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TECHNICAL DATA RECORD

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J. L. Johnson

PAGE 1 OF 42

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DEPT. & GROUP NO.

A. P. Hamilton

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TITLE

Developmental Test of SNAP 10A Resistance Thermometers in a Copper Block Attachment Configuration

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PROGRAM

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STATEMENT OF PROBLEM

The developmental testing of resistance temperature detector 10FS24009 to determine the feasibility and accuracy of NaK tube attachment in a copper block clamping configuration.

ABSTRACT:

Three SNAP 10A resistance Temperature Detectors, manufactured by Winsco Instrument Company, were subjected to a developmental test program to investigate the feasibility of attaching the RT sensor to the NaK tube via a prototype copper block clamping configuration. The test was intended to demonstrate the accuracy of the RTD in a thermal vacuum environment of 10^{-3} Torr and 1000°F in the copper block test configuration. The test sequence was performed in an 8 foot Marshall Tube Furnace with provisions for maintaining the RTD transitions below 140°F in a water cooled copper tube while subjecting the temperature sensor to a 1000°F environment. The NaK tube was heated by a tightly coiled calrod heater placed inside the tube to maintain the flat temperature profile which would exist in the presence of liquid metal flowing inside the tube.

The use of 0 - 300°F resistance thermometers at elevated temperatures of 1000°F required the calibration of the devices and additional thermal cycling to confirm their ability to operate in this environment accurately and reliably. The calibration data obtained experimentally compared favorably with the values calculated by the Callender equation for resistance thermometers. After this requirement had been met successfully the test specimens were installed in the copper block, which had been instrumented with eight calibrated thermocouples and the temperature gradients established in the aforementioned environment. The temperature profiles were measured at various vacuum furnace wall temperatures from 100°F to 1000°F to investigate the effects of varying outer space temperatures experienced on the NPU. The RT-12 selected for the copper block test program was subjected to these conditions in three configurations which employed: 1) The copper block without gold-moly foil wrapped around the assembly; 2) with the gold-moly foil and, 3) with Silflake 850 between the RT and the copper block in addition to the gold-moly foil.

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ABSTRACT (continued)

The results of the RTD calibration at temperatures of 1000°F and the thermal cycling at this elevated temperature indicated the temperature transducers may be operated in this environment without a serious compromise in the accuracy or reliability for relatively short periods of time to meet the requirements of this test endeavor. The calibration change which was observed was within the 3°F inherent uncertainty in the measurement and could not be identified as degradation.

The temperature measurements made in the first configuration, with the RTD and copper block, indicated the maximum error in the RT indicated temperature was 35.5°F at a vacuum tube wall temperature of 170°F and NaK tube temperature of 1000°F. The error was reduced to zero in a linear manner as the vacuum chamber wall temperature was increased to a nearly isothermal condition at 1000°F. The large temperature difference at lower chamber temperatures is partly the result of RTD stem conduction removing heat from the copper-block as evidenced by the 24°F lower temperature on the rear of the copper block. A further analysis of the test fixture temperature profiles reveals a second cause for the large sensor temperature error is the apparent poor thermal contact between the RTD and the copper block as observed by the 18°F average temperature difference between the two elements.

The results of the second test with the RTD copper block wrapped in gold-moly foil reflects an RT indicated temperature which was low by 28.5°F at a furnace wall temperature of 115°F and NaK temperature of 1000°F. The error observed decreased to zero as the vacuum chamber wall was increased to 1000°F. The RTD stem conduction and the large gradient along the copper block was reduced to an insignificant value in this configuration by the application of the gold-moly foil as may be seen by the less than 1°F difference in overall block temperature. The temperature gradient between the copper block and the resistance temperature detector remained very large however. This temperature profile was essentially unchanged by the application of the gold-moly foil and is indicative of the need for improved heat transfer between the RTD and the copper block.

The final test with the RTD-copper block employed an application of Silflake 850 between the RTD and the block in addition to the gold-moly foil installation. The analysis of this configuration showed an impressive decrease in the temperature error between the NaK temperature and the resistance temperature sensor. The RT indicated temperature was 8°F low at a chamber wall temperature of 120°F, 6°F at a wall temperature of 800°F, and ultimately to zero in the isothermal condition at 1000°F. The temperature gradient of the copper block was still insignificant in this attachment configuration and the largest gradient between the temperature sensor and the copper block was less than 8°F.

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ABSTRACT (continued)

CONCLUSIONS

The conclusion which becomes apparent from the evaluation of the various RTD attachment configurations is that the errors incurred in a copper block clamping arrangement can be of considerable concern in an application of accurate temperature measurement in an outer space environment of 1000°F. The magnitude of error may be in excess of 35°F for sensor monitored temperatures of 1000°F if the surrounding environmental temperature is 100°F or less. The apparent cause for the large discrepancy in the RTD indicated temperature may be attributed to sensor stem conduction and poor thermal bonding between the sensor and the copper clamping configuration. The test program revealed the possible solution to the problem may be the application of Silflake 850 between the RTD and block in addition to gold-moly foil wrapped around the NaK tube and RTD-copper block. The errors incurred in resistance thermometer attachment incorporating the previously mentioned additions will provide a temperature measurement to be made with an accuracy of 0.8% and when added with the specified accuracy of the RTD system ($\pm 5^\circ\text{F}$) will be a minimum of 1.3% at 1000°F. The testing performed to date has not given any consideration to the likelihood that the space environment experienced by RT-1 and RT-3, located on the SNAP 10A "handlebar" assembly, will be at a temperature less than 100°F. The results of the RTD-copper block in the configuration with gold-moly foil and Silflake 850 indicates an extrapolation of this calibration curve would present an additional error of less than 0.5°F if the temperature dropped as low as -100°F. Additional testing will be required to establish the RTD structural strength clamped in the copper block when the assembly is subjected to a vibration environment and the potential problems of dispersion of the Silflake 850 permitting undesirable electrical conductivity following thermal vacuum environments and vibration.

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1.0 SCOPE

The test is intended to demonstrate the accuracy of 10FS24-009 resistance thermometers at 10^{-5} Torr and 1000°F, attached to a NaK tube in a prototype copper block configuration. The testing will be performed in an 8 foot Marshall Tube Furnace with provisions for maintaining the RTD transition below 140°F while subjecting the temperature sensor to a 1000°F environment. The test will also investigate the ability of 0 - 300°F RTD's to be calibrated at temperatures up to 1000°F and operate at this temperature without exhibiting any significant degradation. The initial thermal vacuum test will subject the test specimens to a minimum of three elevated temperature cycles with calibrations at 300°F and 1000°F to ascertain the extended temperature range of the resistance transducers. The thermal vacuum test in the copper block configuration will subject the test specimens to a program to determine the sensor accuracy and temperature profile in each of the following test fixtures.

1. RTD-Copper Block Test Fixture
2. RTD-Copper Block Test Fixture Wrapped in Gold-Moly Foil
3. RTD-Copper Block Test Fixture Wrapped in Gold-Moly Foil and an Application of Silflake 850

The NaK tube will be heated by a tightly coiled calrod heater element placed inside the tube to simulate the flow of liquid metal. The test fixture is instrumented to determine the temperature profile at NaK temperatures of 1000°F and space environments varying in temperature from 100°F to 1000°F. The degradation and temperature gradients will be monitored by intercomparing the RTD indicated temperature with the temperature of the calibrated thermocouples located at various points on the test fixture. The objectives of the test program will be fulfilled at such time as the errors which would be encountered in various RTD attachment configurations can be tabulated and calibration curves provided. This information may then be evaluated in an attempt to determine the accuracy of the RTD temperature measurement associated with a clamping arrangement and the feasibility of the various attachments for application on the SNAP 10A system.

