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Experiment II: Temperature in a Parachute Recovery Bay During and After Black Powder Ejection Discharge

Research Question:

How much does the temperature in the parachute recovery bay increase during the ejection charge detonation?

Background Information:

Based upon data from the "Material Safety Data Sheet" from OWEN COMPLIANCE SERVICES, INC., the heat from burning black powder is approximately 464°C.

Experimental Design:

We plan on collecting temperature data in the parachute recovery bay (PRB) during the parachute ejection phase of typical High Powered Rocket flight profile. The parachute is ejected by detonating a small quantity of black powder. This will be a data gathering and analysis project which will become baseline data for future experiments. This experiment involves a Parallax Basic Stamp BS2p24 microcontroller programmed to record the temperature measured by a DS2760 module and a thermocouple. This is a K-Type (Chromel/Alumel) thermocouple and it has a temperature range of 0-1023 degrees Celsius. The 24" long thermocouple will be inserted into the PRB between the parachute and the fin can wall to a depth of 22". The temperature sensing end of the thermocouple will be 3" from the black powder ejection charge. A fire/heat retardant blanket will be between the sensor and the black powder ejection charge. (See Diagram 1)

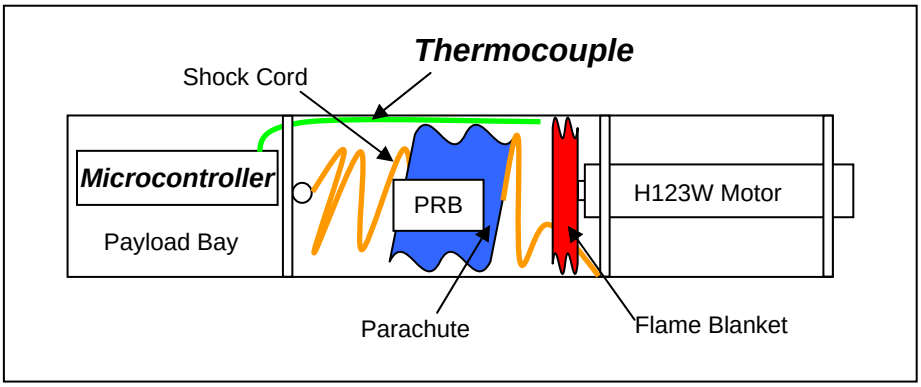
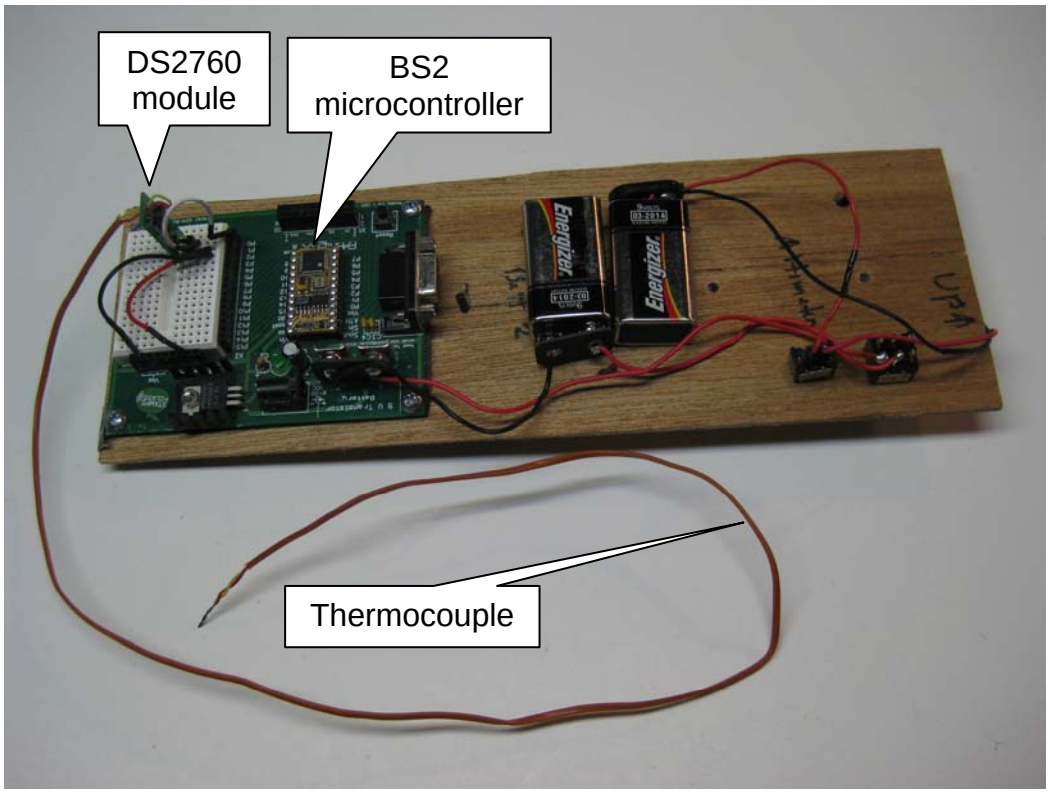


