THEORY & PRACTICE

BY THOMAS INMAN

Selecting Wire

The engineers at aircraft and avionics producing companies do a fine job, but they can't anticipate everything. Occasionally, technicians need to do some engineering in the field. This month, we look at the Federal Aviation Administration guidance for choosing wire of an appropriate size. In most cases, technicians can follow the manufacturers' documentation. But sometimes, the situation is different, and the technician must be the one to determine whether or not a wire is safe.

FAA Advisory Circular 43.13-1B contains charts and instructions on selecting wire. Over the years, this guidance has changed. Many years ago, there were only two charts and a formula. Now, there are six charts and a formula.

When connecting equipment to the voltage buss, there are two main factors to which we must pay attention. The first is voltage drop. Often, we don't think of wire as having any resistance. But in fact, it does, even though it will be a small amount. Small diameter wire has more resistance than large diameter wire. For example, an 18 American wire gauge wire constructed of stranded copper may have a resistance of 6.44 Ω per 1,000 feet. Copper stranded wire of 20 AWG (smaller) has a resistance of 10.25 ohms per 1,000 feet. If we have 10 feet of 20 AWG wire between the buss and the equipment we are connecting, the wire will have a resistance of 0.1025 Ω. If our equipment draws 5 amps, we will have a voltage drop of 0.5125 volts. If this were in a 14-volt system, the voltage drop is too high for safety.

Avionics and other devices are designed to work properly when connected to a proper voltage source. In the example above, 13.75 volts on the buss would drop to below 13.3 volts at the device. Most modern avionics are quite tolerant to voltage variations, but some of the older equipment is not. The FAA places limits on allowable voltage drops. In 14-volt systems, the allowable drop is 0.5 volts for anything that can be operated for more than two minutes and 1.0 volts for any intermittent load. An intermittent load is defined as a current draw lasting under two minutes. These values are doubled for 28 -volt systems and doubled again

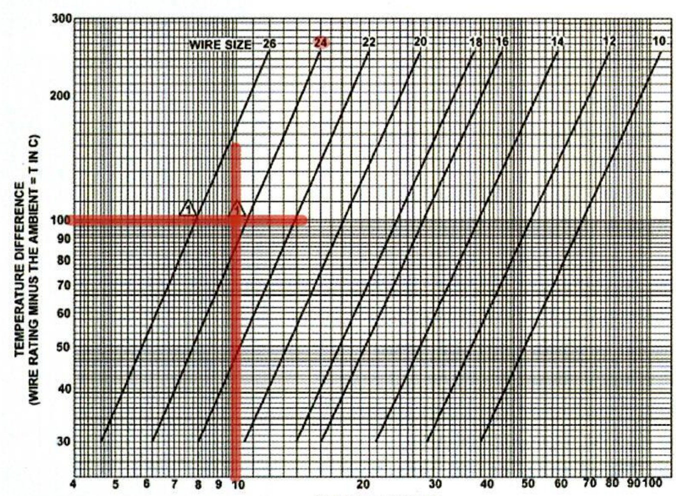
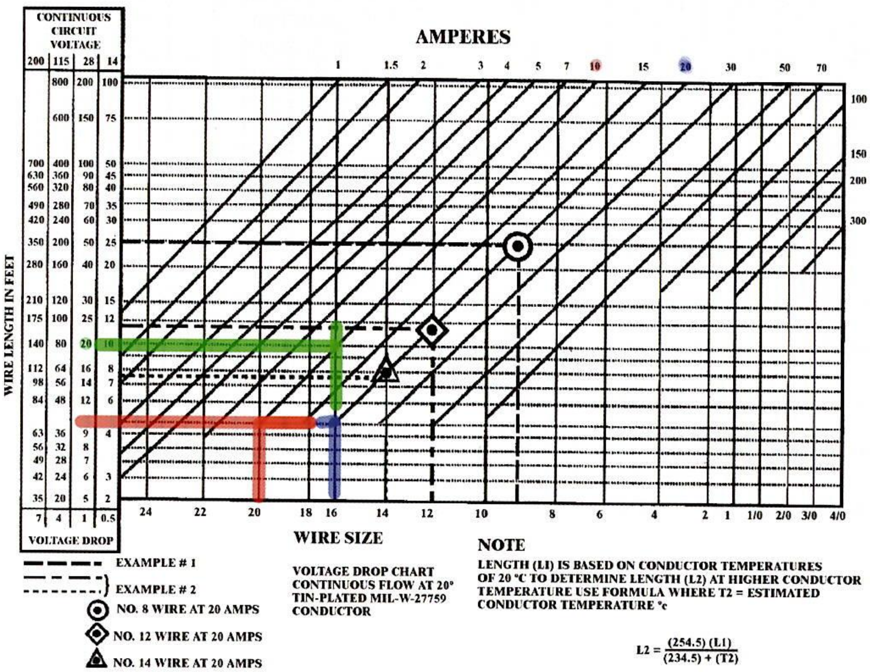


