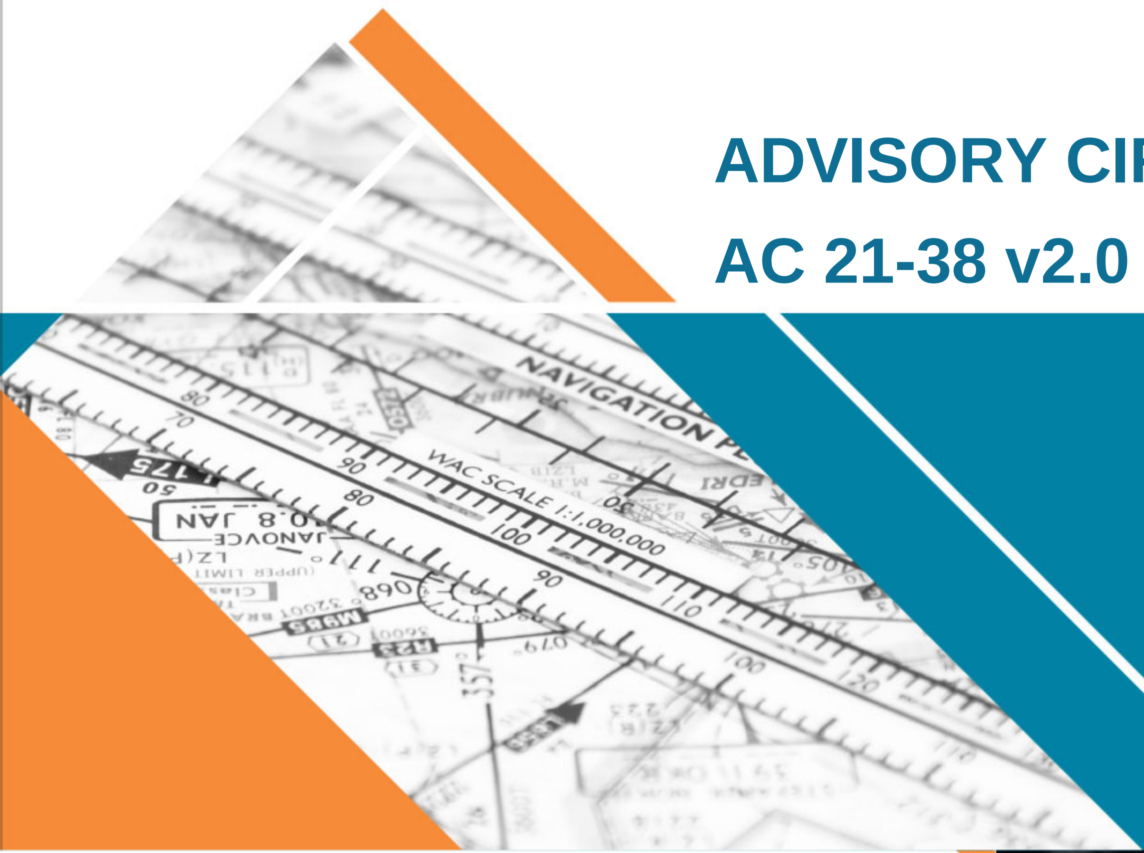
Australian Government
Civil Aviation Safety Authority

ADVISORY CIRCULAR
AC 21-38 v2.0



Aircraft electrical load analysis and power source capacity

Date	September 2017
File ref	D17/280652

Advisory Circulars are intended to provide advice and guidance to illustrate a means, but not necessarily the only means, of complying with the Regulations, or to explain certain regulatory requirements by providing informative, interpretative and explanatory material.

Advisory Circulars should always be read in conjunction with the relevant regulations.

Audience

This Advisory Circular (AC) applies to:

- Subpart 21.B type certificate holders
- Subpart 21.E supplemental type certificate holders
- Subpart 21.J approved design organisations
- Subpart 21.M authorised persons
- Part 42 continuing airworthiness management organisations
- CAR 30 certificate of approval holders.

Purpose

This AC provides guidance material for the preparation or alteration of an electrical load analysis (ELA). This guidance is appropriate in the absence of information from the type certificate or supplemental type certificate holder.

For further information

For further information on this AC, contact Civil Aviation Safety Authority's (CASA's) Airworthiness and Engineering Branch (telephone 131 757).

Status

This version of the AC is approved by the Manager, Airworthiness and Engineering Branch.

> **Note:** Changes made in the current version are not annotated. The document should be read in full.

Version	Date	Details
2.0	September 2017	This version of the AC has been amended to include: • updated references • text from airworthiness bulletin (AWB) 24-005 and AWB 24-007 incorporated into this AC as this information is relevant to modifications of aircraft.
(0)	March 2005	Initial version AC 21-38(0)

Unless specified otherwise, all subregulations, regulations, divisions, Subparts and Parts referenced in this AC are references to the *Civil Aviation Safety Regulations 1998* (CASR).

Contents

1 Reference material

1.1 Acronyms

The acronyms and abbreviations used in this AC are listed in the table below.

Acronym	Description
A	ampere
AC	advisory circular
AC	alternating current
APU	auxiliary power unit
AWB	airworthiness bulletin
CAAP	civil aviation advisory publication
CAO	Civil Aviation Order
CAR	*Civil Aviation Regulations 1988*
CASA	Civil Aviation Safety Authority
CASR	*Civil Aviation Safety Regulations 1998*
CS	certification specifications
DC	direct current
EDTO	extended diversion time operations
EFIS	electronic flight instrument systems
ELA	electrical load analysis
FAA	Federal Aviation Administration (of the USA)
Hz	hertz
JAR	joint aviation requirements (of Europe)
MMEL	master minimum equipment list
pf	power factor
RMS	root mean square
TRU	transformer rectifier unit
V	volt
VA	volt ampere
VAR	volt ampere reactive
W	watt
VFR	visual flight rules

1.2 Definitions

Terms that have specific meaning within this AC are defined in the table below.

Term	Definition
Abnormal electrical power operation	Occurs 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 failure from the remainder of the system before the limits of abnormal operation are exceeded.
Alternate source	Second power source that may be used instead of the normal source, usually due to the failure of the normal source.
Continuous analysis	All loads that last longer than 5 minutes.
Cruise	Condition during which the aircraft is in level flight.
C_{rate}	The discharge rate, in amperes (A), at which a battery can deliver 1 hour (h) of capacity to a fixed voltage endpoint (typically 18 or 20 volts (V) for a 24 V battery). Fractions or multiples of the C_{rate} also are used. C/2 refers to the rate at which a battery will discharge its capacity in 2 h; 2C is twice the C_{rate} or that rate at which the battery will discharge its capacity in 0.5 h. This rating system helps to compare the performance of different sizes of cells.
Electrical source	Electrical equipment that produces, converts, or transforms electrical power.
Electrical system	Consists of electrical power source, the electrical wiring interconnection system and the electrical load(s) connected to that system.
Emergency electrical power operation	Condition that occurs following a loss of all normal electrical generating power sources or another malfunction that results in operation on alternate source of power.
Extended diversion time operations (EDTO) significant system	An aeroplane system whose failure or degradation could adversely affect the safety particular to an EDTO flight, or whose continued functioning is specifically important to the safe flight and landing of an aeroplane during an EDTO diversion.
Ground operation and loading	Time spent in preparing the aircraft before the aircraft engine starts.
Growth capacity	Measure of the power source capacity available in an aircraft electric system to supply future load equipment. This value is expressed in terms of percent of source capacity.
Interval rating	The interval rating of a unit power source is its maximum power output capacity for a specified time interval.
Landing	Condition starting with the operation of navigational and indication equipment specific to the landing approach and following until the completion of the rollout.
Nominal rating	This rating of a unit power source is its nameplate rating and is usually a continuous duty rating for specified operating conditions.
Normal electrical power operation	Assumes that all the available electrical power system is functioning correctly with no failures or within the master minimum equipment list (MMEL) limitations, if a MMEL has been approved, for example, direct current (DC) generators, transformer rectifier units, inverters, main batteries, auxiliary power unit (APU), and so forth.

Term	Definition
Normal source	The normal source is that source which serves an electric power system throughout flight.
Power factor	Ratio of true and apparent power. Power factor of one (unity) indicates the load is purely resistive. Power factor of zero indicates the load is purely reactive.
Primary source	A primary source is equipment that generates electric power from energy other than electrical and is independent of any other electrical source.
Secondary source	A secondary source is equipment that transforms and/or converts primary source power to supply electric power to either alternating current or direct current utilisation equipment.
Shed	Disconnecting loads unnecessary during abnormal or emergency electrical power operations.
Takeoff and climb	Condition starting with the take-off run and ending with the aircraft levelled off and set for cruising.
Taxi	Condition from the aircraft's first movement under its own power to the start of the take-off run and from completion of landing rollout to engine shutdown.

1.3 References

Regulations

Regulations are available on the Federal Register of Legislation https://www.legislation.gov.au/

Document	Title
Part 21	Certification and airworthiness requirements for aircraft and parts
Part 23	Airworthiness standards for aeroplanes in the normal, utility, acrobatics or commuter category
Part 25	Airworthiness standards for aeroplanes in the transport category
Part 27	Airworthiness standards for rotorcraft in the normal category
Part 29	Airworthiness standards for rotorcraft in the transport category
Part 42	Continuing airworthiness requirements for aircraft and aeronautical products
Regulation 42U of the *Civil Aviation Regulations 1988* (CAR)	Modifications and repairs; approved designs
Regulation 42Vof CAR	Maintenance: approved maintenance data
Regulation 42ZP of CAR	Certification not to be made
Civil Aviation Order (CAO) 20.18	(Aircraft equipment - basic operational requirements) Instrument 2014
CAO 100.5	(General requirements in respect of maintenance of Australian aircraft) 2011

Advisory material

CASA's advisory circulars are available at http://www.casa.gov.au/AC

CASA's Civil Aviation Advisory Publications (CAAPs) are available at http://www.casa.gov.au/CAAP

Airworthiness Bulletins (AWBs) are available at https://www.casa.gov.au/airworthiness/standard-page/airworthiness-bulletins

United Kingdom Civil Aviation Authority (UK CAA) guidance material are available at http://www.caa.co.uk/home/

Federal Aviation Administration (FAA) Advisory Circulars are available at http://www.faa.gov/regulations_policies/advisory_circulars/

