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The following article is an excerpt from chapter 14 of the AeroElectric Connection.

THERMOCOUPLE TEMPERATURE MEASUREMENT

I've got a special place in my heart for simple, elegant solutions. The vapor pressure thermometer must surely find a home there along with **thermocouples.**

We're going to spend more time and words discussing thermocouples than any other temperature measurement method. The reason being that compared to all other measurement technologies, thermocouples are easiest to fabricate and put in place. During initial fly-off testing for your project consider the following list of temperatures to be investigated:

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Oil
Voltage regulator
Alternator stator winding
Alternator diode array
Fuel pump(s)
Gascolator
Vacuum pump
Magneto housing(s)
Cylinder heads (checks baffling)
EGT each cylinder (checks
   fuel mixture distribution)
Top radio in stack
Dimmer heatsinks
Electro-hydraulic power pack motor
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Some of these items will be part of your permanent instrumentation. However, most airplanes have one or more equipment items that may be damaged or rendered inoperative by temperature extremes. Each item should be instrumented and investigated for worst case scenarios that may induce adverse temperatures under ordinary flight conditions. These include low-and-slow pattern work (touch and go landings), hot day best angle climb (work'n hard - minimum cooling), heat soak after shutdown, maximum electrical load, etc. The first few hours of flight on a new project are crucial; use mandated fly-off time to assure yourself that heat stress on critical components and systems are within acceptable limits.

IT TAKES GOOD INFORMATION TO MAKE GOOD DECISIONS

This kind of temperature survey is routine during certification work on production airplanes; it's a simply a good idea. Technology historians have suggested that in spite of Russian ability to build bigger and stronger launch vehicles, more than one Russian rocket scientist was fearful for his future when development programs suffered from many, very big disasters. Scholars theorize that US ability to instrument prototypes and operational vehicles made analysis and correction of problems a breeze by comparison; US scientists read tens of thousands of data points on a space flight vehicle while the Russians recorded very few.

In a later chapter, we'll discuss failure mode effects analysis (FMEA) as a tool for enhancing reliability of a flight system. Comfortable outcome of an FMEA assumes that parts are going to fail because they've reached end-of-life (no matter how short). When parts fail because they are not properly installed or operated, the benefits of an FMEA are severely compromised. So when in doubt, **measure** it!

Thermocouples make it relatively easy to do. Thermocouple wire is sold in spools of various sizes and types of insulation. Thermocouples are easy to fabricate and attach to equipment items you wish to monitor. A single readout instrument may be switched to an array of thermocouples; surveys can be conducted with a minimum of expense and cockpit clutter from test hardware. Thermocouples are the ultimate engineering and flight test temperature research tool. I'd bet that US space flight vehicles have more thermocouples on board than any other

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sensor.

THE SEEBECK EFFECT - ELECTRONS ON THE LOOSE:

As we've observed in our daily lives and as I've discussed here, temperature affects materials in a variety of ways. We know that all materials are made of atoms; atoms have electrons whizzing around their nucleus and atoms consist mostly of empty space. It is less commonly known that the atoms within any solid are constantly exchanging electrons to a certain degree depending on the makeup of the material *and its temperature*. Some materials are less capable of hanging onto their rambunctious electrons than others. So, if you put differing materials in contact with each other and if the materials are otherwise reasonable conductors of electricity (metal) then a voltage difference will appear between the two conductors. The material with the stronger grip on its electrons will steal a few from the other material and acquire a more negative potential (voltage) with respect to the other conductor. The amplitude of the potential (voltage) depends both on the type of metals used and upon the temperature which exists at the junction of the dissimilar metals. We've already discussed the concept of absolute zero, a place were all molecular motion stops. It's no leap of faith to understand that the voltage generated by a thermocouple goes to zero volts at 0ºK. Okay! All we gotta do is hook a voltmeter to the two conductors and convert the resulting reading to temperature.

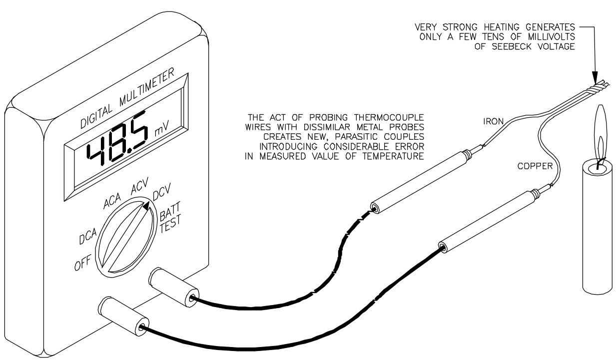

Figure 14-8. Basic Thermocouple.

One may fabricate a thermocouple from any two, ordinary metals. This concept is illustrated in Figure 14-8 where I show an iron wire twisted together with a copper wire. There's a just a couple of very tiny problems: First, the voltage generated between the two materials is small. A typical thermocouple generates a voltage between 20 and 60 **microvolts** per ºC. So even though we've heated the copper/iron junction very strongly with an open flame, the generated voltage is small - a few tens of millivolts. Until a few years ago, dealing with the tiny voltages was a real challenge. I was first introduced to thermocouple measurement techniques in the early '60s. Back then, tiny thermocouple voltages were measured with a cumbersome device called a millivolt potentiometer. It was housed in a box about 10 inches on a side. Voltage measurements were made by rotating a range switch and a large dial until a needle on a meter was centered. Each measurement could take 10-15 seconds. Measured voltages were recorded by hand onto a datasheet and later converted to temperature measurements by referring to charts. It was easy to make mistake in taking a reading especially when taking a lot of measurements in flight.

The second problem with thermocouples arises from installation logistics. Recall that **any two dissimilar metals will form a thermocouple.** In the illustration of Figure 14-8, I've shown plated brass probes making connection to the iron and copper thermocouple wires. These points of contact create two new, parasitic thermocouple junctions. Further, as you advance up the voltmeter lead wires, into and through the instrument's internal wiring, more parasitic thermocouples may be found; each couple contributing or detracting from the reading of interest. Fortunately, dealing with parasitic couples is easy.

