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RN-TM 0598

THE EFFECTS OF CABLE
SPICES ON THERMOCOUPLE
CHANNEL UNCERTAINTIES

May 1970

MASTER

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RN-TM 0598

~~THE~~ EFFECTS OF CABLE SPLICES
ON THERMOCOUPLE CHANNEL UNCERTAINTIES

MAY 1970

by

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Approved

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THE EFFECTS OF CABLE
SPICES ON THERMOCOUPLE
CHANNEL UNCERTAINTIES

By
Richard D. Samuelson

INTRODUCTION

A typical thermocouple circuit contains thermocouple cable splices between the measurement and reference junctions as well as several copper cable splices between the reference junction and the data system input. It should be noted that all wire samples having the same nominal composition do not possess identical emf-temperature characteristics. This should be obvious when one considers the impossibility of controlling, exactly, the chemical and physical properties of wire. Thus, a typical thermocouple circuit employs several discrete wire sections, each of which will usually differ thermoelectrically from all other sections. The purpose of this discussion is to qualitatively describe how thermocouple data channel inaccuracy is affected by the presence of splices between dissimilar cable sections.

SUMMARY

The total measurement uncertainty $(U)_t$ of a thermocouple data channel may be taken as the Root-Sum-Squared summation (RSS) of the thermocouple calibration uncertainty, $(U)_c$; data system signal processing uncertainty, $(U)_d$; cable splice induced uncertainty, $(U)_s$; and the uncertainty of thermal coupling $(U)_e$ between the thermocouple measurement junction and the physical environment being monitored. That is, thermocouple data channel measurement uncertainty can be statistically described by

$$(U)_t = \pm \sqrt{(U)_c^2 + (U)_d^2 + (U)_s^2 + (U)_e^2}$$

From the RSS uncertainty equation, it can be concluded that the sensitivity of the total channel uncertainty $(U)_t$ to splice induced uncer-

tainty $(U)_s$ variations depends on the size of $(U)_s$ relative to $(U)_c$, $(U)_d$, and $(U)_e$.

Thermocouple calibration uncertainties tend to increase as the temperature of the measurement junction extends either above or below normal room temperatures, becoming large as very low or very high temperatures are encountered. Thermal coupling uncertainties increase as the temperature differential between the parameter being monitored and adjacent surroundings increases. Data system induced microvolt uncertainty increases as the full scale millivolt span increases, assuming that data system inaccuracy is a fixed percent of the full scale millivolt span.

From what has been said, it would appear that a channel whose measurement span extends from near cryogenic temperatures (200°R) up to extremely high temperatures (4250°R) should be relatively insensitive to splice induced errors when the measurement junction is at 4250°R . This assumption is confirmed by the data of Table VI. On the other hand, a channel with a narrow measurement range and used to measure water temperatures should be highly sensitive to splice induced uncertainties. This assumption is confirmed by the uncertainty data of Table VIII. Note that the uncertainty data of Table VI and VIII account for calibration, data processing, and splice induced uncertainties but exclude thermal coupling uncertainties.

The microvolt splice induced uncertainty values listed in this report must be considered as infrared engineering approximations rather

than exact measured quantities. The microvolt uncertainty values were derived by employing standard calibration inaccuracy values and tables. The thermocouple sensitivity values for copper/constantan and chromel/alumel thermocouples were derived from National Bureau of Standards Circular #561 while those for tungsten-rhenium were derived from standard calibration tables published by Hoskins Manufacturing Company. The calibration uncertainty values for copper/constantan and chromel/alumel are those recommended by Instrument Society of America Recommended Practice Document RPl.3 for special grade wire. The calibration uncertainty for the tungsten-rhenium thermocouples is that specified by Hoskins Manufacturing Company. Since the sensitivity and calibration uncertainty values of thermocouples acquired for NERVA flight applications may not correspond to the standard values, the splice induced uncertainty values listed for this report may be larger or smaller than those actually generated by flight engine thermocouple channels.

CONCLUSIONS

Several specific "rules" can be stated as a result of this review that will tend to minimize measurement uncertainties.

1. Always use fully annealed special grade wire in thermocouple cables, and copper cables.

2. Reduce the number of transitions to an absolute minimum by using continuous wire lengths whenever possible.

3. If a splice must be made, avoid locating the splice in very hot or very cold regions whenever possible.

As a general conclusion, it can be stated that the relative measurement uncertainty contributed by a cable splice depends on the measurement range, the thermocouple type, and the temperature being monitored.

If a very large measurement range is adopted, one additional thermocouple splice will not seriously affect the overall channel uncertainty. If, however, channel performance is marginal and measurement requirements are difficult to meet, then the number of splices must be held to an absolute minimum regardless of the measurement range, the thermocouple type, or the temperature being measured.

