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	PAGE 1 OF 41	
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SUBACCOUNT TITLE: Expansion Compensator Development

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STATEMENT OF PROBLEM: TEST OBJECTIVES

To verify that an expansion compensator which has been on steady state endurance operation, will continue to operate satisfactorily when the displaced NaK volume is increased due to a system operating temperature increase. The tests will be conducted in accordance with the test procedures shown in Appendices 1 and 2.

ABSTRACT

Two SNAP 10A Secondary Containment Expansion Compensator Units (ECU), S/N's 022 and 023, were subjected to ten temperature-deflection cycles and up to 100 hours of steady state operation at 775°F to determine if ECU's, which have been on long term endurance operation, would withstand additional operation at increased temperatures and bellows deflections.

The tests were consecutively designed to simulate the operating conditions which are proposed to increase the mean system temperature of the FS-3 nuclear ground test system.

The initial operating conditions were to deflect the bellows to a position where a stress level of approximately 90,000 psi was developed at a temperature of 700°F. The cycle procedure was to increase the bellows deflection 0.21 inches, equivalent to an 8.5 cu in. volume displacement per ECU due to a 100°F mean system temperature increase above 700°F, and simultaneously increase the ECU temperature to 775°F.

Both ECU's satisfactorily completed the test program without any significant degradation in ECU performance. Since the test operating conditions developed bellows stresses which were a minimum of 122 percent greater than any anticipated system ECU stress levels, there should be no significant ECU performance changes resulting from the proposed FS-3 system operational changes.

FORM 701-C REV. 10-62

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I. INTRODUCTION

Two expansion compensator units (ECU), which have been on steady state endurance tests, were subjected to ten elevated temperature-bellows deflection cycles to determine if; (1) post endurance operation cycling would cause catastrophic ECU failure, or (2) would degrade the ECU operating parameters (pressure and deflection) to less than those acceptable for continued system operation.

The cycle tests were designed to deflect the bellows by gas pressurization, to develop bellows stress levels of approximately 90,000 psi, and to simultaneously cycle the temperature from 700°F to 775°F.

After the cycling tests were completed the ECU's were maintained on steady state operation at 775°F and the maximum deflection cycle position for up to 100 hours.

These tests were performed to demonstrate that the ECU's could withstand the severe operating conditions prior to increasing the FS-3 nuclear ground test system temperature. The test ECU's performance conservatively demonstrated that they can withstand the anticipated system changes without significant degradation. The ECU bellows were operated at stress levels which varied from 122 percent to 150 percent above the calculated system ECU bellows stress levels for operation at 775°F.

II. TEST SPECIMENS

The two ECU's (S/N 022 and 023) selected for the temperature-deflection cycle tests are of the same type as the two FS-3 system ECU's, S/N's 025 and 028. Both of the test ECU's have been operated on steady state endurance tests at conditions which conservatively represent some phase of the FS-3 system ECU's operation.

ECU S/N 022 has been operated for 6632 hours at a primary bellows volume displacement of 36 cu in., (equivalent bellows deflection of 0.89 in.), and a steady state temperature of 750°F. Argon gas was used as the primary bellows pressurization fluid. The secondary containment volume is NaK filled and pressurized to 10.0 psi. These operating conditions conservatively simulates the performance of an FS-3 system ECU in which the secondary bellows became NaK filled after 82 days of normal system ECU operation. The system ECUs were being operated at approximately 60 cu in. NaK volumetric displacement per ECU and a temperature of 700°F prior to one being NaK filled.

The ECU bellows-auxiliary spring system of S/N 022 was permanently set 0.02 in. above the initial zero reference due to the bellows relaxation which occurred during the endurance test. This bellows-spring relaxation characteristic has been measured on all of the ECUs which have been on extended time operation at elevated temperature.

ECU S/N 023 had completed the SNAP 10A ECU qualification test program for design-steady state operation of 9000 hours at 750°F and 60 cu in. primary bellows displacement. The primary bellows was NaK filled during the qualification testing but was drained prior to the cycling tests. The NaK was drained because the ECU could not be maintained in a 700°F isothermal condition during the pressure versus deflection tests. The test stand was not designed to permit preheating of the NaK. Therefore, when the bellows was pressurized the cold NaK (at room ambient temperature) cooled the 700°F ECU more than the allowable 25°F. Argon gas was used as the pressurizing fluid for all of these tests. The secondary containment volume was evacuated, back filled with helium at 10^{-3} Torr pressure and weld-sealed during the acceptance test which was performed in November 1964.

The bellows-spring system was permanently set 0.06 in. above the zero reference due to the relaxation which occurred during the qualification endurance test. The ECU has been operated at the design steady state conditions which conservatively simulate the initial 82 days of FS-3 system operation.

III. OPERATING PARAMETERS AND BELLOWS STRESSES

The operating cycle requirements of the test program were two fold; (1) displace the primary bellows, by gas pressurization, to a position where the bellows is stressed to 90,000 psi (minimum) at 700°F, and (2) increase the displacement to simulate one-half of the FS-3 system volumetric thermal expansion resulting from a 100°F mean system temperature increase from 700°F to 800°F and simultaneously increase the ECU temperature to 775°F, see reference 1.

The thermal expansion volume absorbed by each system ECU, due to a 100°F temperature rise above 700°F is calculated to be 8.5 cu inches. A volumetric change of 8.5 cu in. causes the bellows to deflect 0.21 in. The operating pressures, deflections, and volumes of each ECU are shown in Table 1. The calculated total bellows stresses test conditions and the anticipated system ECU bellows stresses for 775°F operation are also shown in Table 1. The stresses were calculated by using the equations shown in reference 2.

The primary bellows pressures and deflections necessary to develop the bellows stress levels of conditions 1, see Table 1, were determined from the pressure versus deflection data measured at 700°F. Data is shown in Figures 1 and 6 for ECU S/N 022 and 023 respectively. The calculated stresses at 775°F, conditions 2, were determined from the first temperature-deflection cycle test data shown in Figures 2a and 7a for ECU's S/N 022 and 023, respectively.

TABLE 1

TEST CONDITIONS AND BELLOWS STRESSES

OPERATING PARAMETERS	ECU S/N 022		ECU S/N 023	
	Conditions 1	2	Conditions 1	2
ECU Temperature - °F	700	775	700	775
Primary Bellows Deflection - in.	1.48	1.69	1.50	1.71
Primary Bellows Pressure - psi	6.65	7.51	6.40	7.42
Secondary Bellows Pressure - psi	10.00	10.00	$\sim 10^{-3}$ Torr	$\sim 10^{-3}$ Torr
Equivalent Primary Bellows Volume - cu in.	60.1	68.6	60.9	69.4
Primary Bellows Total Stress - psi	80,350	85,650	90,700	105,650
Secondary Bellows Total Stress - psi	91,400	97,700	55,200	61,500

System ECU Total Bellows Stresses at 775°F; with Secondary Container NaK filled

Primary: 35,500 psi
Secondary: 45,900 psi

without Secondary Container NaK filled

Primary: 70,000 psi
Secondary: 45,900 psi

The stress levels at which the test ECU's were operated exceeded the stress levels which will be developed in the FS-3 system ECU's by 22 percent in ECU S/N 022 and 50 percent in ECU S/N 023. The maximum system ECU stress will be approximately 70,000 psi at 775°F, developed in the ECU which does not have the secondary NaK filled. This stress calculation is based on the assumption that the system ECU bellows pressure relaxation has been similar to the relaxation of ECU S/N 022. Stress is 22 percent less than the minimum stress level developed in the test ECU S/N 022 at the test operation conditions. ECU S/N 023 is stressed to level 50 percent greater than the maximum system ECU stress level.

IV. TEST RESULTS

A. 1. ECU S/N 022

The temperature-deflection cycling and steady state operation tests performed on ECU S/N 022 are shown in Appendix I. The data recorded during the tests are also shown in the appendix.

The test data have been plotted to show the primary bellows pressures as a function of bellows displacements during each temperature-deflection cycle and also for each isothermal pressure-deflection measurement test at 700°F. In Figure 1, the 700°F isothermal pressure and deflection data shows that the ECU bellows-spring system is permanently set 0.02 inches above the zero reference position prior to any cycling. The zero reference is where the top plate and ECU base are in contact.

There was no apparent change in the neutral position as a result of the cycling. However, a pressure relaxation of 0.098 psi was measured between the first cycle, Figure 2a and the tenth cycle, Figure 4a. For comparison, cycles one and ten were plotted in Figure 4b to show the apparent relaxation due to cycling.

The 700°F isothermal pressure versus deflection test was repeated after the cycling and again after the 100 hours of operation at 775°F and 1.69 in. deflection. A change in the bellows neutral position of 0.01 inches was measured after the endurance test, see Figure 5, for a total of 0.03 inches above the zero reference.

2. ECU S/N 023

The temperature-deflection cycling and steady state operation tests performed on ECU S/N 023 and the data recorded during the tests are shown in Appendix II.

The test data have been plotted to show the primary bellows pressures as a function of bellows displacements during each temperature-deflection cycle and also for each isothermal test at 700°F. In Figure 6, the primary bellows pressure versus deflection data shows the bellows neutral position to be permanently set 0.06 inches above the zero reference prior to any cycle testing. The permanent set was increased to 0.09 inches and the pressure relaxed 0.045 psi between the first and tenth cycles, see Figures 7a and 9b respectively. The measured relaxation is within the pressure measurement tolerance of ± 0.050 psi and therefore may not be real. Figure 9b shows the first and tenth cycle data plotted for comparison of the pressure data.

The post-cycling isothermal pressure versus deflection test data are shown in Figure 10 along with the data recorded after 25 hours of steady state operation at 775°F and 1.71 inches deflection. An increase in bellows neutral position of 0.01 inches resulted from the steady state operation test, see Figure 10.

A post test mass spectrometer leak test was performed to determine if there were any holes in the ECU through which helium could leak at a rate exceeding 1×10^{-7} SCC per second. To perform this test, the secondary containment volume vent tube seal was cut off. The inrush of air into the container was audible which indicated that the secondary volume was still in vacuo. Testing of both the primary and secondary bellows and the containment vessel showed there were no leaks greater than 10^{-7} cc's of helium per second.