2.0 APPLICABLE DOCUMENTS

1. Internal Letter: "Test Plan of Thermal-Vacuum Testing of SNAP 10A RTD in Copper Block Configuration," A. P. Hamilton to D. S. Thompson, 4-22-64
2. NAA-SR-TDR-9768, "Developmental Testing of SNAP 10A Resistance Thermometers".
3. Internal Letter, "Determination of the Difference in Temperature Between Sensors Brazed to a Surface and Those Clamped on in a Vacuum", from M. D. Berber to H. Moore, 8-21-63

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2.0 APPLICABLE DOCUMENTS (continued)

4. "Methods of Testing Thermocouples and Thermocouple Materials", NBS Circular 590
5. Bulletin 9612, "Platinum Resistance Temperature Sensors", Rosemount Engineering Company
6. Application Bulletin 1, "Resistance Temperature Transducers", D. J. Gimple

3.0 REQUIREMENTS

One RTD assembly consists of a transducer assembly and a bridge unit part number 10FS24-009. The transducer is a three-wire platinum resistance element on a stainless steel sheath, filled with MGO insulation. The RT-1-RT-4 detectors incorporate a platinum sheath approximately 1 inch long around the sensitive length of the device. The RT construction consists of platinum leads for a minimum of one foot from the sensor and a transition at this point to copper wire. The temperature measured by the sensor is indicated by a millivolt signal from the bridge box. The millivolt signal appears at the output of the bridge box as the result of the unbalance of the DC excited bridge circuit caused by the change in the sensor resistance with temperature. The bridge box contains 16 bridge circuits to permit readout of 16 sensor assemblies and provide a 0 - 50 MV output signal which is proportional to the temperature in the operating range of the transducer. Lead wire resistance compensation from the bridge to the sensor is provided by the three wire transducer assembly which effectively permits only the sensor resistance to be converted to the millivolt signal proportional to the temperature. The resistance transducer was utilized in the test program without the associated bridge circuit since the 0 - 300°F range sensors were used at temperatures of 1000°F. The sensor temperature was therefore measured by correlation of the resistance with the corresponding temperature as is described in the test procedure. The requirement for the RTD system accuracy is $\pm 5^\circ\text{F}$ on the SNAP 10A unit, however this does not account for any temperature measurement errors which may occur because of the method of attachment to the system.

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3.0 REQUIREMENTS (continued)

The test specimens listed below were subjected to the test program described in the test procedure.

Test Specimens:

<u>RT No.</u>	<u>Serial Number</u>	<u>Operating Range</u>	<u>Calibration at 1000°F</u>	<u>Thermal Vacuum Cycling</u>	<u>Copper Block Test Program</u>
11	483	0 - 300	X	X	
12	491	0 - 300	X	X	X
18	540	0 - 300	X	X	

4.0 TEST PROCEDURE

4.1 Thermocouple Calibration The eight chromel alumel thermocouples utilized in the RTD-copper block test program, were calibrated by interconnecting them with Platinum-Rhodium secondary standards at several temperatures from 300°F - 1000°F to adequately determine the calibration. The calibration was performed by attaching the test thermocouple hot junction to the standard thermocouple hot junction by resistance welding. The thermocouples were then placed in a Marshall 16A tube furnace and the temperature of the test T/C's compared with the standard T/C at each predetermined temperature. The appropriate temperature corrections were made to the standard thermocouple measurement and ultimately the observed error of each test thermocouple was computed. The uncertainty in the temperature calibration is $\pm 2.0^\circ\text{F}$ including the transfer of data from the National Bureau of Standards calibration curve.

The calibration was performed in accordance with Standards Laboratory techniques and equipment with calibration records traceable to the NBS.

Results The results of the calibration of the eight thermocouples is tabulated in the Appendix of this document.

The observed error in the test thermocouple measurement varied from 0.6°F high at 500°F on one specimen to a maximum of 6.3°F high at 1000°F on a second specimen. Thermocouples 1 - 4 were taken from one manufacturing lot of wire and 5 - 8 were taken from a second manufacturing lot which accounts for the somewhat larger error observed on the test T/C's 5 - 8. The calibration was performed with the chromel-alumel thermocouples installed in "conflat" flanges in the same configuration utilized in the test program which followed. The installation of the T/C's in this flange should not result in any serious compromise in the accuracy since each thermocouple lead wire penetrates the flange via a hollow nickel tube. This permits electrical isolation of the T/C wire from the nickel except at one

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4.1 Thermocouple Calibration (continued)

point of contact, required for vacuum sealing, on the ambient side of the flange. This configuration is utilized to essentially eliminate any thermoelectric effect between the flange and the thermocouple which would otherwise result during the thermal vacuum testing which followed.

Test Equipment

<u>Name</u>	<u>Manufacturer</u>	<u>Mod. No.</u>	<u>AEC No.</u>	<u>Calib. Due</u>
Tube Furnace	Marshall	16A	171352	DNA
Standard T/C's	Temptron	Plt-Plt 10% Rhodium	TC-1	At the conclusion of 200 hours of elevated tempera- ture testing
Standard T/C's	Temptron	" " "	TC-2	
T/C Reference Junction	Temptron	TRJ	171491	6-1-64
T/C Reference Junction	Pace	BVJ13A	172148	6-1-64
Potentiometer	L & N	8686	163502	3-3-65
Potentiometer	L & N	K-3	169981	9-9-64
Temperature Controller	West	JP	100014	6-10-64

4.2 RTD Calibration The three 0 - 300°F resistance thermometers were calibrated at several temperatures between 32°F and 1000°F by intercomparing them with the chromel-alumel thermocouples calibrated in 4.1. The resistance temperature detectors were calibrated at temperatures above their normal operating range to permit their use in evaluation of the copper block test program at 1000°F. The calibration curve of each RTD up to 1000°F test temperatures is necessary since the resistance-temperature curve is significantly non-linear with temperature operating ranges of this magnitude. The non-linearity is a result of an inherent decrease in the sensitivity of the platinum resistance elements with increasing temperatures.

The calibration was performed at 32°F in an ice bath and subsequently at temperatures up to 1000°F in a 16A Marshall tube furnace. The thermocouples were attached to the RT sensor by spot welding the T/C on the RTD sensor to measure the average temperature of the sensor. The RTD temperature was determined by measuring the difference between the loop resistance and the lead wire resistance of the transducer. This was accomplished by attaching the sensor leads to the test fixture as shown in figure 1. The

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RTD Calibration (continued)

voltage drop across the 1 ohm resistor and the voltage drop across the sensor was measured with a precision voltmeter. The series circuit current flowing through the 1 ohm resistor and subsequently, the resistance of the RTD was calculated utilizing ohms law.

Results The sensor resistance values at the calibration temperatures are tabulated in Section 5.2 of the appendix. The decrease in platinum resistance element sensitivity at 1000°F results in 50°F to 60°F lower indicated temperature than the value obtained by extrapolation of the resistance calibration curve of the RTD in its normal operating range of 0 - 300°F. The sensor resistance was also calculated by the Callender equation at the average temperature of this RTD as indicated by the attached thermocouples. The calculated resistance was invariably lower than the measured value by 0.5 ohms to 3 ohms although inspection of the curve of resistance vs. temperature of the experimental and the calculated values revealed only a translation of values. (See Appendix). The difference in the experimentally measured resistance value and the value determined by Callender equation is accountable to the fact that the thermometer constant of the RTD ($\delta \approx 1.49$) was approximate and was not measured at the boiling point of sulphur as is necessary for precise calculations. The resistance values at R_0 and R_{100} utilized in the equation were the calculated ideal values and were not measured at temperatures of 0°C and 100°C. The calculation was made only to provide information to substantiate the observed sensor resistance in the extended temperature range of 800°F - 1000°F. Sample calculations of the Callender equation are enclosed in the Appendix.