Military Standards are available at http://quicksearch.dla.mil/

ASTM International publications are available at http://www.astm.org/Standard/

Document	Title
AC 21-99	Aircraft wiring and bonding
AC 91.U-04	Airworthiness requirements for performance based navigation
CAAP 37-1	Minimum Equipment Lists (MEL)
AWB 24-7	Electrical Load Analysis
71 FR 12771	Volume 71 US Federal Register page 12771 - Aircraft Electrical Load and Power Source Capacity Analysis
FAA AC 43.13-1B	Acceptable Methods, Techniques, and Practices - Aircraft Inspection and Repair
FAA AC 43.13-2B	Acceptable Methods, Techniques, and Practices – Aircraft Alterations
FAA AC 21-16G	RTCA Document DO-160 versions D, E, F, and G, Environmental Conditions and Test Procedures for Airborne Equipment
FAA AC 23.1309-1E	System Safety Analysis and Assessment for Part 23 Airplanes
FAA AC 25-16	Electrical Fault and Fire Prevention and Protection
FAA AC 25.1309-1A	System Design and Analysis
FAA AC 20-184	Guidance on Testing and Installation of Rechargeable Lithium Battery and Battery Systems on Aircraft
NZ CAA 21-11 & 91-23	New Zealand Civil Aviation Authority - Electrical Load Analysis
UK CAA CAP 562	Civil Aircraft Airworthiness Information and Procedures - Leaflet 24-40
MIL-E-7016	Analysis of Aircraft Electric Load and Power Source Capacity
ASTM F2490-05	Standard Guide for Aircraft Electrical Load and Power Source Capacity Analysis

1.4 Forms

CASA's forms are available at http://www.casa.gov.au/forms

Form number	Title
Form 372	Certificate of Airworthiness Checklist

2 Introduction

2.1 Background

2.1.1 The main purpose of the electrical load analysis (ELA) is to estimate the electrical system capacity needed to supply the worst-case combinations of electrical loads. This is achieved by evaluating the average and maximum demands under various aircraft flight phase.

2.1.2 When equipment is added to aircraft, the weight and balance calculation is conducted with the same rigour as required when any electrical equipment is added or removed. This may include any non-required equipment which still may have an impact on the aircraft electrical system.

2.1.3 The ELA is a summation of the electric loads applied to the electrical system during specified operating conditions of the aircraft. The ELA requires the listing of each item or circuit of electrically powered equipment and the associated power requirement. The power requirement for an ELA may have several values depending on the utilisation for each phase of aircraft operation.

2.1.4 Most ELA only require analysis for direct current (DC) power. If an aircraft uses alternating current power, the ELA will have to include alternating current power sources and loads as well this includes any AC inverters. If a load is connected to a transformer rectifier unit (TRU) the effect on alternating current systems is also required.

2.2 Baseline ELA

2.2.1 The ELA that is produced for aircraft type certification is the baseline document for any subsequent changes. A specific ELA with any differences is produced from the baseline ELA that relates to a particular serial number aircraft. This specific ELA reflects the aircraft status at delivery. Some circuits at delivery are provisioned but not active and these do not need consideration in an ELA. Terminology used in ELAs can vary between different aircraft manufacturers.

2.2.2 The original baseline ELA may lack information on emergency electrical power operation or abnormal electrical power operation; therefore, the ELA may require updating if new equipment is installed. Appendix C has a sample form for tracking changes required for the ELA.

2.3 Changes to ELA

2.3.1 Any modifications which add or remove any electrical equipment will require updating of the specific ELA. It is recommended to use the basic original format for the ELA to ensure consistency in the methodology and approach.

2.3.2 Changes to the ELA can also take the form an ELA supplement. The ELA supplement can take the form of changes in load in the particular electrical bus.

2.3.3 In alternating current (AC) system aircraft, any DC equipment changes connected to TRUs will require verification of the capacity in the corresponding alternating current bus that powers the TRU. The same intent is also required for any AC inverters in a DC powered aircraft.

2.3.4 Installation of an Approved Model List - Supplemental Type Certificate will require further evaluation due to possible cumulative effects of all the modifications on the aircraft.

2.3.5 If equipment is removed it is no longer considered a probable combination and will require a review of the ELA in order to comply with 14CFR23.1351(a)(2), 14CFR25.1351(a)(2),14CFR27.1351(a)(2) and 14CFR29.1351(a)(2).

2.3.6 Any change to any of the following is considered a change to the electrical load data for an aircraft:

- increased or decreased load for circuit breaker or bus
- added or removed load for circuit breaker or bus
- change in power factor, duty cycle or flight phase load
- change in bus to which a circuit breaker is connected (even though there is no load change downstream of the circuit breaker)
- change in circuit breaker number or nomenclature.

2.3.7 Any original equipment manufacturers and third party designed modifications will require careful assessment against the electrical load analysis. Not carrying out these assessments can cause overloads on the combination of probable loads.

3 Applicable regulations

3.1 Airworthiness standards - aircraft systems and components

3.1.1 The operator, maintenance controller or the responsible continuous airworthiness management organisation, should always refer to the certification basis as referenced on the type certificate data sheet in order to determine the applicability of airworthiness standards. In addition to ELA requirements in the regulations below, there are also specific requirements for independent powering of instruments for further information (see paragraph 4.5.4 of this AC).

3.1.2 Compliance with airworthiness standard regulations in Table 1 is required by Parts 23, 25, 27 and 29. These regulations are determined by the applicable airworthiness standards, which are defined in regulation 21.017 or regulation 21.403, as appropriate.

Table 1: ELA airworthiness design standards and CASA requirements

Airworthiness standards: Code of Federal Regulation, Joint Aviation Regulation or Certification Specification (14CFR, JAR, CS)				
Airworthiness standard requirement	**Part 23**	**Part 25**	**Part 27**	**Part 29**
Engine ignition systems	23.1165	25.1165	27.1165	29.1165
Equipment, systems and installations	23.1309	25.1309	27.1309	29.1309
Power source capacity and distribution	23.1310	25.1310		
General	23.1351	25.1351	27.1351	29.1351
Public address system		25.1423		

3.1.3 Airworthiness standards 23.1165, 25.1165, 27.1165 and 29.1165 have requirements for capacity of batteries and generators to meet demands of engine ignition system and greatest demands of any electrical system components that draw from the same source. There are requirements in these airworthiness standards to connect turbine engine ignition systems to an essential electrical supply.

3.1.4 Airworthiness standards 23.1309, 25.1309, 27.1309 and 29.1309 have the requirement for a safety assessment. An overloaded bus can trip and this will have an effect on failure condition. Design standard 23.1310 from amendment 62 and 25.1310 from amendment 123 have moved the power source capacity requirements from 23.1309. The safety assessment is part of the modification certification data.

3.1.5 Airworthiness standards 23.1351, 25.1351, 27.1351 and 29.1351 have the compliance requirement for an ELA or electrical measurements that account for the electrical loads.

3.1.6 Airworthiness standard 25.1423(a)(a) has a requirement for the public address system to operate for at least 10 minutes in emergency conditions.

3.1.7 Legacy aircraft certified under US Civil Aviation Regulations (FAA CAR) also have requirements for an ELA. For example, see US CAR regulations 3.682, 3.685, 4.5823, 6.520 or 7.606 as appropriate. While these aircraft may not come with an ELA, if new equipment is installed, it is appropriate to conduct an ELA to prove compliance to the regulations.

Inadequate certification basis in modifications

3.1.8 The original certification basis for the aircraft, engine or propeller may not adequately ensure safety if a modification consists of a new design or substantially complete redesign. For example, electronic flight instrument systems (EFIS) were not envisaged in the original certification basis of older amendment 14CFR23 or Part 3 of the US Civil Air Regulations aircraft. Installation of EFIS equipment may require adoption of a later amendment status in the certification basis. This will also include any changes to the ELA baseline or development of an ELA baseline.

3.1.9 The change to the latest amendment is only applicable to those portions of the aircraft required to support the modifications.

3.2 Acceptable analysis methods

3.2.1 For any aircraft, CASA recommends Subpart 21.M authorised person or Subpart 21.J approved design organisation use of the type certificate holders ELA procedures as part of the approved design. This will ensure consistency with the original ELA.

3.2.2 In the absence of ELA procedures from the type certificate holder, it is acceptable practice to follow the procedures in this AC or MIL-E-7061F.

3.3 Responsibilities

3.3.1 An ELA needs to establish the baseline electrical capacity of the aircraft. The form this analysis takes is determined by the Subpart 21.B, 21.M or 21.J authorisation holder. The form of this ELA should follow the original equipment manufacturers analysis. An appropriate amendment to the ELA is all that is required for any changes to the original baseline from when the aircraft was originally certified.

3.3.2 The ELA is considered part of the data that describes the design and is used to show compliance with r21.009. The ELA report generated when complete and current becomes part of the aircraft records.

3.3.3 A licensed aircraft maintenance engineer (LAME) can only carry out maintenance that has approved maintenance data in accordance with regulation 42U of CAR or for where there is a Part 21 approval for the design of the modification in accordance with regulation 42.125 of CASR, as appropriate. As per these regulations, a LAME cannot generate approved maintenance data or approved data under Part 21.

3.3.4 For Part 42 aircraft, the continuing airworthiness management organisation must ensure that there is an ELA accompanying an engineering order for any modification or repair that affects the aircraft electrical system, which is required under subregulation

42.325 (2). Non-Part 42 aircraft are required to meet the same intent under regulations 42U, 42V and 42ZP of CAR.

3.3.5 The ELA provides verification that any electrical modification to the aircraft is compliant with:

- the design standards referenced in paragraph 3.1 of this AC
- Civil Aviation Order 20.18
- any other regulated design requirements applicable to the aircraft type.

3.3.6 It is the modification applicant's responsibility, under subregulation 21.420 (1), to establish whether the modification is viable and remains compliant with the design standard against which the certificate of airworthiness was issued.

3.3.7 There is no requirement to conduct an ELA prior to such time that a modification is to be incorporated. The aircraft manufacturer’s original ELA (if it exists) is acceptable provided there have been no modifications to the original configuration.

3.3.8 CASA strongly recommends that the current ELA is obtained in electronic format at the time an aircraft is imported into Australia, to simplify subsequent modifications. This will allow for easier subsequent modifications later on. Field 7 in CASA Form 372 details the modification history of the aircraft when the certificate of airworthiness is issued; the current ELA should reflect all the modifications incorporated in the aircraft.