V. CONCLUSIONS

The satisfactory completion of the test program without any significant changes in the ECU's performances assures that the FS-3 system ECU's can perform satisfactorily under the proposed extended temperature conditions. Since the ECU tests were extremely conservative, a minimum of 22 percent for the operational bellows stresses levels, there should be no significant degradation of system ECU performance and there is no reason to suspect that a catastropic ECU failure would occur as a result of the temperature increase.

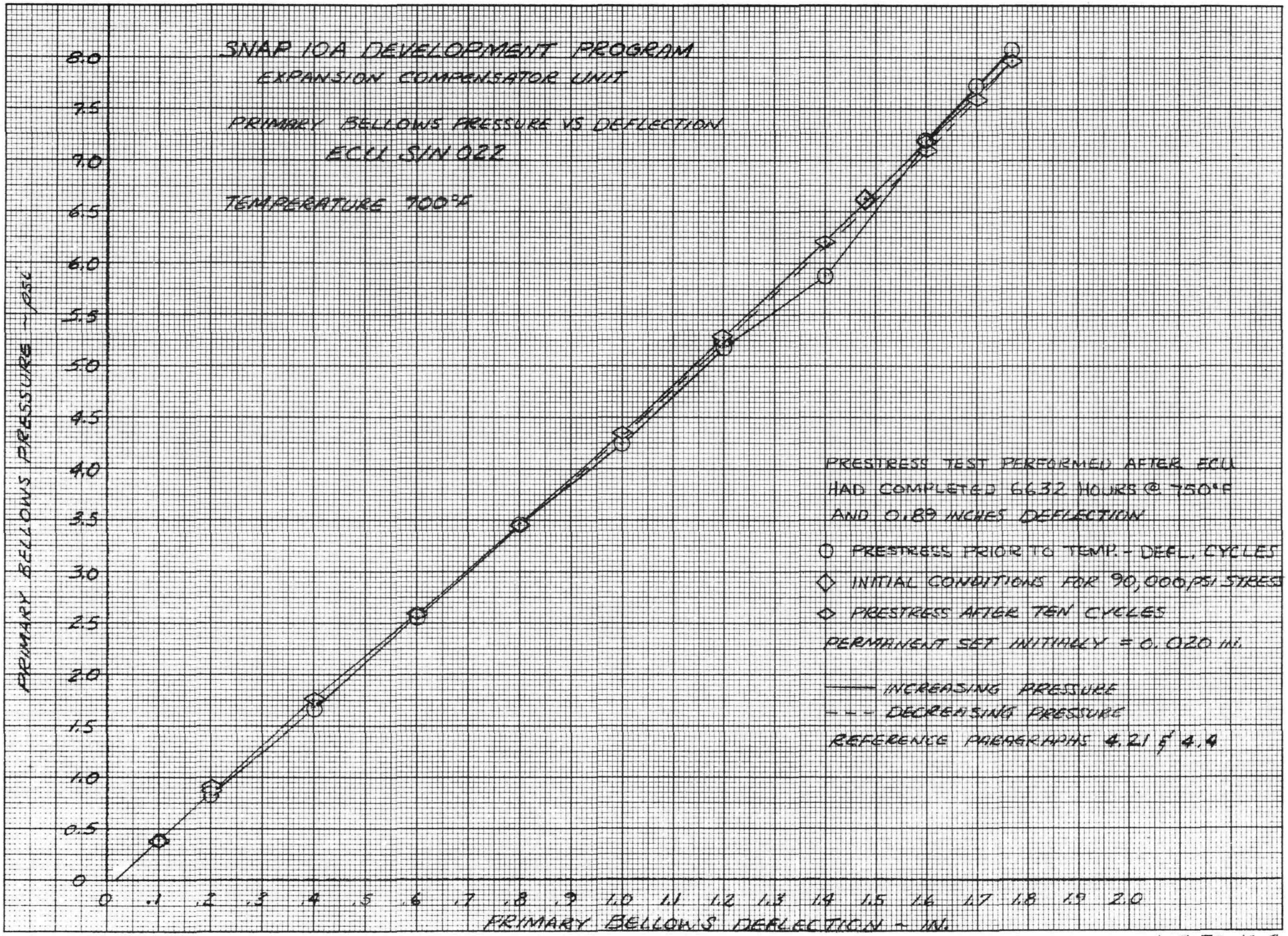

FIGURE 1

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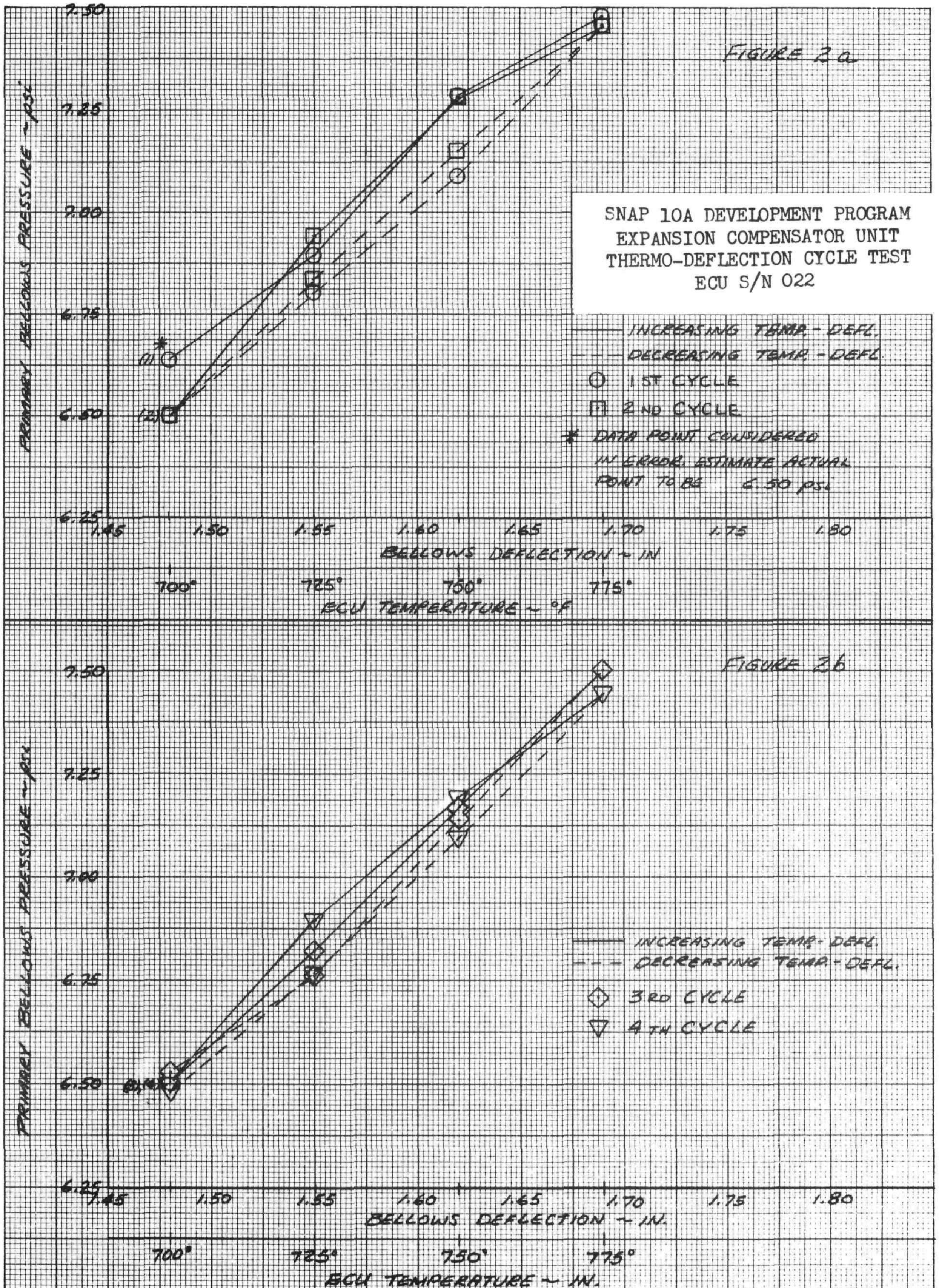

L. R. STONE 2-9-66

FIGURE 2 (a,b)

