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HIGH TEMPERATURE STRAIN GAGE EVALUATION

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ABSTRACT

The structural thermal test of an advanced ramjet missile section required strain measurements as high as 922°K (1200°F). Since there is relatively little experience in the use of strain gages above the 700-755°K (800-900°F) level, a program was initiated to select and evaluate the best available gage.

Candidate gages suitable for measurements up to 922°K (1200°F) were selected. This involved the determination of their operating characteristics, availability, cost, installation aspects, etc. Gages selected were the AILTECH SG-425 (weldable), the BLH type HT 212 (free filament), and the Bean type BPTH-08-600 WD-120 wire dual filament gage.

The evaluation involved the following tests: strain as a function of load at room temperature and apparent strain as a function of temperature.

Based on results of evaluation, the AILTECH (weldable) gage was selected. The choice was based on: 1) total apparent strain of AILTECH is about 10 percent of test strain while that of next best gage is of the same order of magnitude as test strain. In addition, the total apparent strain resulting with the AILTECH is less than the data scatter of the next best gage, 2) moisture sealant on filament gages requires refurbishing after being subjected to temperatures on the order of 700°K (800°F), and 3) AILTECH is comparatively simpler to install.

I. INTRODUCTION

The structural thermal test of an advanced ramjet missile section requires temperature and strain measurements as high as

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922°K (1200°F). Although temperature measurement techniques have been well established for testing in the 922°K (1200°F) there is relatively little experience in the use of strain gages above the 700–755°K (800–900°F) range. While there are numerous gages available, their accuracy, application techniques, and costs vary greatly. In view of this, a program was initiated to select and evaluate the best available gage(s) for the above test.

This paper discusses the evaluation of the candidate gages and the selection of the AILTECH weldable gage.

II. DISCUSSION

A. Candidate Gages

One of the initial requirements of the program was the selection of strain gages suitable for measurements up to 922°K (1200°F). This involved the determination of their operating characteristics, calibration/correlation data, cost, installation aspects, etc. Table I summarizes gages which were considered prior to selection. Some of the criteria which were used in screening and selecting a suitable gage were as follows:

1 Gage must be capable of withstanding temperatures up to 922°K (1200°F) for short periods of time without marked deterioration due to oxidation, moisture or temperature.

2 Gage must be capable of withstanding repeated transient cycles.

3 Gage must be capable of accommodating large thermal stress, including that generated within the gage itself.

4 Gage must be resistant to corrosion.

5 Gage installation should be comparatively simple and require little or no refurbishment.

Three gages were selected for further evaluation based on accuracy, cost, and prior usage history. The gages which were selected were the AILTECH type SG-425-09A-10 weldable gage, the BLH type HT 212-4A/4B free filament gage, and the Bean type BPTH-08-600 WD-120 wire-dual filament gage. Details for each of these are available in vendor catalogs, References 1, 2, and 3, respectively.

TABLE I

High Temperature Strain Gage Selection Chart

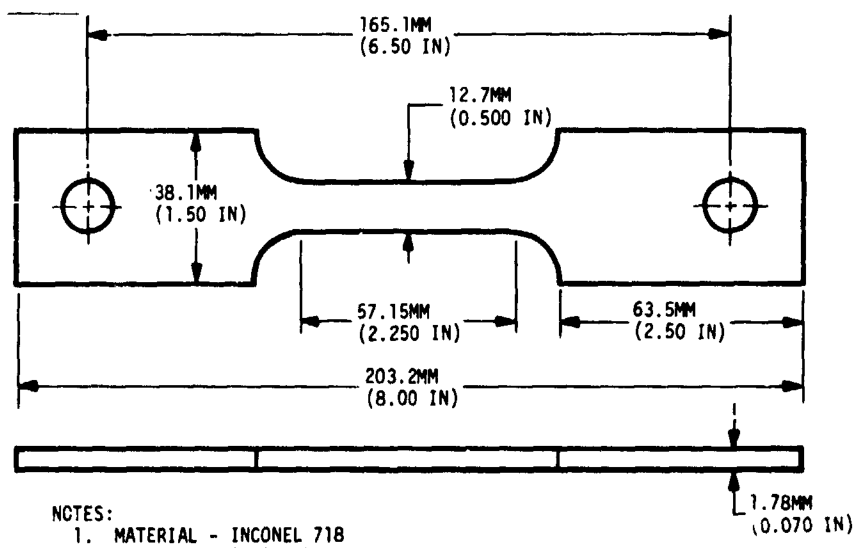
Manufacturer	Type	Temperature Limit Error 5 Percent	10 Percent	20 Percent	State of the Art	Remarks
BLH Electronic, Inc.	FNW9-50-12		644°K (700°F)	922°K (1200°F)	Available	Weldable bond. Physical size too large for our requirements.
	[illegible]WFR9-50-12		811°K (1000°F)	922°K (1200°F)	Available	
	HT-212-4A, 4B	589°K (600°F)	811°K (1000°F)	922°K (1200°F)	Available	Ceramic and flame spray bond. High temperature capabilities. Has been used with success. Selected for evaluation.
William T. Bean, Inc.	BPTH-08-600WD-120	589°K (600°F)	700°K (800°F)	922°K (1200°F)	Available	Ceramic and flame spray bond. High temperature capabilities. Has been used with success. Selected for evaluation.
Hitec Corp.	HFP 12-125-SCW		811°K (1000°F)	1366°K (2000°F)	Available (New)	Ceramic and flame spray bond. High temperature capabilities. Recommended for dynamic testing
AILTECH, Inc.	SG-425-09A-10	644°K (700°F)	783°K (950°F)	922°K (1200°F)	Available	Weldable bond. Physical size is large but acceptable. High temperature capabilities. Selected for evaluation.
Hughes Aircraft Co.	CSG-201	922°K (1200°F)	1089°K (1500°F)	1228°K (1750°F)	Available Development	Capacitance type gages. Weldable bond. Excellent high temperature capabilities. Cost of gage and necessary readout equipment prohibitive.
Boeing Aerospace Company	CS-20-100	922°K (1200°F)	1089°K (1500°F)		Available Development	Capacitance type gages. Weldable bond. Excellent high temperature capabilities. Cost prohibitive.