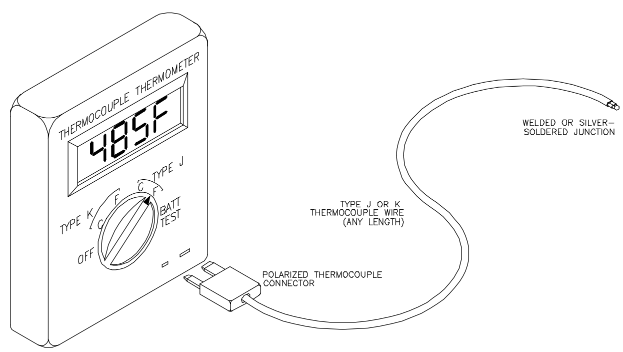

Figure 14-9. Off-the-Shelf Thermocouple Instrument.

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Nowadays, one may purchase direct readout thermocouple thermometers for as low as $80 (see Figure 14-9). These handy instruments have internal cold-junction or "ice-bath" compensators. They are also programmed to compensate for small non-linearities in voltage vs. temperature curves. Further, even the low cost instruments will utilize either type J or K thermocouple wire. Finally, one may choose to read either ºF or ºC. Some low cost, hand held instruments have two jacks to allow switching between two thermocouples. I don't recommend paying extra for a dual thermocouple device. In my experience, every time I've needed to measure more than one temperature at a time in an airplane, it was always more than two. Invariably, I have to rig a multi-pole thermocouple switch which I will describe later in this chapter.

Table 14-2. Thermocouple Voltage (mV) Vs. Temperature (Reference to Ice-Bath).

Temp ºC	Temp ºF	Type J Wire	Type K Wire
-40	-40	-1.96	-1.50
-30	-22	-1.48	-1.14
-20	-4	-1.00	-0.77
-10	14	-0.50	-0.39
0	32	0.00	0.00
10	50	0.50	0.40
20	68	1.02	0.80
30	86	1.54	1.20
40	104	2.06	1.61
50	122	2.58	2.02
60	140	3.11	2.43
70	158	3.65	2.85
80	176	4.19	3.26
90	194	4.73	3.68
100	212	5.27	4.10
110	230	5.81	4.51
120	248	6.36	4.92
130	266	6.90	5.33
140	284	7.45	5.73
150	302	8.00	6.13
160	320	8.56	6.53
170	338	9.11	6.93
180	356	9.67	7.33
190	374	10.22	7.73
200	392	10.78	8.13
210	410	11.34	8.54
220	428	11.89	8.94
230	446	12.45	9.34
240	464	13.01	9.75
250	482	13.56	10.16
260	500	14.12	10.57
270	518	14.67	10.98
280	536	15.22	11.39
290	554	15.77	11.80
300	572	16.33	12.21

Before we discuss practical applications of thermocouples let's explore their operation in more detail. Further, let's define several new terms: "type J" and "type K" wire along with "ice-bath" and "cold-junction." There are dozens of thermocouple wire types - each was developed for a specific task. The two most common thermocouple wires for aircraft instrumentation are fabricated from some pretty strange sounding stuff: iron-constantan (type J) and chromel-alumel (type K). Constantan, chromel and alumel are special alloys designed specifically for thermocouple use. Their characteristics are carefully controlled and agreed upon by international industry standards. Any spool of thermocouple wire marked type J or type K will yield consistent, predictable results according to Table 14-2. When designing a useful thermocouple one must consider Seebeck voltage (some combinations of alloys generate much higher voltages per degree than others), operating temperature (you don't want the thing to melt!) and resistance to materials in the environment to be measured (strong acids, oxidizers, caustics, etc., may dissolve the sensor). Finally, one must select an insulation suited to the operating environment.

Type K alloys are suitable for any kind of measurement on an airplane including exhaust gas temperatures. Type J has a recommended upper limit that suggests it not be used in exhaust stacks but it is fine everywhere else. As you can see from voltages in Table 14-2, Type J wire has a little more output for a given temperature than does Type K but for most purposes, either is satisfactory. The most universal insulation is a woven Fiberglas which is not very neat to work with but it has very good high temperature characteristics. My favorite is Kapton covered wire. It's smooth, strips nicely and has temperature characteristics that work everywhere except in the exhaust gas stream - no big deal; you need special, shielded probe for EGT work anyhow. Here's how you identify type J and K wires:

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Table 14-3. Thermocouple Conductor Identification.			
Conductor	Insulation Color	Voltage Polarity	Magnetic ?
Type J Wire: Iron/Constantan			
Iron	White	Positive	Yes
Constantan	Red	Negative	No
Type K Wire: Chromel/Alumel			
Chromel	Yellow	Positive	No
Alumel	Red	Negative	Yes

Spooled thermocouple wire has a unique appearance and usually conforms to marking conventions that make it easy to identify. First, any thermocouple wires you are likely to encounter are always paired. The outer jacket may be any color. Insulation over the inner conductors usually follows industry standards: For type K wire the positive conductor is made of chromel, insulated in yellow and identifiable as non-magnetic. The negative wire is made of alumel, insulated in red and will be attracted by a magnet. In type J wire, the positive conductor is made of iron, insulated in white and magnetic. The negative conductor is constantan, insulated in red and is non-magnetic. These identifying attributes are summarized in Table 14-3.

An aforementioned consideration for working with thermocouple wire is the issue of parasitic couples - all electrical circuits are fabricated from some kind of metal (conductor). There's no way to get electrons to flow from point A to point B without bringing two pieces of metal together. So, making the transition from thermocouple wire to instruments requires special attention. One of the neat things about working with thermocouple is that parasitic couples don't have to be eliminated, they just need to be accounted for. For every parasitic couple in one side of a thermocouple lead, you need one of equal potential but opposite polarity in the other lead.