TECHNICAL DISCUSSION

The approximate method used to estimate splice induced microvolt uncertainties shall be demonstrated by example. Consider a special grade copper/constantan thermocouple whose measurement and reference junctions are at the ice point, whose calibration uncertainty at the ice point is $\pm 0.75^\circ\text{R}$, and whose microvolt per degree Rankine sensitivity at the ice point is approximately $21.35 \mu\text{V}/^\circ\text{R}$. Thus, the microvolt calibration uncertainty is defined by

$$\begin{array}{l} \text{Calibration UNC of c/c} \\ \text{thermocouples at } 32^\circ\text{F} \end{array} = \pm (0.75)(21.35) = \pm 16.01 \mu\text{V}$$

It is assumed that this uncertainty results from the random error con-

tributed by the combined action of the reference junction termination and the measurement junction termination. As a result, the microvolt uncertainty of a single copper/constantan cable termination at 32°F may be approximated by

$$\begin{array}{l} \text{Microvolt UNC of a single} \\ \text{copper/constantan termination} \\ \text{at the ice point (at 32°F)} \end{array} = \pm \frac{16.01}{\sqrt{2}} = \pm 11.32 \mu V$$

To determine the cable termination uncertainty of a copper/constantan thermocouple at -300°F, note that the calibration uncertainty and thermoelectric sensitivity at this temperature is $\pm 3^\circ R$ and $9.70 \mu V/^\circ R$, respectively. Thus, the calibration uncertainty of a copper/constantan thermocouple with the measurement junction at -300°F and the reference junction at 32°F is found from

$$\begin{array}{l} \text{Calibration UNC of c/c} \\ \text{thermocouples at -300°F} \end{array} = \pm (3)(9.70) = \pm 29.10 \mu V$$

The -300°F calibration uncertainty value may be thought of as being composed of two random independent quantities, the measurement junction termination microvolt uncertainty and the reference junction termination microvolt uncertainty. However, since the reference junction has been previously determined to be $\pm 11.32 \mu V$, the -300°F measurement junction uncertainty may be determined as shown below

$$\begin{array}{l} \text{Microvolt UNC of a single} \\ \text{copper/constantan cable} \\ \text{termination at -300°F} \end{array} = \pm \sqrt{(29.10)^2 - (11.32)^2} = \pm 26.81 \mu V$$

A splice may be thought of as the joining of two cable terminations. Therefore, the splice induced uncertainty of special grade copper/constantan thermocouple cable at -300°F and at the ice point (32°F) may now be determined as shown below

$$\begin{array}{l} \text{Splice induced uncertainty} \\ \text{of c/c cable at -300°F} \end{array} = \pm \sqrt{2} (26.81) = \pm 37.91 \mu\text{V}$$

$$\begin{array}{l} \text{Splice induced uncertainty} \\ \text{of c/c cable at 32°F} \end{array} = \pm \sqrt{2} (11.32) = \pm 16.01 \mu\text{V}$$

Repeating the preceeding computation sequence for different temperatures and for different types of thermocouples yields the tabular data of Table I.

Table I - Approximate splice induced microvolt uncertainty for thermocouple cables.

Splice Temperature	Thermocouple Cable Type			
	c/c	c/A	W/W26Re	W5Re/W26Re
-300°F	$\pm 37.91 \mu\text{V}$	$\pm 72.58 \mu\text{V}$		
-200°F	$\pm 35.29 \mu\text{V}$	$\pm 69.25 \mu\text{V}$		
-100°F	$\pm 18.41 \mu\text{V}$	$\pm 25.68 \mu\text{V}$		
0	$\pm 14.64 \mu\text{V}$	$\pm 41.11 \mu\text{V}$		
32°F	$\pm 16.01 \mu\text{V}$	$\pm 43.96 \mu\text{V}$	$\pm 11.20 \mu\text{V}$	$\pm 55.76 \mu\text{V}$
200°F	$\pm 22.00 \mu\text{V}$	$\pm 48.53 \mu\text{V}$	$\pm 33.24 \mu\text{V}$	$\pm 75.20 \mu\text{V}$
400°F	$\pm 60.94 \mu\text{V}$	$\pm 53.70 \mu\text{V}$	$\pm 45.60 \mu\text{V}$	$\pm 91.22 \mu\text{V}$
600°F	$\pm 102.82 \mu\text{V}$	$\pm 58.87 \mu\text{V}$	$\pm 76.69 \mu\text{V}$	$\pm 100.71 \mu\text{V}$
1000°F		$\pm 116.61 \mu\text{V}$	$\pm 133.17 \mu\text{V}$	$\pm 139.15 \mu\text{V}$
2000°F		$\pm 218.36 \mu\text{V}$	$\pm 332.15 \mu\text{V}$	$\pm 259.96 \mu\text{V}$

When calculating the data of Table I, the thermocouple sensitivity values for copper/constantan and chromel/alumel were derived from National Bureau of Standards Circular #561 while those for Tungsten-Rhenium thermocouples were derived from standard calibration tables published by Hoskins Manufacturing Company. The calibration uncertainty values for copper/constantan and chromel/alumel are those recommended by Instrument Society of America Recommended Practice document RP 1.3 for special grade thermocouple wire. The calibration uncertainty for the tungsten-rhenium thermocouples is that specified by Hoskins Manufacturing Company.