The AILTECH gages were purchased with a magnesium oxide (MgO) insulated integral stainless steel jacketed copper lead-wire 3.048m (10 feet long). The strain element is a platinum tungsten alloy. These gages were temperature compensated for Inconel 718 (we provided vendor with sample of material) over a range of temperatures from room to 922°K (1200°F). The BLH gages have free-filament wire grids and the strain sensing element is a nickel-chormel alloy. The HT-212 gage does not have temperature compensation. Chromel alumel thermocouples come installed in the -4B series while the -4A series does not have thermocouples. The Bean gage grid consists of a stabilized dual platinum filament. The BPTH series is temperature compensated over the range from room temperature to 811°K (1000°F).

The total (thermal and mechanical) strain range for the missile test section is on the order of 1 1/2 percent, 0.015 mm/mm (0.015 in/in). In view of this, ceramic cement gage installations were eliminated since this bonding method is not effective above 1/2 percent mechanical strain, 0.005 mm/mm (0.005 in/in). This affected both of the above filament gage candidates and required that these gages be applied with a flame spray technique.

B. Test Specimen

All gages were mounted on tensile coupons fabricated of Inconel 718 1.78 mm (0.07 inch) thick as shown in Figure 1. The choice of tensile coupon was made to ascertain that we had a constant stress distribution applied over a well defined cross sectional area where gages could be installed. A 1.78 mm (0.07 inch) thickness was used because it is representative of the thinnest wall of the missile test section (Figure 2). This wall thickness is the most likely to be affected by gage application (particularly the weldables). An added feature of this thin wall is that it minimizes undesirable temperature gradients across wall thickness. The coupon was designed to be compatible with the Instron Universal Testing machine. The coupons were heat treated to the same specifications as the missile test section structure.



NOTES:
1. MATERIAL - INCONEL 718
2. DIMENSIONS IN INCHES.
3. DO NOT OVERHEAT DURING MACHINING - 322°K (120°F) MAXIMUM. THIS WILL BE CHECKED METALLURGICALLY. OVERHEATING WILL CAUSE ERRONEOUS RESULTS.
4. THE MARKED IDENTITY MUST BE RETAINED ON EACH SPECIMEN.
5. AFTER MACHINING HEAT TREAT:
   992±8°K (1325°F ±15°F) - HOLD FOR 8 HRS
   FURNACE COOL TO
   894±8°K (1150°F ±15°F) - HOLD FOR 8 HRS
   AIR COOL