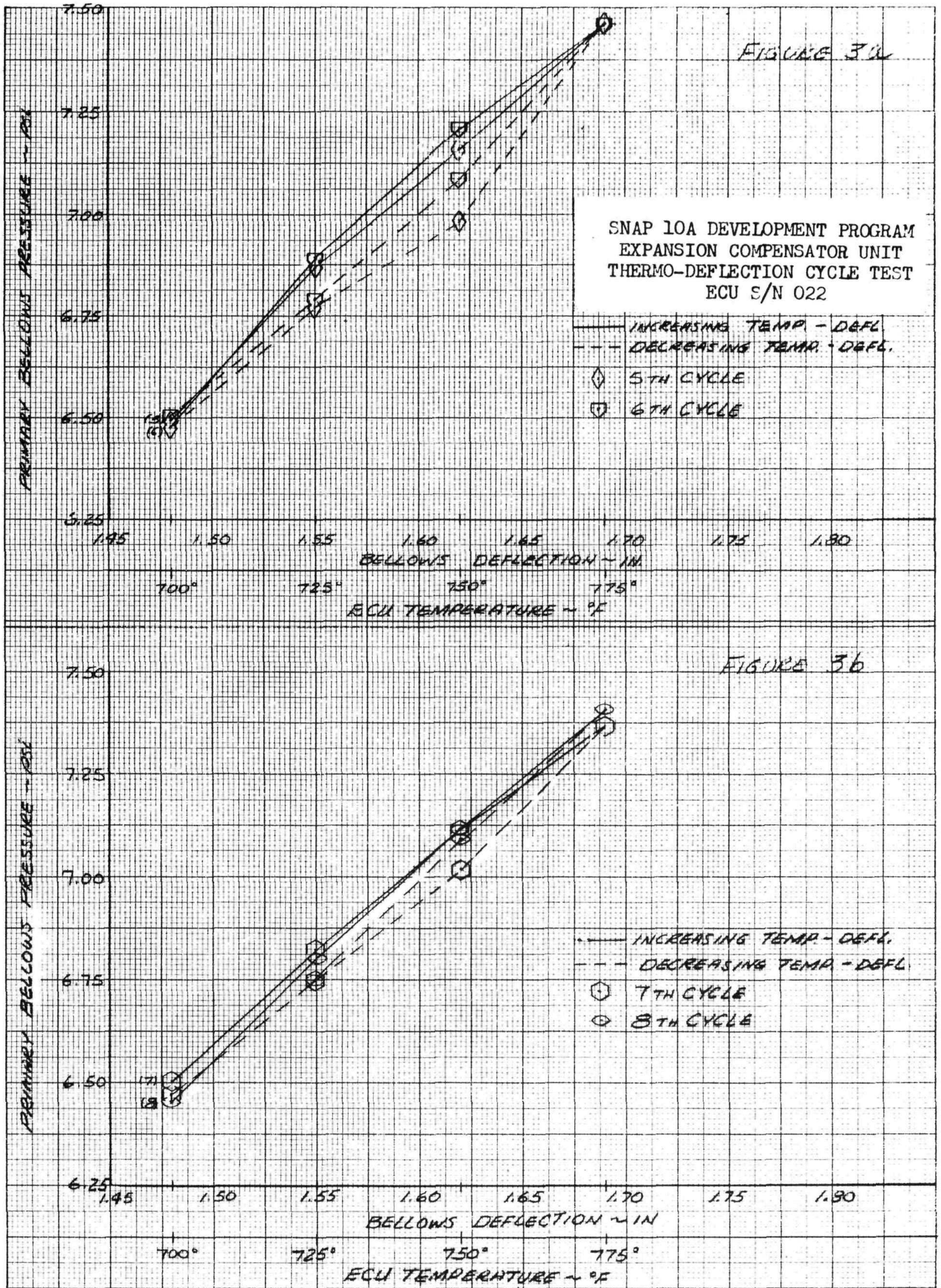

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FIGURE 3 (a, b)

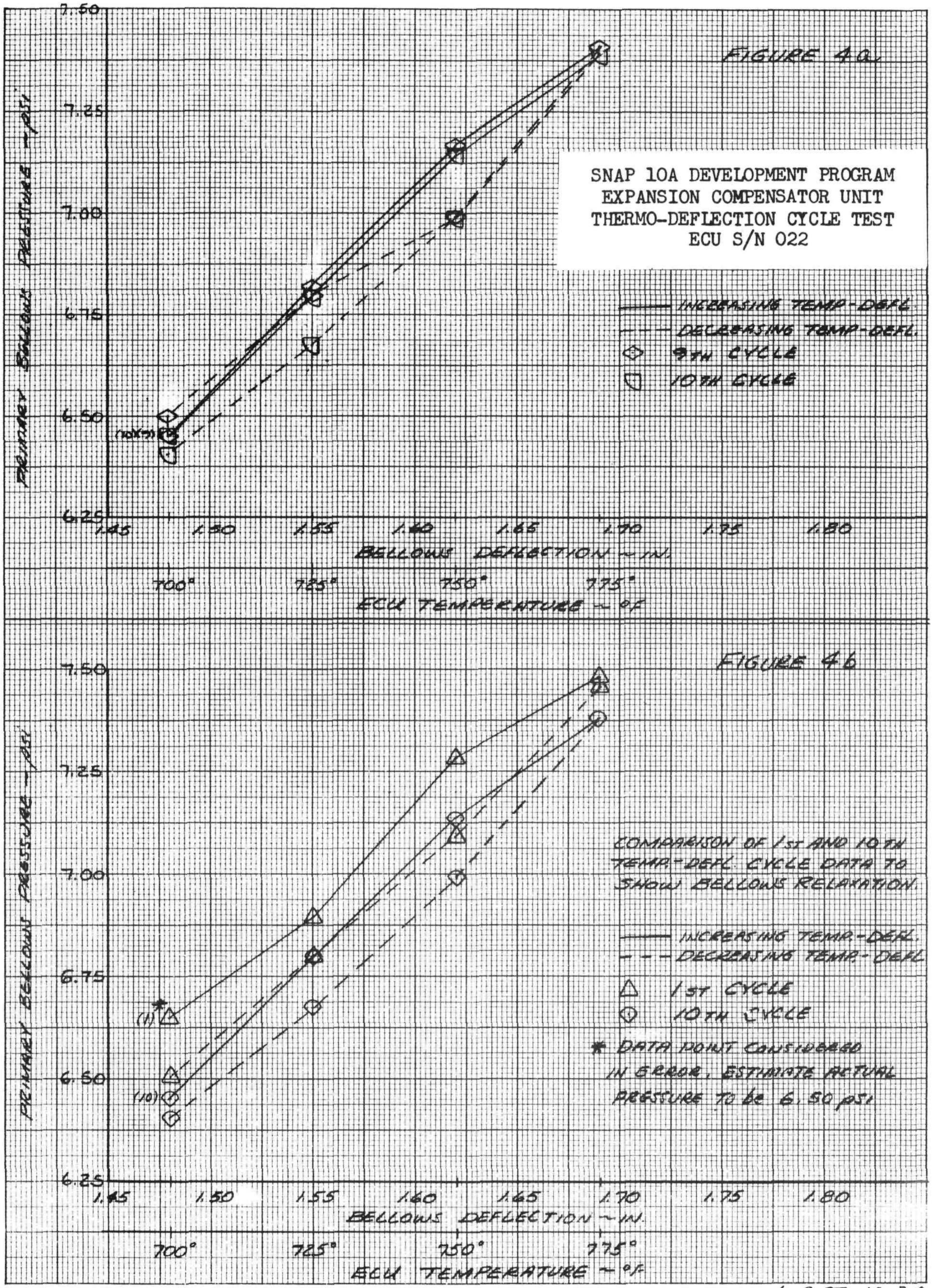

FIGURE 4 (a, b)

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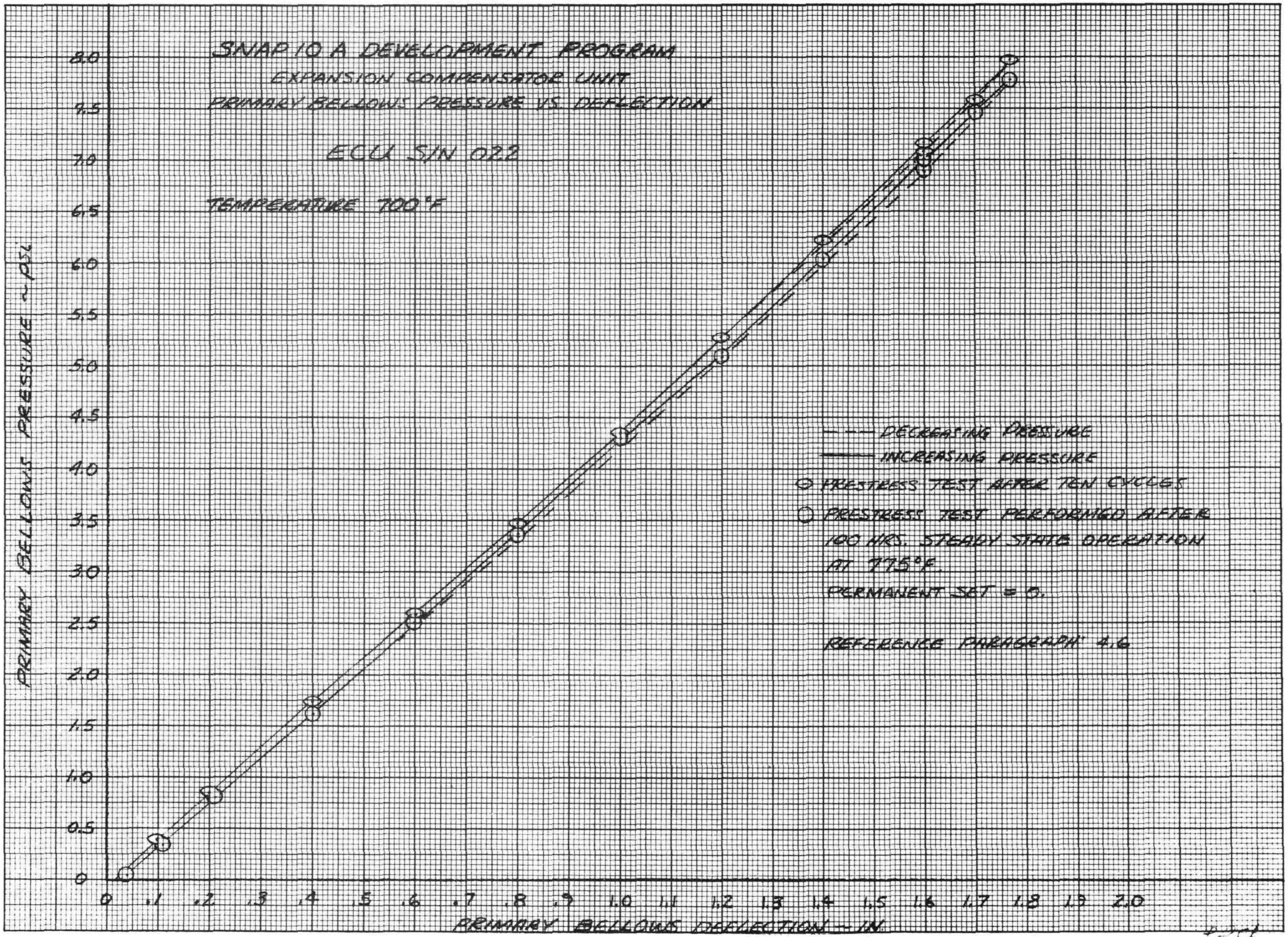
SNAP 10 A DEVELOPMENT PROGRAM
EXPANSION COMPENSATOR UNIT
PRIMARY BELLOWS PRESSURE VS DEFLECTION
ECU S/N 022
TEMPERATURE 700°F
PRIMARY BELLOWS PRESSURE ~ PSI
PRIMARY BELLOWS DEFLECTION ~ IN
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
DECREASING PRESSURE
INCREASING PRESSURE
PRESTRESS TEST AFTER TEN CYCLES
PRESTRESS TEST PERFORMED AFTER 100 HRS. STEADY STATE OPERATION AT 775°F.
PERMANENT SET = 0.
REFERENCE PARAGRAPH 4.6

