019 | This revision provides clarity around the expected content of an electrical load analysis, its place within the aircraft records, and its intended purpose. |

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# 1. Introduction

1.1 An electrical load analysis (ELA) is a fundamental document part of the aircraft records verifying the airworthiness of an aircraft by providing evidence that the aircraft electrical generation, storage and distribution systems have sufficient capacity to power all installed electrically-powered equipment in both normal and emergency flight conditions. As such, an ELA has two main purposes—

(a) to ensure generating capacity is sufficient to supply the greatest demand of the equipment

(b) to ensure the battery has sufficient capacity to power the required systems in the event of an emergency.

1.2 From a regulatory perspective, there are two areas where the required performance may be stipulated—

(a) the original design basis for the aircraft; or

(b) the operating rule under which the aircraft operates.

1.3 An ELA provides a means of showing compliance against these requirements.

1.4 This AC has been generated with reference to MIL-E-7016F and ASTM F2490-05.

1.5 The initial ELA generated for type certification provides the baseline for subsequent changes and this should be kept updated with all future configuration changes. Where role equipment is to be used, the impact of this equipment should be immediately available so the operator can determine safety, suitability and any operating limitations prior to departure.

# 2. Applicability

2.1 This AC is applicable to all aircraft and is specific to the actual configuration of the aircraft. If at any stage avionics or electrically controlled/actuated equipment is added or removed, or the generating/storage devices altered, the ELA should be revised accordingly.

2.2 In the absence of an ELA, practical testing is a suitable method of verifying electrical loads.

# 3. Definitions

3.1 The definitions specifically pertaining to an ELA are included in Appendix 2 to this AC.

# 4. General Requirements

4.1 An ELA does not compensate or cover design or installation. Any changes to the aircraft for which the ELA was created or updated still need to be done in accordance with the required design standards and specifications pertaining to the aircraft type and operation. (ie any changes to the aircraft require acceptable technical data per rule 21.503.

4.2 The ELA is a living document and should stay with the aircraft and be updated to constantly reflect the aircraft configuration. Where role equipment is permissible for the aircraft, the effect of installing that role equipment should be readily summarised and be able to be applied to the overall aircraft ELA.

4.3 This AC has been generated at a high level to provide an overview and means of compliance. In some instances it may be necessary to provide greater detail and determine more specific details of the aircraft's electrical system, such as the discharge and recharge characteristics of the battery. In these instances or where a greater level of understanding is desired by the designer/person generating the ELA, reference to MIL-E-7016F and ASTM F2490-05 should be made.

## 5. Basic Principles

5.1 An ELA is essentially a summation of the electrical loads applied to the electrical system during specified operating conditions and then the demand analysed with respect to the supply. The ELA requires the listing of each item of equipment or system, the power requirement for that system/equipment and identification of when the item is used during the phases of flight.

5.2 To determine the overall evaluation of power requirements, it is necessary to consider the transient demands of equipment and determine whether these require inclusion. The in-rush currents on motors and momentary/intermittent operation of relays are not included unless considered significant by the person compiling the ELA.

5.3 Load shedding may be applied to reduce the power requirement on the battery in an emergency. Unless the aircraft system provides automatic load shedding it is assumed a five-minute period is required before any manual load shedding is completed by the flight crew after a generating capacity failure. If there is no clear unambiguous attention getting warning of the generating failure the time required can be as much as 10 minutes after failure. If there are reasonable assumptions that this time is less than 5 minutes, other than automatic load shedding, these reasons and assumptions must be clearly documented in the ELA.

5.4 Any load shedding applied in the ELA should be referenced in the document. Consideration should be given to the minimum required equipment in *Part 91 General Operating and Flight Rules* (and certificated operator rules, where applicable) for the kind of operation the ELA is being prepared for. Load shedding in the ELA can only be applied to systems that have automatic load shedding or can be shed by the flight crew. Systems that do not have a switch or a circuit breaker that can be manually tripped (pulled) within normal reach should remain operational throughout the entire flight. Any load shedding applied must not invalidate any procedures or requirements of the aircraft flight manual or associated supplements.

