AEROSPACE INFORMATION REPORT	AIR6540™	REV. C
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Fundamentals in Wire Selection and Sizing for Aerospace Applications

RATIONALE

The revision of this document aligns numerical values in accordance with formulae in 3.4.1.1 and updates formulae and numerical examples accordingly in Sections 4 and 5.

INTRODUCTION

The selection of aerospace wire sizes per AS50881 is a straightforward process to complete. For electrical power feeders, protection devices, and distribution applications, additional information not found in AS50881, as well as environmental and installation constraints information, is required to size correctly a wire(s) to a precise set of design requirements.

1. SCOPE

The scope of this report is to capture fundamental principles of selecting a wire size for an aerospace application using the method prescribed in AS50881 and additional calculations, not found in AS50881, to ensure the wire selection will adequately perform in the specific physical and environmental conditions.

This report covers wire selection and sizing as part of the electrical wire interconnection systems (EWIS) used in aerospace vehicles. Aerospace vehicles include manned and unmanned airplanes, helicopters, lighter-than-air vehicles, missiles, and external pods. This document does not apply to wiring inside of airborne electronic equipment but shall apply to wiring externally attached to such equipment.

Wire selection must consider physical and environmental factors to size wires such that they have sufficient mechanical strength, do not exceed allowable voltage drop levels, are protected by materials or circuit protection devices, and meet circuit current carrying requirements. For electrical power feeders and distribution or EWIS applications, other information and environmental and installation limitations are also needed to adequately evaluate and select the correct wire size for a specific application and meet design requirements.

This report presents only fundamental principles and guidelines and cannot adequately cover all aspects and complexities associated with wire selection and sizing. Some of the calculations in this report have been simplified to demonstrate the process for validating a wire size selection for a design application. More precise calculations should be investigated and evaluated to ensure proper assessment of each individual calculation in this report.

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2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS29606A Wire, Electrical, Stranded, Uninsulated Copper, Copper Alloy, or Aluminum, or Thermocouple Extension, General Specification for

AS50881 Wiring Aerospace Vehicle

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM B193 Standard Test Method for Resistivity of Electrical Conductor Materials

2.1.3 ECA Publications

Available from Electronic Component Association, 2500 Wilson Boulevard, Arlington, VA 22201-3834, Tel: 703-907-7500, www.eia.org.

EIA Standard RS-21 Method for Calculation of Current Rating on Hookup Wire, November 1958.

2.1.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 43.13-1B FAA, AC_43.13-1B_w-chg1_Adv_Circ Aircraft_Electrical_Systems_Chapt. 11

2.1.5 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-STD-7080 Selection and Installation of Aircraft Electric Equipment Section 4.9

MIL-W-5088L Aerospace Vehicle Wiring Specification

NOTE: MIL-W-5088L, dated December 9, 1992, is inactive for new design and is no longer used, except for replacement purposes. Future designs should refer to AS50881.

2.1.6 Other Publications

2.1.6.1 Exner, D.W. and Singer, G.H. (1953). Impedance data for 400-cycle aircraft distribution systems. *Transactions of the American Institute of Electrical Engineers, Part II: Applications and Industry, 71*(6). https://doi.org/10.1109/TAI.1953.6371310.

2.1.6.2 Dwight, H.G. (1954). *Electrical Elements of Power Transmission Lines*, Chapter 8. Macmillan.

2.1.6.3 Fink, D.G. and Beaty, H.W. (1978). *Standard Handbook for Electrical Engineers* (11th ed.). McGraw Hill.

2.1.6.4 Schach, M. and Kidwell, R.E. (1953). Continuous current and temperature rise in bundled cables for aircraft. *Transactions of the American Institute of Electrical Engineers, Part II: Applications and Industry, 71*(6). https://doi.org/10.1109/TAI.1953.6371304.

2.1.6.5 Stevenson Jr., W.D. (1962). *Elements of Power System Analysis* (2nd ed.), Chapter 4. McGraw Hill.

2.1.6.6 Woodruff, L.F. (1953). *Principles of Electric Power Transmission* (2nd ed.), Chapter 2, Item 18. John Wiley & Sons.

2.2 Abbreviations

ASTM American Society for Testing and Materials

AWG American Wire Gauge

IACS International Association of Classification Societies

SI International System of Units

2.3 Definitions

AIRCRAFT: An airplane, helicopter, or lighter-than-air vehicle.

AIRPLANE: Any heavier-than-air vehicle that is supported for flight by the dynamic action of air on its surfaces.

BRANCH: A section of wire harness that divides off and extends to a point of termination.

BUNDLE: Any number of wire harnesses groups or branches routed and supported together along some distance within the aircraft.

CHAFING: Repeated relative motion between wiring system components, or between a wiring system component and structure or equipment, that results in a rubbing action that causes wear, which will likely result in mechanical or electrical failure during the aerospace vehicle's specified service life.

COMPONENT: A component is an aircraft article made up of parts and approved for installation on a type-certificated aircraft. Type-certification is awarded when applicable design data has been granted an approval (for example, type certificate, supplemental type certificate, technical standard order authorization, parts manufacturer approval, or equivalent) by the relevant civil aviation authority. Examples of components are motors, gearing assemblies, generators, alternators, inverters, converters, drives, controls, switches, fuses, buses, distribution units, wire harnesses, batteries, solenoids, relays, and others.

CONNECTOR PLUG: The connector containing the coupling ring or active retention device of the mating pair.

CONNECTOR RECEPTACLE: The connector containing the static retention device of the mating pair.

ELECTRICAL CABLE: Two or more insulated conductors, solid or stranded, contained in a common covering, or two or more insulated conductors twisted or molded together without common covering, or one insulated conductor with a metallic covering shield or outer conductor.

ELECTRICAL WIRING INTERCONNECT SYSTEM (WIRING) - EWIS: Wires, electrical or fiber optical cables, groups, harnesses and bundles and their terminations, associated hardware, and support installed in the aircraft. When used as a verb, it is the act of fabricating and installing these items in the vehicle.