Figure 1: FAA Figure 11-4a:
A temperature derating chart for a single copper wire in free air.

Figure 2: FAA Figure 11-2: The continuous flow conductor chart. This chart can be used to determine the wire size necessary for a certain length of wire and current draw. Alternatively, it can be used to determine how long a wire could be, starting with a wire size, and current draw.



for 115-volt systems. At 200 volts, the continuous allowable voltage drop is 7 volts and the intermittent allowable voltage drop is 14 volts.

When resistance drops voltage, heat is generated. Modern avionics equipment may be tolerant to low voltage operation, but we still need to worry about heat. Staying below the voltage drop requirements is the first step in ensuring we don't generate a dangerous amount of heat in the wiring. Not only do we need to be concerned with the resistance of the wire, but also the effects of altitude, ambient temperature, and combined heat of multiple wires. Fortunately, AC 43.13-1B has charts to help.

For explanation purposes, we will use a 28-volt aircraft, with a service ceiling of 15,000 feet. We plan to have two wires (power and ground) supplying power to a device that draws 10 amps continuously and will require 10 feet of wire to make the connection. In addition, we are planning to route these wires as part of a bundle with eight other wires. Our wire has a heat rating of 150 degrees Celsius, and the environment in the aircraft could get as hot as 50 degrees Celsius.

I tell my students to start with AC 43.13-1B Figure 11-4a, shown as Figure 1. In order to cover a range from zero to 1,000 amperes, the FAA has provided two charts. These charts do not take length into consideration, so technicians get data from them that may seem rather strange. In our example, we start with the difference between the wire rating and the highest possible ambient temperature. In this case, this difference is 100 degrees Celsius. We draw a straight line to the right. Then we start at the bottom of the chart, the abscissa, and draw a straight line up from the 10-amp point. We observe where they cross and then select the next wire shown to the right, which in this case is 24 AWG. The chart warns us 24 AWG is not to be used as a single wire. But that's OK; ours is in a bundle. We will find out soon that 24 AWG wire is too small for us to use. We can move on to the next chart. As long as our next chart gives us a wire size greater than 24 AWG, we will not have any worries.

As you look at these charts, please note the wire sizes shown are the wire sizes available. There are no odd-numbered sizes.

Time to move on to Figure 2, which in AC 43.13-1B is called Figure 11-2. This is another one of two charts. This figure is for continuous current draw; its companion chart is designed for intermittent (less than two minute) current draw. On the left side of Figure 2, we have wire lengths shown in columns, with system voltage at the top and allowable voltage drop on the bottom. Since our example aircraft has a 28-volt system, we will use the column with 28 at the top and 1 at the bottom. We estimate or interpolate where 10 feet of wire starts and draw a line toward the right, as shown in red. The diagonal lines on the

$$T_2 = T_1 + (TR - T_1) * (\sqrt{I_2/Imax})$$

Figure 2A: The calculation required to determine T_2

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Figure 3: FAA Figure 11-5: Bundle derating curves, which is used to determine the derating factor for wires in a bundle.