***Note:*** *Where Part 91 requires more than one identical system as part of the minimum required equipment for the operation being carried out, only one of those systems is required to be kept operational after an electrical generation failure.*

5.5 If load shedding is applied to systems not covered in, or additional to the flight manual, or where the aircraft flight manual refers to descriptively vague procedures like "reduce electrical loads as required" it should be made clear in the ELA and included on ELA summary CAA form 24021-20 which systems were load shed.

***Note:*** *Where the aircraft flight manual emergency procedures load shed a system that is required under the minimum equipment requirements under Part 91, the flight manual procedures have precedent but reference to the manual by part number and revision should be included in the ELA.*

# 6. Content

6.1 ELA should contain the following information as a minimum.

### 6.1.1 Introduction

(a) A brief overview of the aircraft describing, the intended operating role of the aircraft, the electrical system and its function. The description should include details of alternator(s)/generator(s) fitted, their manufactured rating and if applicable any de-rating by the aircraft original equipment manufacturer (OEM). Battery details should include make, model and capacity rating. If multiple units are used to increase voltage and/or rating, the connection method should be included in the description.

(b) An electrical schematic and bus wiring diagram can be included to assist in establishing this overview.

### 6.1.2 Assumptions and criteria

(a) A list or summary of all the assumptions and design criteria used as the basis for the ELA.

(b) The kind of operation the ELA is prepared for (VFR, IFR, Part 91 or the certificated operating rule(s) applicable).

(c) This should include a description of the operating conditions and the equipment that is operating in each scenario including duty cycles and details of the non-standard operating cycles. Examples of operating conditions are but not limited to: day-VFR, night-VFR, IFR, night IFR in known icing conditions, landing, aircraft mission.

(d) Unless otherwise stated, radios are assumed to be transmitting 10% and receiving 90% of the operating time.

### 6.1.3 Table of values (an example is included in Appendix 1 to this AC)

(a) In any table of values generated, it should be clear what information is displayed in what value. If the value displayed is a multiplication of units like amp-min ensure the table of values displays enough information to make this clear without the need of recalculation by the reader. This can be achieved by including units of measurements and/or multiplication in column headers.

(b) The starting point with any ELA is the generation/distribution network. As such identify the capacity of the generator(s) and battery.

(c) For each bus, identify the equipment (by system - e.g. VHF radio, fuel, etc.) and its rated current draw.

(d) For each system, identify the operating time, or annotate C for continuous, and identify the phase of flight it is used in. For each load, for each phase of flight, an ampere-hour figure should be derived.

Most ELAs produced by OEMs will use ampere minutes for each load for each phase of flight as it gives a more accurate number less affected by rounding. As both ampere hour and ampere minute are a measure of electric current multiplied by time, they are equally acceptable in use. 1 ampere hour equals 60 ampere minutes.

(e) Additionally, if the system or component is used in the situation of a generator failure, annotate that in the separate column for emergency.

***Note:*** *Transient/ intermittent loads (such as valves and relays) are not included. In-rush currents on motors are not included. The overload design ratings of the sources should however be adequate to cope with these.*

(f) For those aircraft with AC generation and distribution systems, additional requirements need to be considered such as—

(1) phase balance/loading per phase

(2) connection architecture (star/delta)

(3) power factor

(4) reactive power, true power and apparent power.

(g) If the AC powered systems are powered via an inverter during operation (either normal operation or emergency) the DC inverter load should be calculated and included in the DC calculations of the ELA.

### 6.1.4 Emergency and standby operations

6.1.4.1 Where standby power is provided by a non-time-limited source - such as RAT, APU or pneumatic/hydraulic motor, the emergency loads should be listed and evaluated to ensure that demand does not exceed capacity.