FIBER OPTIC CABLE: A cable designed to transmit light waves between a light transmission source and a receiver. In signal applications, the transmitter and receiver include devices that are used to convert between optical and electronic pulses. Typical cables include a glass or plastic core, a layer of cladding having a lower refractor index to refract or totally reflect light inward at the core/cladding boundary, a buffer, strength members, and jacketing to protect the inner cable from environmental damage.

FIREPROOF: The capability of a material or component to withstand a 2000 °F flame (±150 °F) for 15 minutes minimum while still fulfilling its design purpose. Clarification: The term "fireproof," when applied to a connector, backshell, or accessory hardware mounted and secured to a structure used to confine fires within designated fire zones, means that the connector system will perform this function (conduct electrical power and prevent flame/heat penetration) under conditions likely to occur in such zones and will withstand a 2000 °F flame (±150 °F) for 15 minutes minimum. A connector system consists of mated connectors, fully wired, backshells or conduit assemblies, and mounting hardware installed on a structural panel (firewall).

FIRE RESISTANT: The capability of a connector system (as defined in "fireproof") to perform its intended function in designated fire zone areas under heat and other abnormal conditions, as encountered in power plants and auxiliary power unit (APU) installations, that are likely to occur at the location or area and to withstand a 2000 °F flame (±150 °F) for 5 minutes minimum.

FIREWALL: A structural panel designed to prevent a hazardous quantity of air, fluid, or flame from exiting a designated fire zone in which a fire may erupt and cause additional hazard to the aircraft. This structural panel permits penetration of fluid carrying lines (fuel and hydraulics), ducts, electrical power, and control cables or rods using suitable fireproof components or fittings. The firewall and the attached components or fittings shall withstand flame penetration and shall not exhibit backside ignition for the required test time (15 minutes). The backside temperature should not exceed 450 °F maximum and the structural panel should have fireproof insulating material installed to limit the backside temperature.

GROUP: A "wire group" is several wires and/or electrical or optical cables and their terminations secured together within the structure of a bundle or harness. Groups normally contain wires and/or electrical or optical cables pertaining to a single circuit or routed to a single item of equipment.

HARNESS: An assembly of any number of wires, electrical or optical cables, and/or groups and their terminations that is designed and fabricated to allow for installation and removal as a unit. A harness may be an open harness or a protected harness.

HIGH DENSITY HARNESS: A protected harness designed to save weight and space that has a majority of wire types specified for protected wire applications.

OPEN HARNESS: An assembly of wires and/or electrical or optical cables that does not include a protective outer covering.

PROTECTED HARNESS: A harness that employs some overall outer covering to provide additional electromagnetic and/or mechanical protection for the wires and/or electrical or optical cables contained within. The added protection may consist of an overbraid, tape wrap, conduit, or some other form of protection.

WIRE: A single metallic conductor of solid, stranded, or tinsel construction, designed to carry current in an electric circuit, but not having a metallic covering, sheath, or shield. For this guidebook, "wire" refers to "insulated electric conductor."

WIRING (see Electrical Wiring Interconnect System - EWIS): The term "wiring" wherever used throughout this report shall be interpreted as EWIS.

WIRING DEVICES: The necessary parts and materials that are used in the installation of electrical or optical wiring, such as terminals, connectors, junction boxes, conduit, clamps, insulation, and supports.

WIRING SEGMENT: A length of wire that is continuous and unbroken between its two intended points of termination. A wire segment that has been broken and then repaired is still considered to be one wire segment.

3. WIRE SELECTION PROCEDURE

This report provides fundamental guidelines to simplify the process for selecting the proper wire size based on the AS50881 standard, as well as other equations not found in AS50881. It also provides valuable information for the electrical design engineer to verify the proper wire selection and validate a set of system design requirements, which includes meeting environmental and installation constraints. This report does not make recommendations on insulation system voltage ratings. Some practical examples will be provided and focus on selecting wire sizes for power feeder applications.

Prior to starting the process of wire selection and sizing, all loads must be known not only for steady-state conditions, but also for transient or dynamic operations, including faulted conditions. This requires calculating and knowing the nature of the peak and continuous values of the loads in a circuit, including whether the wires connect to flight critical, mission critical, or noncritical loads.

Wire selection must consider physical and environmental factors to size wires such that they have sufficient mechanical strength, they do not exceed allowable voltage drop levels, are protected by materials and circuit protection devices, and they meet circuit current carrying requirements.

All wire sizes have a maximum continuous current rating; the maximum current of each wire will dictate the size of most wires in an aircraft. Current carrying capacity is related to the effects of heat on wire insulation due to the resistance and current flow; maximum operating temperatures must not be exceeded. If wire materials had zero resistance, then any size wire could carry any amount of current; however, this is not the case. Wire gauge dictates a resistance over the wire length, usually expressed in ohms per foot; longer wires have increased resistance, so larger wire sizes may be required. The ability of a wire to reject heat is a function of the surface area and the availability of a heat transfer path to reject heat; wires in a bundle or harness do not reject heat as efficiently. In this report, the effect of heat conduction in axial direction is not addressed.

Wire selection may follow a straightforward approach; however, it is also important to understand the variables involved and the design and environmental constraints that factor into wire selection and sizing. There are fundamental principles and guidelines captured in numerous references listed, which should be consulted, that provide specific requirements. While basic calculations presented are simplified to illustrate the process, more precise calculations must be investigated and evaluated to ensure accurate assessments. Also rules of thumb or table look-ups in most cases result in underestimated values compared to calculated values, and calculation methodologies also differ, so pick the “best” one for the application.

Wire selection involves either calculating or using table look-ups to determine the allowable current carrying capacity (also coined “ampacity”) and maximum acceptable voltage drop in the load circuits between the bus and the utilization equipment ground. Simply, the wire size of a wire is defined by the wire construction and insulation temperature limits, the load current, and by the tolerable, allowable voltage drop.

3.1 Background Information

3.1.1 American Wire Gauge (AWG) Sizing Calculations

Two examples are given below for calculating a wire diameter and circular mil (cmil) values for a given size wire. These formulas provide some quick estimating calculations that are used in several popular publications, which are only provided as example calculations and are not to be used in the selection of wire in aerospace applications. The wire sizing convention is a simple mathematical law, details of which can be found in the Standard Handbook for Electrical Engineers (see 2.1.6.3).