In Figure 14-10, View -A-, I show two chromel-alumel thermocouples hooked in series with their alumel wires brought together. This means that the "hot" junction generates a voltage opposite in polarity to the "cold" junction. If both couples were at the same temperature, the net voltage at the instrument is zero. Now, let's place the "cold" couple in a known temperature environment, say a bath of crushed ice and water. We know that while any ice exists, the bath is 0ºC. Now the voltage measured between the two couples is proportional to temperature difference between the "hot" and "cold" junctions. Further, note that our voltmeter is now connected to two constantan wires. The two parasitic couples at the voltmeter terminals now have equal but opposite effects on the voltage of interest. In other words, irrespective of their voltage, they are opposing polarities and equal to each other - they cancel each other out. Now our instrument need be concerned only the calibrated difference voltage between hot and cold

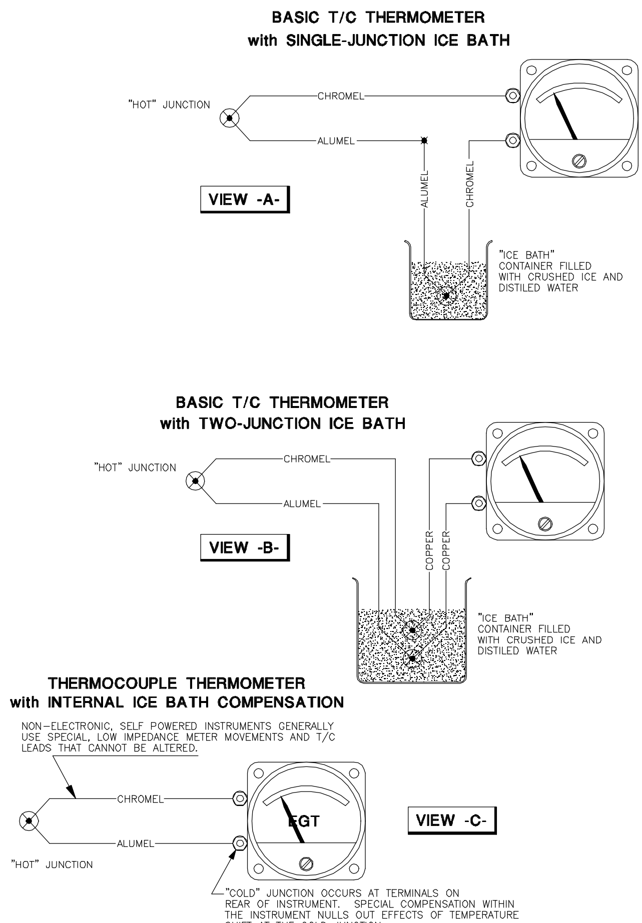

Figure 14-10. Generic T/C Thermometers and Various Cold Junction Techniques.

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junctions. Further, the hot junction's temperature will be represented by the voltages described in Table 14-2.

View -B- shows a two-junction ice bath. This setup is useful if you have a very long run between thermocouple and instrument - it's less expensive to do the long run in copper wire. In this case we may transition from any thermocouple wire into copper. Now we have two parasitic couples: one is chromel-copper, the other is alumel-copper. It turns out this system works fine when **both** transition junctions are referenced in the ice bath.

Needless-to-say, an ice bath isn't a convenient temperature reference to carry around in an airplane *(although years ago, I did it - had a special Thermos bottle with a cork that had a number of reference junction thermocouples sealed in it).* Fortunately, electronic replacements for a reference junction are possible. There are a number of instruments flying in airplanes that appear to be no more than a meter with a thermocouple attached. Common examples include exhaust gas temperature (EGT), cylinder head temperature (CHT) and a smattering of carburetor air temperature gages. If you find one of these indicators separated from its companion thermocouple you need to know that the thermocouple is matched to the instrument. The instrument contains a special, low voltage movement along with reference-junction compensation. Low voltage movements tend to draw quite a bit of current - perhaps as much as 100 milliamps! Therefore, resistance of the companion thermocouple assembly is part of the instrument's calibration. As a general rule, un-amplified instrument thermocouples cannot be shortened or extended. When Smiley Jack's Almost-Good-As-New Airplane Parts Emporium offers you such an instrument, be sure to check its calibration just be sure that the thermocouple supplied is really the one that belongs with it. Boiling water is a good calibration bath at 212ºF (100ºC); an ice bath is 32ºF (0ºC); etc. If in doubt, any instrument shop can take a quick look at it to be sure it's working properly.

Except for a few cautions, the unpowered thermocouple gage is quite attractive. It can be accurate and requires no wiring to ship's DC power. Such an instrument is illustrated in View -C-. Obviously, the reference-junction for this instrument exists right where the thermocouple wires bolt to the back of the instrument. Reference-junction compensation doesn't have to look like a 0ºC ice bath. The reference-junction compensator just needs to know what the temperature is at the studs on the back of the instrument case; no problem since the compensation circuitry is right inside the case!

The basic tenets of thermocouple measurement are: (1) use two couples in series opposing so that the voltage to be measured is a function of temperature difference between the two couples and (2) design the measurement system so that all parasitic thermocouples exist in opposing pairs. With these concepts in place, we can discuss techniques for switching multiple thermocouples to a single instrument.

Let's suppose you wish to log a bunch of temperatures during your fly-off hours. Consider building your own thermocouple selector switch. Purchase a 12-position, 2-pole rotary switch from one of the catalogs listed in Appendix-A. Mount the switch on one side of an aluminum box and along with two, 13-position terminal strips. Figure 14-11 illustrates the right and wrong way to configure a thermocouple selector switch. You may use ordinary hook-up wire (22AWG aircraft wire is fine) to wire it. It is true that considerable **error** is introduced by each joint of non-thermocouple metal introduced in each leg of a thermocouple. The secret is that errors of **equal** and **opposite** amplitude are created in pairs - one on each side. By observing the second law of thermocouples, errors induced by our switch box cancel each other out.

Readers have called to ask what was wrong with their modern, digital display for CHT or EGT where they were attempting to switch a single instrument between multiple thermocouples. The first question is, "Are you using a two pole selector to switch **both** sides of the thermocouple?" There are expensive, commercial equivalents to the thermocouple selector switch just described. If you can find a used one for a reasonable price (like 30-50 dollars), buy it and donate it to your local EAA chapter. Every new airplane should be surveyed for a variety of temperatures during flyoff hours or after some kinds of major modifications to the power plant. After that, your selector switch and thermocouple readout will sit on the shelf and gather dust. It would be better if your local chapter owned a thermocouple selector switch and indicator for loan to members. That way a few pieces equipment would suffice for many projects as needed.