6.1.4.2 Where standby power is provided by an equipment specific backup (internal) battery this battery power may be used to load shed the equipment of the main battery during emergency procedures, where the power source can be manually selected by the operator and this source is certified to provide power for a time greater than that the main battery is required to last. The device is still to be included in preload shedding consumption as it uses the battery prior to switching over.

6.1.4.3 Where the backup battery switching is automatic by a logic interface without input of the operator, this battery power may only be used to load shed the equipment of the main battery calculation where the switching happens at a voltage greater than fully charged battery voltage and lower than the nominal generating-device voltage and the battery is certified to provide power for a time greater than 30 minutes.

***Note:*** *For example; Model 182S/182T/T182T Maintenance Manual (rev 20) 24-00-00 states "If there is an alternator failure, the standby battery controller will not let the standby battery discharge to the G1000 essential bus until the depletion or failure of the main battery." As such this does not relieve the G1000 system as a battery load for the purpose of the ELA.*

### 6.1.5 Calculations and results

6.1.5.1 Once the results have been tabulated, the following calculations can be completed.

(a) System capacity. This is derived by accumulating the highest continuous demand load at any point in time and ensuring that it is within the required rated capacity. Unless stipulated elsewhere, the standard guide is that continuous loading should be less than 85% of rated generating capacity[1]. Consideration must be taken towards possible peak

[1] *The rated capacity of the generating device as fitted to the airframe, some aircraft manufacturers de-rate the device rating. Refer to the aircraft maintenance manual for details.*

and inrush loads, not to exceed the rated capacity of the generating device (if no peak endurance is given in the manual or on the data plate of the generating device, the rated value must be assumed as the maximum for peak loads).

(b) Duration on emergency power. This is duration in minutes and is derived by calculating the time that the equipment connected to the emergency bus can operate before the main battery voltage drops to the point that the equipment cannot be relied on. This figure is calculated based on industry wide assumptions[2] made about the condition and type of the battery, the time it takes to disconnect the non-emergency buses (this factor changes if auto-load shedding occurs), the load required for landing and the load drawn by the emergency equipment. The standard duration required on emergency power varies with design or operating rule requirements. The current industry design rules and ACs can be summarised as follows.

(1) Fixed wing VFR:

(i) Certified prior to 11 March 1996; 14 CFR 23 Amendment 49: 5 minutes

(ii) Certified on or after 11 March 1996; 14 CFR 23 Amendment 49: 30 minutes

(2) Fixed wing IFR with maximum certified altitude at or below FL250: 30 minutes.

(3) Fixed wing IFR with maximum certified altitude above FL250 if:

(i) certified prior to 31 January 2012; 14 CFR 23 Amendment 62 : 30 minutes, or

(ii) certified on or after 31 January 2012; 14 CFR 23 Amendment 62 : 60 minutes

(4) Rotary wing VFR: Time required for an autorotative descent to sea level from the maximum certified operating altitude, or 5 minutes whichever is the greater.

(5) Rotary wing IFR: Unless it can be shown that a lesser time is adequate the battery endurance shall be at least half of the rotorcraft endurance, or the flight manual limitations section should define aircraft endurance. However, an endurance of less than 30 minutes would not normally be acceptable.[3]

### 6.1.6 Summary and conclusion

6.1.6.1 The summary should provide evidence that for each operating condition the available power can meet the loading requirements, with adequate margin for both peak loads and maximum continuous loads under normal and abnormal conditions. For AC systems these summaries should include power factor and phase loadings.

6.1.6.2 The conclusion should include statements confirming that the power sources can satisfactorily supply electrical power to necessary equipment during abnormal /emergency operations under the highest-demand conditions.

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[2] *The assumptions made are particular to the battery conditions and drop-off points. These have been captured in the underlying specifications.*

[3] *FAA AC29-2C, Change 4 Date 1 May 2014.*

# 7. Test Regime

7.1 In the absence of sufficient data to enable a comprehensive analysis, when validation of data is required or when it is considered more desirable by the operator to decide, testing is a suitable alternative to analysis. The principle of the testing is the same as the analysis. To prove that the aircraft's generation system can supply the equipment needs and to ensure that sufficient emergency capacity exists in the event of generator failure.