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Test Equipment

<u>Name</u>	<u>Manufacturer</u>	<u>Mod.No.</u>	<u>AEC No.</u>	<u>Calib. Due</u>
Tube Furnace	Marshall	16A	171352	DNA
Chromel Alumel Thermocouples (1-8)	AI		None	At the completion of 200 hours of tempera- ture testing
TC-Reference Junction	Pace	BRJ13A	172148	6-1-64
Potentiometer L & N		8686	163502	3-3-65
Potentiometer L & N		K-3	169981	9-9-64
Temperature Controller	West	JP	100014	6-10-64
Precision Voltmeter	John Fluke	825A	172087	6-2-64
RTD Loop Resistance Test Fixture	AI			DNA

PREPARED BY: <i>P. Hamilton</i> CHECKED BY: DATE: <i>6-9-64</i>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC. <i>RTD LOOP RESISTANCE TEST</i> <i>FIXTURE</i>	PAGE NO. <i>7</i> OF NAA-SR-TDR- REPORT NO. <i>10084</i> MODEL NO. <i>6-15-64</i>
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IDEAL RTD SENSOR RESISTANCE VALUES			
RTD NO.	RTD RES. AT 32°F	RTD RES. AT 0°F	RTD RES. AT 300°F
11	114.50	106.71	180.0
12	114.50	106.71	180.0
18	114.50	106.71	180.0

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4.3 Test Fixture The test fixture utilized for the thermal vacuum test program permitted the RTD sensitive element to be located in a 1000°F region of the vacuum furnace where the RT transitions and polyelfin insulation are maintained below 140°F. A photograph of the test configuration is enclosed on page 9. The resistance transducer is attached to the NaK tube via a copper block clamping arrangement, photograph page 25 and liquid metal coolant flow simulated by a calrod heater tightly coiled inside the tube. The temperature of the RT copper block test fixture is monitored by the eight calibrated thermocouples attached in the locations shown on figure 2 which permits an evaluation of the fixture temperature profile to be made. The thermocouples were spot welded to the NaK tube and attached to the copper block by drilling a small hole the size of the T/C bead and peening the T/C into the hole.

This method of attachment was necessary due to the poor resistance welding characteristics of chromel alumel to copper.

A tantalum baffle was installed between the 1000°F region of the vacuum furnace and the low temperature end to provide thermal isolation, thereby reducing the cooling requirement of the RT transition. The resistance thermometer transition and polyolefin insulation is maintained below 140°F by the water cooled copper tube as seen in the photograph on page 10. The electrical penetrations required through the vacuum furnace are made at the end flange through "conflat" vacuum feedthroughs of solid nickel for the RTD's and hollow nickel tubes for the thermocouples. The test configuration described was placed in an 8 foot Marshall vacuum furnace with 10^{-3} Torr vacuum capabilities and five equally spaced individually controlled zone heaters placed around the outside of the vacuum tube. The RTD temperature was determined in much the same manner as described in 4.1, Loop Resistance Measurements. The thermocouple temperature was also determined in the same manner as described in 4.2 and with the appropriate calibration corrections for the test temperature

THERMAL VACUUM TEST FIXTURE

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RESISTANCE THERMOMETER TRANSITION COOLING COIL

P. Harrison PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 11 OF NAA-SR- TDR 10084 REPORT NO.
CHECKED BY:	TEST fixture Thermocouple LOCATION	MODEL NO. 6-15-64
DATE: 6-9-64		

figure - 2

TC-7: LOCATED ON INSIDE SURFACE OF VACUUM CHAMBER AT CENTERLINE OF TEST FIXTURE

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4.4 Thermal Vacuum Testing

4.4.1 RTD Calibration in Vacuum Furnace The three 0 - 300°F resistance thermometers were placed in the 8 foot Marshall vacuum furnace in the test configuration outlined in 4.3 with the exception of the copper block and NaK tube. The test specimens were subjected to three thermal vacuum cycles at 10^{-3} Torr from ambient to 1000°F to determine the capability of the test setup to permit accurate temperature measurements and the ability of the 0 - 300°F RTD's to withstand 1000°F environments without exhibiting measurable degradation. The resistance transducer indicated temperature was compared with four calibrated thermocouples at ambient, 300°F, 800°F, and 1000°F during each of the three temperature cycles.

The RTD temperature was determined by computing the sensor resistance as described in 4.1 and observing the difference between the computed temperature and the temperature-resistance relationship from the calibration curves previously obtained. The temperature environment for the thermal cycling was provided by the vacuum furnace skin heaters of which only numbers two and three were utilized.

Test Results The calibration data obtained during the thermal vacuum cycling is tabulated in the Appendix. The observed change in calibration was found to be insignificant as evidenced by the RTD temperature measurements at 1000°F and 300°F. The magnitude of change was within the 3°F uncertainty of measurement and in general was less than 2°F.

RESISTANCE THERMOMETER-THERMAL VACUUM CALIBRATION
CONFIGURATION AND THERMOCOUPLE LOCATION

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4.4.2 Thermal Vacuum Test of RTD and Copper Block The RTD test program in the copper block configuration was limited to the investigation of only one RTD-copper block test fixture during each test due to the maximum feedthrough capability of the furnace end flange. The RT 12 Serial number 491, selected from the three test specimens, was clamped in the copper block as shown in figure 2, and the test assembly described in 4.3 installed in the Marshall vacuum furnace prior to subjection to 10^{-3} Torr and temperature environments up to 1000°F. The resistance transducer calibration was checked at 300°F to confirm the proper operation of the test setup and observe the temperature gradient between the RTD and the NaK tube. The 300°F temperature environment and subsequently the 1000°F test was made with the vacuum furnace wall at ambient temperature and the NaK tube heated by the calrod heater coiled inside. The NaK tube temperature was maintained at 1000°F $\pm$ 10°F and the vacuum furnace wall temperature increased in predetermined increments to provide the temperature profile data of the test fixture for varying temperatures of the furnace wall. This portion of the test was intended to simulate the resistance thermometer operation on the SNAP 10A system at 1000°F in an outer space environment at temperatures ranging from 100°F to 1000°F. The eight thermocouples attached to the test fixture were monitored at each temperature extreme to determine the error which would be incurred by attachment of the sensors to the NaK tube in this manner. The location of the T/C's, figure 2, permitted an evaluation of the temperature gradients of the NaK tube, copper block, NaK tube-copper block, and the entire test fixture with the RTD. The thermocouple temperature was measured by the methods described in 4.2 with the appropriate calibration made. The RTD temperature was measured with the test fixture and methods discussed in 4.1.

Test Results The data taken during this part of the test is tabulated on the following page. A graph has been constructed indicating the temperature gradient between the average tube temperature and the indicated RTD temperature. There are two additional curves on the graph to permit additional analysis of the attachment configuration. The two curves are of the copper block temperature gradient from the RT tip end to the open end; and the heat transfer of the copper block to the RTD by conduction. The graph is the plot of the normalized values of each temperature profile investigation. The temperature gradient between the average NaK tube temperature and the indicated RTD temperature was found to decrease as a linear function as the vacuum furnace wall temperature increased. The magnitude of temperature gradient was 35.5°F at a wall temperature of 170°F and 0°F at a wall temperature of 1000°F. The NaK tube temperature was maintained at 1000°F during all of the above measurements. The temperature gradient from the front end of the copper block to the back was found to vary from 24°F at wall temperature of 170°F to 0°F at 1000°F. This is the result of stem conduction of the heat away from the block by the stainless steel sheath lead of the RTD. The temperature gradient

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Test Results (continued)

between the average copper block temperature and the indicated RTD temperature increased from 18°F at a furnace wall temperature of 170°F to 0°F at a wall temperature of 1000°F. The large gradient at lower temperatures between the RTD and the copper block indicates a possible problem of poor heat transfer between the block and the RTD although this information is partially obscured by the RTD stem conduction previously discussed. The uncertainty in the thermocouple temperature measurement is increased $\pm 3^\circ\text{F}$ from the original T/C calibration in the application of this test configuration. The total uncertainty in each thermocouple temperature is then increased to $\pm 5^\circ\text{F}$ including the uncertainty inherent in the initial calibration. The uncertainty of the temperature repeatability is $\pm 3^\circ\text{F}$ which is the important criteria for this test since the data is intended to demonstrate the error which might be incurred by attachment of the sensor via the copper block if there is not an isothermal condition between the NaK tube and the space environment.