When deriving the data of Table I, it was assumed that the standard thermocouple sensitivity and calibration uncertainty values were experimentally derived by employing the circuit of Figure 1A while, in actuality, the actual circuit more closely resembled that of Figure 1B.

Figure 1. Thermocouple Calibration Circuits

The circuit configuration of Figure 1A ignores the microvolt uncertainty contributions provided by the splice between thermocouple materials "A" and "B" and the two copper lead wires. Thus, the uncertainty values of Table I tend to be conservative.

Another problem area results from the unknown statistical confidence level assigned to commonly accepted calibration uncertainty values adopted by the Instrument Society of America or Hoskins Manufacturing Company. For this study, it is assumed that the published standard values were derived from normally (gaussian) distributed experimental data and that a three standard deviation data spread was adopted.

As seen in Table I, cable splice induced microvolt uncertainties increase as very cold or very hot splice regions are encountered. It is assumed that the temperature of the various NERVA engine splice regions may extend from the liquid hydrogen point (-423°F) to a maximum of 600°R (140°F) during space flight. Reference to Table I indicates that the magnitude of splice induced microvolt uncertainties at 140°F may be interpolated as being approximately half that expected at -423°F . However, since reliable thermocouple sensitivity and calibration uncertainty data is unavailable for tungsten-rhenium thermocouples at -423°F , a 140°F cable splice temperature will be assumed so that comparisons can be made between the splice induced errors incurred in different types of thermocouple data channels. Thus, the calculated splice induced uncertainties to be used for the remainder of this report are those listed in Table II.

Table II - Approximate cable splice induced microvolt uncertainties generated by a single splice at 140°F

<u>Cable Type</u>	<u>Microvolt Uncertainty</u>
Copper/Constantan	$\pm 18.2 \mu\text{V}$
Chromel/Alumel	$\pm 46.0 \mu\text{V}$
W/W26Re	$\pm 15.0 \mu\text{V}$
W5RE/W26Re	$\pm 63.8 \mu\text{V}$
Copper/Copper	$\pm 4.6 \mu\text{V}$

The microvolt uncertainty data entry for copper/copper cable was abstracted from RN-TM-0362. The measurement uncertainty induced by a combination of cable splices can be arrived at by applying RSS summation techniques. As an example, if a channel incorporated two copper/constantan cable transitions and four copper/copper cable transitions at 140°F, the probable microvolt uncertainty would be

$$\text{Overall Uncertainty} = \pm \left[2 (18.2)^2 + 4(4.6)^2 \right]^{\frac{1}{2}} = \pm 27.3 \mu\text{V}$$

To determine the equivalent cable transition induced measurement uncertainty in degrees Rankine, it is necessary to determine the thermoelectric sensitivity ($^{\circ}\text{R}/\mu\text{V}$) at the temperature level being monitored and multiply it by the splice induced microvolt uncertainty. In general, the degree Rankine per microvolt thermoelectric sensitivity of thermocouples becomes larger as the temperature of the measurement junction decreases. Thus, worst case effects shall be obtained by assuming that the measurement junction of each type of thermocouple will be at the lower limit of its

normal operating range. Assumed normal lower range limit and corresponding thermoelectric sensitivity values are listed in Table III.

Table III - Assumed lower range limits and corresponding sensitivity values

<u>Thermocouple Type</u>	<u>Normal Lower Limit</u>	<u>Corresponding Thermoelectric Sensitivity ($^{\circ}\text{R}/\mu\text{V}$)</u>
c/c	-425 $^{\circ}\text{F}$	0.382 $^{\circ}\text{R}/\mu\text{V}$
c/A	-300 $^{\circ}\text{F}$	0.099 $^{\circ}\text{R}/\mu\text{V}$
W/(W-26%Re)	32 $^{\circ}\text{F}$	0.714 $^{\circ}\text{R}/\mu\text{V}$
(W-5%Re)/(W-26%Re)	-260 $^{\circ}\text{F}$	0.303 $^{\circ}\text{R}/\mu\text{V}$

The worst case measurement uncertainty, expressed in degrees rankine, for a copper/constantan thermocouple channel containing 2 copper/constantan and 4 copper/copper cable splices at 140 $^{\circ}\text{F}$ may now be calculated as shown below

$$\begin{array}{l} \text{Splice Induced} \\ \text{Measurement Error} \end{array} = \pm (27.3)(0.382) = \pm 10.4^{\circ}\text{R}$$

A listing of "worst case" splice induced measurement error approximations are presented in Table IV for the various types of thermocouples being considered for NERVA.