Diagram 1 (not to scale)

The microcontroller is programmed to monitor the temperature measured by the thermocouple. The program will start recording the temperature after the

temperature in the PRB exceeds 30 degrees Celsius. It will then record fifty temperature readings over a time span of about 8 seconds. The data will be recorded in the microcontroller's EPROM.

Photo 1 shows the BS2 microcontroller, the Parallax DS2760 thermocouple module, the K-Type (Chromel/Alumel) thermocouple the batteries and the back side of the switches for the microcontroller and the altimeter.



Data:

Table 1 is the raw data from the BS2p24 EPROM. The numbers represent temperatures in degrees Celsius.

```
0000 0000 0039 0000 0079 0000 0119 0000 0158 0000 0198 0000 0238 0000 0021 0
001 0061 0001 0101 0001 0141 0001 0181 0001 0221 0001 0005 0002 0045 0002 00
85 0002 0125 0002 0165 0002 0206 0002 0246 0002 0030 0003 0070 0003 0111 000
3 0151 0003 0192 0003 0232
```

Table 1

Table 2 is temperature versus time. Because of the way that the data is recorded, the numbers have been interpolated where there is change greater than 100. This variation appears as a result of data storage speed that is quicker than the response time of the thermocouple.

Seconds	Smoothed	Seconds	Smoothed	Seconds	Smoothed
0.00	0	2.78	101	5.55	165
0.16	0	2.94	101	5.71	186
0.33	39	3.10	121	5.88	206
0.49	59	3.27	141	6.04	226
0.65	79	3.43	161	6.20	246
0.82	99	3.59	181	6.37	230
0.98	119	3.76	201	6.53	214
1.14	139	3.92	221	6.69	199
1.31	158	4.08	207	6.86	183
1.47	178	4.24	194	7.02	167
1.63	198	4.41	180	7.18	151
1.80	218	4.57	166	7.35	151
1.96	238	4.73	152	7.51	172
2.12	211	4.90	139	7.67	192
2.29	183	5.06	125	7.84	212
2.45	156	5.22	125	8.00	232
2.61	128	5.39	145		

Table 2

Chart 1 represents the data from Table 2. The green line is the trend of the temperature.