3.3.9 CASA recommends that a Subpart 21.M authorised person or Subpart 21.J approved design organisation obtains advice from the type certificate holder before connecting any electrical loads on essential, emergency or battery busses (see note). Without advice from the type certificate holder, the operator will require thorough verification that the aircraft still complies with airworthiness requirements. Connecting loads to these buses can introduce unintended consequences for abnormal and/or emergency operation, and may result in non-compliance with airworthiness standards prescribed in regulations 23.1309, 25.1309, 27.1309 or 29.1309.

Note: This recommendation does not apply to simple aircraft designs with single DC batteries and buses.

4 Content of ELA

4.1 Overview

4.1.1 The ELA should follow the same format provided from the original equipment manufacturer or at least follow guidance given in the ELA procedure provided by the TC holder. In the absence of this information, this section provides detail on the content of an ELA.

4.1.2 The principle of an ELA requires the listing of each item or circuit of electrically powered equipment and the associated power requirement. An ELA may have an impact of choice of an appropriate gauge wiring to cope with the expected load for all expected modes of operation.

4.1.3 The power requirement for a piece of equipment or circuit may have several values depending on the utilisation during each phase of aircraft operation.

4.1.4 In order to arrive at an overall evaluation of electrical power requirement, it is necessary to give adequate consideration to transient demand requirements that are of a capacity or duration to impair system voltage and/or frequency stability; or to exceed short-time ratings of power sources (i.e. intermittent/momentary and cyclic loads). This is essential, since the ultimate use of an aircraft's ELA is for the proper selection of characteristics and capacity of power-source components and resulting assurance of satisfactory performance of equipment, under normal, abnormal and emergency operating power conditions.

4.2 ELA report

4.2.1 The introduction to the ELA report should include the following information in order to assist the reader in understanding the function of the electrical system with respect to the operational aspects of the aircraft.

4.2.2 Approved data is required in order to generate an ELA report. This will allow for easier amendments or when reviewing the ELA after an extensive modification.

4.2.3 The circuit breaker and load data sheet in Appendix A has a form that is useful to track load requirements for each circuit breaker load.

4.2.4 The core of the ELA report should contain all analyses at:

- power source level
- converter level
- distribution level (including busses, power centres)

4.2.5 The ELA report is usually impacted by post aircraft delivery modifications. A reassessment of the ELA is not required for existing installations which are not affected by modifications.

Typically, the introduction to the ELA would contain details of the following:

- a brief description of aircraft type, which may also include the expected operating role for the aircraft

- a list of installed electrical equipment
- an electrical system operation, which describes primary and secondary power sources, bus configuration with circuit breakers and connected loads for each bus
- a copy of the bus wiring diagram or electrical schematic applicable to the specific aircraft
- the operating logic of system (e.g. automatic switching, loading shedding etc.)
- alternators and other power source description and related data, including such items as battery discharge curves, TRU, inverter, APU, ram air turbine, etc.

4.2.6 Various sample ELAs for both alternating current and DC systems have been included in Appendix A. It is recommended to detail information in a table for the power distribution provided for all affected busbars with their power capacity.

4.2.7 Typical data supplied for power sources would be as follows:

Table 2: Identification of power sources

Identification	1	2	3
Item	**DC Starter Generator**	**Inverter**	**Battery**
Number of Units	2	1	1
Continuous Rating 5 second rating 2 minute rating	250 A 400 A 300 A	300 volt ampere (VA) (Total)	40 Ah
Voltage	30 V	115 VAC	24 VDC
Frequency		400 hertz (Hz)	
Power Factor (pf)		0.8	
Efficiency		95%	
Manufacturer	Starter/Generator company	Aircraft invertor company	Aircraft battery company
Model No	1234	4567	7890
Voltage Regulation	±0.6 V	±2%	
Frequency Regulation		400 Hz ±1%	

4.3 Assumptions for ELA design and criteria

4.3.1 Assumptions can vary depending on the design. CASA recommends the Subpart 21.M authorised person or Subpart 21.J approved design organisation review the type certificate holder's baseline ELA for any impacts. These assumptions will determine the calculations required in each flight phase to faithfully reproduce an ELA at any time based on the equipment installed. CASA recommends the use of a spreadsheet to easily track changes in electrical loads.

4.3.2 Maximum load is generally not used as this will depend on the fight phase and other factors listed in paragraph 4.3.3. Maximum loads will have an impact on selection of wiring and circuit protection.[1] Not all equipment is operating in every phase (see Figure 1).

4.3.3 Typical assumptions for an ELA, depending on the flight phase, can include:

– most severe loading conditions and operational environment in which the aeroplane operates are at night and in icing conditions (as appropriate if type certified for icing) (See Note 1)
– 85% capacity maximum for each circuit breaker (Note 3)
– 80% maximum generator (Note 3)
– passenger loading
– inflight entertainment equipment or other non-required equipment
– losses with transformer rectifier units and invertors
– momentary/intermittent loads, such as electrically operated valves, which open and close in a few seconds are not included in the calculations
– galley utilisation
– motor load demands are shown for steady-state operation and do not include starting inrush power. The overload ratings of the power sources should provide adequate capacity to provide motor starting inrush requirements
– efficiency$_2$ of TRUs and invertors, some type certificate holders will specify efficiency actual or estimated power factor (pf)$_2$ of alternating current loads, some type certificate holders will specify this
– intermittent loads such as communications equipment (i.e. radios - very high frequency/high frequency communications), which may have different current consumption depending on operating mode (i.e. transmit or receive)
– consideration of duty cycles for cyclic loads such as heaters, pumps, de-icing systems
– estimation of load current, assuming a voltage drop between busbar and load.

Note1 In some cases the icing system is de-energised or has power off to operate. Therefore, in the ‘off’ condition power is applied to the circuit placing a drain on the electrical system.

Note2 Efficiency and pf can vary with load applied.

Note3 Unless stated otherwise from type certificate holder. See FAA AC 25-16.

Note4 Unless stated otherwise from type certificate holder. See Paragraph 11-35 of FAA AC 43.13-1b.

4.3.4 In some cases, a representative database of load consumptions measured at source level (generator and Transformer Rectifier Unit) based on in-service fleet using a statistical approach is acceptable. The statistical approach should aim at defining ELA margins levels at the power source.

[1] For further information on wiring and circuit protection see AC 21-99.

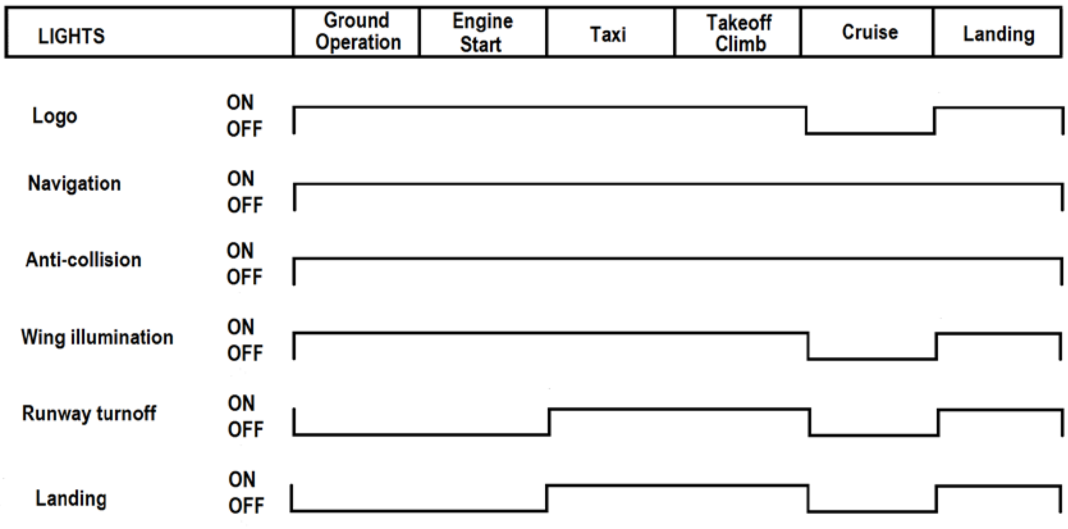


Figure 1: Example of lights operating at different flight phases

4.4 Alternating current and DC load analysis – tabulation of values

4.4.1 The easiest way to detail an ELA is in a spreadsheet, which will allow for easier modification in due course. Sample spreadsheets with automated calculations for both alternating current and DC systems can be found at Annex A. However, using a spreadsheet can introduce rounding errors and inaccuracies in the generation of ELA values.

4.4.2 Calculation of DC values is an iterative process. Calculation of alternating current values may require conversion taking vector addition into account. See Figure 2 for an example of the alternating current power triangle, which shows the relationship between apparent power, real power and reactive power. These common units are calculated using standard mathematical Pythagorean and trigonometrical functions (see Appendix B for examples of calculations).

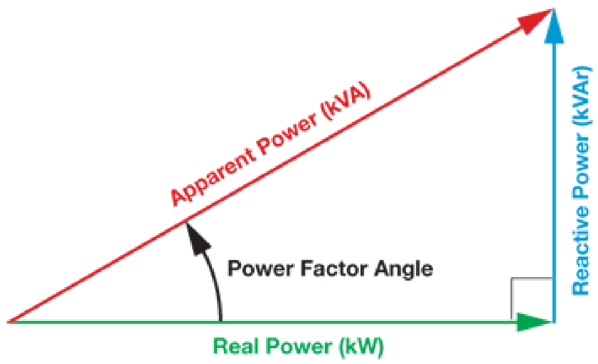


Figure 2: AC power triangle

4.4.3 Equipment usage

4.4.3.1 Equipment is not always powered for all flight phases. Some equipment is only operated in certain flight phases and under certain conditions.

4.4.3.2 The normal operating condition takes into account no loss of primary power generation. This normal operating condition is broken down into flight phases. Further expansion of each phase may assist in further detailing occasional loads for example cargo loading or cabin servicing, which can place further load on electrical supplies.

4.4.3.3 The following is a commercial fixed wing aircraft, typical flight phase duration:

Ground Operation and Loading	- 30 min
Engine Start	- 5 min
Taxi	- 10 min
Take-off and Climb to optimum cruise height	- 30 min
Cruise as appropriate for aircraft endurance time	Depending on endurance
Landing	- 30 min

4.4.3.4 The following is a rotary wing aircraft, typical flight phase duration:

Engine start and warm-up at night	- 30 min
Take-off and climb at night	- 5 min
Cruise at night	- 30 min
Cruise during day	- 30 min
Landing at night	- 10 min
Emergency landing at night	- 5 min

4.4.3.5 Abnormal operating conditions can take into account the following conditions:

- one generator operating cruise at night (- 10 mins)
- abnormal—for example with only one generator available
- emergency—no generators and only battery power available
- abnormal operations have been included in the sample ELAs in appendices A.2, A.4 and A.8.