FIGURE 5

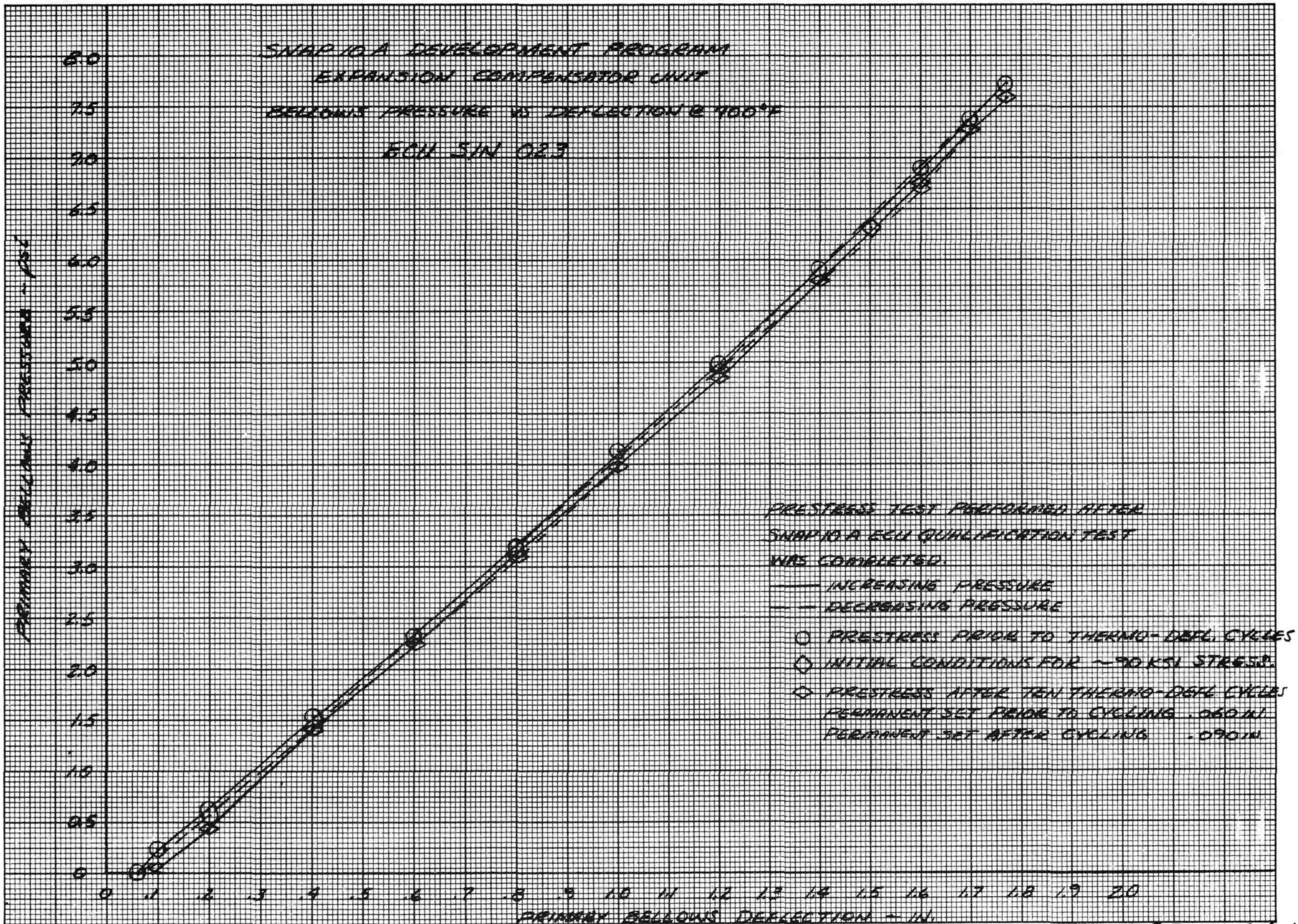

FIGURE 6

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2-4-66

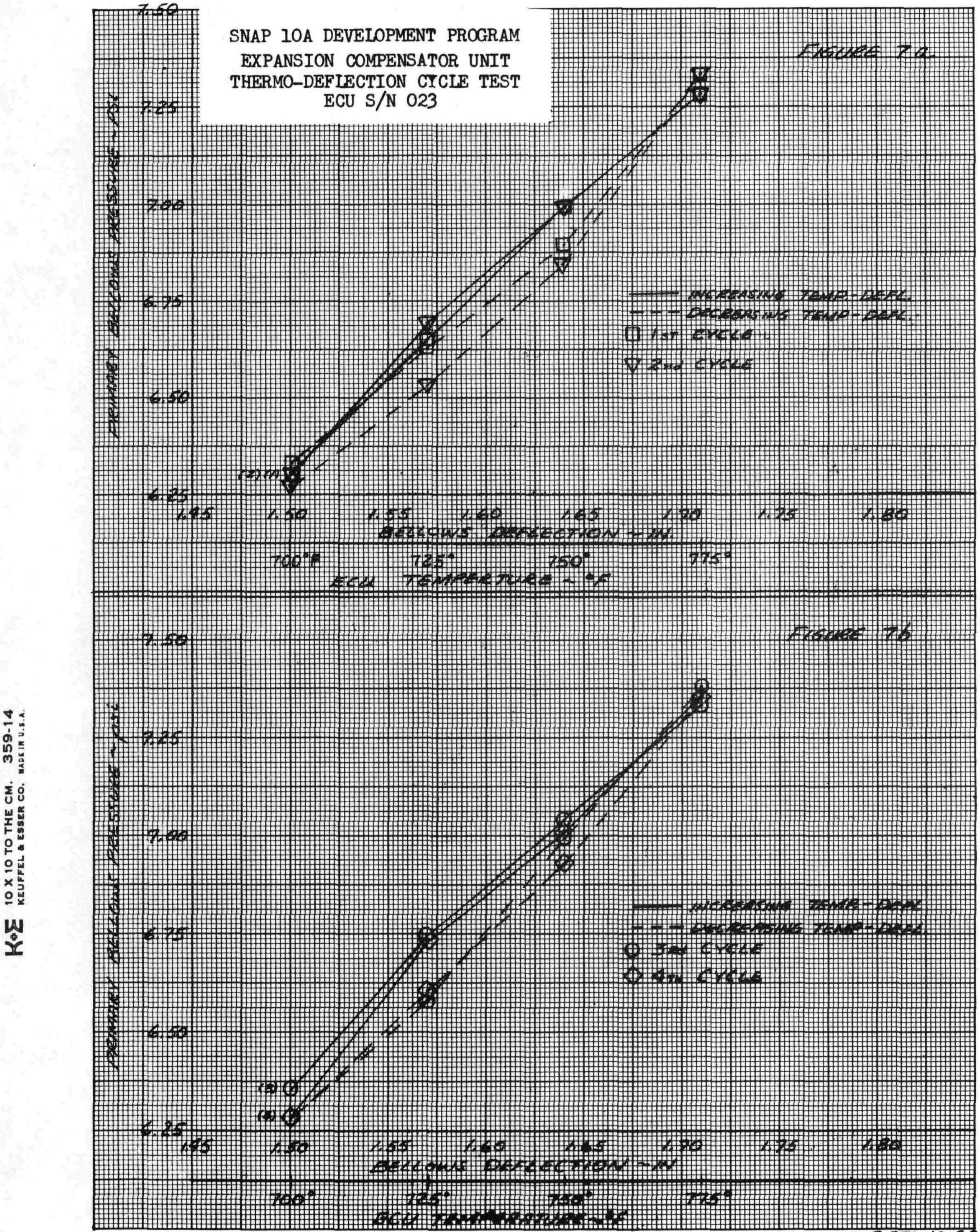

FIGURE 7

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FIGURE 8

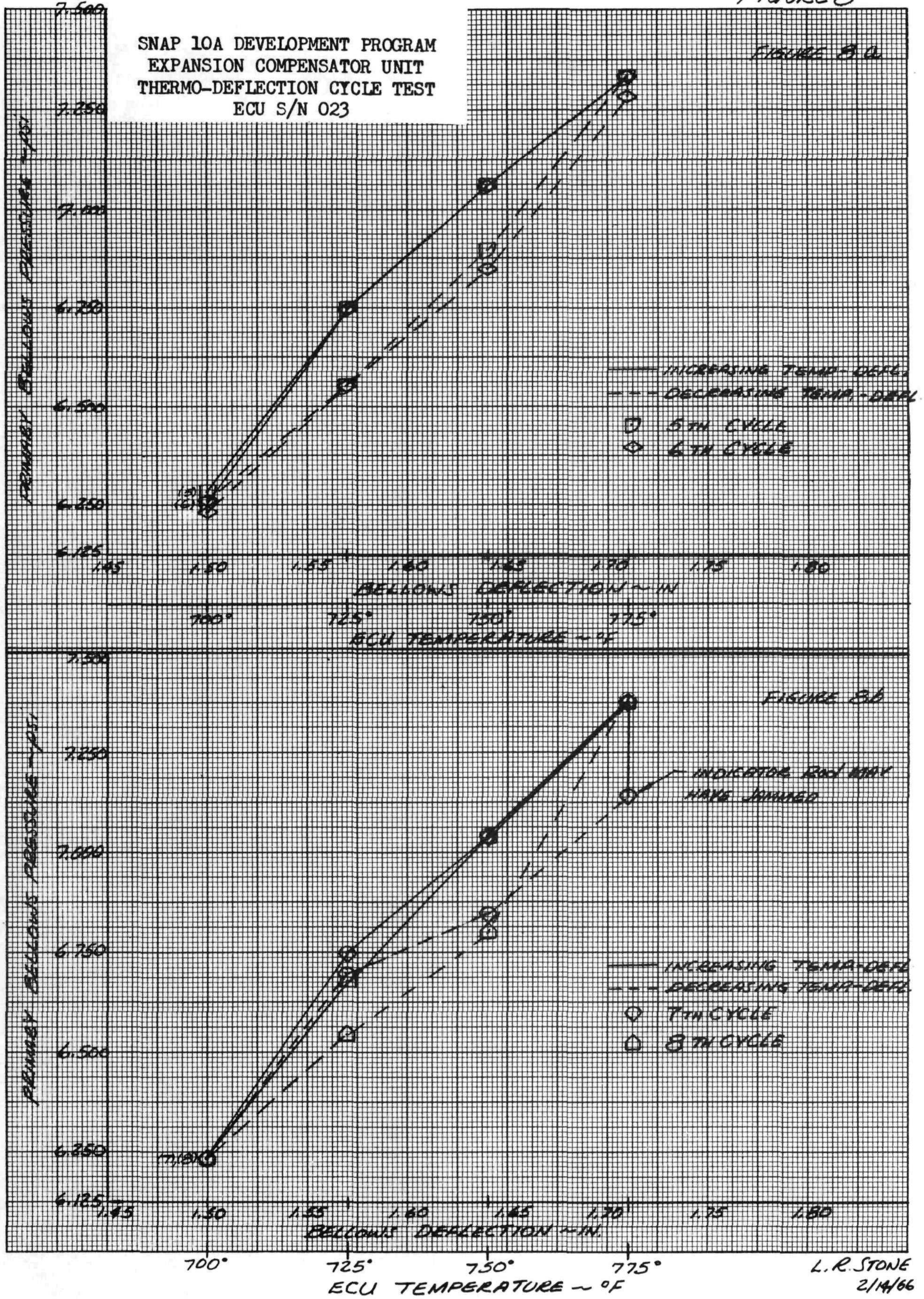

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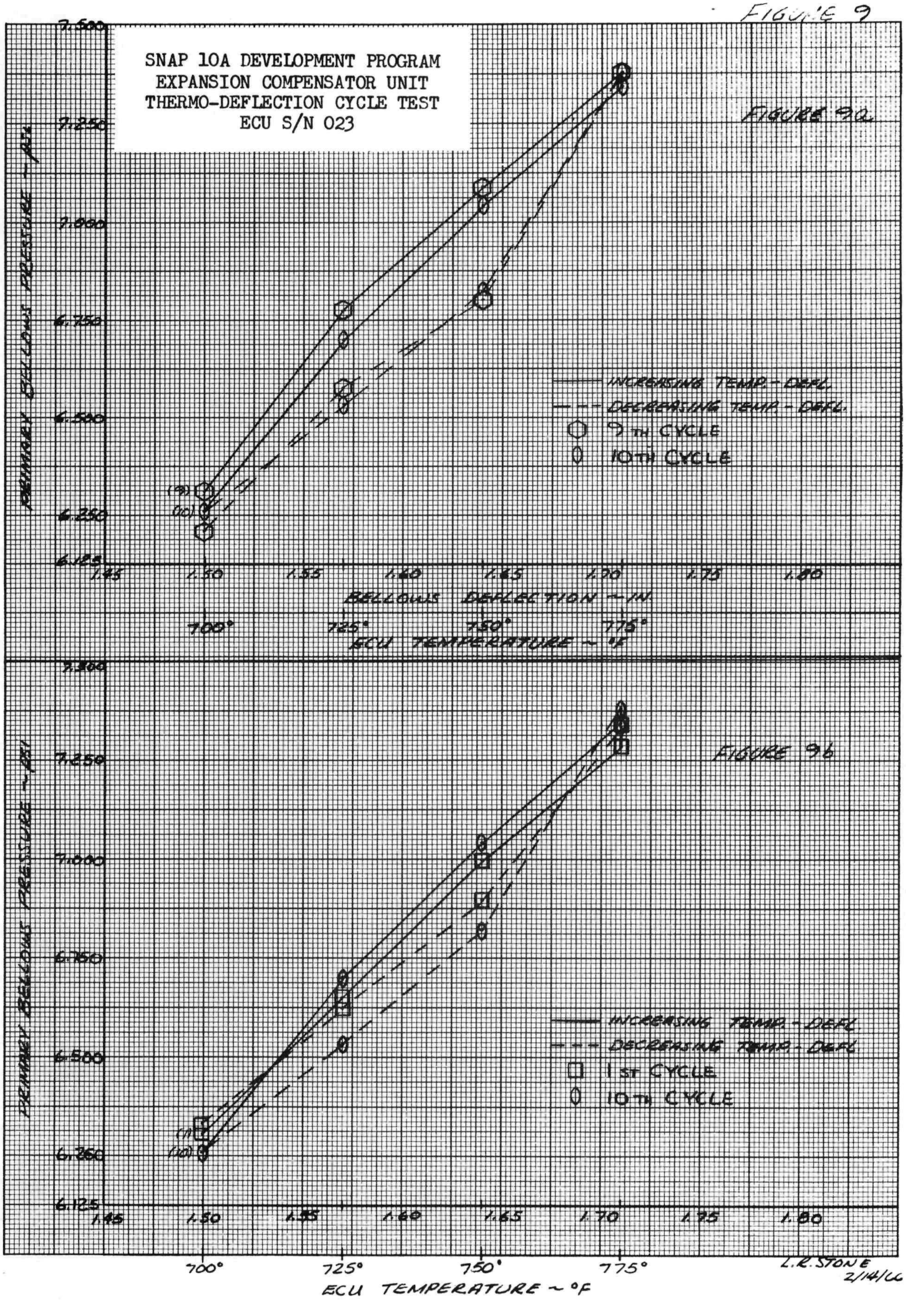
FIGURE 9


SNAP 10A DEVELOPMENT PROGRAM
EXPANSION COMPENSATOR UNIT
THERMO-DEFLECTION CYCLE TEST
ECU S/N 023
FIGURE 9a
INCREASING TEMP. - DEFL.
DECREASING TEMP. - DEFL.
9 TH CYCLE
10TH CYCLE
PRIMARY BELLOWS PRESSURE ~ PSI
BELLOWS DEFLECTION ~ IN.
ECU TEMPERATURE ~ °F
FIGURE 9b
INCREASING TEMP. - DEFL.
DECREASING TEMP. - DEFL.
1 ST CYCLE
10 TH CYCLE