Equation 1 is a good approximation for determining the wire diameter (WireDia_inch), in inches, based on its wire size.

$$WireDia\_inch(awg) = .3249 * e^{-.116*awg} \qquad \text{(Eq. 1)}$$

For wire sizes larger than #0, use a negative value to represent wire size in these equations; for instance, use -1, -2, and -3 for 2/0, 3/0, and 4/0 wire sizes, respectively.

For Equation 2, input the wire size number to calculate the cmils of a given wire size. After further inspection of this calculation for this equation, as compared to several M22759 series cmil values, the error amount from this equation should provide the evidence to invalidate this equation as an accurate estimating tool.

$$AWG2Cmil = [5 * (92^{(36-awg)/39})]^2 \quad \text{(Eq. 2)}$$

3.1.2 Current Carrying Capacity Rule

Various rules of thumb are representative by a ratio of wire cross-sectional area to current carrying capacity. The current carrying capacity values vary considerably. These rules of thumb are influenced by conductor material, constraints peculiar to an application such as ambient temperature range, available cooling, and permissible voltage drop. Equation 3 is one of those “rule of thumb” calculations found on several popular websites. The rule determines the current carrying capacity based on the cross-sectional of copper conductor’s area should be a value of 700 “circular mils” per amp or below with the parameter Diam in inches.

$$Iamps(Diam) = \frac{10^6 * Diam^2}{700/amp} \quad \text{(Eq.3)}$$

After reviewing several references, some authors suggested different values for the stated “700 cmil per amp” of 500, 300, or 200 “circular mils” per amp.

Equation 3 was employed to compare the results using two different cross-sectional area values, 700 cmil/A and 500 cmil/A. Table 1 demonstrates that the equation is inappropriate to be applied in an aerospace application, when comparing it to the data in Table 1 of AS50881 at 105 °C.

Table 1 - Current carrying capacity comparison in amperes

AWG	Data from AS50881, Table 1 Amps at 105 °C	Using 700 cmil/A	Using 500 cmil/A
20	4	1.46	2.05
10	17	14.8	20.7
1/0	128	150	211

3.1.3 Density and Temperature Coefficient (per Degree Celsius)

The following information was taken from ASTM B193. These values are typically used in calculating resistance value for a wire. Exercise care in selecting the correct values when working with various wire types in aerospace applications.

- 100% IACS Copper at 20 °C
  - Approximate density, δ = 8.89 g/cm^3
  - Temperature coefficient of resistance, α = 0.00393
- Silver Coated Copper
  - Class B density, δ = 8.93 g/cm^3
  - Temperature coefficient of resistance, α = 0.00393
- Nickel Coated Copper
  - Class 2 density, δ = 8.89 g/cm^3
  - Temperature coefficient of resistance, α = 0.00395
- Aluminum 1350 61.0% IACS
  - Approximate density, δ = 2.705 g/cm^3
  - Temperature coefficient of resistance, α = 0.00403

3.1.4 Pouillet's Law

Pouillet’s law states: The resistance of a given material will increase with the length but decrease with increasing cross-sectional area.

Electrical resistivity (ρ) is an intrinsic property that quantifies how strongly a given material opposes the flow of electric current.

Electrical conductivity (σ) or specific conductance is the reciprocal of electrical resistivity and measures a material’s ability to conduct an electric current.

Pouillet’s law will show up in different forms when calculating a resistance value for a conductor. Close attention to the use of the numerical units should be exercised, especially when converting from SI to English units.

3.2 Resistance Calculations Examples

Equations 4 and 5 are two equations for calculating DC resistance. Equation 4, the most commonly used, will calculate the DC resistance (Rdc) of a given length of wire.

NOTE: Equation 1 calculates the diameter of the wire, which then can be used as an input to calculate the value of area for a wire. Remember to pay attention to the units.

$$Rdc = \frac{Length}{Area(awg) * \sigma} \quad \text{(Eq. 4)}$$

Equation 5 calculates DC resistance and compensates for increased temperature in the conductor. With conductor conductivity σ, it is typically given at a laboratory temperature of 20 °C, but this should always be verified before being adjusted for a higher or lower temperature. This will provide an accurate value for calculating, for instance, voltage drop value for a given wire length.

$$Rdc = \frac{Length}{Area(awg) * \sigma}[1 + (Temp - 20) * \alpha] \quad \text{(Eq. 5)}$$

As noted in FAA AC 43.13-1B Chapter 11, Section 5, 11-66: The resistance of the current return path through the structure is generally considered negligible, based on the assumption that adequate bonding to the structure or a dedicated electric current return path has been incorporated that is capable of carrying the required current with negligible voltage drop.

Resistance calculations for AC current can be found in 4.2.

3.3 AS50881 Wire Selection Procedure

This is a brief outline of the process for selecting a wire gauge based on a set of design requirements and environmental and installation constraints.

Wire selection in AS50881 follows the following process:

- Wire ampacity (current carrying capacity) value calculation
- Bundle de-rating factor
- Altitude de-rating factor

Assumed factors taken into account in this process:

- Heat-storage capacity of the wire and bundle
- Heat-storage capacity of the wire insulation
- Altitude, reduced convective air density

3.3.1 Wire Ampacity Curves

Figure 1 is one of two diagrams from AS50881 showing ampacity curves for a given set of wire sizes. The ampacity values are based on a single copper wire in free air. For aluminum conductors, the prescribed de-rating value of 20% is found in AS50881.