4.4.3.6 The analysis should also identify authorised permissible unserviceabilities in the master minimum equipment list (MMEL) during the certification of the aircraft and should include calculations appropriate to these cases.[2]

4.4.3.7 In some cases, the ELA will include a specific section covering extended range operations requirements and will address ‘total loss of normal generated electrical power’ for the extended range conditions specified.

4.4.3.8 In some cases, the aircraft is utilised in a specialised role (e.g. search and rescue, oil rig operations or other emergency use). The ELA should be revised accordingly to take into account any changes to the conditions or operating times that were specified in the original ELA. Any non-required equipment may have an impact on the ELA.

4.4.3.9 At the start of each flight phase the regular assumption is that all equipment that operates during that phase is switched ‘on’, with intermittent loads gradually being switched ‘off’.

4.4.3.10 For intermittent peak loads, CASA recommends the Subpart 21.M authorised person or Subpart 21.J approved design organisation use root mean square (RMS) values of

[2] See Civil Aviation Advisory Publication (CAAP) 37-1 and AC 91.U-04 for further information on permissible unserviceabilities.

current. Where the currents are continuous, the RMS and the average values are considered the same; however, where several intermittent peak loads are spread over a period of time, the RMS value is usually more accurate than the average.

4.4.3.11 In some cases, the currents drawn at battery voltage (e.g. 20-24 volts [V] DC) are higher than at the generated voltage (e.g. 28 VDC) and will influence the emergency flight conditions on battery. However, for resistive loads, the current drawn is reduced due to the lower battery voltage.

4.4.4 Phase unbalance

4.4.4.1 This section on phase unbalance is useful in the design of an electrical system. A phase unbalance will cause current to flow in the neutral line. The Subpart 21.M authorised person or Subpart 21.J approved design organisation should review the type certificate holder's data on phase unbalance limitations. Phase unbalance can cause an increase in power system harmonics, which can lead to nuisance tripping in circuit breakers. It may require changing the equipment to different phase connections or buses to limit the percentage of phase unbalance.

4.4.4.2 Some type certificate holders will specify limits on phase unbalance such as a particular value of power units. If the type certificate holder has not specified a limit, the general rule of thumb is an unbalance greater than 2 % may require redesign.

4.4.5 Regulated voltages

4.4.5.1 The system voltage and frequency is regulated to ensure reliable and continued safe operation (see Table 3) of all essential equipment while operating under the normal and emergency conditions, taking into account the voltage drops that occur in the cables and connections to the equipment. The following definitions are provided in RTCA/DO-160G for maximum, nominal, minimum and emergency operations (12 and 28 VDC system).

Table 3: Regulated voltages

	28 VDC system	12 VDC system
Maximum	30.3	15.1
Nominal	27.5	13.8
Minimum	22.0	11.0
Emergency	18.0	9.0

4.4.5.2 The defined voltage that is supplied at the equipment terminals and allows for variation in the output of the supply equipment (e.g. generators, batteries etc.) as well as voltage drops due to cable and connection resistance.

4.4.5.3 Voltage drop between busbar and equipment should be considered in conjunction with busbar voltages under normal, abnormal and emergency operating conditions in the estimation of the terminal voltage at the equipment (i.e. reduced busbar voltage in conjunction with cable volt drop could lead to malfunction or shutdown of equipment).

4.4.5.4 The connected load tables should include the following:

- aircraft busbar, circuit description and circuit code
- load at the circuit breaker - ampere loading for DC circuits and watts/ volt ampere (VA), volt ampere reactives (VARs), pf for alternating current circuits
- estimation of load current, assuming a voltage drop between busbar and load.

4.4.5.5 Operating time is usually expressed as a period of time (seconds/minutes) or as continuous, where appropriate (see Figure 3). Equipment operating time is often related to the average operating time of the aircraft. If the ‘on’ time of the equipment is the same or close to the average operating time of the aircraft, then it is possible to consider that the equipment is operating continuously for all flight phases.

4.4.6 In such cases, where suitable provision has been made to ensure that certain loads cannot operate simultaneously, or where there is reason for assuming certain combinations of load will not occur, appropriate allowances are suitable. These allowances may include a revision to the aircraft flight manual supplement as an operational mitigator. Include a concise explanation in the conclusion and summary section of the ELA.

4.4.6.1 In some instances, it is useful to tabulate the data using a specified range for equipment operating times, such as follows:

- 5-second analysis - All loads that last >0.3 seconds and ≤5 seconds, enter in this operating time column as detailed at Appendix A
- 5-minute analysis - All loads that >5 seconds and ≤5 minutes, enter in this operating time column as detailed at Appendix A
- Continuous analysis - All loads that last longer than five minutes enter in this operating time column as detailed in the Appendix A

Note: these durations intervals may differ between types of aircraft refer to the OEM ELA (if applicable).

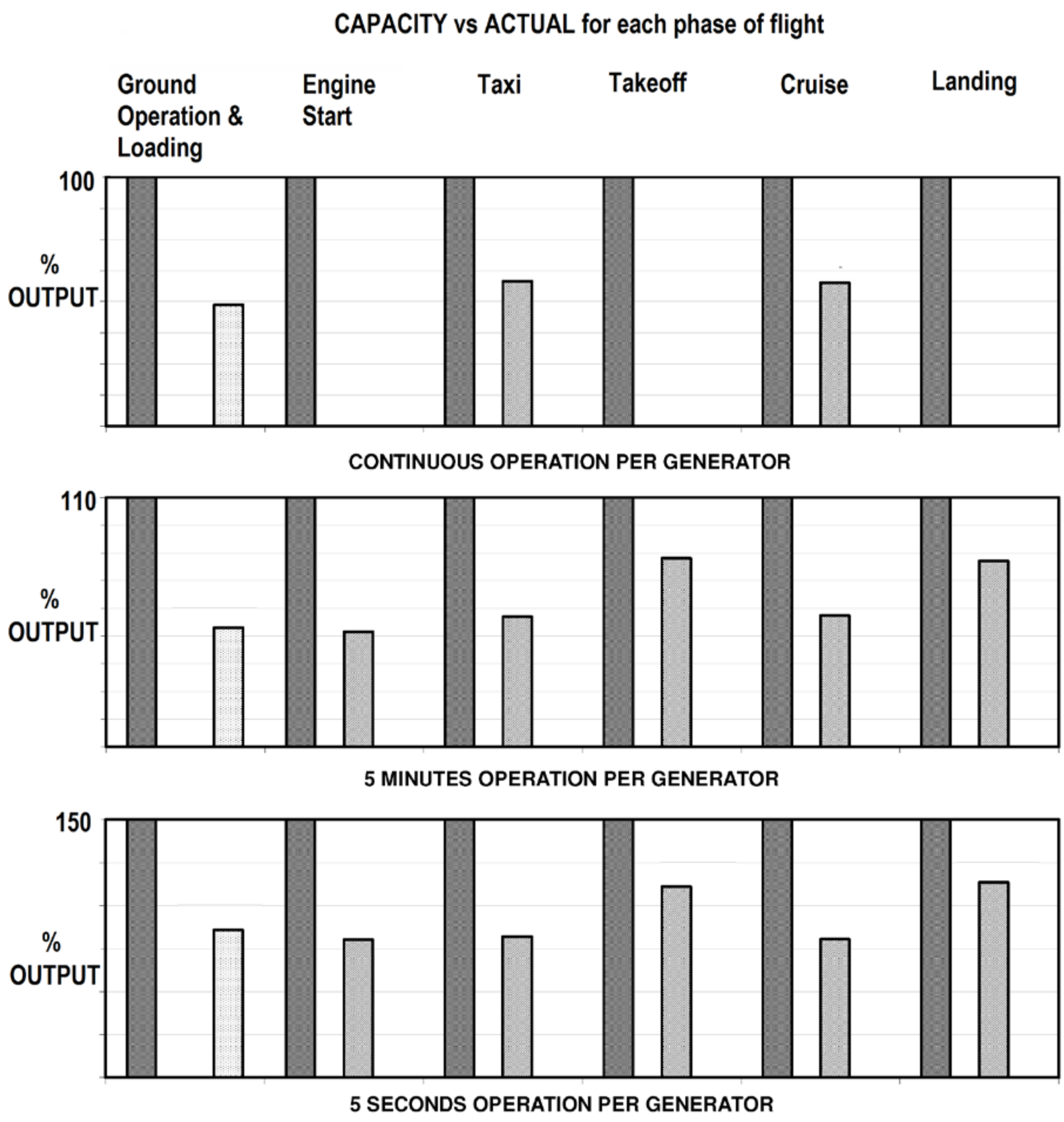


Figure 3: Continuous, 5 minute and 5 second operation example

4.4.6.2 In the examples given in Appendix A of this AC, the approach taken is to show either continuous operation or to identify a specific operating time in seconds/minutes.

4.4.7 Load shedding

4.4.7.1 Following the loss of a power source or sources, the general rule of thumb is that a 5 minute period will elapse prior to any manual load shedding by the flight crew, provided that the failure warning system has clear and unambiguous attention-getting characteristics. However, the general rule of thumb is that any automatic load shedding takes place immediately. Buses may have a priority ranking order for their shedding.

4.4.7.2 Where there is no flashing warning provided to the flight crew, 10 minutes elapse time is appropriate. If automatic load shedding is provided, including a description in the flight manual supplement of the shed load(s) with any specific sequencing.

4.5 Emergency or standby power operations

4.5.1 Where standby power is provided by non-time limited sources, such as a ram air turbine, auxiliary power unit (APU), pneumatic or hydraulic motor, the operator should list the emergency loads and evaluate to ensure that the demand does not exceed emergency generator capacity.

4.5.2 Where batteries are used to provide a time limited emergency supply for certain flight phases, an analysis of battery capacity is needed. This is compared with the time necessary for the particular flight phase (e.g. from slat extension to landing including rollout) where batteries are utilised in lieu of non-time limited sources. The data sheet at Appendix C can assist with modifications to aircraft battery buses or DC power systems.