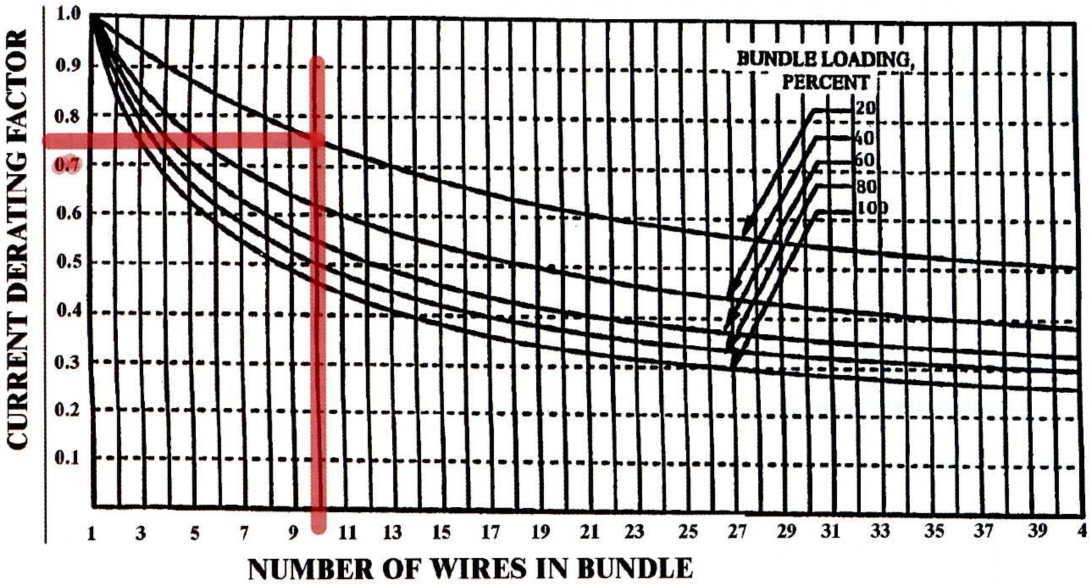

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chart are amperage draws. Our device draws 10 amps, so we will draw our red line rightward to the 10-amp diagonal and then go straight down. It seems to work perfectly, giving us a wire size of 20 AWG.

20 AWG would work on the ground at 68 degrees, in a bundle where no other wires are carrying current. These perfect conditions won't exist. The aircraft could be flying at 15,000 feet. The temperature could be as high as 122 degrees Fahrenheit (50 degrees Celsius) and two of the wires in our bundle carry current. This means we aren't done yet.

Let's move on to Figure 3, which in AC 43-13-1B is known as Figure 11-5. We need to be concerned with the combined heat of multiple wires within the same bundle. Our wires are in a 10-wire bundle, and two of them (20%) are carrying current. On this chart, we start at the bottom with the line representing 10. We move up to the 20% line and then move to the left. Once on the left side of the chart, we have a decision to make. The FAA allows technicians to interpolate, but people tend to interpolate a little differently. To avoid any possibility of an argument with someone over whether or not our line arrived at 0.75 or 0.76, I advise people to move downward to the next figure marked clearly. In this case, 0.7. This move is in the direction of more safety, and no one can make any argument we are interpreting this in an unsafe manner.

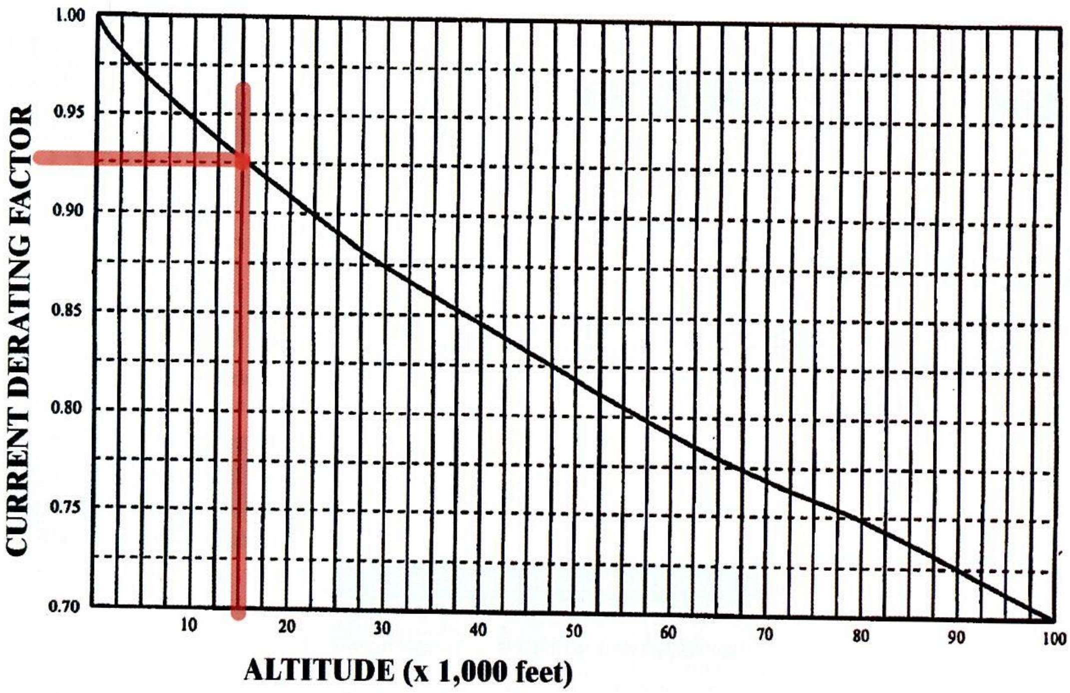
So what do we do with the 0.7? We simply take the 10 amps our device draws and divide it by 0.7. This gives us an answer of 14.29. For combined heating purposes, we will need to select a wire that can carry 14.29 amps safely. But before we go back to Figure 2, we need to do one more derating.