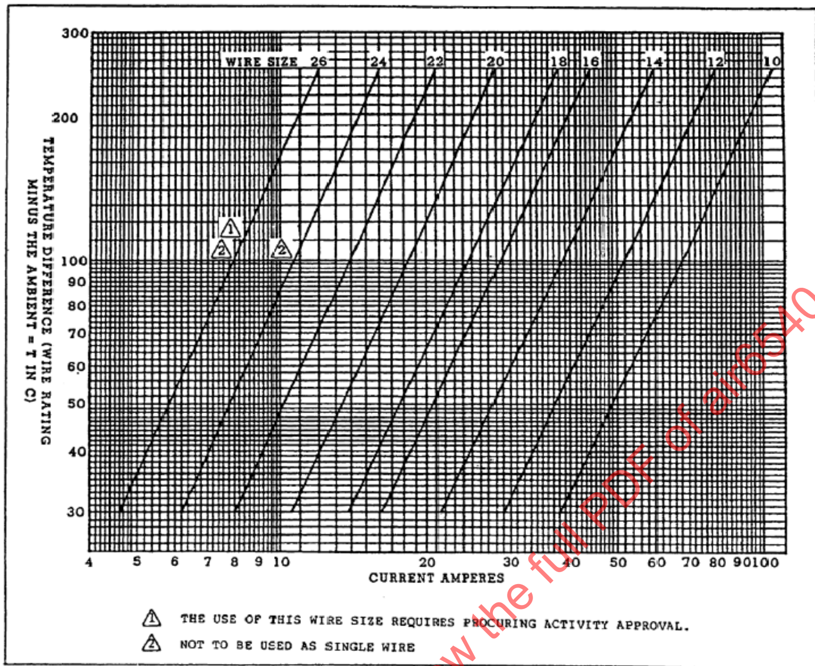

Figure 1 - Wire ampacity graph from AS50881

These graphs can also be found in MIL-W-5088. These values have not changed in 60 years or more. M. Schach and R.E. Kidwell wrote one of several articles published in the 1940s and 1950s that first captured the data for a 400 Hz application (refer to 2.1.6.4).

The MIL-W-5088 graphs did not appear until Revision F in 1976; previously, they had a generic current limit by wire for single free air wire and 15 wires in a bundle operating at 20% loading. MIL-W-5088L, dated December 9, 1992, is inactive for new aircraft designs and is no longer used except for replacement purposes. Future designs should refer to AS50881.

3.3.2 Wire Ampacity Database

The single copper wire ampacity values for each wire size within Figure 1 (Figure 3 of AS50881) are provided in AS50881, Table 3. The equations within Table 3 of AS50881 provide several other useful calculations that can be incorporated into algorithms that can assist in investigating different wire sizing solutions for a particular electrical system application.

3.4 De-Rating Factors

Two types of wire ampacity de-rating factors are found in AS50881, which offers an expedited means in the selection of a wire size(s) for a single/group of wires based on ambient temperature, altitude, wire temperature rating, and the percent number of power wires in a bundle. Since aircraft cables are commonly grouped together, a method for determining individual current limits for each size needed ensuring that proper ampacity limits are not exceeded. This procedure ensures the hottest conductor will not exceed a predetermined temperature limit.

De-rating factors increase the ampacity margins based on temperature rating compensation without performing elaborate modeling calculations.

The next two de-rating methodologies are from the procedure outlined in AS50881. The purposes of these de-rating factors are to consider the composition of the wire (bundle) and installation environment in the vehicle. Both de-rating factors consider the current carrying capacity for a given wire size and thermal considerations based on the number of heat sources and thermal dissipation attributes.

3.4.1 Bundle De-Rating Factor

The bundle de-rating factor from AS50881 is shown in Figure 2. An example curve-fit equation has been provided to estimate the bundled de-rating factor values for selecting a wire size based on the number of wires in the bundle (NoWire) and total bundle loading percent value of power wires divided by the total number of wires in the bundle (Bundle%Load).

Also provided are two results comparing the values from Figure 2 with Equation 6. You will notice that the calculated values are not precise in both cases, but from further analysis of the process, one can determine the error does not contribute largely to a significant error, with all other factors taken into account, for selecting a correct wire size, except for a case where wire selection is reaching 100% utilization value.

Equation 6 is the bundle de-rating factor curve-fit equation based on a total bundle loading percentage value between 40% and 100%.

$$BundleFact(NoWire, \text{Bundle\%Load}) = (-0.138 * Ln(\text{Bundle\%Load}) + 0.352) * \ln(NoWire) + (0.067 * \ln(\text{Bundle\%Load}) - 0.259) * \sqrt{NoWire} - 1.454 * 10^{-3} * \text{Bundle\%Load} + 1.086 \quad \text{(Eq. 6)}$$

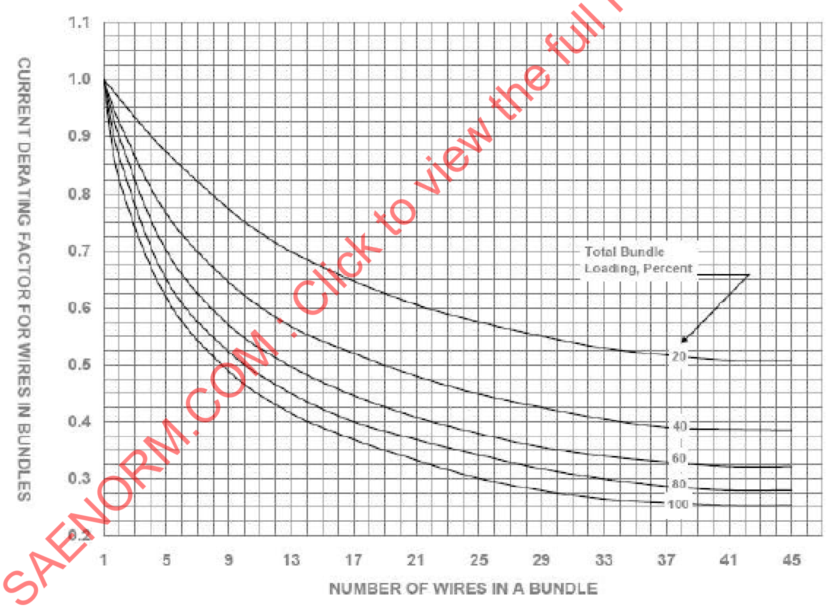

Figure 2 - Bundle de-rating factor graph

3.4.1.1 Sample comparison calculation results between Figure 2 and Equation 6.

- From Figure 2, three wires at 100% bundle loading = 0.726
- Calculated value, three wires at 100% bundle loading = 0.715
- From Figure 2, three wires at 80% bundle loading = 0.759
- Calculated value, three wires at 80% bundle loading = 0.752

3.4.2 Altitude De-Rating Factor

The altitude de-rating curve from AS50881 is shown in Figure 3. An example curve-fit equation has been provided to estimate the altitude de-rating factor values for selecting a wire size.