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<u>Name</u>	<u>Manufacturer</u>	<u>Mod. No.</u>	<u>AEC No.</u>	<u>Calib. Due</u>
8 foot Vacuum Chamber	Marshall		104521	6-10-64
Chromel Alumel Thermocouples (1-8)	AI		None	At the completion of 200 hours of temperature testing
T/C Reference Junction	Pace	BRJ13A	172148	6-1-64
Potentiometer	L & N	8686	163502	3-3-65
Potentiometer	L & N	R-3	169981	9-9-64
Precision Voltmeter	John Fluke	825A	172087	6-2-64
RTD Loop Resistance Test Fixture	AI		None	DNA
Ammeter	Weston		167700	7-13-64
Potentiometer	L & N	8692	171356	9-30-64
Power Supply	Harrison	809A	169980	9-30-64

MARSHALL TUBE FURNACE TEST CONFIGURATION

PREPARED BY: J. H. HARRIS

CHECKED BY:

DATE: 6-10-64

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TEST SET UP - BACK DISTRIBUTION
Thermal Vacuum Testing

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MODEL NO. 6-15-64

figure -3

4.4.3 Thermal Vacuum Test of RTD and Copper Block with Gold-Moly Foil

This sequence in the RTD-copper block test program is essentially the same test as described in 4.4.2 with the addition of the gold-moly foil installation. The gold-moly foil is intended to reduce the copper block temperature gradient observed in the previous test by effectively thermally isolating the NaK tube and copper block from the vacuum furnace temperature and thereby reduce or eliminate the RTD stem conduction. The gold-moly foil was installed by wrapping the foil as shown in the photograph on page 25 and resistance welding the two moly surfaces together with a nickelfoil interface between them. The end of the foil enclosure is clamped to the NaK tube as shown.

The test setup was installed in the vacuum furnace and a calibration performed at 300°F and 10^{-3} Torr to confirm the proper operation of the test setup and the temperature gradient between the RTD and the NaK tube. As in the previous test; the measurements at 300°F and subsequently at 1000°F were made with the vacuum furnace wall at ambient temperature and the NaK tube heated by the calrod heater located inside of it. The NaK tube temperature was maintained at $1000^{\circ}\text{F} \pm 10^{\circ}\text{F}$ and the vacuum furnace wall temperature increased in predetermined increments as described in 4.4.2. The eight thermocouples attached to the test fixture were monitored at each temperature environment to determine the error which would be incurred in temperature measurement by the RTD attachment in this configuration. The thermocouple location is the same as in the previous test and as shown in figure 2 to permit a complete evaluation of the test fixture temperature profile to be made. The RTD temperature and thermocouple temperature was measured as described in 4.1 and 4.2

Results The results of this temperature investigation is tabulated on the attached pages and graphs have been constructed to illustrate the relative temperature gradients at various vacuum furnace wall temperatures. The information which was obtained from this test indicates the temperature gradient between the NaK tube and the indicated RTD temperature was 28.5°F at furnace wall temperatures of 115°F, and 0°F at furnace wall temperatures of 1000°F. The measurements are made with the NaK tube at $1000^{\circ}\text{F} \pm 10^{\circ}\text{F}$ and the values which appear on the graph have been normalized. The average copper block temperature gradient has been reduced to an insignificant value in this configuration as has the RTD stem conduction by the application of the gold-moly foil. The temperature difference between the average copper block temperature and the indicated RT temperature is relatively unchanged in this test configuration from that observed in the previous test. The temperature gradient is 22.5°F at a wall temperature of 115°F and 0°F at a wall temperature of 1000°F. This large temperature difference between the RTD and the block points to the apparent poor thermal conduction between the two elements. The cause for the non-linear change in temperature gradient as the furnace

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Results (continued)

wall temperature is increased and the plateau which occurs between 500°F - 700°F is not apparent at this time. A hypothetical explanation may be found if consideration is given to the possibility of a change in the heat transfer characteristics of the copper block, RTD and gold-moly foil with the change in the furnace wall temperature. The uncertainty in the thermocouple repeatability is still $\pm 3^\circ\text{F}$. The uncertainty in the absolute temperature measurement is $\pm 5^\circ\text{F}$ as was discussed in 4.4.2.

Test Equipment Same as 4.4.2

PREPARED BY <i>P. Hamilton</i>	ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	PAGE 23 OF
CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 6-5-64	RTD - COPPER BLOCK WRAPPED IN gold-moly foil	MODEL NO. RT-12 S# 491

DATE	5-14	5-14	5-18	5-18	5-15	5-15	5-15	5-15	5-19
TIME	1350	1550	1615	1310	1330	1440	1600	1645	915
PRESSURE	6 in	7 in	6 in	6 in	8 in	7 in	7 in	7 in	5 in
TC-1 MV	3.5335	19.685	19.725	19.85	19.765	19.655	19.93	19.804	3.541
TC-1 °F	301.9	1001.8	1003.7	1009.4	1005.7	1000.6	1012.6	1007.6	302.2
TC-2 MV	3.532	19.68	19.745	19.88	19.81	19.705	19.98	19.85	3.5465
TC-2 °F	302.3	1000.9	1004	1009.9	1007.2	1002	1014	1008.8	303
TC-3 MV	3.5355	19.64	19.705	19.84	19.785	19.69	19.975	19.86	3.5355
TC-3 °F	302.6	1000.2	1002.8	1009.2	1006.8	1002.2	1014.6	1010	302.6
TC-4 MV	3.506	19.58	19.64	19.78	19.714	19.62	19.906	19.79	3.5205
TC-4 °F	301.8	997.8	1000.2	1006.6	1003.4	999.4	1011.9	1007.1	302.4
TC-5 MV	3.561	19.765	19.80	19.92	19.84	19.72	19.985	19.835	3.547
TC-5 °F	301.7	1004.1	1005.9	1010.7	1007.4	1001.9	1013.3	1007.3	301.2
TC-6 MV	3.558	19.83	19.88	20.0	19.875	19.745	19.99	19.80	3.555
TC-6 °F	301.1	1004.4	1006.4	1011.2	1006.2	1000.5	1010.8	1003.2	301
TC-7 MV									
TC-7 °F	78	109	339	500	697	794	902	997	93
TC-8 MV	3.5374	19.795	19.845	19.945	19.845	19.715	19.96	19.78	3.534
TC-8 °F	301	1002.5	1004.5	1009.3	1006.1	998.5	1009.1	1001.7	300.86
MV DRIP BLK-RED	517.7	727.5	724.6	730.2	732.1	732.9	737.4	737.2	514.6
MV DRIP LEAM	2.862	2.17	2.137	2.125	2.14	2.137	2.124	2.123	2.818
MV DRIP RED-WH	10.1	11.55	14.81	17.41	20.40	22.04	23.53	24.97	10.39
MV DRIP LEAM	4.534	4.536	4.472	4.469	4.462	4.586	4.475	4.469	4.472
RTD SENSIV RESISTANCE	179.1	332.95	335.69	339.1	337.95	338.68	340.74	340.42	179.9
RTD MEAS TEMP.	299.5	929.6	942	951	948	947	959	959	299.5
RTD CALIB TEMP.	301.3	949.7	951.5	955.8	952.4	946.8	954.7	950.6	301
RTD ATC CORRECTION	+1.8	+20.1	+9.5	+4.8	+4.4	-0.2	-4.6	-8.4	+1.5
AT RTD COPPER BLOCK	+2.7	+17.85	+7.7	+3.9	+4.9	+1.9	-.3	-4.7	-3.1
AT FRONT- BLOCK CO. BLK	+ .1	0	+ .74	+ .64	+ .89	+ .59	+ .34	0	+ .6