Figure 4, which is FAA Figure 11-6, will help us compensate for altitude. The insulation of our wire works with air. In addition, air helps with dissipation of heat. Our sample aircraft can reach an altitude of 15,000 feet where there is much less air than at sea level. On this chart, we start at the bottom and find the line associated with the service ceiling of our aircraft. We move upward from the 15,000-feet line to the reference line and then left to the derating factor. Like the bundle chart, if my work ends up between lines, I'll move downward (in the safe direction) toward the next clearly marked line. In this case, the line comes out clearly at 0.925. Now we divide again.

Previously, we derated to 14.29 amps. So now, we divide 14.29 by 0.925. Our answer is 15.45 amps, and we will need to find a wire capable of handling 15.45 amps. Now it's time to go back to Figure 2. We make a continuation from our red line. We continue to just beyond the 15-amp line. Now we have ended up between the 18 and 16 AWG wire sizes. We move to the right and find that now we need to use 16 AWG wire.

I've known many technicians who stop here, but they shouldn't. Below the note in Figure 2, there is a

Figure 4: FAA Figure 11-6: Altitude derating curve, which is used to determine the derating factor for wires based on altitude.



formula. We need to work this formula, because it will adjust the chart away from 20 degrees Celsius to the actual ambient temperature. The hardest part of this formula isn't shown on the chart. We need to find the value for T_2. Figure 2A shows the formula necessary to determine T_2. T_1 is the ambient temperature, which could be as high as 50 degrees Celsius. We also found the difference between the temperature rating of the wire and the ambient temperature, which is 100 degrees. We add this difference to T_1, get an answer of 150, and move on to the other set of parentheses. I_2 is the actual current load, which we know is 10 amps. Imax is the maximum current with our selected wire (now 16 AWG) could handle at 10-feet length. Going back to the graphic and starting at the bottom at the 16 AWG wire mark, we move up to the 10-feet length line. These are marked with blue. The angle line we find is 20 amps. So we take 10 amps divided by 20, which gives us 0.5. Now we take the square root of 0.5, which is 0.7071. With the parentheses on both sides complete, we can multiply and get T_2, which is 106.07.

Now we go back to Figure 2 in order to determine L_1. We need to answer this question: Using 16 AWG wire, how far could we go when drawing 10 amps? To get the answer, we start again at the bottom of the chart and move upward to the 10-amp line, this time highlighted green. Then we move back to the left and find the 28-volt column. We read 20 feet. We multiply 20 feet by the constant we are given, which is 254.5. Our answer is 5,090. Now for the bottom part of the formula, we add the actual current load T_2 to another constant, 234.5, and that gives us an answer of 244.5. We are ready now to compute L_2. We take 5,090 and divide it by 244.5. Our answer is 20.82 feet. If our answer is higher than the actual length we are using, we are safe. In this case, we can still use the 16 AWG wire, because 20.82 feet is a higher number and longer than 10 feet if L_2. If this number is lower than our actual length, we will need to move to a larger wire and try again.

We need to do this only in rare occurrences. Still, we need to know how to use these charts. Often, avionics technicians have a reputation for being the smart guys in the shop. For that reason, you may have a mechanic coming to you for help. Those of us who learned in the 1970s and 1980s used the old version of AC 43.13 with only one chart, so some technicians might not be familiar with the current methodology. In closing, let me remind you AC 43-13-1B helps you also determine derating factors for switches and relays, which is important for safety and the longevity of parts. ❑