PRIMARY BELLOWS PRESSURE ~ PSI
ECU TEMPERATURE ~ °F
L.R. STONE
2/14/66

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. 46 1513 MADE IN U.S.A. KEUFFEL & ESSER CO.

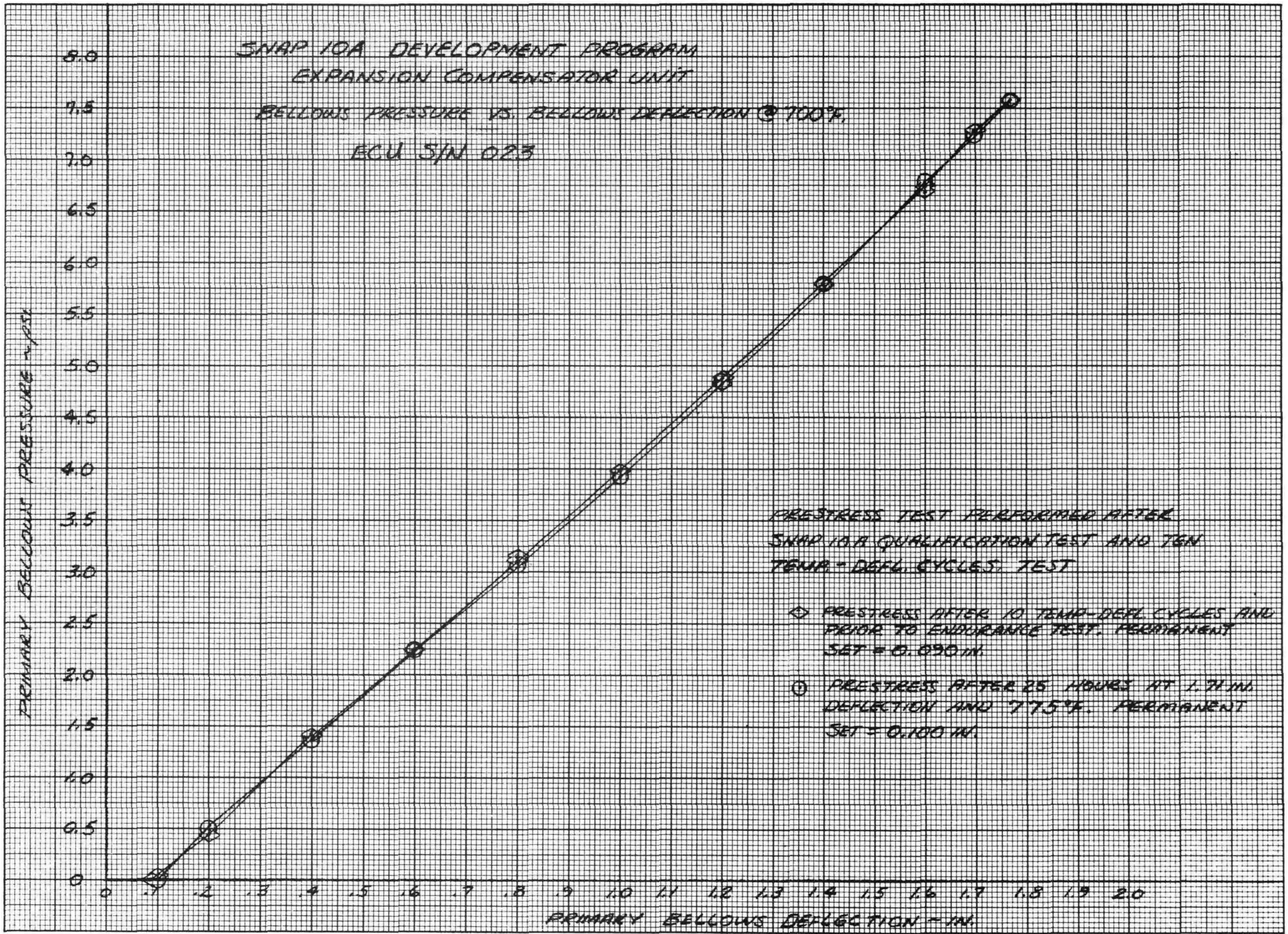


FIGURE 10

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2/16/66

APPENDIX I

SNAP 10A Expansion Compensator Development Program

Thermal-Deflection Cycle Test Simulating
FS-3 System Conditions
ECU S/N 022

1.0 Object:

The purpose of conducting a thermal-deflection cycle test is to verify that an expansion compensator, which has been on steady-state endurance operation, will continue to operate within the specified system operating limits when the NaK volume is increased due to an operating temperature increase.