Fig. 1-Typical test specimen

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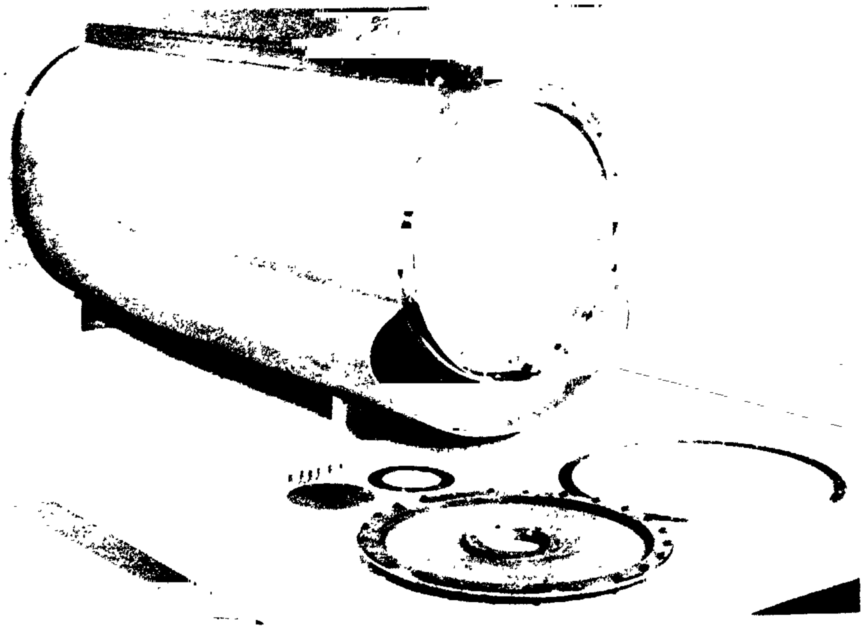

Fig. 2-Missile test section

C. Gage Installation

Figures 3, 4, and 5 show photographs of installed AILTECH, Bean, and BLH gages, respectively. One AILTECH gage was applied to each side of the specimen. The AILTECH gage was spot welded along its flange as per the instructions in Reference 4.

Four chromel alumel thermocouples (28 gage, two on each side of the specimen coupon) were installed on the specimen next to each AILTECH gage. Figure 3 shows gage and thermocouple installations along with auto collimator target tips. Each of the AILTECH gages was designed to read separately in a full bridge circuit.

Both the Bean and BLH filament gages were applied with the Rokide flame spray process which is well detailed in the literature. One Bean gage was applied to each side of the specimen (Figure 4). Again, four chromel alumel theromcouples, two on each side of the specimen, were installed. Each of these gages was wired to read separately in a full bridge circuit similar to that used with the AILTECH gage.

Two BLH gages were applied on each side of the specimen (Figure 5). Each of the two gages was applied in a Poisson bridge installation and also wired in a full bridge circuit.

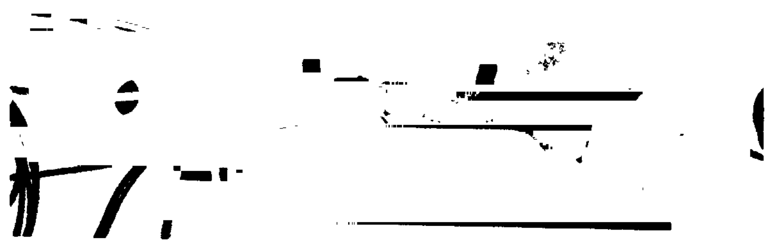

Fig. 3-Test specimen with AILTECH gage, dual center thermo-couples, and collimator target tips

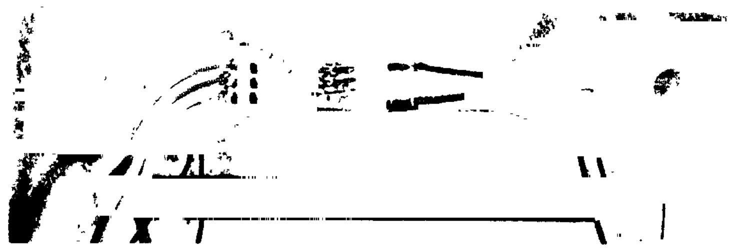

Fig. 4-Bean strain gage installation

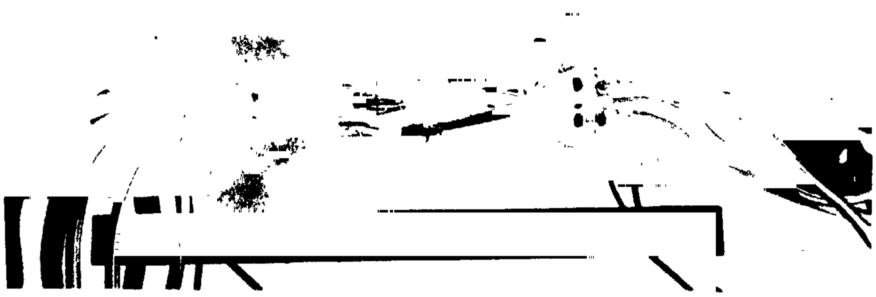

Fig. 5-BLH strain gage installation

D. Test Equipment/Instrumentation

The primary items of equipment in the test setup (Figure 6) consisted of the following:

1 Research Incorporated one channel temperature programmer and power regulator, Model 5052S (3KVA). The regulator delivers power to two quartz lampbanks. Each lampbank houses eight 2000 watt quartz lamps. One feedback thermocouple (which is one of four attached to specimen) completes the closed loop null balance system.