RTD IN COPPER BLOCK ATTACHMENT CONFIGURATION

RTD IN COPPER BLOCK TEST FIXTURE WRAPPED
WITH GOLD-MOLY FOIL

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4.4.4 Thermal Vacuum Test of RTD-Copper Block with Gold-Moly Foil and Silflake 850

The resistance thermometer 12 was placed in the test fixture as described in 4.3 with the application of Silflake 850 between the resistance transducer and the copper block to promote good thermal contact between the elements. The Silflake is a colloidal mixture of 85% silver and 15% denatured alcohol by weight which essentially silver plates the mating surfaces following the evaporation of the alcohol. The gold-moly foil was installed around the RTD-copper block test fixture as indicated in the test description 4.4.3. The test was again installed in the Marshall vacuum furnace and a calibration performed at 300°F NaK tube temperature and 10^{-3} Torr to assure the proper operation of the test fixture and determine the temperature gradient between the RT and the NaK tube. The NaK tube was then increased to 1000°F and the fixture temperature profile measurements made with the furnace wall at 120°F. The NaK tube temperature was maintained at 1000°F $\pm$ 10°F and the vacuum furnace wall varied in increments from ambient to a nearly isothermal condition at 1000°F. The eight calibrated thermocouples were monitored during the test to provide the desired temperature profile data of the test configuration. The RTD temperature and thermocouple temperature was measured and the necessary calibration corrections made as described in 4.1 and 4.2.

Test Results The data obtained in this test is tabulated on the attached pages with graphs which were constructed to relate the temperature gradients of the test fixture at various vacuum furnace wall temperatures. The data displays a significant decrease in the temperature gradient between the resistance thermometer and the NaK tube. The maximum temperature difference between the RT and the NaK tube was 7.8°F at a furnace wall temperature of 120°F and decreased less than 2°F until a furnace wall temperature of 800°F. The gradient decreased from 6°F at 800°F to 0°F at 1000°F wall temperature. As previously mentioned the NaK tube temperature was maintained at 1000°F $\pm$ 10°F by the calrod heater coiled inside the NaK tube. The calrod heater provided a very uniform temperature along the length of the tube in the location of the copper block in this test and in the previous tests conducted. This flat temperature profile would most nearly simulate the flow of liquid metal inside the tube and introduce a negligible error in the RT-copper block temperature investigation. The data indicates there is still a small gradient between the RTD and copper block in spite of the Silflake although the measured difference may be partly accountable to the uncertainty in the temperature measurement. The temperature profile of the copper block, from front to back, is still relatively flat as indicated in the previous test with the gold-moly foil. The graph on page 30 is intended to provide a means of comparing the RTD attachment to the NaK tube via the copper block without the gold-moly foil, with gold-moly foil, and with gold-moly foil and Silflake. The gold-moly doesn't appear to improve the accuracy of the temperature measurement until the vacuum furnace wall temperature falls below 700°F which is a function of the stem conduction of the RTD versus temperature. The test configuration with

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Test Results (continued)

the gold-moly and the Silflake provides an RTD sensor accuracy of better than 0.8% at NaK temperatures of 1000°F which if added to the RTD system accuracy requirement of $\pm 0.5\%$ ($\pm 5^\circ\text{F}$) provides a total tolerance band of $-.3\%$ to -1.3% in the most severe case.

Test Equipment Same as 4.4.2

PREPARED BY P. HAMILTON	ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	PAGE 28 OF
CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 6-5-64	RTD - COPPER BLOCK WRAPPED IN GOLD-MOLY foil WITH SILFLAKE 850	MODEL NO. RT-12

DATE	5-26	5-26	5-28	5-28	5-28	6-1	6-1	6-1	6-2
TIME	1320	1515	1100	1510	1630	1310	1400	1620	1045
PRESSURE	5u	5u	5u	5u	7u	7u	7u	7u	5u
TC-1 MV	3.396	19.565	19.535	19.61	19.595	19.65	19.665	19.755	3.531
TC-1 °f	295.4	997	995.83	998.8	998.2	1000.4	1001.1	1005.2	301.8
TC-2 MV	3.372	19.54	19.515	19.635	19.625	19.68	19.695	19.725	3.529
TC-2 °f	294.9	995.4	994.35	999.2	998.75	1000.9	1001.6	1005.5	302.2
TC-3 MV	3.332	19.48	19.465	19.60	19.615	19.68	19.69	19.78	3.525
TC-3 °f	293.8	993.8	993.2	998.59	999.2	1001.8	1002.2	1006.6	302.2
TC-4 MV	3.383	19.47	19.45	19.565	19.55	19.615	19.625	19.715	3.516
TC-4 °f	295.9	993.43	992.6	996.9	996.6	999.2	999.6	1003.4	302.2
TC-5 MV	3.419	19.70	19.665	19.75	19.67	19.685	19.70	19.755	3.549
TC-5 °f	295.2	1000.85	999.5	1003.4	999.7	1000.25	1000.9	1003.6	301.3
TC-6 MV	3.429	19.76	19.725	19.775	19.665	19.67	19.685	19.72	3.556
TC-6 °f	295.3	1001.2	999.5	1002.3	996.8	997	997.6	999.2	301.0
TC-7 MV	-1.585	-1.641	3.6	7.72	14.38	17.27	17.32	19.495	-1.575
TC-7 °f	80.6	122.4	307	491.8	779.2	901.8	903.6	993.8	125.8
TC-8 MV	3								
TC-8 °f									
MV DROP BLK-RED	514.3	727.05	725.3	727.35	729.4	728.95	729.05	730.45	514.15
MV DROP 1ohm	2.812	2.124	2.116	2.111	2.108	2.105	2.105	2.10	2.78
MV DROP RED-WH	9.95	11.57	14.56	17.23	21.60	23.69	23.30	24.6	10.70
MV DROP 1ohm	4.47	4.575	4.45	4.44	4.425	4.412	4.412	4.405	4.429
RTD SENSOR RESISTANCE	180.27	339.47	339.25	340.61	340.11	340.63	340.72	341.92	182.08
RTD MEAS. TEMP	301	953	953	957	953	957	957	962	309
RTD CALIB. TEMP	295.33	946.7	946.1	948.95	945	945.4	945.8	947.8	301.14
RTD AYC CORRECTION	-5.7	-6.3	-6.9	-7	-8	-11.2	-11.2	-14.2	-7.86
ΔT RTD COPPER BLOCK	-5.7	-7.4	-11.2	-11.45	-8	-9.45	-9	-11.5	-6.9
ΔT FRONT- DIPPER CO. BL.	-86	0	-15	+45	+64	+1	+1	0	-2

RTD - NAK TUBE TEMPERATURE
 Probes for NAK TEMPERATURE
 at 1000°F and VACUUM CHAMBER
 TEMPERATURE FROM AMBIENT - 1000°F
 RTD ATTACHMENT IS VIA COPPER
 BLOCK WITH GOOD THERMAL CONDUCTIVITY
 SURFACE 850

6-15-64

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Tech: HAMILTON

DATE: 4-1-64

THERMOCOUPLE CALIBRATION

Job.# 1222

TEST THERMOCOUPLES

Type SN-1 - SN-8

Chromel Alumel 289A.