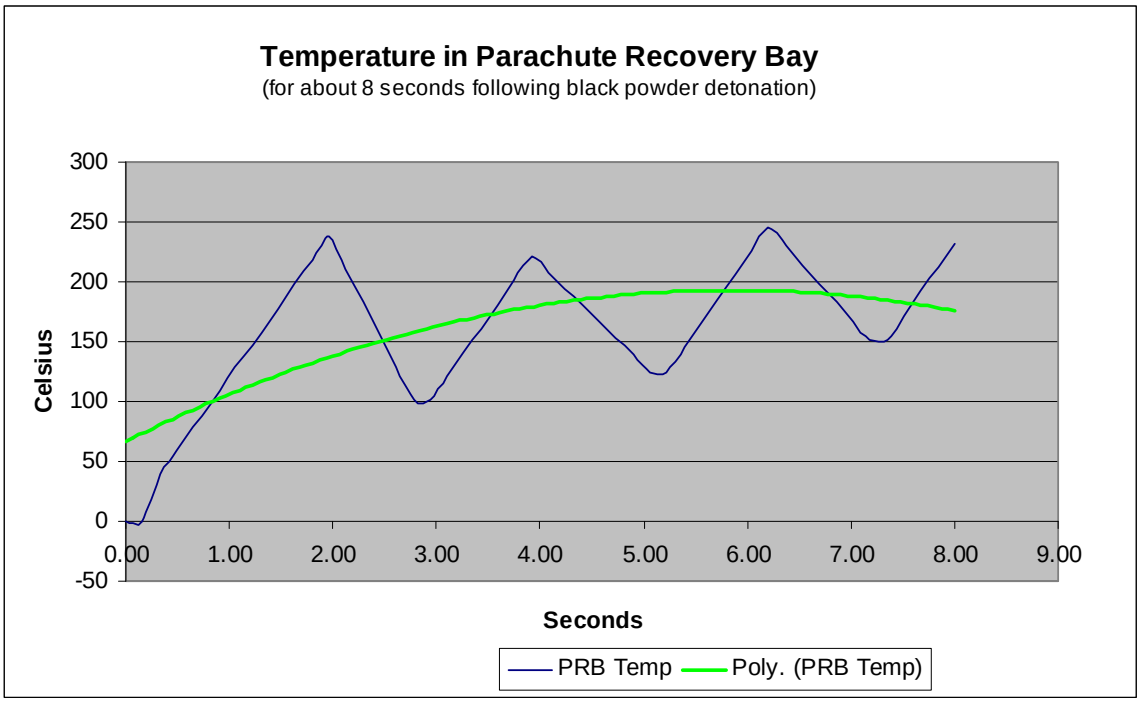


Chart 1

This is the weather conditions at Richard Bong Recreational Area, May 1, 2010, 1415.

Wind: 10-15kts
Temperature: 72F
Barometric Pressure: 29.92

Materials:

Mad Cow 4" Patriot high powered rocket

Length: 52.5 inches
Diameter 4.0 inches
Weight: 44oz

Parallax Basic Stamp BS2p24
Parallax "Board of Education" development board
Parallax DS2760 thermocouple module
K-Type (Chromel/Alumel) thermocouple
2 - 9 volt batteries
Aerotech H123W motor
28" rip stop nylon parachute

15’ tubular nylon shock cord
8”-square flame retardant protective blanket
Kestral 4000 Portable Weather Station

Procedure:

A thermocouple consists of two dissimilar wires that when connected together, produce an electrical current when heated. The DS2760 thermocouple module was assembled with the Chromel/Alumel thermocouple according to the instructions provided with the module. This involved stripping both ends of the thermocouple, twisting the wire pairs at one end and inserting the wires into the module. The module was then connected to the “Board of Education”.

The microcontroller was programmed using the Basic Stamp Editor for Windows, version 2.4.2. The code is Appendix 1. The programming language is PBasic.

We verified the operational functionality of this project by submitting the thermocouple to a small butane torch. The flame was applied to the thermocouple sensor for 1 second. Data was recorded and temperatures showed a steady increase (with big valleys) for the remaining 7 seconds. Cooling temperatures occurred near the end of the 8 second recording time. We did a post flight test to verify that the thermocouple and data storage mechanism were still functional and that the data followed the pre and actual flight data pattern. We hypothesized that the intense heat from the black powder would heat the thermocouple and allow it to cool within the 8 seconds that we allotted. See Appendix for pre and post flight tests.