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2 Instron Universal Testing Machine Model PTD, 9072 kg (20,000 pound) maximum capacity. The 2268 kg (5000 pound) range has an accuracy of ±1 percent of full scale, i.e., 22.7 kg (50 pounds).

3 BLH Digital Indicator Model 902 used in conjunction with a strain gage conditioning unit model 130. The indicator could be read to 10 microstrain. Its accuracy was approximately ±1 percent of full scale.

4 CEC Oscillograph Recorder Model 5-124 with 7-347 galvanometers for temperature reading.

5 Plotomatic X-Y Plotter Model 690 with an accuracy of ±1 to 2 percent of full scale.

Fig. 6-Overall view of test equipment and instrumentation

Other ancillary test equipment used included an Electro Scientific Resistance Bridge (Model 231), Westronics four channel continuous temperature recorder (Model DD 11E), PhysiTech Electro Optical Auto Collimator (Model 440), and Satec elevated temperature extensometer (Figure 7).

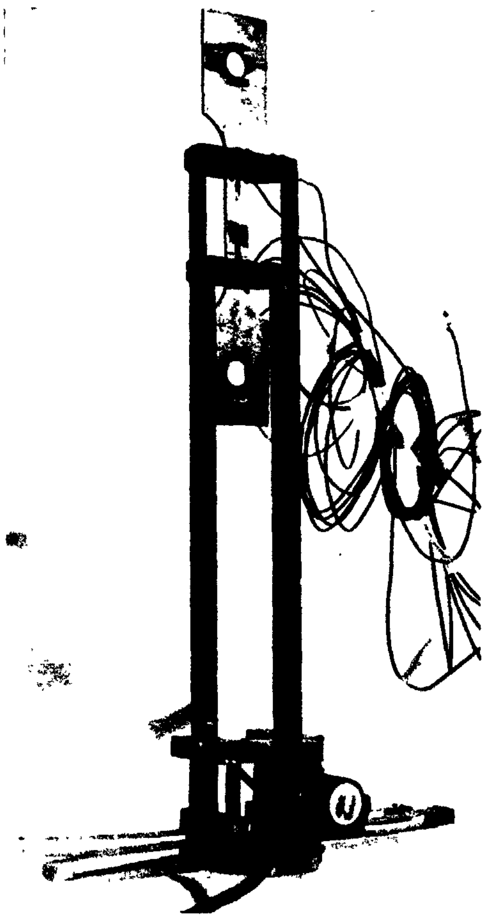

Fig. 7-Instrumented test specimen installed in Sates extensometer

E. Test Setup/Procedure

The test procedure for all candidate gages consisted essentially of the same steps. After mounting specimen with gages in the Instron, dummy (balance) resistors were sized and wired into the complete circuit. The complete circuitry included the initial high temperature leadwire plus vinyl extensions required to reach the common junction chassis box. Additional setup included the sizing and wiring of a shunt resistance (R_{CAL}) for calibrating the strain indicators.

1. AILTECH

Two problems were encountered with the AILTECH gages that required above average attention. One was the mechanics of leadwire attachment and the other, the moisture absorption in the gage/leadwire that reduced the insulation resistance (IR) or resistance to ground.

During the initial test phase we found that the three-wire leads (this system was used to minimize leadwire error) at the end of the stainless steel sheath were very fragile and could not sustain normal flexing or handling. These leads had to be potted against a support backing that prevented their being flexed or pulled apart. Subsequent to the above, the vendor advised that the leadwire could be provided with potting boots and vinyl extensions as an integral feature. From this point on tests were conducted on gages with an integral potting boot that had a 3.18 mm (1/8-inch) diameter (OD).

Moisture absorption with the above (initial) exposed three-wire leads was a major area of concern and required special attention. Although the vendor provided all gages with sealed ends and IR on the order of 1000 megohms, moisture absorption was experienced. We determined that with normal storage and handling the IR dropped from 1000 to 3 megohms in a 3-month period. Attempts were made to drive the moisture out (as per instructions in Reference 4) by heating the last 152.4 mm (6 inches) of leadwire with a heat gun. Since this proved too time consuming, our procedure was changed to storing gages in a 333°K (140°F) oven. One overnight stay in the oven increased the IR from 3 to 150 megohms. The impact of initial IR values on indicated strain readings can be significant. For example, assuming a straight resistance to ground, strain versus IR is as follows:

Indicated Strain μ mm/mm	Insulation Resistance (IR) Megohms
3.2	10
32	1

Although the installation of potting boots minimized moisture absorption, our test procedure required the storage of gages in either a 333°K (140°F) oven or a dry nitrogen environment.