2.0 Scope:

The tests will be conducted on ECU S/N 022 which is being continued on endurance test after completing 6500 hours at a steady-state operating condition representative of an ECU primary bellows failure, 750°F at 36 cu in. NaK volume displacement. The tests consist of ten thermal deflection cycles between 700°F and 775°F with a corresponding NaK thermal expansion volume change of 8.5 cu in. The change in volume is approximately equal to one-half of the system NaK volume expansion due to a 100°F temperature change between 700°F and 800°F.

3.0 Test Measurements and Tolerance:

All of the test equipment and instrumentation must meet the applicable requirements specified in the Qualification Test Procedure NA0408-011, paragraph 3.3.

4.0 Test Procedure:

4.1 Record the operating time and bellows pressures at 750°F and 0.89 in. primary bellows displacement.

4.2 Decrease the ECU temperature to 700°F and allow a minimum of 30 minutes for temperature stabilization.

4.2.1 Perform a pressure versus deflection test, maintaining the temperature at 700°F. Report this data to the requesting engineer for immediate evaluation. Do not continue the test until the deflection limits are established for paragraph 4.2.2.

4.2.2 Deflect primary bellows by argon gas pressurization to 1.48 inches deflection.

4.3 Conduct ten thermal-deflection cycles by applying power to the test chamber radiant heaters and argon gas pressure to the ECU primary bellows. Heat-up and cool down rates shall not exceed 5°F per minute. Each cycle shall be between 1.48 inches and 1.69 inches primary bellows deflection. Simultaneously, the temperature shall be cycled between 700°F and 775°F. The 1.69 inch primary bellows deflection will be held for one hour on each cycle. The chamber vacuum shall be maintained at 10^{-2} Torr or better. The temperature-deflection cycling schedule is shown in Table 4.

4.4 After the tenth thermal-deflection cycle is complete, repeat the pressure deflection test per paragraph 4.4.1.

4.5 Increase the ECU temperature to 775°F and the deflection to 1.69 inches. Maintain the temperature and deflection at these conditions and operate the test for 100 hours continuously.

4.6 Reduce the temperature to 700°F and repeat the pressure versus deflection test per paragraph 4.2.1.

4.7 Return the ECU to steady state endurance operation at 750°F and 0.89 in. primary bellows deflection.

5.0 Test Data

Submit one copy of the test data to the requesting engineer. File the original copy in an approved AI data log book.

Thermal Deflection Cycle Tests Procedure

ECU S/N 022

Data Record

4.1 ECU Temperature 750°F

Time on Test 6632 hrs

Primary Bellows Argon Pressure 7.80 in. of Hg
3.81 psi

Secondary Bellows NaK pressure 20.45 in. of Hg
10.00 psi

4.2.1 Required ECU temperature 700°F Secondary bellows pressure

Actual Temperature 695°F 20.50 in. of Hg

Ambient Temperature 79°F 10.02 psi

Vacuum Chamber Pressure: 3.5×10^{-5} Torr

Primary Bellows Deflection		Primary Bellows Pressure	
Required (in.)	Actual (in.)	Indicated (in. of Hg)	Calculated (psi)
0	0.02	0.05	0.024
0.10	0.10	0.75	0.37
0.20	0.20	1.705	0.83
0.40	0.40	3.45	1.69
0.60	0.60	5.23	2.56
0.80	0.80	7.10	3.47
1.00	1.00	8.70	4.25
1.20	1.20	10.61	5.19
1.40	1.40	12.00	5.87
1.60	1.61	14.70	7.19
1.70	1.70	15.77	7.71
1.77	1.77	16.50	8.07
1.60	1.60	14.68	7.18
1.20	1.20	10.70	5.23
0.80	0.80	7.11	3.48
0.40	0.40	3.60	1.76
0	0.02	0.05	0.024

4.2.1 (continued)

Ambient Temperature 81°F

Secondary bellows pressure 20.50 in. of Hg 10.02 psi

Date: 2-3-66

4.3 Thermal deflection cycles

Cycle number 1 Date: 2-3-66

Time Hr: Min		ECU Temp °F		Bellows Deflection (inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1340	700	695	1.48	1.480	13.60	6.650
	1404	725	725	1.55	1.546	14.10	6.895
	1415	750	750	1.62	1.620	14.90	7.286
t_1	1430	775	775	1.69	1.685	15.30	7.482
t_1 + 1 hr	1532	775	778	1.69	1.685	15.25	7.457
	1547	750	750	1.62	1.620	14.50	7.091
	1558	725	725	1.55	1.546	13.90	6.797
t_2	1604	700	700	1.48	1.480	13.30	6.504
t_2 + 30 min	2/4/66 0825	700	702	1.48	1.480	13.30	6.504

Cycle Number 2 Date: 2-4-66

Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	0825	700	702	1.48	1.480	13.30	6.504
	0840	725	725	1.55	1.556	14.20	6.944
	0847	750	750	1.62	1.620	14.85	7.262
t_1	0901	775	775	1.69	1.685	15.26	7.462
t_1 + 2 hr	1001	775	775	1.69	1.685	15.26	7.462
	1014	750	750	1.62	1.620	14.64	7.159
	1022	725	725	1.55	1.545	14.00	6.846
t_2 + 30 min	1036	700	703	1.48	1.480	13.30	6.504
t_2	1106	700	700	1.48	1.480	13.30	6.504

4.3 Thermal deflection cycles (continued)

Cycle number 3 Date: 2-4-66

Time Hr: Min		ECU Temp °F		Bellows Deflection (inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1106	700	700	1.48	1.480	13.30	6.504
	1120	725	727	1.55	1.546	13.95	6.822
	1127	750	750	1.62	1.620	14.66	7.169
t_1	1136	775	775	1.69	1.695	15.35	7.506
t_1 + 1 hr	1238	775	775	1.69	1.695	15.35	7.506
	1253	750	750	1.62	1.620	14.60	7.139
	1300	725	725	1.55	1.556	13.85	6.773
t_2	1315	700	700	1.48	1.480	13.35	6.528
t_2 + 30 min	1345	700	700	1.48	1.480	13.30	6.504
Cycle Number 4 Date: 2-4-66							
	1345	700	700	1.48	1.480	13.30	6.504
	1356	725	725	1.55	1.556	14.10	6.895
	1402	750	750	1.62	1.620	14.70	7.188
t_1	1410	775	775	1.69	1.685	15.23	7.447
t_1 + 1 hr	1510	775	775	1.69	1.685	15.23	7.447
	1519	750	750	1.62	1.620	14.50	7.091
	1528	725	725	1.55	1.550	13.85	6.773
t_2	1538	700	700	1.48	1.480	13.25	6.479
t_2 + 30 min	1612	700	700	1.48	1.480	13.25	6.479
Cycle Number 5 Date: 2-4-66							
	0816	700	700	1.48	1.480	13.28	6.494
	0829	725	725	1.55	1.556	14.05	6.870
	0837	750	750	1.62	1.620	14.65	7.164
t_1	0847	775	775	1.69	1.695	15.26	7.462
t_1 + 1 hr	0947	775	775	1.69	1.695	15.26	7.462
	0958	750	750	1.62	1.610	14.28	6.983
	1007	725	725	1.55	1.546	13.85	6.773
t_2	1018	700	700	1.48	1.480	13.25	6.479
t_2 + 30 min	1098	700	705	1.48	1.480	13.25	6.979

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4.3 Thermal deflection cycles (continued)

Cycle number 6 Date: 2-4-66

Time Hr: Min		ECU Temp °F		Bellows Deflection (inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1048	700	705	1.48	1.480	13.25	6.479
	1058	725	725	1.55	1.556	14.09	6.890
	1106	750	750	1.62	1.620	14.75	7.213
t_1	1114	775	775	1.69	1.685	15.26	7.462
t_1 + 1 hr	1217	775	775	1.69	1.685	15.26	7.462
	1232	750	750	1.62	1.620	14.49	7.086
	1238	725	725	1.55	1.546	13.88	6.787
t_2	1243	700	700	1.48	1.480	13.30	6.504
t_2 + 30 min	1333	700	705	1.48	1.480	13.30	6.504
Cycle Number 7 Date: 2-8-66							
	1333	700	705	1.48	1.480	13.30	6.504
	1344	725	725	1.55	1.546	13.95	6.822
	1353	750	750	1.62	1.620	14.55	7.155
t_1	1401	775	775	1.69	1.685	15.05	7.359
t_1 + 1 hr	1502	775	777	1.69	1.685	15.05	7.359
	1516	750	750	1.62	1.620	14.35	7.017
	1523	725	725	1.55	1.546	13.80	6.748
t_2	1536	700	700	1.48	1.480	13.23	6.469
t_2 + 30 min	1608	700	698	1.48	1.480	13.23	6.469
Cycle Number 8 Date: 2-8-66							
	0840	700	705	1.48	1.480	13.20	6.455
	0853	725	725	1.55	1.596	13.92	6.807
	0902	750	750	1.62	1.620	14.55	7.155
t_1	0911	775	775	1.69	1.685	15.15	7.408
t_1 + 1 hr	1011	775	775	1.69	1.685	15.15	7.408
	1023	750	750	1.62	1.620	14.50	7.091
	1030	725	725	1.55	1.546	13.80	6.748
t_2	1040	700	700	1.48	1.480	13.20	6.455
t_2 + 30 min	1111	699	1.48	1.48	1.480	13.20	6.455