The battery mount on the “Board of Education” is positioned in such a manner that it wouldn’t fit into the Patriot therefore we built a battery connector with a switch so that we could power the board on and off via an opening in the rocket’s payload bay.

The assembly was then mounted on the same 1/8” plywood electronics board that held the RDAS-Tiny altimeter and the video camera. This board slid into the payload bay and was held in place by fitting snugly between the nose cone and the payload bay’s aft bulkhead. Lateral movement was confined by wooden rails mounted on the interior walls of the payload bay.

After the rocket was placed on the launch rail, the electronics were turned on. The program monitored the temperature reported by the thermocouple and did not start recording the temperature until the thermocouple reported a temperature greater than 30 degrees Celsius. The data was stored in the EPROM of the BS2p24, a “permanent” memory data storage area feature of the BS2p24.

Data was recovered from the BS2p24 EPROM after the rocket landed via a PBasic program developed for this purpose.

Results:

The PRB temperature increased from ambient temperature to a maximum of 246 degrees Celsius during the 8 seconds of recording. It starts to decrease near the 8 second mark.

Conclusion:

We expected that there would be a sudden rise in temperature after the black powder detonation and then a gradual cooling as the gases dissipated. There is a significant rise within the first 2 seconds to 238 degrees, slightly more than half of the expected black powder burn temperature. Since the heat had to travel through the flame retardant blanket and the heat was mixed with the cool air within the PRB, these temperatures appear to be realistic.

We examined the data and hypothesize that the widely varying numbers that plot to a four-lobed cycle may be the result of the program recording data faster than the thermocouple could be monitored for temperature. Therefore we eliminated those low samples, particularly since the low numbers were evenly distributed between the higher numbers. We plotted a trend line by calculating the least squares fit through points using the formula:

$$Y=b+p_1x + p_2x^2 + \dots +p_nx^n$$

Microsoft Excel applies this formula when adding a trend line to a chart.

The lag time from heat being applied to the thermocouple sensor tip and then sensor tip being heated itself is probably why the temperature continued to climb well after the black powder detonation. This lag may also explain why cooling didn’t start until near the end of the recording time.

Pre and post tests confirm the consistency of the hypothesized lag time.

Application

Although this is only a one-time data gathering, the temperature gradient indicates that thermal protection is definitely necessary to protect the nylon parachute. Nylon melts from 185-250 degrees Celsius, depending upon the grade. Kevlar starts to decompose at 427 degrees Celsius and as stated earlier, black powder temperatures are in the 464 degrees Celsius range.