2. Bean and BLH Gages

Moisture absorption is also a problem with these type gages. The moisture problem is not with the leadwire sealant (as with the AILTECH) but instead with the alumina (flame spray) rod and the foil itself. Both of these type gages have a moisture sealant coating applied as an end item. This coating cooks off at 700°K (800°F) and needs to be reapplied if continued moisture sealant is required. It is apparent that in view of our missile section test requirements this is a decided disadvantage.

F. Calibration Techniques

Various calibration techniques were considered to support these tests. Calibration candidates included extensometer, auto collimator, cantilevered beam and analyses.

1. Extensometer

Extensometers considered were the Instron strain gage (room temperature type) and the Satec (elevated temperature). The Instron type is capable of room temperature (RT) readings only. Besides temperature, other limitations included the fact that the gage span was 50.8 mm (2 inches) (this presented a problem in installing strain gages between knife edges) and also with a full scale of 5.1 mm (0.20 inch) and an accuracy of at best 0.1 percent the reading would be ±200 microstrain (0.0002 mm/mm).

The Satec (Figure 7) and similar elevated temperature extensometers also have the above gage span problem. The elevated temperature capability is solely at steady state and only for mechanical loads. Once a steady state temperature is achieved, mechanical load is applied and data read. Thus, for any mechanical load and steady state temperature, only the strain due to load can be read.

Since the calibration standard must have the capability of operating during transient temperature conditions (rates as high as 8°K/sec), consideration was given to insulating the extensometer linkage. This, however, was not considered practical. Based on the above, the use of the extensometer as a standard was abandoned.

2. Auto Collimator

The PhysiTech Model 440 Electro Optical Auto Collimator (Figure 6) is designed to measure angular motion simultaneously in two mutually perpendicular axes. The system is completely self-contained and requires only a mirrored or reflective surface as a position transmitter. Relative position and linear displacement can be obtained with the auto collimator.

From the standpoint of measuring strain due to temperature alone, the collimator performs with an accuracy on the order of ±0.0005 mm/mm. The strain data read compared favorably with available test data.

With mechanical load alone, the minimum test strain is on the order of 0.0005 to 0.001 mm/mm. This small value of elongation, ΔL of about 0.025-0.051 mm (0.001 to 0.002 inch), together with the fact that both target tips move over a large distance, about 1.02 mm (0.040 inch), created a problem with the use of the collimator. Since the lens heads must track both targets, then large amplifier full scale settings are required. Thus, a full scale sensitivity problem exists due to test facility, wherein the movement between target tips on a specimen is small but yet individually the tips can have a large movement. This dual requirement makes the use of the collimator unfeasible.

3. Cantilever Beam

Use of the cantilever beam approach was not considered feasible because of the inability to handle high transient heating rates.

4. Summary

In view of the above, analytical techniques based on experimentally generated modulus of elasticity and linear coefficient of expansion were used as the calibration standard.

G. Test Results

All candidate gages were subjected to two tests, the first (Test 1) generated strain as a function of load (at RT) and the second (Test 2) apparent strain as a function of temperature. In Test 1 the load was varied from 0 to 1134 kg (0 to 2500 pounds) in 113 kg (250 pound) increments. Test 2 determined the strain as a function of temperature, while the load was kept constant at 0 kg. These are the data which are used to generate apparent strain curves. Based on the results of Tests 1 and 2 the best gage was selected for further tests.

1. Strain as a Function of Load (at RT)

Figure 8 shows a compilation of strain at RT data for candidate gages. The (R.S.) and (L.S.) for both Bean and BLH refers to gages on the right and left side of the test specimen. All data are for the second cycle where repeatability was achieved. The Bean data are very close to the analytical strain uncorrected for the effect of gage installation (X). The BLH (R.S.) and AILTECH gage numbers 4660-5 and -7 are slightly low. The analytical strain corrected for the effect of AILTECH gage installation is noted (θ). The low readings on AILTECH -4 and BLH (L.S.) may be due to installation procedure.