STANDARD-USED

SN-1 & SN-2

PLATINUM-PLATINUM + 10% RHODIUM

Obs EMF OF STD. T/C (MV)	SWITCH NUMBER	T/C NUMBER	T/C NUMBER	SWITCH NUMBER	Obs EMF OF TEST T/C (MV)	CORRECTION ON STD. ° F	CORRECTED EMF OF STD (MV)	TEMP OF STD. ° F	TEMP OF TEST T/C ° F	EMF CORRECTION OF TEST T/C (MV)	TEMP CORRECTION OF TEST T/C ° F
.6685				1	3.768	+ .43		312.33	314.72		- 2.39
.6685				2	3.757				314.28		- 1.95
.6685				3	3.754				314.16		- 1.83
.6685				4	3.745				313.8		- 1.97
.6675				5	3.799	+ .61		312.26	315.96		- 3.70
.6675				6	3.809				316.45		- 4.19
.6675				7	3.771				314.84		- 2.58
.6675				8	3.794				315.76		- 3.50
1.4435				1	7.437	+ 1.16		478.98	479.48		- 1.0
				2	7.434				479.32		- .84
				3	7.435				479.4		- .92
				4	7.428				479.12		- .64
1.453				5	7.538	+ 1.63		480.88	483.52		- 2.64
				6	7.570				484.8		- 3.92
				7	7.521				482.84		- 1.96
				8	7.580				485.2		- 4.32
2.878				1	13.949	+ 1.52		758.77	790.96		- 2.19
				2	13.955				761.2		- 2.43
				3	13.937				760.98		- 1.71
				4	13.938				760.52		- 1.75
2.819				5	13.727	+ 3.09		749.28	751.08		- 1.80
				6	13.78				753.2		- 3.92
				7	13.685				749.4		- .12
				8	13.785				753.4		- 4.12

Job. # 1222

STANDARD-USED

Chrom. Alum. 28 gA.

PLATINUM - PLATINUM + 10% RHOBIUM

Obs EMF OF STD. T/C (MV)	SWITCH NUMBER	T/C NUMBER	TC NUMBER	SWITCH NUMBER	Obs EMF OF TEST T/C (MV)	CORRECTION ON STD. °	CORRECTED EMF OF STD (MV)	TEMP OF STD. °F	TEMP OF TEST T/C °F	EMF CORRECTION OF TEST T/C (MV)	TEMP CORRECTION OF TEST T/C OF
3.552			1	1	16.90	+1.47	-	884.38	886		-1.62
				2	16.91				886.4		-2.02
				3	16.895				885.8		-1.42
				4	16.887				885.55		-1.17
3.475				5	16.63	+3.14		871.84	876.15		-4.31
				6	16.69				876.45		-4.61
				7	16.571				871.84		0
				8	16.692				877.6		-5.76
4.0857				1	19.21	+1.43		981.83	983.4		-1.57
				2	19.227				984.08		-2.25
				3	19.206				983.24		-1.41
				4	19.205				983.2		-1.37
4.0572				5	19.161	+3.04		978.29	981.44		-3.15
				6	19.23				984.12		-5.83
				7	19.097				978.88		-.59
				8	19.24				984.6		-6.31

PREPARED BY <i>P. Harrison</i>	ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	PAGE 33 OF
CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 4-9-64	RTD CALIBRATION DATA	MODEL NO. RT 11 SERIAL No. 483

DATE	4-9-64	4-9-64	4-10	4-13	4-13	4-13	4-13	4-14	
TIME	10:30	16:30	8:20	10:50	15:5	15:50	16:30	10:00	
PRESSURE	1.5u	2.0u	1.5u	3.0u	4.5u	4.5u	4.5u	3.5u	
TC-1 MV	1.745	3.328	3.34	3.591	19.98	19.835	19.66	3.4965	
TC-1 °F	73.2	293.7	294.7	305.2	1014.3	1008.5	1006.5	301.4	
TC-2 MV	1.745	3.338	3.379	3.674	19.755	20.055	19.86	3.555	
TC-2 °F	73.2	294.3	296.8	304.8	1004.4	1016.8	1009.	304.	
M.V. DROP BLK.-Red	435.23	549.7	545.	543.9	762.4	763.2	761.1	538.5	
M.V. DROP 1 OHM	3.44	3.04	3.015	2.96	2.235	2.232	2.24	2.952	
M.V. DROP Red-Wh.	8.29	11.09	10.99	11.02	19.40	19.41	19.30	11.93	
M.V. DROP 1 OHM	4.86	4.83	4.785	4.725	4.70	4.695	4.697	4.67	
R.T.D. SENSOR RESISTANCE	124.8	178.7	178.9	181.17	336.87	338.9	335.4	180.2	
R.T.D. MEAS. Temp.	74.2	293.4	295	305	944	948	939	302.5	
ΔT R.T.D. AVE. TC	-1.0	+0.6	+0.75	0	+65.3	+64.6	+68.8	+0.3	
CAL. R.T.D. Resistance									
DATE	4-15-64	4-15	4-15	4-16	4-17	4-23	4-23		
TIME	11:00	13:30	16:00	11:00	9:00	9:00	11:15		
PRESSURE	12u	12u	12u	9u	8u	Ambient	Ambient		
TC-1 MV	1.6645	3.7685	12.457	1.9.605	4.062	3.728	15.165		
TC-1 °F	76.8	312.9	695.9	998.3	326.6	311.7	805.2		
TC-2 MV	1.654	3.806	12.524	19.70	4.107	3.682	15.018		
TC-2 °F	77.3	315.12	698.	1001.6	329.2	309.9	808.4		
M.V. DROP BLK.-Red	426.9	546.1	682.1	761.5	547.8	541.2	708.9		
M.V. DROP 1 OHM	3.35	2.945	2.492	2.255	2.906	2.955	2.405		
M.V. DROP Red-Wh.	8.15	11.19	15.67	19.23	11.12	8.70	10.13		
M.V. DROP 1 OHM	4.735	4.715	4.70	4.708	4.68	4.714	4.703		
R.T.D. SENSOR RESISTANCE	125.76	183.13	275.17	333.9	184.1	181.66	292.85		
R.T.D. MEAS. Temp.	78.2	313	674	932.6	326.0	308	763		
ΔT R.T.D. AVE. TC	-1.2	+1.0	+22.9	67.3	+19	+2.8	43.8		
CAL. R.T.D. Resistance									

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CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 4-24-64	RTD CALIBRATION DATA.	MODEL NO. ET-11 SERIAL NO. 483

DATE	4-24-64	4-24	4-24	4-24	4-24	4-24	4-24	4-27-64
TIME	9:50	11:00	11:42	13:40	14:50	16:15	16:30	08:20
PRESSURE	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient
TC-2 MV	14.703	17.025	19.1	19.23	17.18	15.191	14.790	1.767
TC-2 °F	790.92	888.8	976.69	981.9	895.8	808.57	794.4	72.3
TC-6 MV	14.604	16.920	19.0	19.155	17.112	15.136	14.758	1.7695
TC-6 °F	789.16	886.8	975.0	981.2	894.6	811.4	795.3	72.2
M.V. Drop B.K.-Red	699.8	723.7	744.1	744.6	724.8	704.4	699.7	412.
M.V. Drop 1-OHM	2.39	2.305	2.24	2.235	2.295	2.37	2.38	3.265
M.V. Drop Red-Wh.	10.11	10.37	10.61	10.61	10.36	10.15	10.14	7.83
M.V. Drop 1-OHM	4.665	4.66	4.664	4.661	4.659	4.66	4.66	4.60
R.T.D. Sensor Resistance	290.83	311.78	329.73	330.73	313.78	294.25	291.83	124.5
R.T.D. Meas TEMP.	156	840	914	919	849	772	758	73
ΔT RT.D.- Ave. TC	34.64	47.8	61.8	62.6	46.2	38	37.1	-0.6
CAL. RT.D. Resistance	290	311	329					

DATE	4-28-64	4-28	4-28	4-28	4-29
TIME	10:00	13:00	16:00	16:30	8:15
PRESSURE	6u	5u	5u	5u	3u
TC-2 M.V.	3.4825	14.745	19.595	19.693	3.878
TC-2 °F	300.7	793.3	997.9	1001.84	318.5
TC-6 M.V.	3.518	14.937	19.86	19.955	3.899
TC-6 °F	302.5	800.6	1009.05	1012.9	319.7
M.V. Drop B.K.-Red	529.7	696.5	745.	744.5	532.5
M.V. Drop 1-OHM	2.912	2.355	2.19	2.186	2.86
M.V. Drop Red-Wh.	10.65	16.65	18.75	18.82	10.77
M.V. Drop 1-OHM	4.625	4.595	4.586	4.58	4.58
R.T.D. Sensor Resistance	179.7	292.37	336.39	306.89	184.15
R.T.D. Meas TEMP.	299	761	941	941.4	317.5
ΔT RT.D.- Ave. TC	+2.6	35.9	62.5	66.3	+1.62
CAL. RT.D. Resistance					

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CALIBRATION CURVE RT-11

SERIAL NO. 483

- ① SENSOR RESISTANCE MEASURED VS CALIBRATION TEMPERATURE.
- ② SENSOR RESISTANCE CALCULATED VS CALIBRATION TEMPERATURE.
- ③ SENSOR INDICATED TEMPERATURE VS STANDARD T/C TEMPERATURE

PREPARED BY <i>P. H. H. H. H. H.</i>	ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	PAGE 36 OF
CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 4-9-64	RTD CALIBRATION DATA.	MODEL NO. RT 12 SERIAL NO. 491

DATE	4-9-64	4-9	4-10	4-13	4-13	4-13	4-14		
TIME	10:30	16:30	8:20	10:50	15:50	16:30	10:00		
PRESSURE	1.5u	2.0u	1.5u	3.0u	4.5u	4.5u	3.5u		
TC1 M.V.	1.745	3.335	3.341	3.5945	19.85	19.68	3.4977		
TC1 °F	73.18	294.	294.7	305.4	1009.1	1001.3	301.5		
TC2 M.V.	1.745	3.387	3.38	3.669	20.062	19.875	3.554		
TC2 °F	73.18	296.3	296.8	304.6	1017.1	1009.6	304.		
M.V. DROP RIK-Red	436.36	552.3	547.5	546.1	768.1	767.6	541.8		
M.V. DROP 1 OHM	3.439	3.035	3.005	2.955	2.213	2.219	2.94		
M.V. DROP Red-Wh.	10.35	14.52	14.3	14.41	26.47	26.5	14.18		
M.V. DROP 1 OHM	4.85	4.816	4.775	4.715	4.672	4.677	4.69		
R.T.D. SENSOR RESISTANCE	124.9	178.98	179.4	181.95	341.34	340.34	181.47		
R.T.D. MEAS. TEMP.	74.5	296	296.5	307.5	962	956	306.5		
ΔT R.T.D. AVE. TC	-1.32	-.86	-.8	-2.5	+52.1	+49.3	-3.2		
CAL. R.T.D. RESISTANCE									
DATE	4-15-64	4-15	4-15	4-16	4-17	4-23	4-23		
TIME	11:00	13:30	16:00	11:00	9:00	9:30	11:30		
PRESSURE	12 u	12 u	12 u	9 u	7 u	Ambient	Ambient		
TC1- M.V.	1.662	3.758	12.462	19.615	4.058	3.630	15.247		
TC1 °F	76.9	312.9	696.1	1000.4	326.5	307.1	813.5		
TC2 M.V.	1.657	3.798	12.525	19.706	4.10	3.575	15.072		
TC2 °F	77.15	314.72	698.	1004.23	328.82	304.8	806.7		
M.V. Drop RIK-Red	428.73	548.6	686.9	767.8	550.8	544.1	713.8		
M.V. DROP 1 OHM	3.345	2.937	2.477	2.23	2.895	2.952	2.38		
M.V. DROP Red-Wh.	10.13	14.54	21.33	26.06	14.52	10.72	12.12		
M.V. DROP 1 OHM	4.725	4.705	4.68	4.683	4.67	4.712	4.697		
R.T.D. SENSOR RESISTANCE	125.85	183.9	272.9	338.94	187.39	181.98	297.41		
R.T.D. MEAS. TEMP.	78.5	316	682	948.2	331	309	782		
ΔT R.T.D. AVE. TC	-1.5	-2.2	+1.5	+53.1	-3.4	-3.1	28.1		
CAL. R.T.D. RESISTANCE									

PREPARED BY <i>P. Hamison</i>	ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	PAGE 37 OF
CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 4-24-64	RTD CALIBRATION	MODEL NO. RT-12 SERIAL NO. 491

DATE	4-24-64	4-24	4-24	4-24	4-24	4-24	4-27		
TIME	10:05	11:07	11:45	13:20	14:00	16:00	08:20		
PRESSURE	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient		
TC1 M.V.	15.162	17.16	19.25	19.34	17.31	15.352	1.767		
TC1 °F	809.2	895.3	983.1	987.1	901.7	819.08	72.3		
TC5 M.V.	14.987	16.96	19.05	19.15	17.13	15.190	1.768		
TC5 °F	805.9	888.4	977.	981.	895.5	813.6	72.3		
M.V. DROP BLK.-Red	708.	728.6	749.2	749.6	729.4	709.2	414.38		
M.V. DROP 1 OHM	2.36	2.29	2.225	2.22	2.28	2.351	3.26		
M.V. DROP Red-Wh.	12.13	12.35	12.65	12.64	12.40	12.16	9.76		
M.V. DROP 1 OHM	4.655	4.65	4.655	4.65	4.648	4.65	4.595		
R.T.D. SENSOR RESISTANCE	297.39	315.34	333.29	334.28	316.83	299.39	124.88		
R.T.D. MEAS. TEMP.	782	853	929	931	862	789	74.5		
AT R.T.D. AVE. TC	+25.5	+38.97	+51.1	+53.1	+36.6	+27.3	-2.2		
CAL. R.T.D. RESISTANCE	294.5	312.5	331	332	313	296		CALCULATED BY CALCULATING EQUATION	
DATE	4-28	4-28	4-28	4-28	4-29				
TIME	10:00	13:00	16:00	16:30	8:15				
PRESSURE	6 in	5 in	5 in	5 in	3 in				
TC1 M.V.	3.4875	14.7435	19.60	19.70	3.8755				
TC1 °F	307.	793.20	998.1	1002.1	318.4				
TC5 M.V.	3.5306	14.940	19.87	19.965	3.906				
TC5 °F	303.05	800.8	1009.5	1013.3	320.04				
M.V. DROP BLK.-Red	533.3	701.1	750.05	150.8	536.5				
M.V. DROP 1 OHM	2.90	2.335	2.171	2.166	2.846				
M.V. DROP Red-Wh.	13.91	22.30	25.55	25.59	13.95				
M.V. DROP 1 OHM	4.615	4.58	4.565	4.56	4.57				
R.T.D. SENSOR RESISTANCE	180.49	296.14	340.41	340.4	185.45				
R.T.D. MEAS. TEMP.	303	776	958	957	322				
AT R.T.D. AVE. TC	-1	+23	+45.8*	+50.6	-2.8				
CAL. R.T.D. RESISTANCE									

PREPARED BY: P. Harrison	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 38 OF NAA-SR-TDR-10084
CHECKED BY: 6-10-64	CALLendar EQUATION SAMPLE CALCULATIONS	REPORT NO. 6-15-64
DATE:		MODEL NO.

$$T = 100 \left(\frac{R_T - R_0}{R_{100} - R_0} \right) + \delta \left(\frac{T}{100} - 1 \right) \frac{T}{100}$$

CALLendar EQUATION
for RESISTANCE TEMPERATURE
DETECTORS

R_T = RESISTANCE AT $T^\circ\text{C}$

R_0 = RESISTANCE AT 0°C

R_{100} = RESISTANCE AT 100°C

T = TEMPERATURE OF MEASUREMENT

δ = DELTA, THERMISTOR CONSTANT MEASURED AT SULPHUR
BOILING POINT

R_0 IDEAL FOR RT-12 = 114.5 ohms

R_{100} IDEAL FOR RT-12 = 158.4 ohms

$\delta \cong 1.49$

$T = 526.6^\circ\text{C}$ AVERAGE TEMPERATURE OF ATTACHED T/C's

$$526.6 = 100 \left(\frac{R_T - 114.5}{158.4 - 114.5} \right) + 1.49 \left(\frac{526.6}{100} - 1 \right) \frac{526.6}{100}$$

$R_T = 331$ ohms

R_T MEASURED = 333.29

ΔR_T IS ACCOUNTED FOR BY APPROXIMATE VALUES OF

R_{100} , R_0 , AND δ WHICH WOULD HAVE TO BE

MEASURED VERY ACCURATELY BY EXPERIMENTAL MEANS.

6-15-64

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CALIBRATION CURVE RT-12SERIAL NO. 491

- ⊙ SENSOR RESISTANCE MEASURED VS CALIBRATION TEMPERATURE
- SENSOR RESISTANCE CALCULATED VS CALIBRATION TEMPERATURE
- ⊙ SENSOR INDICATED TEMPERATURE VS STANDARD TIC TEMPERATURE

PREPARED BY P. HAMILTON	ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	PAGE 40 OF
CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 4-9-64	RTD CALIBRATION DATA	MODEL NO. RT-18 SERIAL NO

DATE	4-9-64	4-9	4-10	4-13	4-13	4-13	4-14		
TIME	10:30	16:30	8:20	10:50	15:50	16:30	9:00		
PRESSURE	1.5 m	2.0 m	1.5 m	3.0 m	4.5 m	4.5 m	3.5 m		
TC 3 M.V.	1.743	3.339	3.338	3.6002	19.912	19.68	3.5035		
TC 3 °F	73.3	293.7	294.2	305.3	1010.3	1000.	303.1		
TC 4 M.V.	1.744	3.349	3.340	3.607	19.963	19.728	3.505		
TC 4 °F	73.2	293.7	294.3	305.7	1014.1	1004.	303.2		
M.V. DROP BLK-Red	438.68	554.7	549.8	548.1	768.4	768.5	543.6		
M.V. DROP 1 OHM	3.427	3.026	3.00	2.945	2.213	2.216	2.938		
M.V. DROP Red-Wh.	15.87	22.90	22.54	22.84	43.1	42.78	22.49		
M.V. DROP 1 OHM	4.83	4.79	4.745	4.685	4.618	4.621	4.665		
R.T.D. SENSOR RESISTANCE	124.72	178.7	178.7	181.6	337.67	337.75	180.18		
R.T.D. MEAS. TEMP.	73.85	293	293	305	938	947	301		
ΔT R.T.D. AVE. TC	- .6	+ .7	+1.22	+ .5	74.2*	+55	+ .4		
CAL. R.T.D. RESISTANCE					BAD READING				
DATE	4-15	4-15	4-15	4-16	4-17	4-17	4-23	4-23	
TIME	11:00	13:30	16:00	11:00	9:00	9:50	9:00	12:40	
PRESSURE	12 m	10 m	12 m	9 m	7 m	7 m	Ambient	Ambient	
TC 3 M.V.	1.6583	3.745	12.427	19.545	4.047	4.0175	3.594	14.99	
TC 3 °F	77.1	312.1	693.7	994.7	325.7	324.2	305.06	802.5	
TC 4 M.V.	1.6587	3.711	12.341	19.495	4.041	4.011	3.5975	15.018	
TC 4 °F	77.1	310.7	691.0	994.4	325.4	323.9	305.2	804.9	
M.V. DROP BLK-Red	430.63	550.3	688.9	767.4	552.4	551.4	544.5	711.1	
M.V. DROP 1 OHM	3.335	2.93	2.47	2.23	2.89	2.89	2.95	2.385	
M.V. DROP Red-Wh.	15.51	23.0	34.4	42.27	22.4	22.44	16.07	17.48	
M.V. DROP 1 OHM	4.71	4.675	4.635	4.627	4.645	4.637	4.695	4.675	
R.T.D. SENSOR RESISTANCE	126.21	183.08	271.57	334.86	186.67	185.65	181.07	294.26	
R.T.D. MEAS. TEMP.	76.8	311	677	936	327	325	305	767	
ΔT R.T.D. AVE. TC	+ .3	+ .4	+25.4	+58.55	-1.5	-1.0	+ .1	+36.7	
CAL. R.T.D. RESISTANCE									

PREPARED BY <i>P. Hamilton</i>	ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	PAGE 41 OF
CHECKED BY		REPORT NO. NAA-SR-TDR-10084
DATE 4-24-64	RTD CALIBRATION DATA	MODEL NO. RT-18 SERIAL NO.

DATE	4-24	4-24	4-24	4-24	4-24	4-24	4-27		
TIME	10:35	11:17	11:45	13:00	14:50	15:50	18:20		
PRESSURE	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient		
TC 3 M.V.	15.256	17.22	19.34	19.32	17.37	15.422	17.69		
TC 3 °F	813.2	896.8	985.9	984.9	902.8	823.9	72.2		
TC 4 M.V.	15.2745	17.235	19.385	19.335	17.39	15.448	17.69		
TC 4 °F	815.8	899.1	989.9	987.1	905.3	824.9	72.2		
M.V. DROP									
BLK.-Red	707.9	728.4	749.1	747.2	728.6	709.6	416.1		
M.V. DROP									
1 OHM	2.36	2.29	2.222	2.223	2.285	2.35	3.255		
M.V. DROP									
Red.-Wh.	17.55	17.80	18.12	18.10	17.85	17.52	14.91		
M.V. DROP									
1 OHM	4.637	4.636	4.64	4.63	4.63	4.63	4.58		
R.T.D. SENSOR									
RESISTANCE	296.21	314.16	333.09	332.09	311.14	298.22	124.75		
R.T.D. MEAS.									
Temp.	777	850	927.5	924	858	784.5	74		
AT R.T.D.									
Ave. TC	+37.53	+47.97	+60.36	+61.99	+46.1	+39.9	-176		
CAL. R.T.D.									
RESISTANCE	295.5	313.5	332.5						
DATE	4-28	4-28	4-28	4-28	4-29				
TIME	10:00	13:15	16:00	16:30	8:15				
PRESSURE	6 in	5 in	5 in	5 in	3 in				
TC 3 M.V.	34765	14.838	19.78	19.875	38496				
TC 3 °F	300.2	795.5	1004.9	1008.86	317.08				
TC 4 M.V.	3.4475	14.730	19.645	19.745	3.827				
TC 4 °F	298.8	792.05	1000.53	1004.9	316.2				
M.V. DROP									
BLK.-Red	534.3	702.5	750.1	750.2	537.2				
M.V. DROP									
1 OHM	2.895	2.332	2.175	2.17	2.845				
M.V. DROP									
Red.-Wh.	21.68	36.12	41.71	41.76	21.93				
M.V. DROP									
1 OHM	4.585	4.532	4.56	4.506	4.545				
R.T.D. SENSOR									
RESISTANCE	179.76	293.07	335.87	336.74	183.77				
R.T.D. MEAS.									
Temp.	299.5	764	939	943.9	316				
AT R.T.D.									
Ave. TC	0	34.77	+63.7	+62.9	+6.1				
CAL. R.T.D.									
RESISTANCE									

CALIBRATION CURVE RT-18

SERIAL NO. 540

- ⊙ SENSOR RESISTANCE MEASURED VS CALIBRATION TEMPERATURE
- SENSOR RESISTANCE CALCULATED VS CALIBRATION TEMPERATURE
- ⊗ SENSOR INDICATED TEMPERATURE VS STANDARD T/C TEMPERATURE