Resources

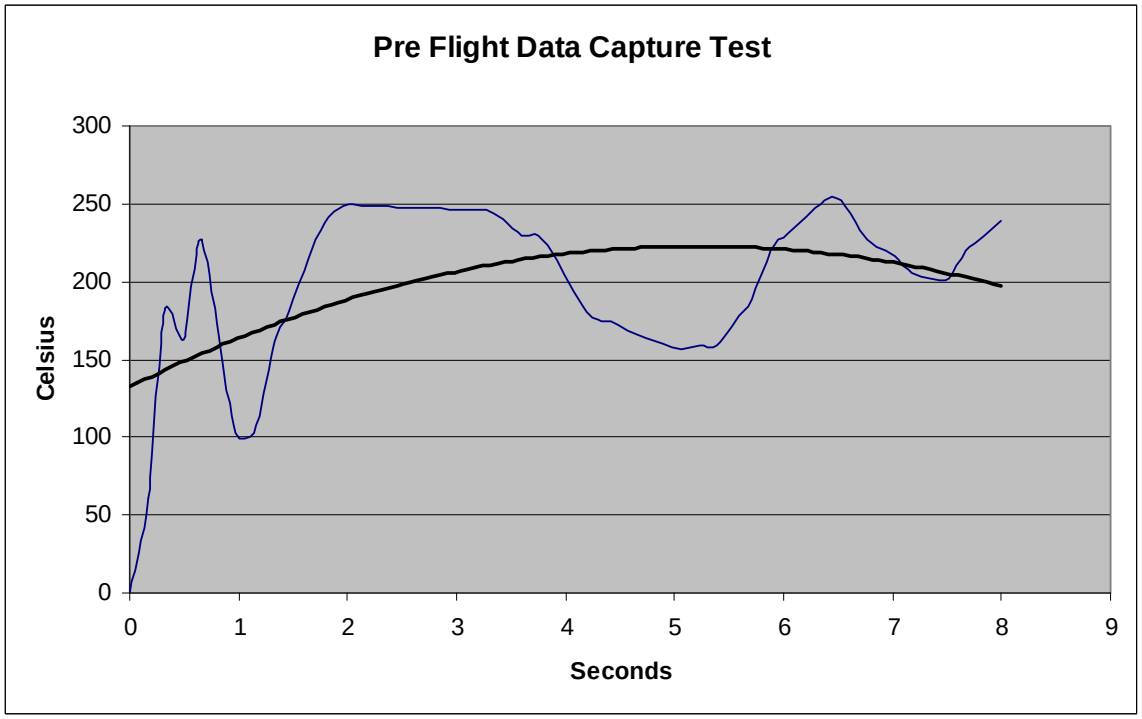
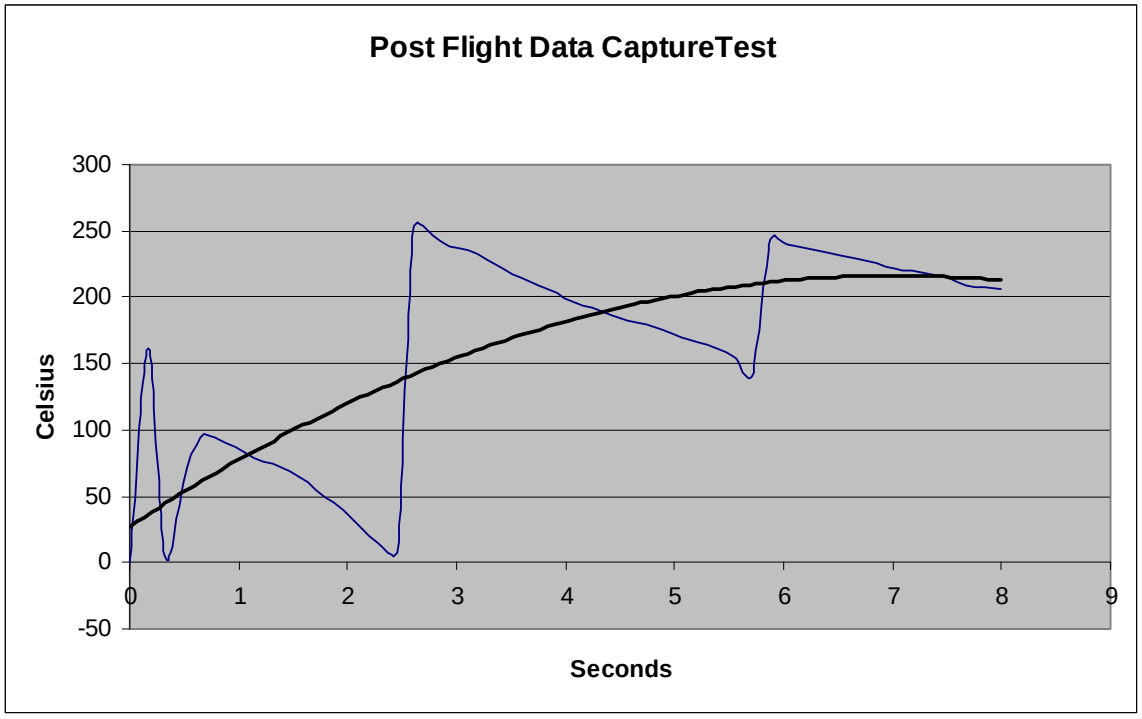
Kevlar Technical Guide, http://www2.dupont.com/Kevlar/en_US/assets/downloads/KEVLAR_Technical_Guide.pdf, April 1, 2010
Material Data Sheet for Black Powder: http://www.ocsresponds.com/ref/msds/msds-bp.pdf, March 20, 2010
Thermocouple Technical Reference Data, http://instserv.com/rmocoupl.htm, March 20, 2010
JB Plastic-Nylon, http://www.jbcplastic.com/nylon.htm, March 20, 2010