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When setting up for multiple measurements with a selector switch, be certain the instrument you use is a **high input impedance** device that doesn't care about thermocouple resistance . . . self-powered instruments mentioned earlier are not good candidates for this task. However, any modern, digital thermocouple thermometer will be fine.

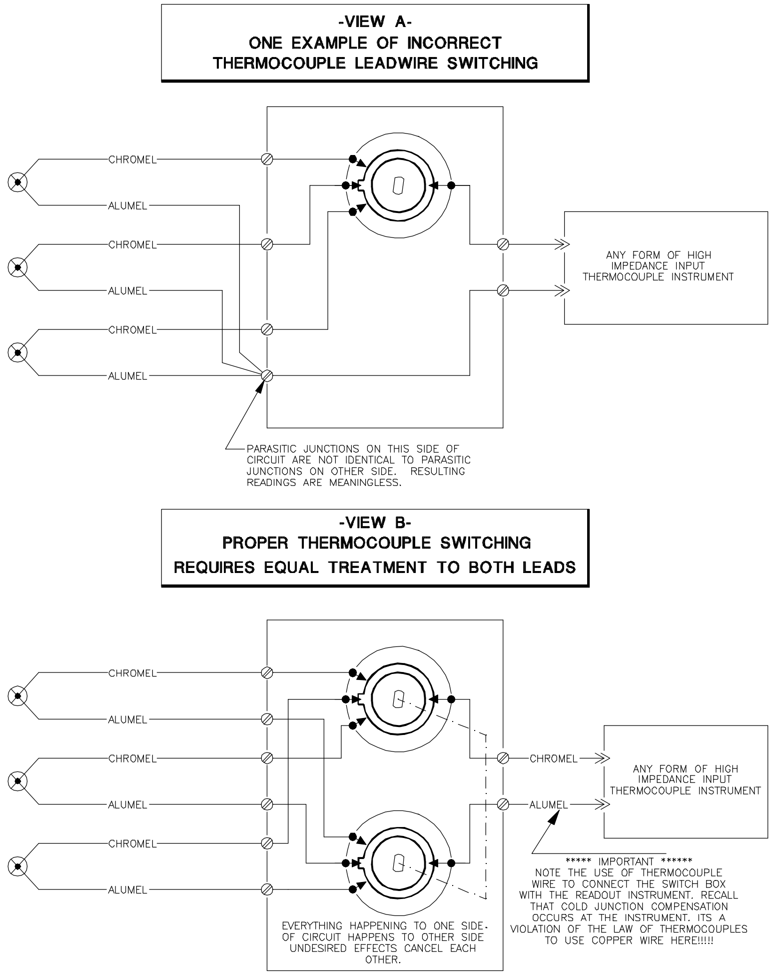

Figure 14-7. Switching Multiple Thermocouples to a Single Instrument.

AMPLIFIED THERMOCOUPLE THERMOMETERS

While on the topic of high impedance instruments for thermocouples, I'll call your attention to Figure 14-12. In View -A- the hot-junction and reference-junction setup is similar to Figure 14-10, View -A- except: an electronic amplifier inserted between thermocouple wires and indicator. Some interesting things happen when you add an amplifier. (1) the indicator becomes a simple, much less expensive, voltmeter and (2) the current flowing in the thermocouple wires is for all practical purposes, zero. Length of thermocouple wire is no longer critical; insertion of a selector switch to manage many thermocouples is feasible. The last inconvenience to eliminate is the requirement for an ice bath . . . .

A company called Analog Devices builds integrated circuits for thermocouple signal conditioning. A sample circuit is shown in Figure 14-12, View -B-. The AD594 integrated circuit is designed to provide amplification, cold junction compensation and linearity compensation for type J thermocouple wire, the AD595 is used with type K wire. The device outputs a voltage of 10 millivolts per ºC of thermocouple temperature. These circuits will work in the minus temperatures if two power supplies (+5 and -5 volts) are provided. Thermocouples work best above 0ºC and are quite suited for oil, EGT and CHT measurements. For these parameters, temperatures of interest are well above 0ºC. Therefore, a single +5 volt supply works find for measurements between 10ºC (.10 volts) and about 300ºC (3.00 volts).

For example: Let us suppose you want to display oil temperature over the range of 30 to 130 degrees C (86 to 266 degrees F). The output from the AD595 and type K wire will be 300 to 1300 millivolts over that range (10 millivolts per degree C). So, instead of designing a differential voltmeter for 10-16 volts as in Chapter 7, we're going to design for 300 to 1300 millivolts. The values shown in Figure 14-12 are appropriate for a meter having a full scale current of 1 milliampere and internal resistance of 200 ohms. Resistors for other meters can be calculated using techniques described in Chapter 7 *(OR you can simply use a digital panel meter with the decimal point set in the right place to display 10 mV/ºC as temperature.)*

Now, remove the meter's existing scale plate and paste a new scale on having a calibration and label as shown. A similar technique could be applied to cylinder head and exhaust gas temperature indicators. So, you see that one may consider building some instruments that are accurate, calibratable and **repairable** by you, the builder. I have a variety of scale plates already drawn in AutoCAD that would be easily customized to any basic meter movement. If you'd like to take a whack at building thermocouple driven temperature gages, let me know.

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A final note on the AD594/AD595. If you own a decent digital or analog voltmeter you may use one of these devices to build a small adapter for measuring temperatures with thermocouples. You'll need to mentally place the decimal point for conversion of volts to degrees, e.g. 1.000 volts = 100ºC; 0.550 volts = 55ºC, etc.

SPLICING THERMOCOUPLE WIRES

Thermocouple wires are easily repaired, carried through connectors or extended by splicing. However, you're now aware that special techniques are required. A number of companies sell splicing devices for joining two thermocouple conductors. One may purchase butt splices that are similar in appearance to those designed for joining ordinary copper wire. If you wish to bring a thermocouple pair through a multi-conductor, bulkhead connector, crimpable terminals of the proper alloys are available but they are not cheap . . . I've paid as much as $25.00 per pin for chromel-alumel pins to fit MS3120 series connectors . . . that's $100 for parts to bring one pair of wires through a connector! I try to avoid bringing a thermocouple through any kind of connector along with other wires. There's a lot of temptation on the part of builders to bring all wires penetrating a firewall through on some kind of connector. For cost, weight and time savings, I recommend fabricating firewall penetrations from ordinary grommets with sheet metal fire shields.