4.5.3 Battery endurance is determined by either a:

- practical test, which involves applying typical aircraft loads for a period of time
- calculation (see paragraph B.2).

4.5.4 Extended diversion time operation (EDTO) aircraft will have additional power requirements depending on the approved design. These systems are classified as EDTO significant systems.

4.5.5 Design standards on standby power

4.5.6 Design standard 14CFR23.1351 (g) from amendment 43 in 1993 requires analysis or test, or both so the aircraft operates safely in visual flight rules (VFR) conditions, for a period of not less than five minutes, with the normal electrical power (electrical power sources excluding the battery and any other standby electrical sources) inoperative. The general rule of thumb is that 5 minutes is an adequate amount of time to cope with such an emergency so that the pilot can operate the airplane safely and assess the reason for the loss of normal electrical power.

4.5.7 Design standard 14CFR25.1351 (d) amendment 41 (1977), requires analysis or tests, or both, so the aircraft operates safely in VFR conditions, for a period of more than 5 minutes, with the normal electrical power (electrical power sources excluding the battery) inoperative.

4.5.7.1 Amendment 62 (2012) of 14CFR23 requires endurance for storage batteries to provide power for the needs of all electrical instruments, navigation, communications and engine control systems. The reliance on electrical power has increased since the original airworthiness design standards in 14CFR23.1353 (h) requires a battery capable of providing electrical to essential loads for at least:

- 30 minutes for aircraft with maximum altitude of ≤ 25,000 ft

  or

- 60 minutes for aircraft that are certified with maximum altitude of > 25,000 ft.

4.5.8 Requirements for instrument power in Civil Aviation Order 20.18

4.5.8.1 Civil Aviation Order (CAO) 20.18 has instrument power requirements for fixed wing and rotary wing aircraft depending on operating conditions. Check the appropriate appendix in CAO 20.18 for the intended aircraft operation.

4.5.8.2 Duplicated power sources or separate independent power source in single engine aircraft or helicopters is difficult to achieve and demonstrate. Additional engine driven generators or vacuum pumps have been installed to comply with this requirement.

4.5.8.3 Alternate acceptable methods of complying with CAO 20.18 are that the operator provides:

- separate emergency bus running directly from the battery to provide the required independence for these instruments
- instruments with an internal battery sufficient to power the instruments in an emergency.*

Note: This method requires additional instructions for continuing airworthiness to ensure the batteries ability to perform the essential task when required.

4.5.9 Approved single engine turbine-powered aeroplanes—electrical requirements

4.5.9.1 Clause 9 of Appendix 2 to CAO 100.5 has requirements for increased electrical storage capacity of the aeroplane’s prime battery to conduct 2 engine start attempts, lower the flaps and undercarriage. There is alleviation for 1 engine start with conditions specified for automatic fuel feed system, continuous air intake anti-icing and automatic ignition system. There are also requirements to provide an ELA for CASA approval if the aircraft avionics and electrical configuration differs from the approved configuration or is altered after approval of the configuration.

4.5.10 Battery capacity

4.5.10.1 Capacity is normally expressed in amperes hours (A-h), but for a typical load analysis calculations are usually expressed in amperes per minutes (A-h x 60). The A-h capacity available from a fully charged battery depends on its temperature, rate of discharge, and age. Normally, aircraft batteries are rated at room temperature (25°C), the C_{rate} (1-hour rate) and beginning of life. C_{rate} refers to the calculated current drawn and not necessarily the actual measured rate, which can vary due to a number of factors including age and temperature. Sample battery capacity analysis has been included in paragraph A.6.

4.5.11 The capacity of a battery is not a linear function as with heavier discharge currents the discharge time decreases more rapidly so the available power is less. To make an accurate assessment of battery duration, refer to the manufacturers discharge curves. This AC can assist if manufacturers discharge curves are unavailable (see Figure 4).

4.5.11.1 Bus voltage may drop under battery only conditions. When the bus is being supplied by the battery only, the current will reduce if the loads are resistive. This drop may require adjustments to the ELA especially when considering emergency equipment and abnormal conditions. The current consumption of operating equipment when powered from the generator or the battery is not usually the same. Current consumption is confirmed against equipment datasheets or determined through testing.

4.5.11.2 Because the definition of capacity is problematic, it is important to ensure that all calculations are based on the one-hour rate. Some manufacturers, however, do not give this on the nameplate and quote the five-hour rate. For these calculations, as a general rule of thumb, ensure that the one-hour rate is 85% of the quoted five-hour rate.

4.5.11.3 Following the generator system failure, and before the pilot has completed the load shedding drills, the battery can supply high discharge currents with a resultant loss of efficiency and capacity on the principle explained at section 4.5.8.4.

4.5.11.4 To make allowance for such losses, the calculated power consumed during the pre-load shed period should factor an additional 20% if the average discharge current in amperes is numerically more than twice the one-hour rating of the battery.

4.5.11.5 The discharge rate of a lead-acid battery is different than that of a nickel cadmium battery. The graph in Figure 4 shows a typical discharge curve for lead-acid and nickel-cadmium battery at a 5A discharge rate.

4.5.11.6 Unless otherwise stated by the type certificate holder, a battery capacity at normal ambient conditions of 80% of the nameplate rated capacity, at the 1 hour rate, and a 90% state of charge, is assumed (i.e. 72% of nominal demonstrated rated capacity at +20°C).

4.5.11.7 An analysis of battery charging effectiveness should show the battery state of charge versus the charging time, assuming that the battery is completely discharged when charging is initiated. The analysis should assume the most adverse battery temperature.

4.5.12 Alternate batteries

4.5.13 Batteries of different chemistry will have a different discharge curves. If a battery is changed to a different type this will require consideration in the ELA as capacity and nominal voltage will change.

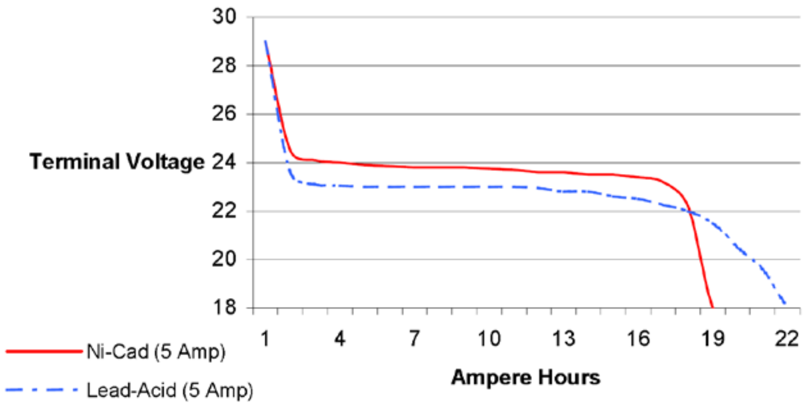


Figure 4: Discharge rates of lead-acid and nickel-cadmium batteries

4.5.13.1 At present, there is limited in-service experience with the use of installed rechargeable lithium batteries. There are known potential safety problems resulting from overcharging, over-discharging, internal cell defects and flammability of cell components. In general, lithium batteries are significantly more susceptible to internal cell failures due to the increased energy density.[3]

4.6 Preparing the summary and conclusion

4.6.1 The summary and conclusion provides statements that are used to satisfy regulations referenced in Chapter 3. Summary and conclusions can form a single merged section.

Summary

4.6.2 The summary will assist as the starting point for future electrical load modifications. ELA summary provides evidence that for each operating condition, the available power can meet the loading requirements with adequate margins for both peak loads and maximum continuous loads. This should take into account both normal and abnormal (including emergency) operating conditions. For alternating current power systems, these summaries should include pf and phase loadings.

4.6.2.1 The requirements in term of analysis whether the load is permanent or intermittent may require conservative consideration as a permanent load.

4.6.2.2 The recommended thresholds (85% by considering permanent loads only ; 100% or circuit breaker trip curve (max t°C) by considering permanent + intermittent).

4.6.2.3 Computation shall consider load shedding directly implemented at equipment level such as technologies used on some IFE system for example.

4.6.2.4 Detail of any circuit breakers used for protecting the equipment as the result of the ELA or ELA change. The circuit breaker could use 85% max in steady state or below worst case trip curve for managing eventual inrushes.

[3] For further information on installation of lithium batteries in aircraft see FAA AC 20-184.

Conclusion

4.6.3 The conclusion should provide a declaration that confirms the various power sources can satisfactorily supply electrical power to necessary equipment during normal and abnormal operation under the most severe operating conditions as identified in the analysis. This is required to show compliance to the regulations referenced in section 2.3.3.

Appendix A

Sample ELAs

A.1 Electrical load analysis (DC – Current) – normal operating conditions

BUS – DC1						NORMAL CONDITIONS					
Circuit/Service	**CB**	**Load at circuit breaker**	**Op time**	**Appropriate conditions**	**Notes**	**Taxiing (Night) 30 mins**		**Take off & land (night) 10 mins**		**Cruise (night) 60 mins**	
		Amps	**mins**			**Amps**	**Amps-mins**	**Amps**	**Amps-mins**	**Amps**	**Amps-mins**
AIR CONDITIONING											
Dump Ditch Motors	AB1	0.90	0.1			-	-	-	-	-	-
Cabin Alt Warning	AB2	0.04	Cont			0.04	1.2	0.04	0.4	0.04	2.4
Man. Pressure Control	AB3	0.60	Cont			-	-	-	-	-	-
COMMUNICATIONS											
ACARS Memory	BC1	0.08	Cont			0.08	2.4	0.08	0.8	0.08	4.8
Electrical Power											
Battery 1 Charge	CD1	3.50	Cont			3.50	105.0	3.50	35.0	3.50	210.0
**	**	**	**			**	**	**	**	**	**
--	**	**	**			**	**	**	**	**	**
--	**	**	**			**	**	**	**	**	**
--	**	**	**			**	**	**	**	**	**
Battery 1 Temp Probe	CD2	0.04	Cont			0.04	1.2	0.04	0.4	0.04	2.4
		Totals	Total (Amp-Mins)				200		100		300
			Maximum demand (Amps)			15		24		12	
			Average Demand (Amps)			6.7		10		5	