Table IV - Estimated worst case measurement uncertainties attributed to splices only (all splice temperatures being 140°F).

TC Type	Number of TC Cable Transitions Before the TC Ref. Junction	Number of Copper-Copper Wire Cable Transitions After the TC Ref. Junction				
		1	2	3	4	5
Copper/Constantan	0	$\pm 1.76^{\circ}\text{R}$	$\pm 2.49^{\circ}\text{R}$	$\pm 3.04^{\circ}\text{R}$	$\pm 3.51^{\circ}\text{R}$	$\pm 3.93^{\circ}\text{R}$
	1	$\pm 7.17^{\circ}\text{R}$	$\pm 7.38^{\circ}\text{R}$	$\pm 7.59^{\circ}\text{R}$	$\pm 7.79^{\circ}\text{R}$	$\pm 7.99^{\circ}\text{R}$
	2	$\pm 9.99^{\circ}\text{R}$	$\pm 10.14^{\circ}\text{R}$	$\pm 10.29^{\circ}\text{R}$	$\pm 10.44^{\circ}\text{R}$	$\pm 10.59^{\circ}\text{R}$
	3	$\pm 12.17^{\circ}\text{R}$	$\pm 12.30^{\circ}\text{R}$	$\pm 12.42^{\circ}\text{R}$	$\pm 12.54^{\circ}\text{R}$	$\pm 12.67^{\circ}\text{R}$
	4	$\pm 14.02^{\circ}\text{R}$	$\pm 14.13^{\circ}\text{R}$	$\pm 14.23^{\circ}\text{R}$	$\pm 14.34^{\circ}\text{R}$	$\pm 14.45^{\circ}\text{R}$
Chromel/Alumel	0	$\pm 0.46^{\circ}\text{R}$	$\pm 0.64^{\circ}\text{R}$	$\pm 0.79^{\circ}\text{R}$	$\pm 0.91^{\circ}\text{R}$	$\pm 1.02^{\circ}\text{R}$
	1	$\pm 4.58^{\circ}\text{R}$	$\pm 4.60^{\circ}\text{R}$	$\pm 4.62^{\circ}\text{R}$	$\pm 4.64^{\circ}\text{R}$	$\pm 4.67^{\circ}\text{R}$
	2	$\pm 6.46^{\circ}\text{R}$	$\pm 6.47^{\circ}\text{R}$	$\pm 6.49^{\circ}\text{R}$	$\pm 6.50^{\circ}\text{R}$	$\pm 6.52^{\circ}\text{R}$
	3	$\pm 7.90^{\circ}\text{R}$	$\pm 7.91^{\circ}\text{R}$	$\pm 7.93^{\circ}\text{R}$	$\pm 7.94^{\circ}\text{R}$	$\pm 7.95^{\circ}\text{R}$
	4	$\pm 9.12^{\circ}\text{R}$	$\pm 9.13^{\circ}\text{R}$	$\pm 9.14^{\circ}\text{R}$	$\pm 9.15^{\circ}\text{R}$	$\pm 9.16^{\circ}\text{R}$
W/W26Re	0	$\pm 3.28^{\circ}\text{R}$	$\pm 4.64^{\circ}\text{R}$	$\pm 5.69^{\circ}\text{R}$	$\pm 6.57^{\circ}\text{R}$	$\pm 7.34^{\circ}\text{R}$
	1	$\pm 11.20^{\circ}\text{R}$	$\pm 11.67^{\circ}\text{R}$	$\pm 12.13^{\circ}\text{R}$	$\pm 12.56^{\circ}\text{R}$	$\pm 12.99^{\circ}\text{R}$
	2	$\pm 15.50^{\circ}\text{R}$	$\pm 15.84^{\circ}\text{R}$	$\pm 16.18^{\circ}\text{R}$	$\pm 16.51^{\circ}\text{R}$	$\pm 16.83^{\circ}\text{R}$
	3	$\pm 18.84^{\circ}\text{R}$	$\pm 19.12^{\circ}\text{R}$	$\pm 19.40^{\circ}\text{R}$	$\pm 19.68^{\circ}\text{R}$	$\pm 19.95^{\circ}\text{R}$
	4	$\pm 21.67^{\circ}\text{R}$	$\pm 21.92^{\circ}\text{R}$	$\pm 22.16^{\circ}\text{R}$	$\pm 22.40^{\circ}\text{R}$	$\pm 22.64^{\circ}\text{R}$
W5Re/W26Re	0	$\pm 1.39^{\circ}\text{R}$	$\pm 1.97^{\circ}\text{R}$	$\pm 2.41^{\circ}\text{R}$	$\pm 2.79^{\circ}\text{R}$	$\pm 3.12^{\circ}\text{R}$
	1	$\pm 19.38^{\circ}\text{R}$	$\pm 19.43^{\circ}\text{R}$	$\pm 19.48^{\circ}\text{R}$	$\pm 19.53^{\circ}\text{R}$	$\pm 19.58^{\circ}\text{R}$
	2	$\pm 27.37^{\circ}\text{R}$	$\pm 27.41^{\circ}\text{R}$	$\pm 27.45^{\circ}\text{R}$	$\pm 27.48^{\circ}\text{R}$	$\pm 27.52^{\circ}\text{R}$
	3	$\pm 33.51^{\circ}\text{R}$	$\pm 33.54^{\circ}\text{R}$	$\pm 33.57^{\circ}\text{R}$	$\pm 33.60^{\circ}\text{R}$	$\pm 33.63^{\circ}\text{R}$
	4	$\pm 38.69^{\circ}\text{R}$	$\pm 38.71^{\circ}\text{R}$	$\pm 38.74^{\circ}\text{R}$	$\pm 38.76^{\circ}\text{R}$	$\pm 38.79^{\circ}\text{R}$