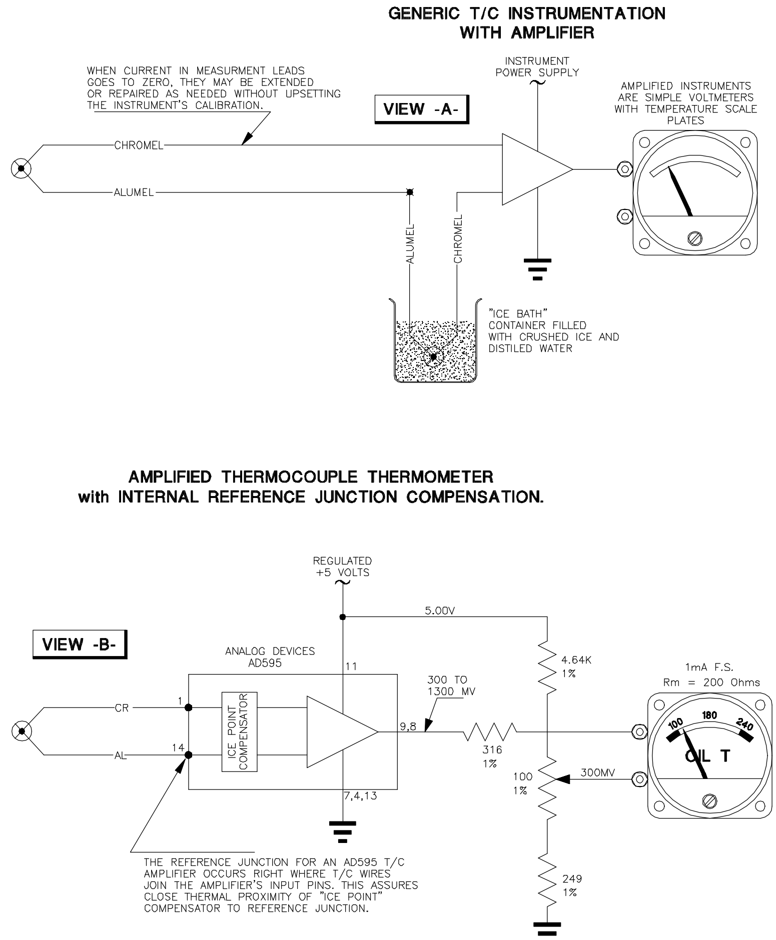

Figure 14-12. Amplified Thermocouple Thermometers.

One may purchase small, polarized connectors with molded plastic housings. These are generally attached to the conductors with tiny set screws. I believe they are offered both for semi-permanent splicing and as mated-pair connectors that permit breaking and rejoining a splice for maintenance. These connectors are not outrageously expensive. If you would like to remove an engine without de-mounting oil, cylinder head and/or exhaust gas thermocouples, these low cost connectors should be considered.

Occasionally, one simply wishes to permanently join a pair of conductors when a repair or replacement of a thermocouple is done. Other times, a thermocouple wire installation task is made easier by breaking up a thermocouple wire run into two or more segments. Chromel-alumel and iron-constantan conductors may be soldered. Unfortunately, they do not alloy with ordinary tin-lead solder. I prefer silver-solder so a torch is required to achieve adequate temperatures for joining. Further, at silver-solder temperatures, you are going to smoke some insulation on the wires - a condition that does not occur with ordinary electronic soldering operations. The trick is to minimize the damage and to end up with a clean looking splice.

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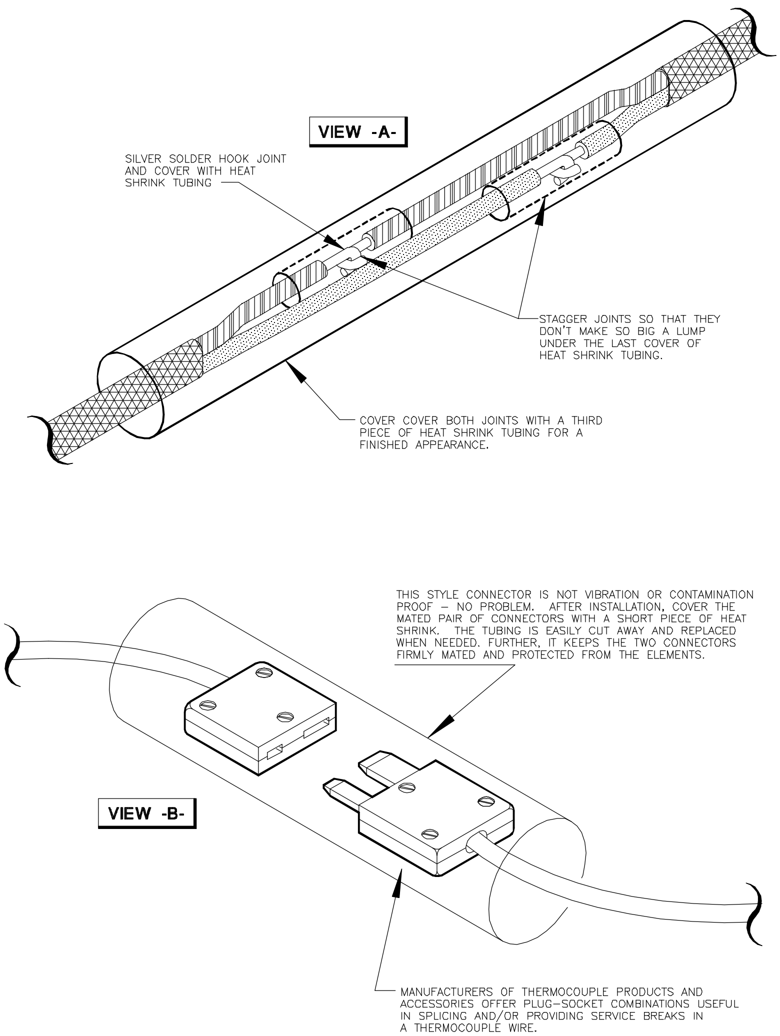

Figure 14-3. Splicing Therocouples.