Appendix 1 - PBasic Code for Thermocouple Experiment

```
'   File...... FNL Thermocouple Experiment.BPE
'   Purpose... Thermocouple temperature measurement using the DS2760 in a Patriot 4" HP Rocket
'   Author.... Parallax, Inc. & Anna Haywood, modified by Gary Brandt
'   E-mail.... gbrandt@nwic.edu
'   Started... 3/1/10
'   Updated... 4/28/10
'
'   {$STAMP BS2p, KTablePos.BPE}
'   {$PBASIC 2.5}
'
' =========================================================================


' -----[ Program Description ]-------------------------------------------
'
' This program lets a BS2p read [positive] temperature from the
' Parallax DS2760 thermocouple module.  User input of thermocouple type
' K and temperature display is via the Debug terminal window for
‘ static test. Data is recorded in EPROM during flight.


' -----[ I/O Definitions ]-----------------------------------------------

OW              PIN     0                       ' 1-Wire buss pin


' -----[ Constants ]----------------------------------------------------

ReadNet         CON     $33                     ' read OW net address
SkipNet         CON     $CC                     ' skip OW net address
RdReg           CON     $69                     ' read register

test            CON     10

' -----[ Variables ]----------------------------------------------------
x               VAR     Byte
idx             VAR     Byte                    ' loop counter
char            VAR     Byte                    ' display byte/char
type            VAR     Nib
vIn             VAR     Word                    ' in millivolts
tmpCJ           VAR     Word                    ' device temp in C
tCuV            VAR     Word                    ' thermocouple millivolts
sign            VAR     Word                    ' TC sign bit

cjComp          VAR     Word                    ' temp compensation
tempC           VAR     Word                    ' temp in Celsius
tempF           VAR     Word                    ' temp in Fahrenheit

tblLo           VAR     Word                    ' table pointers
tblHi           VAR     Word
eePntr          VAR     Word
testVal         VAR     Word                    ' test value from table
error           VAR     Bit                     ' 1 = out of range


' -----[ EEPROM Data ]--------------------------------------------------


  type = 1
  STORE type                                    ' point READ to table


' -----[ Program Code ]-------------------------------------------------
'GOTO READ_DATA     ' Read data afterwards
```

```
' Wait for ejection ---------------------------------------------
 DO WHILE tempc<30
   DEBUG CRSRXY, 7,0, "waiting for deployment"

   GOSUB Read_TC_Volts                        ' read Seebeck voltage

   DEBUG DEC2 tcuv, " "

   GOSUB Read_CJ_Temp                         ' read cold junction temp
   READ (tmpCJ * 2), Word cjComp              ' get compensation voltage

   ' combine cjComp and tCuV
   '
   IF sign THEN
     ' TC below cold junction
     IF (tCuV < cjComp) THEN
       cjComp = cjComp - tCuV
     ELSE
       cjComp = 0                             ' limit to 0C
     ENDIF
   ELSE
     ' TC above cold junction
     cjComp = cjComp + tCuV
   ENDIF

   LOOKUP type-1, [1023, 1023, 400], tblHi       ' set high end of search
   GOSUB TC_Lookup                            ' reverse lookup of table
  LOOP


Main:
FOR x=1 TO 50 'STEP 2

   GOSUB Read_TC_Volts                        ' read Seebeck voltage