Table IV lists the worst case splice induced uncertainties for various kinds of thermocouple channels. Unfortunately, the table can be misleading. As an example, the tabulated data of Table IV could be improperly interpreted as stating that copper/constantan thermocouples are more sensitive to splice induced error than are chromel/alumel thermocouples. However, tabulated copper/constantan thermocouple splice induced uncertainties exceed those listed for chromel/alumel thermocouples only because a lower base temperature is assumed for copper/constantan (see Table III). A more meaningful comparison between thermocouple types can be made by normalizing the uncertainty data of Table IV. Normalization shall assume that the optimum splice configuration shall consist of no splices before the reference junction and only two interface splices after the reference junction. Thus, the tabular data of Table IV will be normalized to column 2, row 1, data values and the results presented in Table V.

Table V, Normalized, worst case splice induced uncertainties; data system, thermocouple calibration, and thermal coupling induced uncertainties excluded (all splice temperatures at 140°F).

TC Type	Number of TC Cable Transitions Before the Ref. Junction	Number of Copper-Copper Wire Cable Transitions After the TC Ref. Junction				
		1	2	3	4	5
Copper/Constantan	0	± 0.71	± 1.00	± 1.22	± 1.42	± 1.58
	1	± 2.88	± 2.96	± 3.05	± 3.13	± 3.21
	2	± 4.01	± 4.07	± 4.13	± 4.19	± 4.25
	3	± 4.89	± 4.94	± 4.99	± 5.04	± 5.09
	4	± 5.63	± 5.67	± 5.71	± 5.76	± 5.80
Chromel/Alumel	0	± 0.71	± 1.00	± 1.22	± 1.42	± 1.58
	1	± 7.16	± 7.19	± 7.22	± 7.25	± 7.30
	2	± 10.01	± 10.11	± 10.14	± 10.16	± 10.19
	3	± 12.34	± 12.36	± 12.39	± 12.41	± 12.42
	4	± 14.25	± 14.27	± 14.28	± 14.30	± 14.31
W/W26Re	0	± 0.71	± 1.00	± 1.22	± 1.42	± 1.58
	1	± 2.41	± 2.52	± 2.61	± 2.71	± 2.80
	2	± 3.34	± 3.41	± 3.49	± 3.56	± 3.63
	3	± 4.06	± 4.12	± 4.18	± 4.24	± 4.30
	4	± 4.67	± 4.72	± 4.78	± 4.83	± 4.88
W5Re/W26Re	0	± 0.71	± 1.00	± 1.22	± 1.42	± 1.58
	1	± 9.84	± 9.86	± 9.89	± 9.91	± 9.94
	2	± 13.89	± 13.91	± 13.93	± 13.95	± 13.97
	3	± 17.01	± 17.03	± 17.04	± 17.06	± 17.07
	4	± 19.64	± 19.65	± 19.66	± 19.68	± 19.69

Table V indicates the relative splice induced uncertainty for different kinds of thermocouples. For instance, W5Re/W26Re thermocouples are found to be more sensitive to splice induced uncertainties than are the other kinds of thermocouples being considered for NERVA applications. Both Table IV and Table V indicate that splice induced errors increase with the total number of splices and that all thermocouple channels are particularly sensitive to thermocouple cable splices located before the reference junction.

The effect of adding a splice depends upon the kind of splice to be added and the number of existing splices. As an example, assume that one W5Re/W26Re splice and two copper cable splices exist. The addition of one more W5Re/W26Re splice will increase the spliced induced uncertainty by $100(13.91-9.86)/9.86$ or 41%. If the circuit originally contained three W5Re/W26Re splices and two copper cable splices, then the addition of one more W5Re/W26Re splice would only increase the splice induced uncertainty by 15%.