Figure 14-13 illustrates two methods for joining segments of thermocouple wire - solder or install a thermocouple connector. To solder as in View -A-, strip outer jacket of thermocouple pair about 4-inches on each end to be joined. Cut the conductors to be joined so that the solder joints are staggered; one joint about 1-1/2" from the first outer jacket; the second an equal distance from the other outer jacket. Strip inner insulation from each conductor about 1/2". Slip a 6-inch piece of 3/16" heat-shrink tubing over the outer jacket of one pair and 2-inch pieces of 1/8 or 3/32 inch heat shrink over each of the long conductor stubs. If you can find high-temp, Teflon heat shrink for this task, great. However, plain vanilla variety will do nicely too. Bend a J-hook in the very tip of the first two wires to be joined, interlock them and close the hooks with pliers.

Now, if your propane torch were to be compared with a Star Trek hand-fazer, we're going to set it for "gentle stun" mode; just enough energy to get a humming bird's attention without knocking it off its feet. One-fourth inch of dark blue, inner flame cone extending past the end of the mixing chamber is about right. Some torches I've used for this task wouldn't burn well at this setting until they've burned at a higher setting for a few minutes to warm up.

First, coat the joint of interlocked wires with silver-solder flux. Now, the task is to form a tiny joint with minimal melt-back on the insulation. Success depends on getting solder to melt at the same time the wires get up to alloying temperature. Generally, the solder heats slower than the wires so I try to bring the tip of the inner blue flame tip up to the wires about two or three seconds after putting the end of the solder into the flame tip. If you're really nimble with this process you will be on and off the joint with the torch in about 6-8 seconds. You may want to practice with a few scraps of wire before you climb into you airplane to try this. Be aware that silver solder flows at red-heat temperatures. Further, be prepared for more melt-back than you would really like to see.

In words this probably sounds more difficult than it really is. Further, there is no great sin in smoking a little more insulation than you'd like . . . we're going to cover the dirty deed with two layers of plastic! When the first solder joint has cooled, clean off any flux residue that will now look like a thin coat of glass over your finished joint. Use needle nose pliers to simply crush the fused flux - it will fall away easily. Slip heat shrink over the finished joint and shrink into place. Put another piece of small heat-shrink over the other long stub and interlock two j-hooks. *Electronic stores, like Radio Shack, sell a "third hand" soldering aid that you may find useful in fixturing your victims for this operation. In a pinch, build your own fixture by soldering two alligator clips to a 6" piece of 10AWG bare copper wire and bending it into a U-shape so that the clips can support your wires to be joined on either side of the joint.*

Solder then shrink a cover over the second joint. Finally, position and shrink the large tubing over the whole business and you're done. The judges at Oshkosh will marvel over your

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clever joining of the "un-joinable" and never know how badly the insulation suffered in the process. Furthermore, instrument panel temperature gauges will read exactly what they are supposed to read: temperature at the far end of the thermocouple pair, unaffected by temperatures encountered along the way.

Figure 14-13, View -B-, shows a small, mating pair of thermocouple connectors sold by virtually every firm specializing in thermocouple products and accessories. Digital thermocouple thermometers often feature a female side of this style connector right on their front panel as shown in an earlier figure. These connectors are inexpensive . . . a few dollars per mated pair. Use these guys to break thermocouple leads when dismounting an engine without having to remove the thermocouples from the engine. Text in Figure 14-13, View -B-, suggests a means for securing these connectors from separation under vibration and protecting them from most environmental hazards.

FABRICATING & REPAIRING THERMOCOUPLES

The really neat thing about thermocouple wire is that you can make your own temperature sensors at the end of any desired length of thermocouple wire. Simply extend the wire from the instrument to a site where temperature is to be measured. Strip the insulation off the end and twist the wires together. Various laboratories I've worked in were equipped with thermocouple welders. These are nifty little machines that allow one to twist a thermocouple pair of wires together and use an electric arc to fuse them to form a neat thermocouple. The operation occurs so quickly and with so much energy concentrated at the joint that melt-back of adjacent insulation is minimized. Further, no foreign metals are introduced into the joint. Since we're not looking for laboratory grade accuracy in aircraft systems temperature measurements, the silver solder joining technique makes an excellent alternative to the purchase of a laboratory welder and uses inexpensive tools and techniques available to the amateur airplane builder. Just twist the stripped ends of the thermocouple wire together, solder with silver solder, break away flux residue and trim overall length as desired. A thermocouple joint can never be too small to function. Size of wire is purely a logistical consideration. You can buy thermocouple wire in gages (.001" diam) suitable for taking a bumble bee's temperature. On the other hand, hefty wires (18AWG for example) are available for very rough environments. Either wire is read by the same instrument!

Insulation becomes the last consideration. Most thermocouples wires found on factory installed aircraft instruments will have a form of Fiberglas insulation on them. This insulation is resistant to most environmental stresses found on airplanes. Thermocouple wires are also commonly insulated with materials like Kapton and Kynar and Teflon. Since thermocouples are most often used to read temperatures well above ambient levels, they are purchased with heat resistant insulations. If you stumble across some thermocouple wire as a surplus item, it's probably suited to measuring about anything found on an airplane. The tough one is EGT which requires type K wire and Fiberglas insulation.

PERMANENT THERMOCOUPLE THERMOMETERS

There are at least 3 situations where you may wish to install permanent, thermocouple driven instruments on the panel. One each for oil temp, cylinder head temp (hottest one as surveyed during flyoff) and EGT (hottest one as surveyed during flyoff). As illustrated back in Chapter 7, it's not difficult to configure a meter to read any desired range of voltages. With a few more components, you can make the meter read a range of temperatures as well.

CALIBRATED ELECTRONIC TEMPERATURE SENSORS

Back in the days of germanium transistors, designing solid state circuitry to operate over wide temperature ranges was challenging. We cursed the fact that solid state devices had strong, undesirable responses to temperature. Thirty years later, clever designers of electronic components have capitalized on these phenomena to take advantage of certain temperature effects. In fact, the AD595 integrated circuit described earlier uses an internal solid state temperature sensor to develop a voltage for reference junction compensation. If resistance versus temperature devices are called RTDs, I guess we could call voltage versus temperature devices VTDs.