7.2 To conduct the test, the participant should develop a similar table as per the template in Appendix 1 to this AC, in which the participant identifies the equipment that will be operating during each phase of flight. By means of measuring the current at a suitable location with a calibrated device, determine the current draw of individual systems where possible, and combine system loads where individual current cannot be practicably determined.[4] The rest of the process can then be followed as per an ELA by analysis. Identify in the ELA whether current values are obtained by measurement or documented data, especially when a mixture of both exist in the ELA.

7.3 To measure the current draw, it is important to ensure that the current being measured is purely related to the equipment current draw. As such, the battery needs to either be isolated (if testing with generator) or current draw assessed purely off battery. It is preferable to use external current measuring as most aircraft ammeters do not require calibration and cannot be guaranteed as accurate.

7.4 Aircraft with air/ground sensing, and/or retractable gears need to be on jacks to accurately determine in-flight system loads. When measuring communication loads ensure the radio is tuned to an active station while measuring current draw while receiving and measure transmitting current while modulating the carrier wave. Transponder and/or DME equipment need to be measured while receiving/replying to interrogations (by use of ground stations or suitable test equipment). Similar considerations should be made for all equipment on board, "does my ground measurement equal in-flight condition?"

7.5 If it is considered that in-flight forces will affect the current draw on the system (eg. control surfaces), a factor may be applied to the measured result and this needs to be identified and explained in the assumptions that accompany the test results.

# 8. Failure

8.1 A load analysis may show the aircraft is not meeting the requirements for the kind of aircraft and operation the ELA was prepared for. This may happen after installation of additional or new equipment or if the operation requirements change. It may also show on older aircraft that have been certified before design criteria were amended or better defined.

8.2 These non-compliances usually come to light when the aircraft is being modified and being altered from the original design, which may mean the electrical system may need to be modified to meet current design standards.

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[4] *As an ELA is a living document identifying loads per system will make future amendments/revisions easier by not having to do a complete re-measure.*

8.3 There are multiple ways of upgrading the electrical system to meet ELA requirements as not only avionics technology evolved but also electrical technology. Some old systems draw a lot of current especially when compared to modern equivalents. The following are some changes that are worth considering.

(a) Replacing circuit breakers with ones that can be manually tripped “pulled” to aid load shedding.

(b) Replacing incandescent lighting technology with LED types.

(c) Replacing the aircraft battery to a high capacity sealed type.

***Note:*** *This AC does* ***not*** *constitute approved technical data to make these changes.*

# 9. Documentation

9.1 In addition to the electrical load analysis itself being retained with the aircraft records,[5] a summary of the ELA should be completed on CAA form 24021-20. This form informs the crew of the conclusions from the ELA. It also informs the crew of what systems were load shed to reach the conclusion. This can aid in situations where the flight manual procedures are descriptively vague and uses terms like “as required”. This form should be kept with the aircraft in a place accessible to the flight crew such as the folder containing the flight manual.

[5] *The current CAA logbooks have a divider to hold the aircraft ELA*

# A1. Appendix 1— Sample Template

## A1.1 Example Template- ELA (DC)

**Generator** ____________________ **Amps**

**Battery** ____________________ **Amp minutes**

| | Circuit breaker / fuse rating | Operating Time / Duty Cycle (C-continuous) | Normal Operation Night, IFR, Icing | | | | | | | | Emergency-Operation Night IFR Icing | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Taxi/Take-off (X min) | | Cruise ( X min) | | Mission, Spraying, Hoist, Sling (X min) | | Approach/ Landing (X min) | | Pre-load shedding (5 min) | Battery Cruise (X min) | Battery Approach/ Landing (5 min) |
| | | | Ampere | Amp-min | Ampere | Amp Min | Ampere | Amp-min | Ampere | Amp-min | Amp-min | Amp-min | Amp Min |
| **Bus** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Item | | | | | | | | | | | | | |
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| Bus-Total | | | | | | | | | | | | | |
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| Bus | | | | | | | | | | | | | |
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| Item | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | |
| Bus Total | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Aircraft –Total** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Average Load* (Ampere) | | | | Total Amp-min divided by X time | | Total Amp-min divided by X time | | Total Amp-min divided by X time | | Total Amp-min divided by X time | Total Amp-min divided by X time | Total Amp-min divided by X time | Total Amp-min divided by X time |

*) A way of achieving a continuous load, is to take the total phase amp-min and divide them by phase time, this gives a number containing all continuous loads plus the average of intermittent loads, giving a better reflection of continuous generator loading.

### A1.1.1 Generator Loading Calculation

Highest aircraft average phase load = Amp (a)

Generator/alternator Continuous-supply rating = Amp (b)

Generator/Alternator loading = (average phase load / generator rating) x 100 = ((a) / (b)) x 100 = %

### A1.1.2 Battery Duration Calculation – Emergency

| | | | |
|---|---|---|---|
| Battery capacity (Amp min) = | ______________ | Amp-min | (1) |
| Derated battery capacity ((1) x 0.75) = | ______________ | Amp-min | (2) |
| Preload shed (5min x night, ice, cruise load) = | ______________ | Amp-min | (3)* |
| Emergency Load = | ______________ | Amp | (4) |
| Landing load (5min x landing load) = | ______________ | Amp-min | (5) |

$$\text{Duration} = \frac{\text{Derated Battery Capacity – Pre Load shed – Landing Load}}{\text{Emergency Load}} = \frac{(2)-(3)-(5)}{(4)} \quad \text{minutes} \quad (6)$$

Total Duration= Pre load shed time (5min) + Landing Time (5 min) + Duration (6) minutes

*Following a generator system failure and before load shedding has been completed, the battery may be subject to high discharge currents which result in a loss of efficiency and capacity. To make allowance for such losses apply the following. Where the average pre-load shed current draw in ampere is greater than twice the 1 hour rating of the battery by numerical value this is to be increased by 20%.

For example: C1 rating is 20Ah m average preload shed current = 30A, preload shed does not have to be corrected for efficiency, but if the average preload shed current = 41A or greater, the preload shed consumption has to be increased by 20%.

## A1.2 Example Template—ELA (AC)

**Generator** ____________ **Volt-Amps**

**Inverter** ____________ **Volt-Amps**

| | **Connected Load (VA)** | **Power Factor** | **Operating Voltage** | **Source Generator / Inverter / Both** | **Operating Time** (C-continuous) | **Normal Operations, Night, IFR, Icing** | | | | **Emergency-Operation Night IFR Icing** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Taxiing / Take-off** | **Cruise** | **Mission (spraying, hoist, etc)** | **Approach /Landing** | **Pre-Load shedding** | **Battery Cruise** | **Battery Approach / landing** |
| | | | | | | **Volt Ampere** | **Volt Ampere** | **Volt Ampere** | **Volt Ampere** | **Ampere** | **Ampere Min** | **Ampere** |
| **Bus Phase A** | | | | | | | | | | | | |
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| **Item** | | | | | | | | | | | | |
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| **Total** | | | | | | | | | | | | |
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| **Bus Phase B** | | | | | | | | | | | | |
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| **Item** | | | | | | | | | | | | |
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| | | | | | | | | | | | | |
| **Total** | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Bus Phase C** | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Item** | | | | | | | | | | | | |
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| **Total** | | | | | | | | | | | | |
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### A1.2.1 Inverter input calculation

Where the DC load analysis does not give an accurate value for the inverter input current, this may be obtained using the following formula.

$$\text{Formula: } I = \frac{VA\,(1 - n) + va\,(1 + n)}{2 \times E \times n}$$

Where:
- I = Average input current in ampere
- VA = Rated VA output of the inverter
- n = Efficiency of the inverter in decimal form*
- va = va load on the inverter
- E = Input terminal voltage (DC)

* Where the inverter efficiency is not available the following efficiencies are considered appropriate for use:

| Inverter Rating | Rotary 3Ø | Rotary 1Ø | Static 1/3Ø |
|---|---|---|---|
| 0 – 100 VA | 0.35 | 0.25 | 0.60 |
| 101 – 250 VA | 0.40 | 0.35 | 0.65 |
| 251 – 1500 VA | 0.50 | 0.45 | 0.65 |
| 1501 – 2500 VA | 0.55 | 0.50 | 0.65 |
| 2501 VA and on | 0.60 | 0.55 | 0.65 |

# A2. Appendix 2—Electrical Definitions

**Electrical system** consists of an electrical power source, its power distribution system and the electrical load connected to that system.

**Electrical source** is the electrical equipment which produces, converts or transforms electrical power. Some common AC sources are identified as follows: AC alternators, inverters, transformers and frequency changers. Some common DC sources are DC generators, converters and batteries. In practice an electrical source could be a combination of these units connected in parallel e.g. a typical AC bus may have both AC alternators and inverters connected in parallel.

**Primary source** is equipment that generates electrical power from energy other than electrical, and is independent of any other electrical source. For example, the primary source of an AC electric system may be the main engine-driven alternators (s) or Auxiliary Power Unit (APU) driven-alternators (s). The primary source of a DC electrical system may be a battery, main engine-driven generator(s) or APU driven-generator(s). There may be both AC and DC primary power sources in the same aircraft.

**Secondary source** is equipment that transforms and/or converts primary source power to supply electrical power to either AC or DC powered equipment. A secondary source is entirely dependent upon the primary source and is considered part of the load of the primary source. There may be both an AC and DC secondary source in the same aircraft.

**Normal source** is that source which provides electrical power throughout the routine aircraft operation.

**Alternate source** is a second power source, which may be used in lieu of the normal source, usually upon failure of the normal source. The use of alternate sources creates a new load and power configuration, and therefore a new electrical system, which may require separate source capacity analysis.

**Nominal rating** of a unit power source is its nameplate rating. This rating is usually a continuous duty rating for specified operating conditions.

**Growth capacity** is a measure of the power source capacity available to the aircraft electrical system to supply future load equipment. This value is expressed in terms of percent of source capacity.

**Take-off** is that condition commencing with the take-off run, including the climb and ending with the aircraft levelled-off and set for cruising.

**Landing** is that condition commencing with the operation of navigational and indication equipment specific to the landing approach and following to the completion of the rollout.

**Night, ice, cruise** is that condition during which the aircraft is in level flight, at night with full anti-icing equipment (including pitot heat) selected. This is considered the highest demand situation during normal flight.

**Normal electrical power operation (or normal operation)** conditions assume that all of the available electrical power system is functioning correctly within Master Minimum Equipment List (MMEL) limitations (e.g. AC and/or DC generators, transformer rectifier units, inverters, main batteries, APU etc.).

**Emergency electrical power operation (or emergency operation)** is a condition that occurs following a loss of all normal electrical generating power sources or other malfunction that results in operation on standby power (batteries and or other emergency generating source such as an APU or Ram Air Turbine (RAT)) only.

**Power factor** is the ratio of real power (measured in watts) to apparent power (measured in volt-amperes).

**Generating device** is the device generating the electrical power, such as but not limited to: alternator, generator, inverter, ram-air-turbine (RAT).

**Battery capacity** is the capacity of the battery to supply a current over a certain time. This capacity is usually expressed as a C1 AH rating. With any indicated battery capacity ensure it can be related back to a time and the correct multiplications are used in the ELA. (Some battery OEM indicate a 30 minute emergency capacity with a higher amp rating. This means that the battery if required can stand higher load, but please note this rating is less efficient and the emergency rating multiplied by 30 minutes will give you less amp-minutes to sustain your aircraft than the C1 rating times 60 minutes would).