   DEBUG DEC2 tcuv, " "

   GOSUB Read_CJ_Temp                         ' read cold junction temp
   READ (tmpCJ * 2), Word cjComp              ' get compensation voltage

   ' combine cjComp and tCuV
   '
   IF sign THEN
     ' TC below cold junction
     IF (tCuV < cjComp) THEN
       cjComp = cjComp - tCuV
     ELSE
       cjComp = 0                             ' limit to 0C
     ENDIF
   ELSE
     ' TC above cold junction
     cjComp = cjComp + tCuV
   ENDIF

   LOOKUP type-1, [1023, 1023, 400], tblHi       ' set high end of search
   GOSUB TC_Lookup                            ' reverse lookup of table


   IF (error = 0) THEN
     DEBUG CRSRXY, 0, 7,
          "Temp °C..... ", SDEC tempC, CLREOL

     WRITE x, Word tempc


   ENDIF

   PAUSE 100
NEXT
```

```
  DEBUG "done"

 read_Data:
  FOR idx = 0 TO 50' STEP 2

    READ idx, tempc
    DEBUG DEC3 tempc, " "
  NEXT



  END


' -----[ Subroutines ]-----------------------------------------------------

' Reads device input voltage (Vin pin)
' -- mV in millivolts (max reading is 4.75 volts)

Read_Vin:
  OWOUT OW, %0001, [SkipNet, RdReg, $0C]
  OWIN  OW, %0010, [vIn.BYTE1, vIn.BYTE0]
  IF (vIn.BIT15) THEN                        ' check sign
    vIn = 0                              ' disallow negative
  ELSE
    vIn = vIn >> 5 */ $4E1                     ' x 4.88 millivolts
  ENDIF
  RETURN


' Reads current register to get TC voltage
' -- each raw bit = 15.625 uV
' -- tCuV in microvolts

Read_TC_Volts:
  OWOUT OW, %0001, [SkipNet, RdReg, $0E]        ' read current register
  OWIN  OW, %0010, [tCuV.BYTE1, tCuV.BYTE0]
  sign = tCuV.BIT15                          ' save sign bit
  tCuV = tCuV >> 3                           ' correct alignment
  IF sign THEN
    tCuV = tCuV | $F000                        ' pad 2's-compliment bits
  ENDIF
  tCuV = ABS tCuV */ 4000                      ' x 15.625 uV
  RETURN


' Reads cold junction (device) temperature
' -- each raw bit = 0.125 degrees C
' -- returns tmpCJ in whole degrees C

Read_CJ_Temp:
  OWOUT OW, %0001, [SkipNet, RdReg, $18]
  OWIN  OW, %0010, [tmpCJ.BYTE1, tmpCJ.BYTE0]
  IF (tmpCJ.BIT15) THEN                      ' check sign
    tmpCJ = 0                            ' disallow negative
  ELSE
    tmpCJ = tmpCJ.HIGHBYTE                     ' >> 5 x 0.125 (>> 3)
  ENDIF
  RETURN


' Search currently selected TC table for nearest entry
' -- uses modified binary algorithm to find cjComp
' -- high end of search set before calling (tblHi)
' -- successful search sets tempC

TC_Lookup:
  tblLo = 0                              ' low entry of table
  tempC = 22                               ' default to room temp
```

```
READ (tblHi * 2), Word testVal                ' check max temp
IF (cjComp > testVal) THEN
  error = 1                                   ' out of range
ELSE
  DO
    eePntr = (tblLo + tblHi) / 2              ' midpoint of search span
    READ (eePntr * 2), Word testVal           ' read value from midpoint

    IF (cjComp = testVal) THEN
      EXIT                                    ' found it!
    ELSEIF (cjComp < testVal) THEN
      tblHi = eePntr                          ' search lower half
    ELSE
      tblLo = eePntr                          ' search upper half
    ENDIF

    IF ((tblHi - tblLo) < 2) THEN             ' span at minimum
      eePntr = tblLo
      EXIT
    ENDIF
  LOOP
  tempC = eePntr
ENDIF
RETURN
```

Appendix 2 - Pre and Post Flight Thermocouple Data Capture Tests