2. Apparent Strain as a Function of Temperature

Measured apparent strain as a function of temperature is shown in Figure 9 for the AILTECH and Bean gages. Compression is noted as (+) and tension as (-). Data on BLH gages (where each of two gages was applied in a poisson bridge and also wired in a full bridge circuit) were not plotted since they were very erratic. Note that the figure shows the data scatter (vertical bars) for each type gage. The AILTECH data are for an average of three gages and include both first and second cycle results. The AILTECH with its temperature compensation has been designed to go through 0 microstrain at both RT and 922°K (1200°F). Note that the shift at 0 is about 50 microstrain while at 922°K (1200°F) it is larger, 120 microstrain. The average maximum bow in apparent strain specified by the vendor is 318 microstrain at 260°K (500°F).

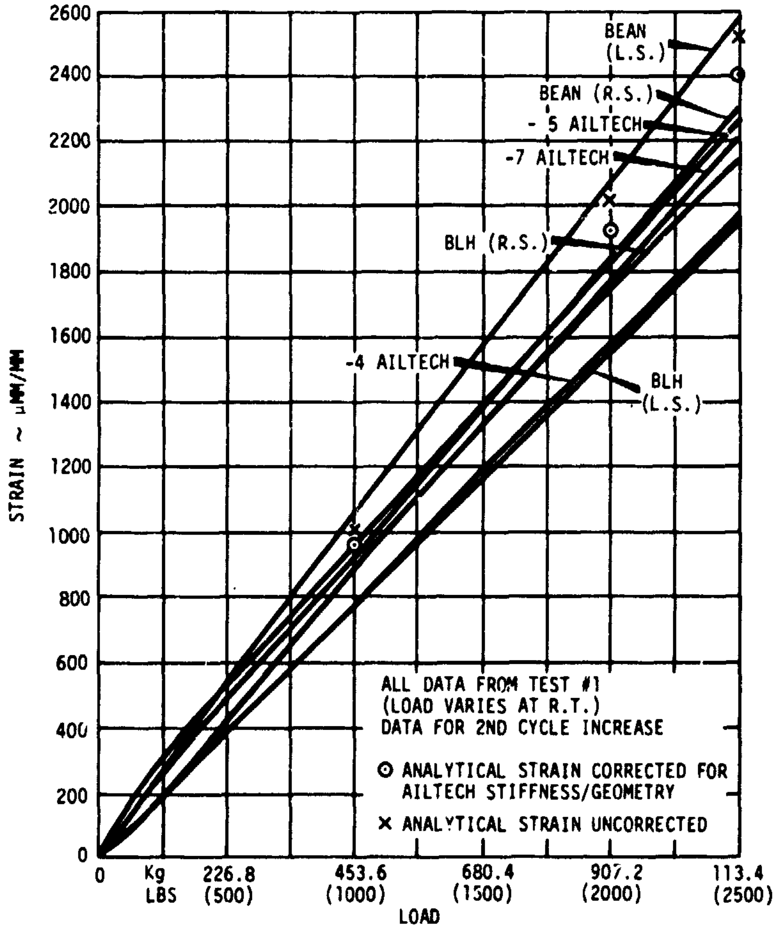

Fig. 8-Strain versus load for candidate gages

The Bean with its temperature compensation is designed to read 0 microstrain at RT and 811°K (1000°F). The shift in the RT reading is quite large. If first cycle results were included, scatter could be as much as 800 to 1000 microstrain.

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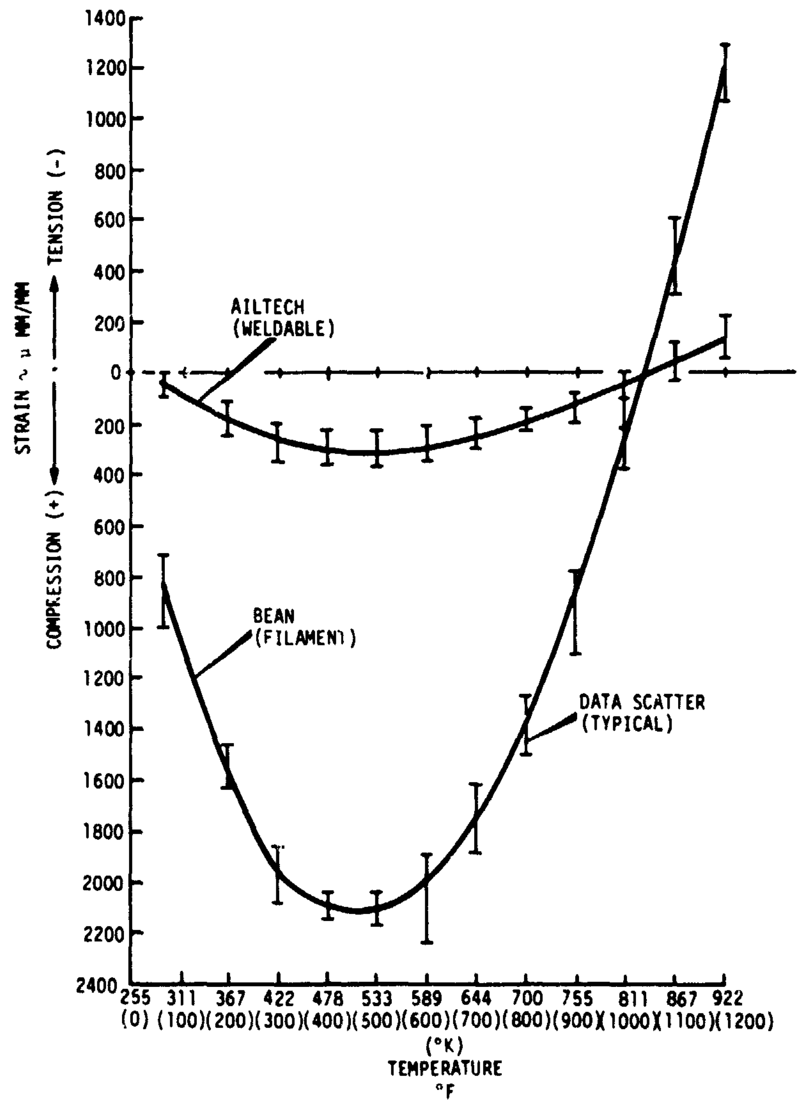