Thus far we have been ignoring the measurement uncertainties contributed by the data acquisition system, the thermocouple calibration, and thermal coupling. In general, measurement system induced uncertainties tend to depend on the measurement range (data span) while calibration induced uncertainties vary with the temperature levels being measured. Thus, there exists an infinite number of system/calibration uncertainty combinations. As a result, a simple table describing the effect of additional splices on the total data channel uncertainty can not be provided.

An example will be provided to describe the effect of adding one additional splice in a thermocouple data channel. This example will assume that a W5Re/W26Re thermocouple channel is being used to measure 4250°R gas temperatures. The assumed data span extends from 200°R to 4380°R to yield a full scale signal of 36 millivolts. It is further assumed that the data system accuracy is $\pm 0.25\%$ of full scale so that a ± 90 microvolt data system induced channel uncertainty is obtained. The assumed thermocouple calibration uncertainty at 4250°R is $\pm 37.9^\circ\text{R}$. Since the thermocouple sensitivity at 4250°R is approximately $6.15 \mu\text{V}/^\circ\text{R}$, the equivalent microvolt calibration uncertainty is $\pm 6.15 \times 37.9$ or ± 233 microvolts. Thus, the combined uncertainty resulting from data system inaccuracies and calibration uncertainties is:

$$\begin{array}{l} \text{System/Calibration} \\ \text{Induced Uncertainties} \end{array} = \pm \left[(90)^2 + (233)^2 \right]^{\frac{1}{2}} = \pm 250 \mu\text{V}$$

The effective uncertainty produced by a single W5Re/W26Re splice is $\pm 63.8 \mu\text{V}$ while that produced by a single copper/copper wire cable splice is $\pm 4.6 \mu\text{V}$ (See Table II).

We now have enough data to estimate the total channel measurement uncertainty, exclusive of thermal coupling errors. As an example, assume that the channel contains two W5Re/W26Re cable splices and four copper/copper cable splices. Then, if the data span extends from 200°R to 4380°R and 4250°R gas temperatures are being monitored, the total channel microvolt uncertainty may be approximated by

$$\text{Total } \mu\text{V UNC} = \pm \left[(250)^2 + 2(63.8)^2 + 4(4.6)^2 \right]^{\frac{1}{2}} = \pm 265.9 \mu\text{V}$$

and the effective uncertainty expressed in engineering units is

$$\text{E.U. Uncertainty} = \pm 265.9/6.15 = \pm 43.23^{\circ}\text{R}$$

Similar calculations are also made for a W/W26Re thermocouple measuring 4250°R gas temperatures and the results presented in Table VII.

Table VI - Effects of splices on total measurement uncertainties for a W5Re/W26Re thermocouple monitoring 4250°R temperatures where the measurement span extends from 200°R to 4380°R (36 mv, F.S.) and all splices are at 140°F

Number of TC Cable Transitions at 140°F before the TC Ref. Junction	Number of Copper/Copper Wire Cable Transitions at 140°F After the TC Ref. Junction				
	1	2	3	4	5
0	$\pm 40.65^{\circ}\text{R}$	$\pm 40.66^{\circ}\text{R}$	$\pm 40.66^{\circ}\text{R}$	$\pm 40.67^{\circ}\text{R}$	$\pm 40.67^{\circ}\text{R}$
1	$\pm 41.95^{\circ}\text{R}$	$\pm 41.96^{\circ}\text{R}$	$\pm 41.97^{\circ}\text{R}$	$\pm 41.97^{\circ}\text{R}$	$\pm 41.98^{\circ}\text{R}$
2	$\pm 43.22^{\circ}\text{R}$	$\pm 43.22^{\circ}\text{R}$	$\pm 43.23^{\circ}\text{R}$	$\pm 43.24^{\circ}\text{R}$	$\pm 43.24^{\circ}\text{R}$
3	$\pm 44.44^{\circ}\text{R}$	$\pm 44.45^{\circ}\text{R}$	$\pm 44.46^{\circ}\text{R}$	$\pm 44.46^{\circ}\text{R}$	$\pm 44.47^{\circ}\text{R}$
4	$\pm 45.64^{\circ}\text{R}$	$\pm 45.65^{\circ}\text{R}$	$\pm 45.65^{\circ}\text{R}$	$\pm 45.66^{\circ}\text{R}$	$\pm 45.66^{\circ}\text{R}$

Table VII - Effects of splices on total measurement uncertainties for a W/W26Re thermocouple monitoring 4250°R temperatures where the measurement span extends from 492°R to 4280°R (36 mv, F.S.) and all splices are at 140°F