4.3 Thermal deflection cycles (continued)

Cycle number 9 Date: 2-4-66

Time Hr: Min		ECU Temp °F		Bellows Deflection (inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1111	700	699	1.48	1.480	13.20	6.455
	1123	725	725	1.55	1.546	13.94	6.817
	1130	750	750	1.62	1.620	14.65	7.164
t_1	1138	775	775	1.69	1.685	15.15	7.408
t_1 + 1 hr	1238	775	777	1.69	1.685	15.15	7.408
	1252	750	750	1.62	1.620	14.30	6.993
	1300	725	725	1.55	1.555	13.90	6.797
t_2	1311	700	700	1.48	1.480	13.30	6.504
t_2 + 30 min	1343	700	700	1.48	1.480	13.20	6.455
Cycle Number 10 Date: 2-8-66							
	1343	700	700	1.48	1.480	13.20	6.455
	1356	725	725	1.55	1.546	13.90	6.797
	1402	750	750	1.62	1.620	14.60	7.139
t_1	1410	775	775	1.69	1.685	15.10	7.384
t_1 + 1 hr	1513	775	777	1.69	1.685	15.10	7.384
	1525	750	750	1.62	1.620	14.30	6.993
	1534	725	725	1.55	1.546	13.65	6.675
t_2	1544	700	700	1.48	1.480	13.10	6.406
t_2 + 30 min	1614	700	698	1.48	1.480	13.10	6.406

Data Sheets (continued) ECU S/N 022

4.4 Pressure versus deflection test at 700°F

Actual ECU Temperature 705°F

Ambient Temperature 75°F

Primary Bellows Deflection		Primary Bellows Pressure	
Required (in.)	Actual (in.)	Indicated (in. of Hg)	Calculated (psi)
0	0.02	0.15	0.073
0.10	0.10	0.80	0.391
0.20	0.20	1.75	0.856
0.40	0.41	3.55	1.736
0.60	0.60	5.30	2.592
0.80	0.80	7.10	3.472
1.00	1.00	8.90	4.352
1.20	1.20	10.80	5.281
1.40	1.40	12.70	6.210
1.60	1.60	14.65	7.164
1.70	1.70	15.50	7.580
1.77	1.77	16.30	7.971
1.60	1.60	14.50	7.091
1.20	1.20	10.65	5.208
0.80	0.80	7.05	3.447
0.40	0.40	3.60	1.760
0.20	0.20	1.85	0.905
0	0.02	0.15	0.073

4.5 Endurance Operation

Required Temperature 775°F   Actual Temperature 776°F

Required Deflection 1.690 in.   Actual Deflection 1.685 in.

Start Time: 1005   Date: 2-9-66

Date	Time	Remarks
2-11-66	1200	Reset deflection to 1.69 in. Pressure 14.87 in. of Hg.
	1447	Reset deflection to 1.69 in. Pressure 14.75 in. of Hg.

Data Sheets (continued) ECU S/N 022

4.5 Endurance Operation (continued)

Date	Time	Remarks
2-11-66	1505	Reduced temperature to 700°F and 0.02 in. deflection for week-end.
2-14-66	0948	Reset deflection to 1.69 in. Temperature increased to 780°F. Pressure 14.65 in. of Hg.
2-16-66	0855	Deflection 1.69 in. Pressure 1450 in. of Hg.

Endurance test completed

Total time at 775°F: 100 hours 7 minutes

4.6 Pressure versus deflection at 700°F

Actual ECU Temperature 702°F

Ambient Temperature 78°F

Primary Bellows Deflection		Primary Bellows Pressure	
Required (in.)	Actual (in.)	Indicated (in. of Hg)	Calculated (psi)
0	0.04	0.10	0.049
.10	0.11	0.70	0.342
.20	0.21	1.65	0.807
.40	0.40	3.30	1.614
.60	0.60	5.10	2.494
.80	0.80	6.90	3.374
1.00	1.01	8.80	4.303
1.20	1.20	10.50	5.135
1.40	1.40	12.35	6.039
1.60	1.60	14.33	7.007
1.70	1.70	15.25	7.457
1.77	1.77	15.90	7.775
1.60	1.60	14.10	6.895
1.20	1.20	10.40	5.086
0.80	0.80	6.85	3.350
0.40	0.40	3.30	1.614
0.20	0.20	1.65	0.807
0	0.04	0.10	0.049

APPENDIX II

SNAP 10A Expansion Compensator Development Program

Thermal-Deflection Cycle Test Simulating
FS-3 System Conditions
ECU S/N 023

1.0 Object:

The purpose of conducting a thermal-deflection cycle test is to verify that an expansion compensator, which has been on steady-state endurance operation, will continue to operate within the specified system operating limits when the NaK volume is increased due to an operating temperature increase.

2.0 Scope:

The tests will be conducted on ECU S/N 023 which has been operated for 9034 hours at design steady-state conditions; 750°F at 60 cu in. NaK volume displacement. The test consists of ten thermal-deflection cycles between 700°F and 775°F with a NaK volume change of 8.5 cu in. This change in NaK volume is approximately equal to one-half of the SNAP 10A system NaK volume expansion which will result from a 100°F temperature change between 700°F and 800°F.

3.0 Test Measurements and Tolerances

All of the instrumentation and test equipment must meet the applicable requirements specified in the ECU Qualification Test Procedure NA0408-011, paragraph 3.3.

4.0 Test Procedure

4.1 Install the ECU in a thermal vacuum test rig.

NOTE: Use argon gas as the pressurization fluid during all phases of the test.

4.2 Calibrate the bellows deflection indicating actuator rod for thermal growth. The qualification test calibration may be used. The 775°F data point may be extrapolated.

4.2.1 Establish a test chamber vacuum of 10^{-2} Torr or better.

4.2.2 With the primary bellows unpressurized (at the same pressure as the test chamber), heat the ECU from room temperature to 700°F at a rate not to exceed 5°F per minute. Stabilize the ECU temperature at 700°F for a minimum of 30 minutes.

4.3 Perform a pressure versus deflection test between zero and 1.77 inches deflection while maintaining the temperature at 700°F.

NOTE: Report this data to the requesting engineer for immediate evaluation. Do not continue the test until the deflection limits are established.

4.4 Conduct ten thermal-deflection cycles by applying power to the test chamber radiant heaters and argon gas pressure to the ECU primary bellows. Heat-up and cool-down rates shall not exceed 5°F per minute. Each cycle shall be between 1.50 inches and 1.71 inches primary bellows deflection. Simultaneously, the temperature shall be cycled between 700°F and 775°F. The 1.71 inches primary bellows deflection will be held at 775°F for one hour on each cycle. The chamber vacuum shall be maintained at 10^{-2} Torr or better.

4.5 After the tenth thermal-deflection cycle is complete reduce the bellows pressure to zero psi and repeat the pressure deflection test per paragraph 4.3.

4.6 Increase the ECU temperature to 775°F and the deflection to 1.71 inches. Maintain the temperature and deflection at these conditions and operate the tests continuously for 100 hours $^{+50\ Hr}_{-\ 0\ Hr}$.

4.7 Reduce the temperature to 700°F and the pressure to zero psi. Repeat the pressure versus deflection test per paragraph 4.3.

4.8 Return the ECU to room ambient temperature and pressure.

4.8.1 Perform a helium leak test of the primary and secondary bellows volumes to measure a leak rate of 1×10^{-7} scc of Helium per second or better. Mark the location of any leaks detected and record the leak rate.

4.8.2 Remove the ECU from the thermal test rig and package for indefinite storage.

5.0 Test Data:

Submit one copy of the test data to the requesting engineer. File the original copy in an approved AI data log book.

ATOMICS INTERNATIONAL
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Thermal Deflection Cycle Tests Procedure

ECU S/N 023

Data Record

4.3 Pressure vs Deflection

Required ECU Temperature: 700°F

Actual Temperature 695°F

Ambient Temperature 78.5°F

Vacuum Chamber Pressure: 5.8×10^{-4} Torr

Primary Bellows Deflection		Primary Bellows Pressure	
Required (in.)	Actual (in.)	Indicated (in. of Hg)	Calculated (psi)
0	0.060	0	0
.10	0.100	0.30	
.20	0.200	1.10	
.40	0.400	2.95	
.60	0.600	4.75	
.80	0.800	6.55	
1.00	1.000	8.50	
1.20	1.200	10.15	
1.40	1.400	11.95	
1.60	1.600	14.15	
1.70	1.700	15.15	
1.77	1.770	15.80	
1.60	1.69	13.40	
*1.20	1.195	5.15	
0.80			
0.40			
0.20			
0		0	0

* Indicator rod jammed and would not follow movement of primary bellows. The temperature was reduced to room ambient and the rod was straightened.

Thermal Deflection Cycle Tests Procedure

ECU S/N 023

Data Record

4.3 Pressure vs Deflection (Repeat)

Required ECU Temperature: 700°F

Actual Temperature 687°F

Ambient Temperature 78°F

Vacuum Chamber Pressure: 5.7×10^{-4} Torr

Primary Bellows Deflection		Primary Bellows Pressure	
Required (in.)	Actual (in.)	Indicated (in. of Hg)	Calculated (psi)
0.06	2.040	0.0	0
0.10	0.110	0.5	0.245
0.20	0.200	1.25	0.611
0.40	0.400	3.15	1.540
0.60	0.600	4.75	2.32
0.80	0.800	6.55	3.20
1.00	1.000	8.45	4.13
1.20	1.200	10.10	4.94
1.40	1.400	12.10	5.92
1.60	1.600	14.10	6.89
1.70	1.700	15.10	7.38
1.77	1.770	15.80	7.73
1.60	1.600	14.20	6.94
1.20	1.200	10.20	4.99
0.80	0.800	6.55	3.20
0.40	0.400	2.95	1.44
0.20	0.200	1.15	0.562
0.06	0.060	0	0

4.3 Thermal deflection cycles ECU S/N 023

Cycle Number 1 Date: 2-7-66

Time Hr: Min		ECU Temp °F		Bellows Deflection (inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1003	700	687	1.500	1.500	12.90	6.308
	1023	725	728	1.570	1.565	13.60	6.650
	1030	750	750	1.640	1.640	14.30	6.993
t_1	1039	775	772	1.710	1.710	14.90	7.286
t_1 + 1 hr	1139	775	774	1.710	1.715	15.00	7.335
	1151	750	751	1.640	1.640	14.10	6.895
	1202	725	725	1.570	1.570	13.55	6.626
t_2	1211	700	702	1.500	1.500	12.95	6.333
t_2 + 30 min	1303	700	703	1.500	1.500	12.95	6.333
Cycle Number 2 Date: 2-7-66							
	1303	700	703	1.500	1.500	12.95	6.333
	1317	725	728	1.570	1.570	13.70	6.699
	1324	750	749	1.640	1.640	14.30	6.993
t_1	1333	775	773	1.710	1.710	14.90	7.286
t_1 + 1 hr	1434	775	773	1.710	1.715	15.00	7.335
	1450	750	749	1.640	1.640	14.00	6.846
	1500	725	725	1.570	1.570	13.35	6.528
t_2	1510	700	702	1.500	1.500	12.83	6.274
t_2 + 30 min	1543	700	701	1.500	1.500	12.83	6.274
Cycle Number 3 Date: 2-7-66							
	0855	700	700	1.500	1.500	13.00	6.357
	0908	725	724	1.570	1.570	13.80	6.748
	0917	750	750	1.640	1.640	14.40	7.042
t_1	0937	775	773	1.710	1.710	15.00	7.335
t_1 + 1 hr	1037	775	773	1.710	1.715	15.10	7.384
	1049	750	750	1.640	1.640	14.20	6.944
	1059	725	724	1.570	1.575	13.45	6.577
t_2	1109	700	701	1.500	1.500	12.85	6.284
t_2 + 30 min	1140	700	700	1.500	1.500	12.85	6.284

4.3 Thermal deflection cycles ECU S/N 023 (continued)

Cycle Number 4 Date: 2-7-66

Time Hr: Min		ECU Temp °F		Bellows Deflection (inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1140	700	700	1.500	1.500	12.85	6.284
	1153	725	726	1.570	1.570	13.77	6.734
	1201	750	750	1.640	1.640	14.35	7.017
t_1	1212	775	775	1.710	1.710	15.05	7.359
t_1 + 1 hr	1312	775	775	1.710	1.710	15.05	7.359
	1319	750	745	1.640	1.640	14.17	6.929
	1332	725	725	1.570	1.570	13.50	6.602
t_2	1341	700	703	1.500	1.500	12.85	6.284
t_2 + 30 min	1411	700	700	1.500	1.500	12.85	6.284
Cycle Number 5 Date: 2-8-66							
	1411	700	700	1.500	1.5	12.85	6.284
	1419	725	727	1.570	1.570	13.80	6.748
	1430	750	749	1.640	1.640	14.45	7.066
t_1	1440	775	773	1.710	1.710	15.00	7.335
t_1 + 1 hr	1540	775	776	1.710	1.710	15.00	7.335
	1554	750	750	1.640	1.640	14.10	6.895
	1604	725	724	1.570	1.570	13.40	6.553
t_2	1613	700	702	1.500	1.500	12.80	6.259
t_2 + 30 min	1643	700	699	1.500	1.500	12.80	6.259
Cycle Number 6 Date: 2-9-66							
	0804	700	709	1.500	1.500	12.80	6.259
	0815	725	726	1.570	1.575	13.80	6.748
	0825	750	749	1.640	1.640	14.45	7.066
t_1	0836	775	774	1.710	1.710	15.05	7.359
t_1 + 1 hr	0937	775	776	1.710	*1.710	14.90	7.286
	0947	750	750	1.640	1.640	14.00	6.846
	0956	725	724	1.570	1.570	13.40	6.553
t_2	1006	700	701	1.500	1.495	12.70	6.210
t_2 + 30 min	1036	700	697	1.500	1.490	12.75	6.235

*Deflection was 1.725 at end of hr. Pressure of 15.3 in. Hg.

4.3 Thermal deflection cycles ECU S/N 023 (continued)

Cycle Number 7 Date: 2-9-66

Time Hr: Min		ECU Temp °F		Bellows Deflection (inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1036	700	698	1.500	1.490	12.75	6.235
	1050	725	728	1.570	1.570	13.80	6.748
	1058	750	754	1.640	1.640	14.40	7.042
t_1	1108	775	773	1.710	1.715	15.10	7.384
t_1 + 1 hr	1208	775	775	1.710	1.710	14.60	7.139
	1223	750	750	1.640	1.640	14.00	6.846
	1231	725	724	1.570	1.570	13.70	6.699
t_2	1241	700	702	1.500	1.500	12.85	6.284
t_2 + 30 min	1341	700	700	1.500	1.500	12.85	6.284
Cycle Number 8 Date: 2-9-66							
	1311	700	700	1.500	1.500	12.85	6.284
	1325	725	728	1.570	1.500	13.65	6.675
	1333	750	749	1.640	1.640	14.38	7.032
t_1	1341	775	773	1.710	1.710	15.08	7.374
t_1 + 1 hr	1441	775	773	1.710	1.710	15.10	7.384
	1453	750	750	1.640	1.640	13.90	6.797
	1502	725	725	1.570	1.570	13.38	6.543
t_2	1512	700	701	1.500	1.500	12.75	6.235
t_2 + 30 min	1542	700	700	1.500	1.500	12.75	6.235
Cycle Number 9 Date: 2-10-66							
	0914	700	702	1.500	1.500	12.9	6.31
	0927	725	726	1.570	1.570	13.85	6.77
	0934	750	751	1.640	1.640	14.50	7.09
t_1	0944	775	774	1.710	1.710	15.10	7.38
t_1 + 1 hr	1044	775	774	1.710	1.710	15.10	7.38
	1055	750	750	1.640	1.640	13.90	6.80
	1104	725	725	1.570	1.570	13.45	6.58
t_2	1115	700	699	1.500	1.500	12.70	6.21
t_2 + 30 min	1145	700	697	1.500	1.500	12.80	6.26

4.3 Thermal deflection cycles ECU S/N 023 (continued)

Cycle Number 10 Date: 2-10-66

Time Hr: Min		ECU Temp °F		Bellows Deflection 0inches)		ECU Pressure	
Required	Indicated	Required	Indicated	Required	Actual	Ind. in. of Hg	Cal. psi
	1300	700	708	1.50	1.50	12.80	6.26
	1311	725	727	1.57	1.57	13.70	6.70
	1317	750	748	1.64	1.64	14.40	7.04
t_1	1330	775	774	1.71	1.71	15.00	7.34
t_1 + 1 hr	1430	775	775	1.71	1.715	15.10	7.38
	1445	750	749	1.64	1.64	13.95	6.82
	1456	725	721	1.57	1.57	13.35	6.53
t_2	1505	700	701	1.50	1.50	12.80	6.26
t_2 + 30 min	1535	700	700	1.50	1.50	12.80	6.26

4.5 Pressure versus deflection test at 700°F

Actual ECU Temperature 700°F

Ambient Temperature 75°F

Vacuum Chamber Pressure 5×10^{-4} Torr

Primary Bellows Deflection		Primary Bellows Pressure	
Required (in.)	Actual (in.)	Indicated (in. of Hg)	Calculated (psi)
0	0.090	0	0
0.10	0.100	0.10	0.049
0.20	0.200	0.90	0.440
0.40	0.400	2.90	1.418
0.60	0.600	4.60	2.249
0.80	0.800	6.45	3.154
1.00	1.000	8.15	3.985
1.20	1.200	9.90	4.841
1.40	1.400	11.85	5.795
1.60	1.600	13.80	6.748
1.70	1.700	14.90	7.286
1.77	1.770	15.50	7.580
1.60	1.600	13.70	6.699
1.20	1.200	10.00	4.890
0.80	0.800	6.35	3.105
0.40	0.400	2.85	1.394
0.20	0.200	0.95	0.465
0	0.090	0	0

4.6 Endurance Operation

Required Temperature 775°F

Actual Temperature 782°F

Required Deflection 1.710 in.

Actual Deflection 1.710 in.

Bellows Pressure 14.6 in. Hg / 7.14 psi

Start Time: 1310

Date: 2-11-66

4.6 Endurance Operation (continued)

Date	Time	Remarks
2-11-66	1500	Reduced temperature to 700°F and 0.090 in. deflection for weekend.
2-14-66	0900	Reset deflection to 1.710 in. increased temperature to 775°F pressure.
2-15-66		Endurance test terminated after 25.5 hours at 775°F. Temperature decreased to 700°F and deflection reduced to 0.10 in. at zero psi.

4.7 Pressure versus deflection at 700°F

Actual ECU Temperature 693°F

Ambient Temperature 76°F

Vacuum Chamber Pressure 4.6×10^{-4} Torr

Primary Bellows Deflection		Primary Bellows Pressure	
Required in.	Indicated in.	Indicated in. of Hg	Calculated psi
0	0.100	0.0	0.0
.10	0.100	0.0	0.0
.20	0.20	1.00	0.489
.40	0.40	2.85	1.394
.60	0.60	4.55	2.225
.80	0.80	6.30	3.081
1.00	1.00	8.05	3.936
1.20	1.20	9.90	4.841
1.40	1.40	11.80	5.770
1.60	1.60	13.85	6.773
1.70	1.70	14.80	7.237
1.77	1.77	15.5	7.580
1.60	1.60	13.65	6.675
1.20	1.20	10.00	4.890
0.80	0.80	6.25	3.056
0.40	0.40	2.80	1.369
0.20	0.20	1.05	0.513
0	0.10	0.0	0.0

Actual ECU temperature of end of test 698°F

4.9 Helium Leak Detection

Ambient Temperature 76°F

Secondary volume vent tube cut: Air filling the evacuated volume was audible.

Secondary volume evaluated to 10^{-5} Torr. External surfaces and primary bellow volume purged with helium. No leaks were detected equal to or greater than 1 x 10^{-7} SCC of helium per seconds.

REFERENCES

1. IL to W. T. Morgan from M. Perlow, SNAP 10A Expansion Compensator Tests January 12, 1966.
2. NAA-SR-TDR-9778, SNAP 10A Expansion Compensator.