Fig. 9-Apparent strain versus temperature

The erratic data of the BLH were attributed to moisture absorption. Another important point regarding the BLH is that it lacks temperature compensation. Its apparent strain is on the order of 18 microstrain per 0.5°K (1°F). This means that we could be reading strains on the order of 18,000 microstrains at 811°K (1000°F) on our test section.

3. Gage Comparisons

The peak expected mechanical strains to be measured during the test are approximately 2000 microstrain. The total apparent strain associated with the AILTECH is about 10 percent of the test value. The total apparent strain with the Bean is of the same order of magnitude as the test value. Also, the data scatter in the Bean apparent strain can be as much as 40 percent of the applied strain. The total apparent strain with the BLH is one order of magnitude greater than the test value. Note that the total apparent strain with the AILTECH is less than the Bean data scatter. Table II provides a summary of this comparison.

TABLE II

Apparent Strain Variations for Candidate Gages

Candidate Gage	Mechanical Strain During Test μ mm/mm	Total Apparent Strain μ mm/mm
AILTECH	2000	320
Bean	2000	2,100
BLH	2000	20,000

4. Gage Factor Evaluation (AILTECH Gage)

Figure 10 shows the percent variation in gage factor (GF) as a function of temperature. Note that our results compare favorably with vendor data (Reference 1). Although our GF versus temperature data compare favorably, there is an initial variation (offset) at RT. Figure 11 shows the total percent variation in experimental strain as a function of temperature. For the present, the cause for this variation has not been determined and is being treated as a gage factor correction.

III. CONCLUSIONS

Based on results of evaluation, the AILTECH (weldable) gage was selected for application on the missile section tests. Reasons for choice were:

1 Total apparent strain resulting with AILTECH is about 10 percent of test strain while that of next best gage is of the same order of magnitude as test strain. In addition, the total apparent strain resulting with the AILTECH is less than the data scatter of the next best gage.

2 Moisture sealant on filament gages requires refurbishing after being subjected to temperature on the order of 700°K (800°F).

3 The AILTECH is comparatively simpler to install. This feature has allowed gages to be located in areas that would normally be inaccessible to flame spray apparatus.

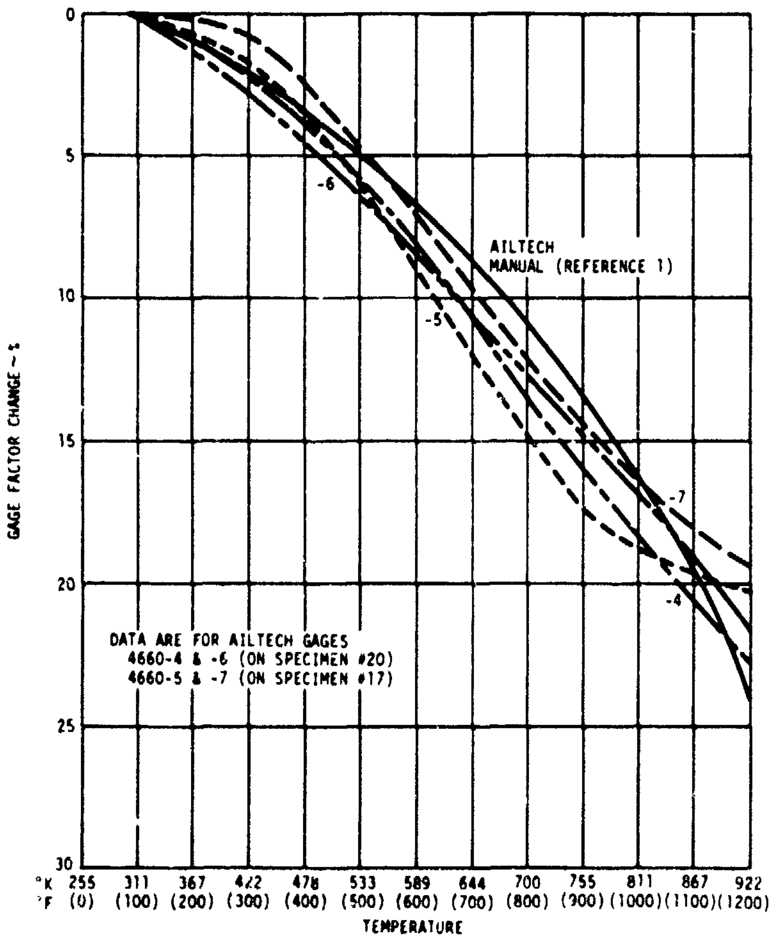

Fig. 10-Gage factor change as a function of temperature

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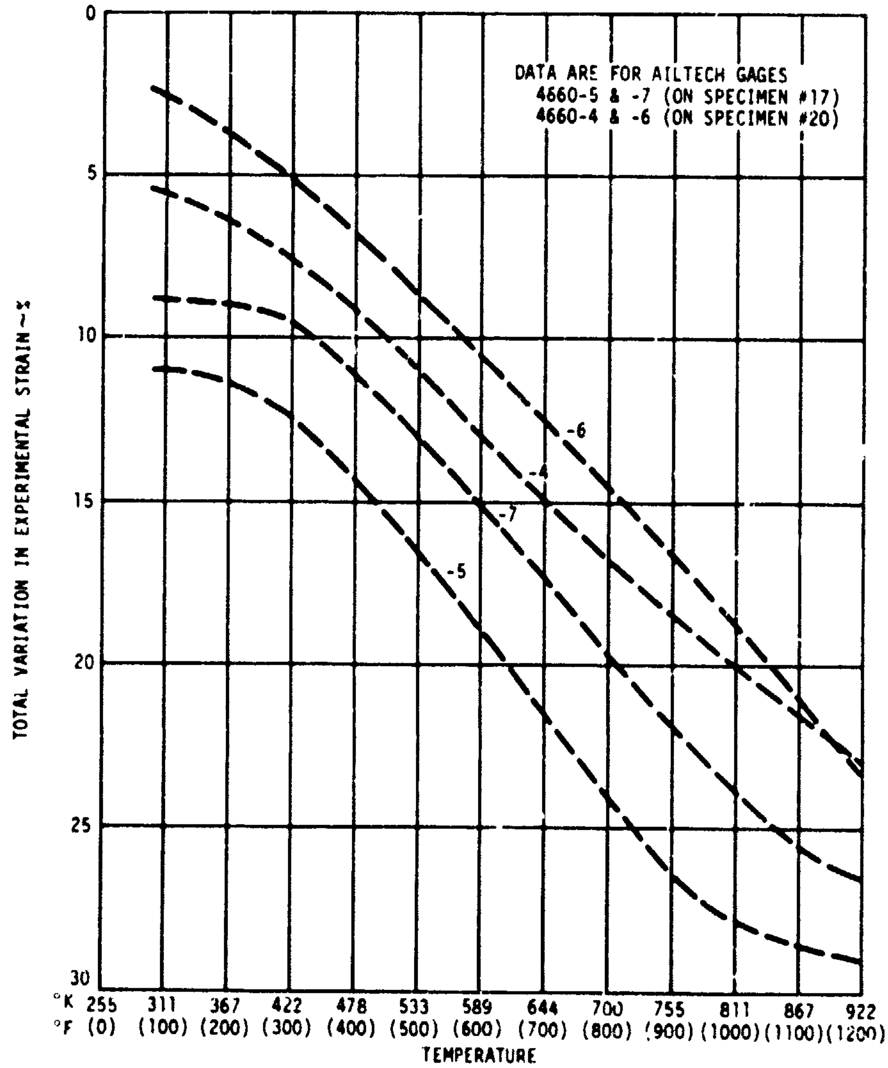

Fig. 11-Total variation in experimental strain as a function of temperature

IV. REFERENCES

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