Number of TC Cable Transitions at 140°F before the TC Ref. Junction	Number of Copper/Copper Wire Cable Transitions at 140°F After the Ref. Junction				
	1	2	3	4	5
0	$\pm 39.24^{\circ}\text{R}$	$\pm 39.25^{\circ}\text{R}$	$\pm 39.25^{\circ}\text{R}$	$\pm 39.25^{\circ}\text{R}$	$\pm 39.26^{\circ}\text{R}$
1	$\pm 39.28^{\circ}\text{R}$	$\pm 39.28^{\circ}\text{R}$	$\pm 39.29^{\circ}\text{R}$	$\pm 39.29^{\circ}\text{R}$	$\pm 39.29^{\circ}\text{R}$
2	$\pm 39.32^{\circ}\text{R}$	$\pm 39.32^{\circ}\text{R}$	$\pm 39.32^{\circ}\text{R}$	$\pm 39.33^{\circ}\text{R}$	$\pm 39.33^{\circ}\text{R}$
3	$\pm 39.35^{\circ}\text{R}$	$\pm 39.36^{\circ}\text{R}$	$\pm 39.36^{\circ}\text{R}$	$\pm 39.36^{\circ}\text{R}$	$\pm 39.37^{\circ}\text{R}$
4	$\pm 39.39^{\circ}\text{R}$	$\pm 39.39^{\circ}\text{R}$	$\pm 39.40^{\circ}\text{R}$	$\pm 39.40^{\circ}\text{R}$	$\pm 39.40^{\circ}\text{R}$

As a point of interest, Table VIII is presented to illustrate the effect of cable splices on a chromel/alumel thermocouple channel that is used to monitor a shield water temperature of 660°R (200°F) where the data channel span extends from 492°R to 711°R to yield a 5 millivolt full scale signal. The sensitivity at 200°F is approximately 23.0 $\mu\text{V}/^\circ\text{R}$

Table VIII - Effects of splices on total measurement uncertainties for a chromel/alumel thermocouple monitoring 660°R temperatures where the measurement span extends from 492°R to 711°R (5 mv F.S.) and all splices are at 140°F

Number of TC Cable Transitions before the TC Ref. Junction	Number of Copper-Copper Wire Cable Transitions After the TC Ref. Junction				
	1	2	3	4	5
0	$\pm 2.08^\circ\text{R}$	$\pm 2.09^\circ\text{R}$	$\pm 2.10^\circ\text{R}$	$\pm 2.11^\circ\text{R}$	$\pm 2.12^\circ\text{R}$
1	$\pm 2.89^\circ\text{R}$	$\pm 2.89^\circ\text{R}$	$\pm 2.90^\circ\text{R}$	$\pm 2.91^\circ\text{R}$	$\pm 2.91^\circ\text{R}$
2	$\pm 3.51^\circ\text{R}$	$\pm 3.52^\circ\text{R}$	$\pm 3.52^\circ\text{R}$	$\pm 3.53^\circ\text{R}$	$\pm 3.53^\circ\text{R}$
3	$\pm 4.04^\circ\text{R}$	$\pm 4.05^\circ\text{R}$	$\pm 4.05^\circ\text{R}$	$\pm 4.06^\circ\text{R}$	$\pm 4.06^\circ\text{R}$
4	$\pm 4.51^\circ\text{R}$	$\pm 4.51^\circ\text{R}$	$\pm 4.52^\circ\text{R}$	$\pm 4.52^\circ\text{R}$	$\pm 4.53^\circ\text{R}$

The data contained in Tables VI, VII, and VIII demonstrate how the relative measurement uncertainty contributed by a cable splice depends on the measurement range, the thermocouple type, and the temperature being monitored. As an example, for the case of channels incorporating no thermocouple splices before the reference junction and two copper cable splices after the reference, the addition of one W/W26Re splice under the operating conditions of Table VII will increase the measurement uncertainty by 0.08% while the addition of one chromel/alumel splice under the operating conditions of Table VIII will increase the measurement uncertainty by 38.28%.

Tables IX and X are provided to illustrate the sensitivity of copper/constantan and chromel/alumel thermocouple channels to splice induced uncertainties when monitoring cryogenic temperatures.