A.2 Electrical load analysis (DC – Current) – emergency operating conditions

BUS – DC1						EMERGENCY (Failure of one power-unit or generator)					
Circuit/Service	**CB**	**Load at CCT Breaker**	**Op time**	**Appropriate conditions**	**Notes**	**Taxiing (Night) 30 Mins**		**Take off & land (night) 10 mins**		**Cruise (night) 60 mins**	
		Amps	**mins**			**Amps**	**Amps-mins**	**Amps**	**Amps-mins**	**Amps**	**Amps-mins**
AIR CONDITIONING											
Dump Ditch Motors	AB1	0.90	0.1			-	-	-	-	-	-
Cabin Alt Warning	AB2	0.04	Cont			0.04	0.2	0.04	2.4	0.04	0.4
Man. Pressure Control	AB3	0.60	Cont			-	-	-	-	-	-
COMMUNICATIONS											
ACARS Memory	BC1	0.08	Cont			0.08	0.4	0.08	4.8	0.08	0.8
Electrical Power											
Battery 1 Charge	CD1	3.50	Cont			3.50	17.5.0	3.50	210	3.50	35.0
**	**	**	**			**	**	**	**	**	**
--	**	**	**			**	**	**	**	**	**
--	**	**	**			**	**	**	**	**	**
--	**	**	**			**	**	**	**	**	**
Battery 1 Temp Probe	CD2	0.04	Cont			0.04	0.2	0.04	2.4	0.04	0.4
		Totals	Total (Amp-Mins)				50		300		100
			Maximum demand (Amps)			15		24		12	
			Average Demand (Amps)			10		5		10	

A.3 Electrical load analysis (alternating current) – normal operating conditions

BUS – AC1							NORMAL CONDITIONS					
Circuit/Service	**CB**	**Load at CCT Breaker**		**Op time**	**Appropriate conditions**	**Notes**	**Taxiing (Night) 30 mins**		**Take off & land (night) 10 mins**		**Cruise (night) 60 mins**	
		Watts	**Vars**	**mins**			**Watts**	**Vars**	**Watts**	**Vars**	**Watts**	**Vars**
AIR CONDITIONING												
Dump Ditch Motors	AB1	33.0	17.0	Cont			33.0	17.0	33.0	17.0	33.0	17.0
Cabin Alt Warning	AB2	30.0		Cont			30.0		30.0		30.0	
Man. Pressure Control	AB3	11.0	7.0	Cont			11.0	7.0	11.0	7.0	11.0	7.0
COMMUNICATIONS												
ACARS Memory	BC1	60.0		Cont			60.0		60.0		60.0	
Electrical Power												
Battery 1 Charge	CD1	4.0		Cont			4.0		4.0		4.0	
**	**			**	**		**	**	**	**	**	**
--	**			**	**		**	**	**	**	**	**
--	**			**	**		**	**	**	**	**	**
--	**			**	**		**	**	**	**	**	**
Battery 1 Temp Probe	CD2	8.0		Cont			8.0		8.0		8.0	
		TOTALS		Bus Total KW/KVAR			400	50	400	50	400	50

A.4 Electrical load analysis (alternating current) – abnormal operating conditions (failure of one generator)

BUS – AC1							NORMAL CONDITIONS					
Circuit/Service	**CB**	**Load at CCT Breaker**		**Op time**	**Appropriate conditions**	**Notes**			**Take off & land (night) 10 mins**		**Cruise (night) 60 mins**	
		Watts	**Vars**	**mins**					**Watts**	**Vars**	**Watts**	**Vars**
AIR CONDITIONING												
Dump Ditch Motors	AB1	33.0	17.0	Cont					33.0	17.0	33.0	17.0
Cabin Alt Warning	AB2	30.0		Cont					30.0		30.0	
Man. Pressure Control	AB3	11.0	7.0	Cont					11.0	7.0	11.0	7.0
COMMUNICATIONS												
ACARS Memory	BC1	60.0		Cont					60.0		60.0	
Electrical Power												
Battery 1 Charge	CD1	4.0		Cont					4.0		4.0	
**	**			**	**		**	**	**	**	**	**
--	**			**	**		**	**	**	**	**	**
--	**			**	**		**	**	**	**	**	**
--	**			**	**		**	**	**	**	**	**
Battery 1 Temp Probe	CD2	8.0		Cont					8.0		8.0	
		TOTALS		Bus Total KW/KVAR					400	50	400	50

A.5 28VDC system

A.5.1 The following table considers a two-engine aircraft of medium range with a DC generator driven by each engine. The headings of each column are self-explanatory and where explanation is considered necessary it is provided below:

- **Column 5:** It is necessary to choose an arbitrary value of voltage for the estimation of current consumption. For this case a value of 95% E_{max} has been used.
- **Column 6:** Provides the drop in line voltage between the busbar and the equipment, assuming the current consumption shown in column 5. This voltage drop should be considered in conjunction with busbar voltages under normal and emergency conditions in the estimation of the terminal voltage at the equipment.
- **Column 10:** Provides the loading conditions immediately following a power-unit failure during take-off. This condition is assumed to persist for 10 minutes. This could be considered as an abnormal operating condition.

Aircraft – Two Power UnitsFlight Duration: 3 Hours Electrical System: Earth Return DC 28V; 2 Generators 3kW at Cruise, 1.5 kW at taxiing; 1 battery 37Ah (Ten-Hour Rate)								**Conditions of Aircraft operations**													
								Normal								**Abnormal (Failure of one power-unit or generator)**					
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**10**		**11**		**12**		**13**		**14**		**15**	
Item	**Service**	**Units per A/C**	**Units op simult**	**Current at 95% volts (amp)**	**Drop in line volts (volt)**	**Op Time (min)**	**No of Times ON**	**Taxi (night) 30 mins**		**Take-off and Land (night) 10 mins**		**Cruise (day) 60 mins**		**Cruise (night) 60 mins**		**Cruise (night) prior to load shed 5 mins**		**Cruise (night) after load shed 60 mins**		**Land (night) 10 mins**	
								amp	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**
1	Motor, Flaps	1	1	120	6	15s	1	120	30	120	30									120	30
2	Prop, feather	2	1	100	5	15s	1			100	25					100	25				
3	Motor, U/C	1	1	160	8	30s	1			160	80										
4	Trim tab motor	3	1	4	1	1	3	4	12	4	12	4	36	4	36	4	12	4	36	4	12
5	Cowl flaps	2	2	10	2	3	2	20	60	20	60	20	60	20	60	20	60	20	60	20	60
6	Water heater	1	1	25	2	10	2					25	500	25	500	25	125				
7	Galley	1	1	40	2	15	1					40	600	40	600	40	200				
8	Radio Trans	1	1	20	2	15	1	20	300	20	200	20	300	20	300	20	100	20	300	20	200

Aircraft – Two Power UnitsFlight Duration: 3 Hours Electrical System: Earth Return DC 28V; 2 Generators 3kW at Cruise, 1.5 kW at taxiing; 1 battery 37Ah (Ten-Hour Rate)								Conditions of Aircraft operations													
								Normal								**Abnormal (Failure of one power-unit or generator)**					
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**10**		**11**		**12**		**13**		**14**		**15**	
Item	**Service**	**Units per A/C**	**Units op simult**	**Current at 95% volts (amp)**	**Drop in line volts (volt)**	**Op Time (min)**	**No of Times ON**	**Taxi (night) 30 mins**		**Take-off and Land (night) 10 mins**		**Cruise (day) 60 mins**		**Cruise (night) 60 mins**		**Cruise (night) prior to load shed 5 mins**		**Cruise (night) after load shed 60 mins**		**Land (night) 10 mins**	
								amp	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**am p**	**amp-min**	**amp**	**amp-min**
9	Fuel Trans pump	2	1	10	1	15	1					10	150		150	10		10	150		
10	Motor de-icing	2	1	5	1.5	Cont	1			5	50	5	75	5	75	5	25	5	75	5	50
11	Prop. Auto Ctl	2	2	5	2	Cont	Cont	10	300	10	100	10	600	10	600	10	50	10	600	10	100
12	Fuel Boost pump	2	2	10	0.5	Cont	Cont			20	200	20	1200	20	1200	20	100	20	1200	20	200
13	Engine Inst.	12	12	1	0.5	Cont	Cont	12	360	12	120	12	720	12	720	12	60	12	720	12	120
14(a)	Int. Lights (essential)	5	5	1	0.5	Cont	Cont	5	150	5	50			5	300	5	25	5	300	5	50
14(b)	Int. Lights (non-essential)	10	10	1	0.5	Cont	Cont	10	300	10	100			10	600	10	50				
15	Nav. Lights	5	5	1	0.5	Cont	Cont	5	150	5	50			5	300	5	25	5	300	5	50

Aircraft – Two Power UnitsFlight Duration: 3 Hours Electrical System: Earth Return DC 28V; 2 Generators 3kW at Cruise, 1.5 kW at taxiing; 1 battery 37Ah (Ten-Hour Rate)								**Conditions of Aircraft operations**													
								Normal								**Abnormal (Failure of one power-unit or generator)**					
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**10**		**11**		**12**		**13**		**14**		**15**	
Item	**Service**	**Units per A/C**	**Units op simult**	**Current at 95% volts (amp)**	**Drop in line volts (volt)**	**Op Time (min)**	**No of Times ON**	**Taxi (night) 30 mins**		**Take-off and Land (night) 10 mins**		**Cruise (day) 60 mins**		**Cruise (night) 60 mins**		**Cruise (night) prior to load shed 5 mins**		**Cruise (night) after load shed 60 mins**		**Land (night) 10 mins**	
								amp	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**amp**	**amp-min**	**am p**	**amp-min**	**amp**	**amp-min**
16	Vent Fans	6	6	5	1.5	Cont	Cont	30	900	5	50	5	300	5	300	5	25				
17	Refrigerato r	1	1	15	2	Cont	Cont	15	450	15	150	15	900	15	900	15	75				
18	Auto pilot Inv.	1	1	5	1	Cont	Cont					5	300	5	300	5	25				
19	Inst. (flight) inv	1	1	5	1	Cont	Cont	5	150	5	50	5	30	5	30	5	25	5	300	5	50
20	Radio Receiver	1	1	5	1	Cont	Cont	5	150	5	50	5	300	5	300	5	25	5	300	5	50
21	Intercomm	1	1	5	1	Cont	Cont	5	150	5	50	5	300	5	300	5	25	5	300	5	50
					Total (amp-min)				3462		1427		6641		7841		1057		4641		1102
					Maximum Demand (amp)			266		526		206		226				126		396	
					Average Demand (amp)			115		143		111		131				77		110	

A.6 Battery capacity analysis

A.6.1 The following table refers to the loading in the case of a forced descent and landing, with all power-units inoperative and the battery supplying power for the electrical loads essential during this period. The battery endurance is 20 minutes.