Also provided are two comparative results from Figure 3 and Equation 7. You will notice that the calculated values are more precise than the bundle de-rating factor, but from further inspection of this process, one can determine the influence of the altitude de-rating factor does not contribute largely in the selecting of the correct wire size, except for the cases where the selection has reached 100% loading capability of the bundle.

The following is an example curve-fit equation for altitude de-rating factor based on Figure 3. The input variable (kft) is in units of 1000 feet.

$$AltFact(kft) = -.25 * Ln(kft + 46.94) + 1.959 \quad \text{(Eq. 7)}$$

Here is the same equation, but the input variable is in kilometers (km).

$$AltFact(km) = -.25 * Ln(km + 14.307) + 1.662 \quad \text{(Eq. 8)}$$

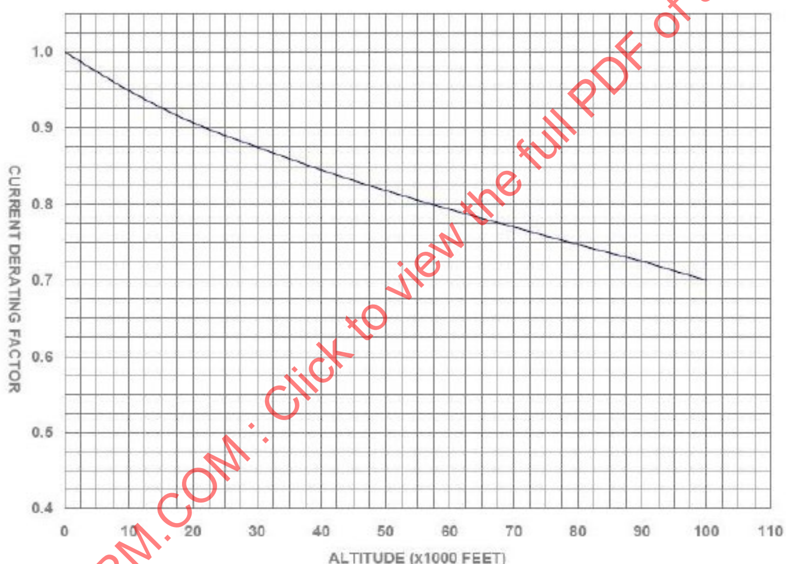

Figure 3 - Altitude de-rating factor graph from AS50881

3.4.2.1 Sample comparison calculation results between Figure 3 and Equation 7.

- Figure 3 altitude 10000 feet value = 0.949
- Curve-fit equation for Alt (10000 feet) = 0.949
- Figure 3 altitude 50000 feet value = 0.820
- Curve-fit equation for Alt (50000 feet) = 0.815

3.5 AS50881 Table 1 Comparisons

The data presented in Table 2 compares values listed from Table 1 in AS50881 to calculated current values using Equations 6 and 7 from 3.4.1 and 3.4.2 using the assumption described in footnote 2 from Table 1 in AS50881.

Table 2 - Calculated data comparison with listed wire ratings from AS50881 Table 1

AWG	AS50881 Wire Group, Current Rating	Calculated (Amps)
20	7	6.6
10	26	24.4
1/0	192	186.2
AWG	AS50881 Wire in Free Air, 105 °C Rated Wire	Calculated (Amps)
20	11	11.1
10	41	40.3
1/0	210	207.4

3.6 AS50881 Table 1 Comparison Example

Figure 4 is a comparison of calculated amp values for each wire size, shown as a red bar, compared to the data from AS50881 Table 1, using footnote 2 (current rating for wire in this table are based on 33 or more wires for sizes 26 through 10, and 9 wires for size 8 and larger, operating at 60000-feet altitude and ambient temperature of 70 °C and with no more that 20% of harness current capacity used) as the blue triangle (see Table 3). The red bar indicates the range of current carrying capacity in amps for a given wire size based on notes 1 and 2 from the conductor material column labeled 150 °C in AS50881 Table 1.

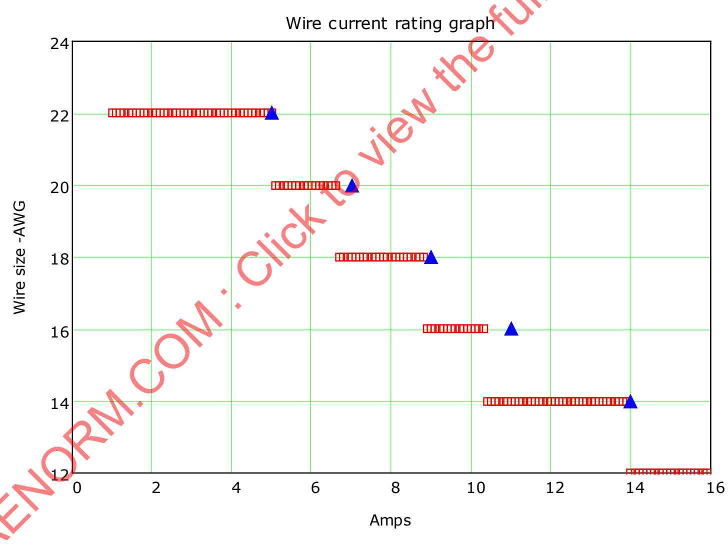

Figure 4 - Wire size calculation results

Table 3 - Extracted data from Table 1 in AS50881 (blue triangle in Figure 4)

AWG	AS50881 Table 1, Amps at 150 °C
22	5
20	7
18	9
16	11
14	14

It should be noted the positional differences between a red bar and blue triangle for any given wire size. Since Equation 6 was updated in this revision of the document, all red bars are to the left of the blue triangles. Also, not all red bars are connected to their corresponding triangle. This can be contributed to the difference in the accuracy of Equation 6 versus an interpretation of reading a value from Figure 2.

4. ADDITIONAL EQUATIONS FOR SIZING WIRES

The following paragraphs in this section are a set of equations that are not specifically called out in the process of sizing a wire gauge in AS50881 standards. Equation 9 is found in AS50881, but it is not directly mentioned in the wire sizing process. Equations 12 through 14 are only used to select a wire size in an AC circuit application.