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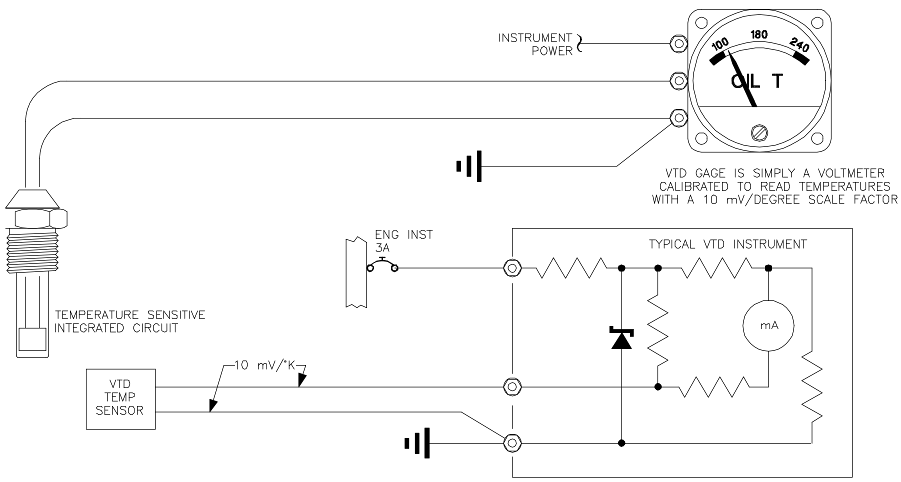

Figure 14-4 Solid State Temperature Sensor.

Several manufacturers build VTDs that look for all the world like a simple, zener diode voltage regulator. However, this "regulator" is very unstable - in fact, it drifts at a rate exactly equal to 10 mV/ºK or 10 mV/ºR. Hmmmm . . we saw that 10 millivolt figure earlier. That's become a sort of industry standard for temperature measurement devices. Everyone builds parts calibrated for measuring C-size degrees, most also make F-size parts too. Figure 14-14 shows a basic thermometer using a calibrated VTD. The indicator is nothing more than a voltmeter with scale factor of 10mV per degree times total degrees of span and an offset equal to 10mV per degree times the lower end of scale temperature reading. The architectures for expanded scale voltmeters described in Figure 14-12 and Chapter 7 are applicable.

VTDs are **calibrated** devices as supplied from the factory. They are quite accurate, typically plus or minus 1.0ºC or better. Their scale factor of 10 mV/ºC is the same as the thermocouple amplifier shown in Figure 14-12, but they are somewhat simpler to use as illustrated in Figure 14-14. Their disadvantage is that their operating temperature ranges do not span as far as thermocouples. They are currently unable to measure exhaust gas temperatures; exhaust gases will remain an exclusive domain of thermocouples. Further, few solid state sensors are rated for temperatures experienced on cylinder heads. However, they do work well at low temperatures (below 0ºC); actually better than thermocouples. Therefore, VTDs are well suited for OAT measurement. Their large inherent scale factor of 10ºC overpowers parasitic thermocouples which exist in the interconnect wiring so leadwires between instrument and solid state temperature sensors require no special treatment.

BEWARE THE LURKING GROUND LOOP

Solid state temperature transducers can suffer the same installation induced inaccuracies as the single wire RTD transducer mentioned earlier. I design all VTD sensors to bring a pair of wires all the way from VTD to indicator. Any time you encounter a single conductor, engine mounted sensor (temperature or pressure), ground the instrument for that sensor to the engine via its own, dedicated ground wire.

INTEGRATED INSTRUMENTATION SYSTEMS

Several folk are offering integrated instrument systems, usually with liquid crystal displays, that present one or more temperatures all at once. Virtually all will use either thermocouples or solid state temperature sensors. Unless instructions for your integrated instrumentation system state differently, you may splice and/or extend sensor leads for companion sensors; technique depends only upon whether they are a thermocouple or solid state sensor.

OIL AND WATER TEMPERATURE PROBES

Most access to water or oil flow in an engine is through tapered, pipe-thread openings. The plumbing department of a well stocked hardware store will yield a brass plug the proper size to fit your engine's oil or water temp sensor opening. Good thermal contact of your temperature sensor (thermistor, thermocouple or solid state) with the fluid being monitored is essential. The usual technique calls for fabricating a "thermowell." A thermowell is illustrated in Figure 14-15. Actually, about every temperature transducer (or sender) is a form of thermowell. The purposes of a thermowell are (1) to extend into a liquid far enough to measure its temperature in the main fluid flow and (2) get as much thermal isolation as possible from the surrounding environment (crankcase, etc.). The thermowell I like to build is illustrated in Figure 14-15. It is fabricated from a brass plug through which I drill a 1/4" hole. A piece of thin-wall, brass tubing is soldered into the plug. The length of the tubing is that which is judged to place the sensor into free flow of fluid inside the engine. The sensor end is squeezed shut and soldered. The sensor is then cemented or soldered into the bottom of the "well." Silicon sealant around

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the wire as it exits the plug is a good idea to prevent damaging the wire by pressing against the edge of the hole. Sometimes, a close wound spring is cemented into place about the wire to provide radius-relief and reduce stress on wire when tugged.

CYLINDER HEAD TEMPERATURE MEASUREMENT

Most modern aircraft engines have thermowells built into the cylinder head. These are generally threaded for an adapter which accepts a spring loaded, bayonet-locking retainer for a thermocouple or RTD probe. I've built CHT probes using salvaged hardware purchased from an engine rebuild shop. What you need are the threaded adapter, retaining ring and the spring which is used to keep the sensor pressed against the bottom of the hole.

You can use generic hardware to build your own CHT thermocouples. Find a threaded plug that fits the thermowell on the engine. Drill through the center and chamfer the edges for wire protection. Find a stainless steel compression spring for use under the plug to hold your fabricated thermocouple against the bottom of the thermowell. Even if your CHT instrument displays one cylinder only, consider techniques outlined earlier to build a selector switch to display any desired cylinder on a single instrument.

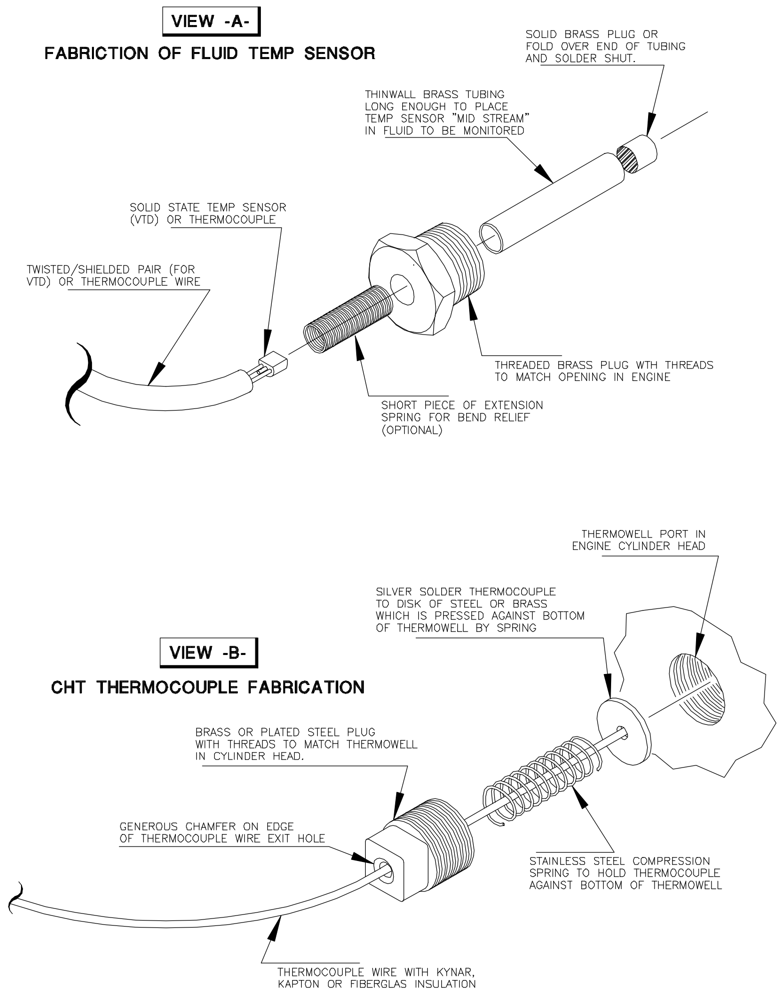

Figure 14-15. Thermowells for Temperature Sensing.

My favorite CHT sensor is the spark plug gasket type thermocouple. Mechanics don't like these things because they break easy. I like them because they are inexpensive an easy to repair! A number of manufacturers sell spark plug gasket probes for $12-$20 each. It's probably not worth the trouble to build from scratch. Recall at the beginning of this chapter I mentioned changes to materials from thermal stress? Well, copper work-hardens if you repeatedly stress it. Take a piece of copper wire and start bending it back and forth. You can sense when the worked part of the wire is getting hard, starts to crack and finally breaks in two.

Well, copper gaskets under a spark plug harden from internal stresses cause by temperature cycles. It's standard practice to put new gaskets under the plugs when removing them for cleaning or replacement. When your CHT thermocouple(s) replaces one or more plug gaskets, inexpensive replacement with each plug change is not an option. Use a propane torch to heat the washer portion of a copper CHT sensor to dull red heat and allow it to slowly cool. This single excursion to so elevated a temperature will soften the copper and make it suitable for sealing the spark plug under which it sets.

If the thermocouple wire breaks off a spark plug CHT sensor, you can repair it yourself by opening the copper wrap around the thermocouple. Fabricate a new thermocouple on the end of the old wire as previously described and wrap it back up in the old fitting. Sometimes the tab breaks off the washer. In this case, I use silver solder to tack the old (or newly fabricated) thermocouple back onto the end of the old stub. Yeah, I know, it's going to break off again. Most plug-gasket, CHT thermocouples get broken when plugs are being removed. Tie the thermocouple wire against the side of the plug for vibration support and it will last until next time you pull the plugs. If you do happen to break it during the next maintenance cycle, just

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think: with a little practice, you can be very quick at repairing it! I personally prefer inexpensive, easily repaired components over expensive and/or non-repairable parts.

EXHAUST GAS TEMPERATURE MEASUREMENT

Getting into an exhaust stack is a little tougher. Needless-to-say, the inside of your exhaust stack is the nastiest environment on the airplane! I've built some EGT probes but I find that they are not expensive to purchase. Alcor (and competitors) build EGT probes for tractors and other industrial engines with type K thermocouple wire. An EGT probe needs to be fabricated from stainless steel for both thermowell and mounting clamp; temperatures are high and the gases corrosive. The "tractor" parts are identical in performance to the "aircraft" parts. Feel free to use purchased EGT thermocouples with another instrument of your choosing as long as it's designed to work with type K wire. Actually, the wire type and reference junction configuration are not terribly critical for EGT. First, an EGT gage is not calibrated for actual degrees, just degrees per some division of the scale; usually 25º/Division. Offset errors which may exist because of poor or no reference junction don't matter. An EGT gage is used to set mixture so many degrees rich or lean of peak. I suspect that most EGT gages have no, or at best, very crude reference junction compensation.

Very few of you will ever find it necessary or attractive to build temperature measurement instrumentation from scratch. However, I hope that what you have seen and read in this chapter has convinced you that you don't have to be a rocket scientist to deal effectively with installation, troubleshooting and repairing a temperature indication system on your airplane. Further, I hope that I have convinced you that when in doubt about the operating temperature of system components, you'll take the time and trouble to make a measurement to find out for sure.

At the beginning of this chapter I asked a question about temperature versus compression of gases in a cylinder. It does happen. This is the basis for operation of a diesel engine. Air is compressed so hard as to raise its temperature well above the ignition point of diesel fuel. When the fuel is injected into the cylinder, immediate ignition occurs. If gasoline is improperly brewed for the compression experienced prior to complete combustion, spontaneous combustion or detonation occurs. A diesel is designed to run under "detonation" while a gasoline engine will be destroyed by it. Temperature has more influence on the physics of flight and flight systems than any other phenomena. It will serve you well to become familiar and comfortable with its measurement and interpretation of readings.

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