Table IX - Effects of splices on total measurement uncertainties for a copper/constantan thermocouple monitoring 160°R temperatures where the measurement span extends from 160°R to 689°R (10 mv, F.S.) and all splices are at 140°F

Number of TC Cable Transitions before the TC Ref. Junction	Number of Copper-Copper Wire Cable Transitions After the TC Ref. Junction				
	1	2	3	4	5
0	$\pm 3.98^{\circ}\text{R}$	$\pm 4.01^{\circ}\text{R}$	$\pm 4.04^{\circ}\text{R}$	$\pm 4.07^{\circ}\text{R}$	$\pm 4.09^{\circ}\text{R}$
1	$\pm 4.40^{\circ}\text{R}$	$\pm 4.43^{\circ}\text{R}$	$\pm 4.45^{\circ}\text{R}$	$\pm 4.48^{\circ}\text{R}$	$\pm 4.50^{\circ}\text{R}$
2	$\pm 4.78^{\circ}\text{R}$	$\pm 4.81^{\circ}\text{R}$	$\pm 4.83^{\circ}\text{R}$	$\pm 4.85^{\circ}\text{R}$	$\pm 4.88^{\circ}\text{R}$
3	$\pm 5.14^{\circ}\text{R}$	$\pm 5.16^{\circ}\text{R}$	$\pm 5.18^{\circ}\text{R}$	$\pm 5.20^{\circ}\text{R}$	$\pm 5.22^{\circ}\text{R}$
4	$\pm 5.47^{\circ}\text{R}$	$\pm 5.49^{\circ}\text{R}$	$\pm 5.51^{\circ}\text{R}$	$\pm 5.53^{\circ}\text{R}$	$\pm 5.55^{\circ}\text{R}$

Table X - Effects of splices on total measurement uncertainties for a chromel/alumel thermocouple monitoring 160°R temperatures where the measurement span extends from 160°R to 689°R (10 mv, F.S.) and all splices are at 140°F

Number of TC Cable Transitions before the TC Ref. Junction	Number of Copper-Copper Wire Cable Transitions After the TC Ref. Junction				
	1	2	3	4	5
0	$\pm 6.51^{\circ}\text{R}$	$\pm 6.52^{\circ}\text{R}$	$\pm 6.54^{\circ}\text{R}$	$\pm 6.55^{\circ}\text{R}$	$\pm 6.57^{\circ}\text{R}$
1	$\pm 7.94^{\circ}\text{R}$	$\pm 7.95^{\circ}\text{R}$	$\pm 7.97^{\circ}\text{R}$	$\pm 7.98^{\circ}\text{R}$	$\pm 7.99^{\circ}\text{R}$
2	$\pm 9.15^{\circ}\text{R}$	$\pm 9.17^{\circ}\text{R}$	$\pm 9.18^{\circ}\text{R}$	$\pm 9.19^{\circ}\text{R}$	$\pm 9.20^{\circ}\text{R}$
3	$\pm 10.22^{\circ}\text{R}$	$\pm 10.24^{\circ}\text{R}$	$\pm 10.25^{\circ}\text{R}$	$\pm 10.26^{\circ}\text{R}$	$\pm 10.27^{\circ}\text{R}$
4	$\pm 11.19^{\circ}\text{R}$	$\pm 11.20^{\circ}\text{R}$	$\pm 11.21^{\circ}\text{R}$	$\pm 11.22^{\circ}\text{R}$	$\pm 11.23^{\circ}\text{R}$

Table XI is provided to illustrate the sensitivity of W5Re/W26Re thermocouples to cable splices when monitoring 200°R temperatures. Since standard calibration uncertainty values are unavailable for W5Re/W26Re thermocouples at 200°R, use is made of the predicted measurement uncertainties for XE-P (RN-S-0495) which lists + 13.78°R as being the calibration uncertainty for W5Re/W26Re at 200°R.

Table XI - Effects of splices on total measurement uncertainties for a W5Re/W26Re thermocouple monitoring 200°R temperatures where the measurement span extends from 200°R to 4380°R (36 mv, F.S.) and all splices are at 140°F

Number of TC Cable Transitions before the TC Ref. Junction	Number of Copper-Copper Wire Cable Transitions After the TC Ref. Junction				
	1	2	3	4	5
0	± 30.59°R	± 30.62°R	± 30.65°R	± 30.68°R	± 30.71°R
1	± 36.18°R	± 36.21°R	± 36.24°R	± 36.26°R	± 36.29°R
2	± 41.02°R	± 41.05°R	± 41.07°R	± 41.09°R	± 41.12°R
3	± 45.35°R	± 45.37°R	± 45.39°R	± 45.41°R	± 45.44°R
4	± 49.30°R	± 49.32°R	± 49.34°R	± 49.36°R	± 49.38°R

It should be emphasized that the tungsten-rhenium thermocouple calibration uncertainty data used to generate Tables VI and VII is that recommended by Hoskins Manufacturing Company. Actual calibration experience at Aerojet indicates that these numbers may be optimistic (smaller than actual). In addition, the uncertainty data of Tables VI through XI do not include the effects of nonperfect thermal coupling between the parameter being measured and the thermocouple measurement junction. Due to the exclusion of thermal coupling errors, the uncertainty data of the Tables are smaller than actual. The tables should, however, adequately describe the relative effects of splice induced uncertainties.