A.6.2 **Column 7:** Provides the maximum demand that the battery must be capable of meeting while maintaining an adequate voltage at any time within the 20 minutes of battery endurance.

A.6.3 The summation of **Column 6** gives a total consumption of 857 amp-min (i.e. 14 amp-hour).

1	2	3	4	5	6	7
Item No	**Equipment**	**Units**	**Total Demand per unit (amp)**	**Time (mins)**	**Amp-min in 20 min period**	**Simultaneous demand (amp)**
1	Motor, Flaps	1	120	0-15 secs	30	120
2	Prop,feather	2	100	0-15 secs	50	100
3	Motor,U/C	1	160	0-30 secs	80	160
4	Trim tab motor	3	4	1	12	4
5	Cowl flaps	2	10	3	60	20
8	Radio Trans	1	15	15	225	15
9	Fuel Trans Pump	2				
10	Motor de-icing					
11	Prop Auto Control	2				
12	Fuel Boost pump	2				
13	Engine Inst	12				
15	Navigation Lights	5	1	Cont	100	5
19	Inst (flight) inv	1	5	Cont	100	5
20	Radio Rcvr	1	5	Cont	100	5
21	Intercomm	1	5	Cont	100	5
Totals					857	439

A.7 Electrical system; 200 Volt 3 Phase 400 Hz - normal

Item No	Service	No of units	Units Op simult	Volt-amp per unit		Op Time (min)	Load distribution				Normal operations							
				Peak	Normal		Normal supply	Standby Supplies		Engine Start	Taxi (night)		Take-off or land (night)			Cruise (night)		
								1st	2nd	A	P	S	A	P	S	A	P	S
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	Starter Motors	2	1	7000	600	0-10sec	A			7000								
2	Propeller-Feathering (P)	1	1	2300	200	0-15sec	A	S										
3	Propeller-Feathering (S)	1	1	2300	2000	0-15sec	A	P										
4	Cowl Gill motor (P)	1	1	150	150	0-20sec	P	A	S		150							
5	Cowl Gill motor (S)	1	1	150	150	0-20sec	S	A	P			150						
6	Main undercarriage (P)	1	1	4000	4000	0-10sec	P	A						4000				
7	Main undercarriage (S)	1	1	4000	4000	0-10sec	S	A							4000			
8	Tail Wheel	1	1	500	500	0-10sec	S	A							500			

Item No	Service	No of units	Units Op simult	Volt-amp per unit		Op Time (min)	Load distribution			Normal operations								
9	Wing Flaps	1	1	500	500	0-20sec	P	A			500			500				
10	Landing Lamps	2	2	200	200	10	P	A	S		400			400				
11	Interior Lights A	Total	Total	100	100	C	P	A	S	100	100			100			100	
12	Interior Lights B	Total	Total	300	300	C	S	A	P			300			300			300
13	Heating Load A	Total	Total	1000	1000	C	P	A			1000			1000			1000	
14	Heating Load B	Total	Total	1000	1000	C	S	A				1000			1000			1000
15	Frequency Changer	1	1	2000	2000	C	S	A	P			2000			2000			2000
16	Frequency Compensator	1	1	2400	2400	C	P	A	S	1800	2400			2400			2400	
17	Pressure Head Heater	1	1	100	100	C	S	A	P									100
18	Engine Controls (P)	Set	Set	200	200	C	P	A	S	200	200			200			200	
19	Engine Controls (S)	Set	Set	200	200	C	S	A	P	200		200			200			200
20	Fuel Boost Pump (P)	1	1	150	150	C	P	A	S	150	150			150			150	
21	Fuel Boost Pump (S)	1	1	150	150	C	S	A	P	150		150			150			150

Item No	Service	No of units	Units Op simult	Volt-amp per unit		Op Time (min)	Load distribution			Normal operations								
22	Fuel Valves (P)	3	1	50	50	0-10sec	P	A	S		50			50			50	
23	Fuel Valves (S)	3	1	50	50	0-10sec	S	A	P			50			50			50
24	Flying Control Servo	3	3	200	200	C & Int	P	A	S		600			600			600	
25	Motor de-ice	1	1	150	150	C	S	A	P									150
26	Refrigerator	1	1	250	250	C	S	A	P			250			250			250
27	Navigation Lights	3	3	25	25	C	P	A	S		75			75			75	
28	Windscreen wiper	1	1	60	60	C	S	A	P	60		60			60			60
29																		
30																		
			Totals	10 seconds Peak Maximum Load (VA)						9660	5625	4160	0	8475	7510	0	4575	4260
				30 seconds Peak Maximum Load (VA)						2660	5575	4110	0	5425	3960	0	4525	4210
				Continuous Maximum Load						2660	4425	3960	0	4425	3960	0	4025	4210

A.8 Electrical system: 200 Volt 3 Phase 400 Hz – abnormal

A.8.1 The following table considers an aircraft with two power-units carrying one alternator per power-unit and an APU, the latter being primarily for use at low altitudes. The determination of the alternator capacity needed to supply the most onerous probable combination of loads is illustrated for the following conditions:

- normal
- abnormal
- emergency (forced descent and land–night).

Item No	Service	No of Units	Units Op Similt	Volt-amp per Unit		Op Time (min)	Load distribution			Abnormal operations										Emerg-ency operation
				Peak	Normal		Normal Supply	Standby Supply		Port power-unit and alternator off			Starboard power-unit and alternator off			APU				Both power units off
										Take off or land (night)		Cruise (night)	Take off or land (night)		Cruise (night)	Taxi (night)		Take-off or land (night)		Forced descent (night and land
								1st	2nd	S	A	S	P	A	P	P	S	P	S	A
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Starter Motors	2	1	7000	600	0-10sec	A													
2	Propeller-Feathering (P)	1	1	2300	200	0-15sec	A	S			2300									
3	Propeller-Feathering (S)	1	1	2300	2000	0-15sec	A	P						2300	2300					
4	Cowl Gill motor (P)	1	1	150	150	0-20sec	P	A	S							150				
5	Cowl Gill motor (S)	1	1	150	150	0-20sec	S	A	P								150			
6	Main undercarriage (P)	1	1	4000	4000	0-10sec	P	A			4000		4000					4000		

Item No	Service	No of Units	Units Op Similt	Volt-amp per Unit		Op Time (min)	Load distribution			Abnormal operations										Emerg-ency operation
7	Main undercarriage (S	1	1	4000	4000	0-10sec	S	A		4000				4000					4000	
8	Tail Wheel	1	1	500	500	0-10sec	S	A		500				500					500	
9	Wing Flaps	1	1	500	500	0-20sec	P	A			500		500			500		500		500
10	Landing Lamps	2	2	200	200	10	P	A	S		400		400			400		400		400
11	Interior Lights A	Total	Total	100	100	C	P	A	S		100	100	100		100	100		100		100
12	Interior Lights B	Total	Total	300	300	C	S	A	P	300		300		300	300		300		300	
13	Heating Load A	Total	Total	1000	1000	C	P	A			1000		1000		1000	1000		1000		
14	Heating Load B	Total	Total	1000	1000	C	S	A		1000		1000		100			1000		1000	
15	Frequency Changer	1	1	2000	2000	C	S	A	P	2000		2000		2000	2000		2000		2000	200
16	Frequency Compensator	1	1	2400	2400	C	P	A	S		1800	2400	2400		2400	2400		2400		1800
17	Pressure Head Heater	1	1	100	100	C	S	A	P			100			100					100
18	Engine Controls (P)	Set	Set	200	200	C	P	A	S				200		200	200		200		200

Item No	Service	No of Units	Units Op Similt	Volt-amp per Unit		Op Time (min)	Load distribution			Abnormal operations										Emerg-ency operation
19	Engine Controls (S)	Set	Set	200	200	C	S	A	P	200		200					200		200	200
20	Fuel Boost Pump (P)	1	1	150	150	C	P	A	S				150		150	150		150		150
21	Fuel Boost Pump (S)	1	1	150	150	C	S	A	P	150		150					150		150	150
22	Fuel Valves (P)	3	3	50	50	0-10sec	P	A	S		50	50	50		50	50		50		50
23	Fuel Valves (S)	3	1	50	50	0-10sec	S	A	P	50		50		50	50		50		50	50
24	Flying Control Servo	3	1	200	200	C & Int	P	A	S		600	600	600		600	600		600		600
25	Motor de-ice	1	1	150	150	C	S	A	P			150			150					150
26	Refrigerator	1	1	250	250	C	S	A	P	250		250		250	250		250		250	
27	Navigation Lights	3	3	25	25	C	P	A	S		75	75	75		75	75		75		75
28	Windscreen wiper	1	1	60	60	C	S	A	P	60		60		60	60		60		60	60
		Totals		10 seconds Peak Maximum Load (VA)						7510	9825	9785	8475	9460	9785	5625	4160	8475	7510	6585
				30 seconds Peak Maximum Load (VA)						3960	6775	9685	5425	5910	9685	5575	4110	5425	3960	6485
				Continuous Maximum Load						3960	3475	6885	4425	3610	6885	4425	3960	4425	3960	5485

Appendix B

Calculations and formulae

B.1 Power calculations

B.1.1 In alternating current systems, the addition of alternating current load using kVA and pf is a vector addition and not an algebraic addition. Circuits will always contain inductance and capacitance; therefore, the current and voltage are usually out of phase to some degree in an alternating current circuit. The resultant combination is called impedance (see Figure 5).