4.1 Bundle Temperature Estimate

To better estimate a voltage drop value correctly, an accurate wire temperature calculation is required. The information from Figure 3 of AS50881 can provide a reasonable temperature value to estimate a good DC resistance compensation factor. Based on more accurate thermal calculation, the calculated temperature value presented here, using the information from Figure 1, is about 10% lower than actual temperature results, based on a utilization factor (see 4.3) of less than 65%.

For this report, the existing information will be used to demonstrate the process for selecting a wire size for a given application. By using an accurate temperature calculation, it will provide the smallest wire size selection for a given set of environmental conditions.

Example equations:

$$NewLoadamps = \frac{ConnectLoad}{BundleFactor * AltitudeFactor} \quad \text{(Eq. 9)}$$

$$TempC = 10\text{^}(\mathrm{SlopeWire} * \mathrm{Log}(\mathrm{NewLoadamps}) - \mathrm{InterceptWire}) \quad \text{(Eq. 10)}$$

The values for the two variables in Equation 10, SlopeWire and InterceptWire, can be found in Table 3 of AS50881. Table 3 equations calculate the ampacity value for a selected wire size given the temperature of the wire (Wire rating - Ambient temperature). Equation 10 calculates the temperature of the wire based on the corrected load in amperes (NewLoadamps).

From AS50881 Table 3, equation for a #4 size wire is:

$$x = 10\text{^}\left(\frac{Log(\Delta T)+2.515}{1.983}\right) \quad \text{(Eq. 11)}$$

The SlopeWire is equal to 1.983 and the InterceptWire is equal to 2.515. These values are also shown in Table 4 of this document.

References similar to Reference 2.1.6.4 and EIA Standard RS-214 will provide information on factors that influence temperature increases in a group of wires in a bundle.

4.2 AC Resistance Correction Factor

Uniform distribution of current throughout a cross section in a wire exists only for applications in a direct current (DC) circuit. In alternating current applications (AC) with increasing frequency levels, the current migrates to the outer edge of the conductor, producing a nonuniform current density distribution. This phenomenon is called skin effect. Refer to 2.1.6.2 for detailed information on the formulation of the principle for AC resistance correction factor.

The application of the AC resistance correction factor to the DC wire resistance value accounts for the skin effect due to higher frequencies above zero. For the purpose of this report, Equations 12 and 13 will calculate an AC resistance correction factor based on a cylindrical conductor having a uniform magnetic field. When a calculated value of “mr” is less than 1.0, then a minimum value of 1.0 should be applied.

$$mr = .01205 * \sqrt{\frac{Freq}{Rdc}} \text{, Where Rdc is } \Omega/1000 \text{ feet} \quad \text{(Eq. 12)}$$

The following curve-fit equation represents information provide in chapter four of W.D. Stevenson's book (refer to 2.1.6.5) regarding skin-effect resistance ratio values; also, this reference has an explanation of the term "mr." The curve-fit equation greatly reduces the computational complexity of using the original form of the equation of a Bessel function.

$$Rac(mr) = .019 * mr^3 - .0235 * mr^2 + .0102 * mr + .9998 \quad \text{(Eq. 13)}$$

This equation is acceptable for applications below 1 kHz and will usually affect wire gauge sizes larger than a size #2.

4.2.1 AC Inductance Equation

For the purpose of this report, the AC inductance calculation will be based on a three-phase tight laced group.

$$Xac = .000383 * freq * Ln(\frac{WireDiam}{K*\sqrt{1*10^{-6}*CMil}}) \quad \text{(Eq. 14)}$$

where:

Xac = ohm/ft

freq = frequency in Hz

K = factor based on the number of strands in a wire

For a 1/O wire, K = 0.449

cmil = value of cmils in the wire; for 1/O, it is 106000

For further information on this topic, refer to 2.1.6.1, reference on calculations of AC inductance. For detailed information regarding the calculating of the variable "k," refer to 2.1.6.6. The variable "k" is part of a calculation to determine the self-inductance factor based on geometric mean distance (GMD) of each individual strand of wire from each other in the conductor.

4.3 Utilization Factor

The utilization factor specifies a percentage of current capacity for selecting a wire size. The usage of this factor, by the electrical design engineer, aids in understanding the remaining current carrying capacity margin that exists for a given wire size selection. Equation 15 is the utilization factor equation:

$$PercentUtilization = \frac{Amp_{Load}*100}{10^{\frac{\log(wireRating-AmbientTemp)-Intercept}{Slope}}} \quad \text{(Eq. 15)}$$

The values for "wireRating," "Intercept," and "Slope" are wire attributes based on the selected wire size. The input information for "AmbientTemp" should be a value of the highest expected continuous temperature that the wire will sustain. "BundleFact" and "AltFact" are calculating using Equations 6 and 7 from 3.4.1 and 3.4.2, respectively.

5. WIRE SELECTION EXAMPLE CASES

5.1 Wire Length Calculations

An overlooked and unappreciated attribute for correctly determining a wire size is the estimated value for wire length. Knowledge of the wire routing in an aerospace vehicle can help avoid costly rework issues later in the development cycle of an aerospace vehicle. Looking at the wire installation routing and knowing the highest ambient temperature condition will influence the correct selection of wire. The routing of a wire may span multiple compartments and environmental conditions. Knowledge of the installation guidelines for the routing of a wire will ensure a correct selection of a wire size.

Things to remember:

- Consider using the actual wire length
- Consider the contour of the vehicle
  - Remember wire sometimes goes around other installed equipment
- Figure in the “return” wiring runs if needed, which may double wire length
- Here are some negative outcomes as a result in underestimating wire run lengths:
  - Under-sizing the required wire gauge size to meet a specific voltage drop limitation and current carrying capacity
  - Underestimating the wire weight
  - Utilizing incorrect heat loss values

5.2 Wire Selection for a DC Load

The following is an example workflow process for selecting a wire size for a DC load application. The first two points of the process are based on AS50881. The last four points are the calculations necessary to validate that a wire size selection meets the desired design requirements.

Workflow process:

- Calculate the load in amperes, corrected for bundle and altitude de-rating factors
- Select wire size based on the difference of the wire rating - ambient temperature
- Estimate the temperature of the wire for a given load and multiply a correction factor
- Calculate the resistance of wire for a given length
- Calculate the voltage drop
- Calculate the percent utilization

5.3 Wire Selection for a DC Load Example

This section will present a practical example for selecting a wire size for a DC power feeder application. The input design requirements are as follows:

- Two-wire feeder distribution
- 200 ampere load
- 35 °C ambient temperature
- 12000-feet altitude
- 50-feet wire length
- 260 °C wire rating
- Maximum voltage drop of 5.0 V

Following the workflow process in 5.2, the first thing to calculate is the corrected current carrying value using bundle and altitude de-rating factors, which will provide the x-axis value that will be used to find the intersection points in Figure 5. NewLoadamps is an example equation for this case. The value of 0.814 is the bundle de-rating factor, calculated from Equation 6 in 3.4.1, and the value of 0.94 is the altitude de-rating factor, calculated from Equation 7 from 3.4.2.

$$NewLoadamps = \frac{200\ A}{0.814 * 0.94} = 261.4\ A\ \ (X - axis) \qquad \text{(Eq. 16)}$$

Next, the y-axis value is determined by subtracting the wire rated temperature from the design ambient temperature.

$$DeltaTemperature = WireRating - AmbientTemperature = 225\ ℃\ \ (Y - axis) \qquad \text{(Eq. 17)}$$

Using the graph from AS50881, the right-hand side shows the intersection of the x and y values to determine the wire size selection. The wire selection is always to the right of the x-y intersection. Here, it would be a 4 AWG shown in Figure 5.

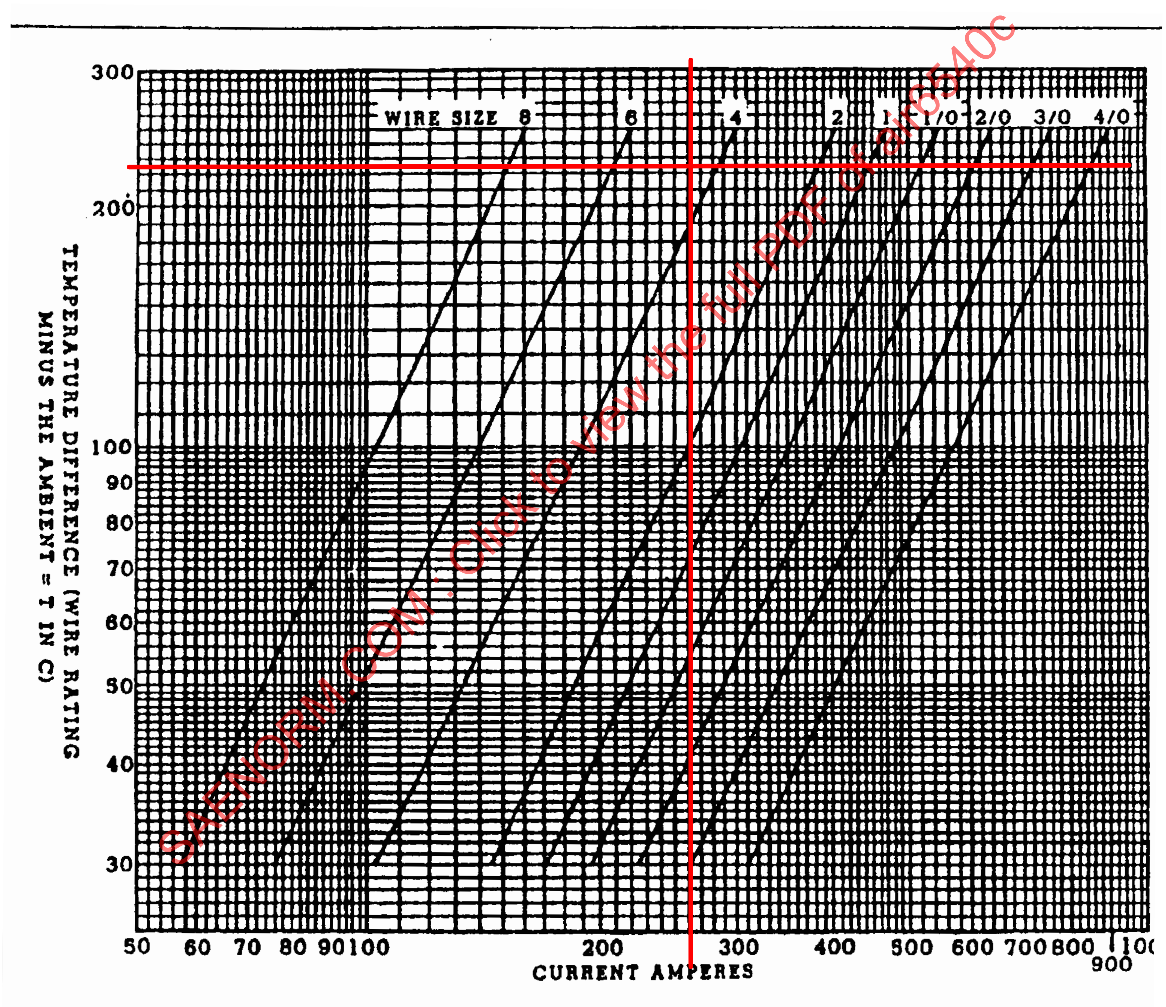

Figure 5 - DC x-y intersection example

Equations 18 through 21 illustrate the calculations used by the electrical power design engineer to validate the selected wire size from the AS50881 process that meet the desired input design parameters in 5.3.

The following values are calculated: bundle temperature estimate, wire resistance, voltage drop, and percent utilization values.

$$TempC = 10^{\wedge}(1.983 * \mathrm{Log}(261.4) - 2.515) = 189.9\ °\mathrm{C} \quad \text{(Eq. 18)}$$

$$Wresis = \frac{.275\ \Omega}{1000 * ft.} * 50\ ft. * (1 + .00393 * (189.9 - 20)) = .0229\ \Omega \quad \text{(Eq. 19)}$$

$$Vdrop = .0229\ \Omega * 200\ A = 4.6\mathrm{V} \quad \text{(Eq. 20)}$$

$$PercentUtilization = 70\% \quad \text{(Eq. 21)}$$

You will notice that the calculated voltage drop is very close to the design limit; it may be prudent for the design engineer to select the next larger size of wire to provide margin. It is important to note here that understanding and validating the design assumptions drive the correct wire size selection. The assumption of the wire length value is usually the most underestimated value of the input design requirements.

5.4 Wire Selection for an AC Voltage

The following workflow procedure details the steps to size a wire for an AC load application. The first two bullet points are the process for selecting a wire size based on AS50881. The next six bullet points are the calculations necessary to validate the wire size to determine if it meets the desired design requirements.

Workflow process:

- Calculate the load in amperes, corrected for bundle and altitude de-rating factors
- Select wire size based on the difference of the wire rating - ambient temperature
- Estimate the temperature of the wire for a given input load value
- Calculate the AC resistance value
- Calculate the corrected new resistance based on temperature, AC resistance, and wire length
- Calculate the AC inductance value
- Calculated the voltage drop
- Calculate the percent utilization

5.4.1 AC Example Input Requirements

This section will present a practical example for selecting a wire size for an AC power feeder application. The input design requirements are as follows:

- Three-phase, four-wire feeder distribution
- 115 VAC (Vref), 400 Hz (freq), 0.95 power factor (pf)
- 350 ampere load (Ia)
- 55 °C ambient temperature
- 55000-feet altitude

- 75-feet wire length
- 260 °C wire rating
- Maximum voltage drop of 4.5 V

Based on the workflow procedure, the first thing to calculate is the corrected current carrying value using the bundle and altitude de-rating factors, which will provide the x-axis value. "NewLoadamps" is an example equation for this case. The value of 0.70 is the bundle de-rating factor for a three-phase wire bundle plus a neutral wire, calculated from Equation 6 in 3.4.1, and the value of 0.803 is the altitude de-rating factor for a design altitude of 55000 feet, calculated from Equation 7 in 3.4.2.

$$NewLoadamps = \frac{350\ A}{0.70 * 0.803} = 623.2\ A\ \ (X - axis) \tag{Eq. 22}$$

Next, the y-axis value is determined by subtracting the wire rated temperature (260 °C) from the design ambient temperature (55 °C).

$$DeltaTemperature = WireRating - AmbientTemperature = 205\ °C\ \ (Y - axis) \tag{Eq. 23}$$

Using the graph from AS50881, the right-hand side shows the intersection of x and y values to determine the wire size selection. The wire selection is always to the right of the x-y intersection. Selecting the gauge curve to the left would result in an overloaded wire. In this case, the wire selection would be a 3/O wire size, which is highlighted in red in Figure 6. The resistance value for a 3/0 wire, from Table 4 for this example, will be 0.071 Ω per 1000 feet (Rdc).

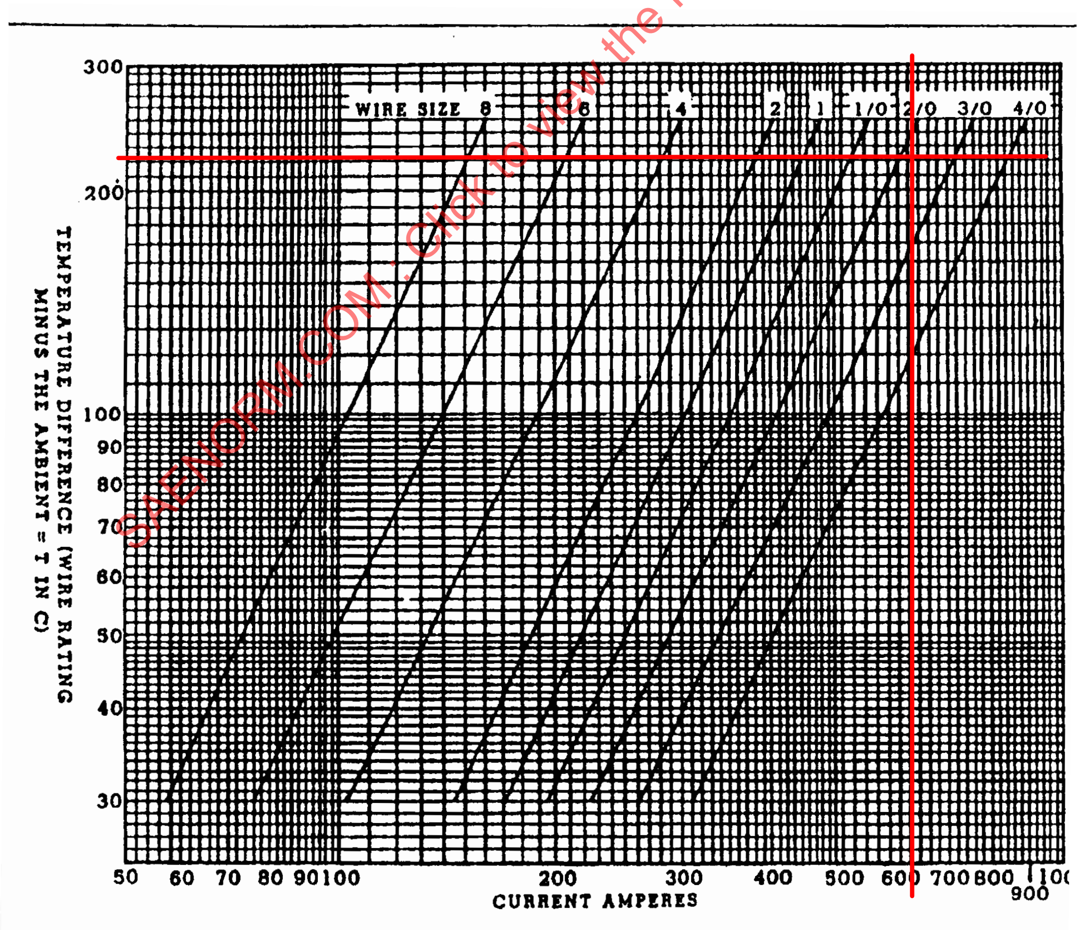

Figure 6 - AC x-y intersection example