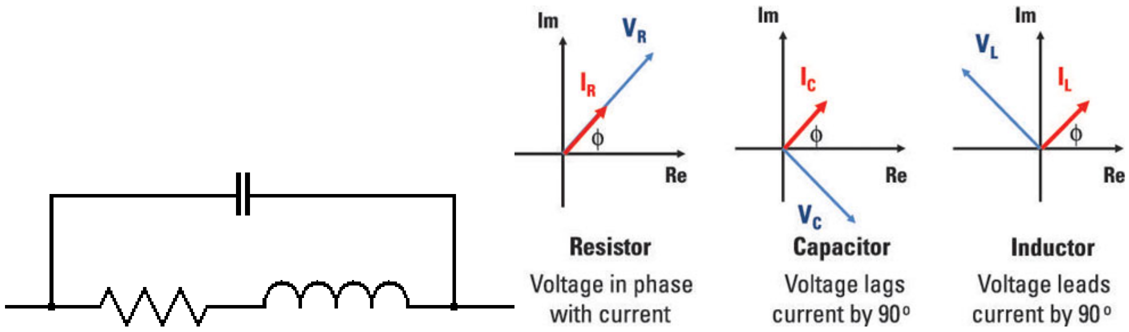


Figure 5: Circuit equivalent components - Impedance

B.1.2 Apparent power (measured in VA) describes the entire power used by an alternating current circuit. Reactive power does not work and is returned to the line. VA is the vector sum of true power and reactive power. In reactive circuits (those that are either capacitive or inductive), the current and voltage are out of phase. The angle by which they are out of phase is proportional to the pf (see Figure 6).

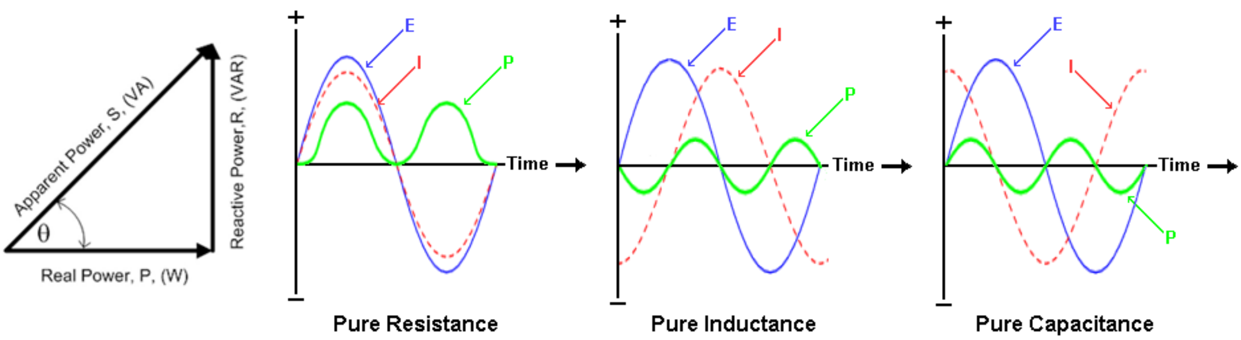


Figure 6: Power triangle and phase relationship

B.1.3 Standard Ohms law formulae are used for DC, or with modification for alternating current circuits. Resistance is abbreviated as R and impedance applicable for alternating current circuits is abbreviated as Z (see Figure 7).

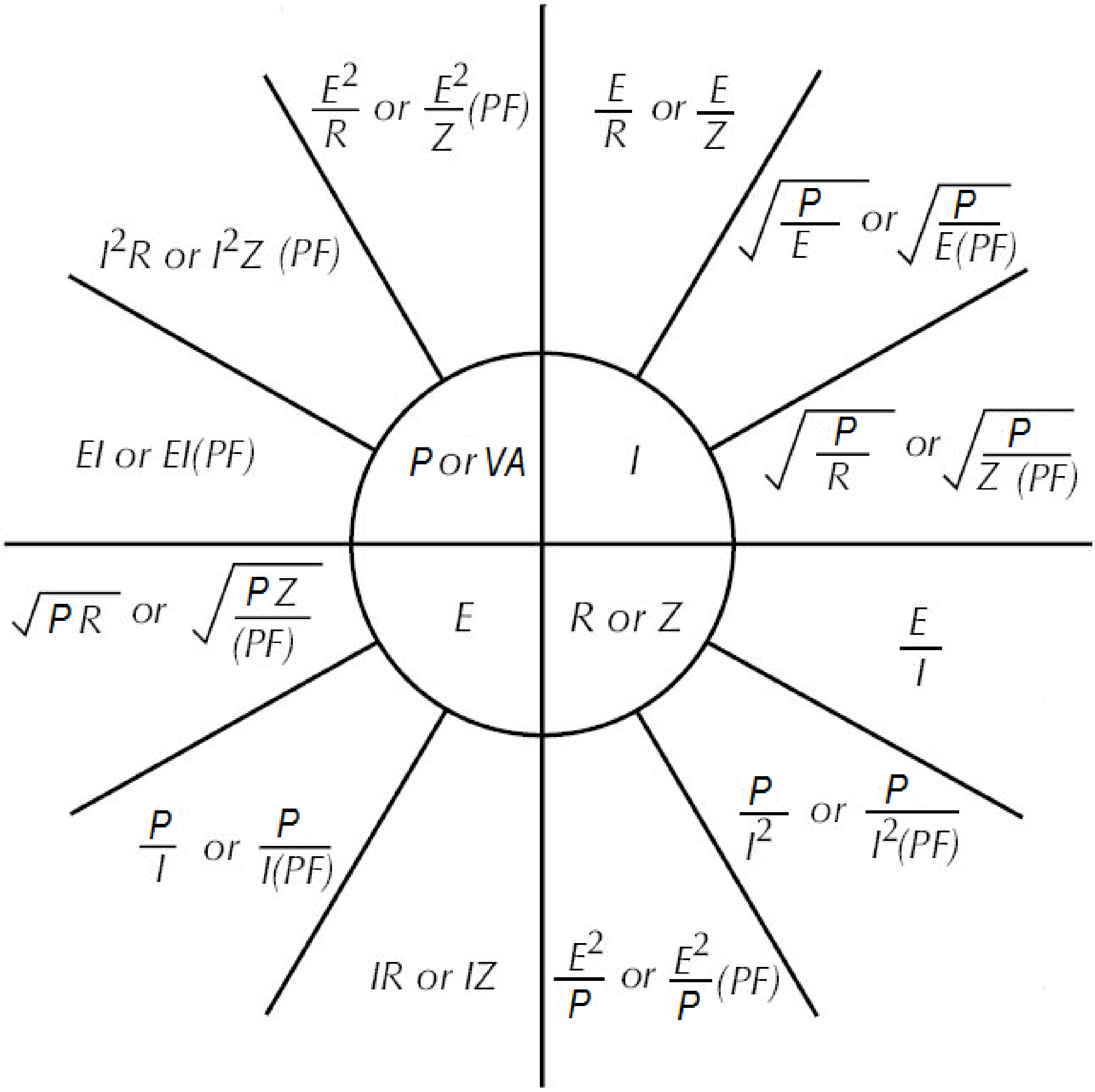


Figure 7: Ohms law formulae for DC and AC circuits

B.1.4 The following calculations are examples to estimate total current, maximum demand and average demand for each of the aircraft during its operating phases:

Total current in A	number of units operating simultaneously × current per unit
Total current in A/min	number of units operating simultaneously × current per unit × operating time in minutes
Maximum demand or load A	number of units operating simultaneously × current per unit
Maximum demand or load in VA or W	number of units operating simultaneously × current per unit × supply voltage
RMS	$\frac{1}{\sqrt{2}} \approx 0.707$
pf	$pf = \frac{W}{VA}$ $pf = \cos ine\phi$
Power in watts	P = V x I x pf **Note:** pf is only used for AC analysis

B.1.5 Worked example of addition of alternating current loads with varying pfs.

Equipment	Type of load	Value	pf
Cabin lighting	Capacitive	20kW	0.92 leading
	kVA1 = $\frac{20}{0.92}$ = 21.73 kVA		
	cos ϕ1 = 0.92 therefore ϕ1 = 23°4’		
	kVAR1 = kVA1sinϕ = 20 x 0.3918 = 7.836kVAR		
Flap motor	Inductive	75kW	0.7 lagging
	kVA2 = $\frac{75}{0.7}$ = 107.2 kVA		
	cos ϕ2 = 0.7 therefore ϕ2 = 45°34’		
	kVAR2 = kVA2 sin ϕ2 = 107.2 x (-)0.7142 = -76.56 kVAR		
Heater	Resistive	45kW	1.0
	kVA3 = 45 = 45.0 kVA which is 0° phase angle		

Total kVAR = -68.72 kVAR

Total kW = 20 + 75 + 45 = 140 kW

Total kVA =

$$= \sqrt{(kw^2 + kVAR^2)}$$
$$= \sqrt{(140^2 + (-68.72)^2}$$
$$= 155.96kVA$$

pf of total load = $\frac{kW}{kVA} = \frac{140}{155.96} = 0.898 lagging$

B.2 Battery charge and discharge calculations

B.2.1 Calculation of battery discharge

B.2.1.1 An accurate theoretical assessment of the battery performance requires a load analysis to be compiled and the discharge figures checked against the battery manufacturers discharge curves and data sheets.

B.2.1.2 The capacity of a battery is calculated by:

- Rate of discharge A x time to discharge.
- Example of how to calculate battery duration.
- Check the nameplate capacity of the battery and assume 75% is available (e.g. 12A-h = 720A-mins).Therefore, 75% is equal to 540A-mins.
- Estimate the normal or pre-load shed cruise consumption (assume worst case cruise at night). For example, 15 A (15 A x 5 mins = 75A-mins).
- This assumes 5 minutes for pilot to shed essential loads following a low voltage warning. Any automatic load shedding can be assumed to be immediate and need not be considered in the pre-load shed calculations.
- Estimate the minimum cruise load necessary to maintain flight after the generator/alternator has failed e.g. 10A.
- Estimate the consumption required during the landing approach e.g. 20A for 5 mins (100A-mins).

B.2.2 Calculation of battery charge

B.2.2.1 The charging current for any aircraft battery is based on the total elapsed time from the beginning of the charge, and is calculated using the following formula:

A = A-h x battery-charging factor taken from the battery-charging curve supplied with battery data (graphical data).

Appendix C

Circuit breaker and load data sheet

C.1 Circuit breaker and electrical load data

Circuit: Model: Serial number:

Change identifier:

Circuit breaker number:

Name of electrical bus:

Location:

Wiring diagram/schematic details:

Action (tick): Add ☐ Revise ☐ Delete ☐ Move ☐

DC Load characteristics

		Flight phase loading						Standby loads
	Connected 100%	Ground operation & loading	Engine start	Taxi	Takeoff Climb	Cruise	Landing	Battery
Duty cycle								
Amps								

AC Load characteristics (if used)

		Flight phase loading						Standby loads
	Connected 100%	Ground operation & loading	Engine start	Taxi	Takeoff Climb	Cruise	Landing	Battery
Duty cycle								
Amps								

Notes:

Signed: Date: