R-5290

Study of Physical Prop. etc
for Sol Fuel Prog

R-5290

STUDY OF PHYSICAL PROPERTIES NECESSARY FOR SATISFACTORY FUNCTIONING OF AN O-RING

ROCKETDYNE

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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FOREWORD

This report was prepared under G. O. 8347 in compliance with Contract AF04(607)-7339, Item 2 and Appendix A, Section III, Task II (CCN 28).

ABSTRACT

~~Presented are~~ the results of a study of ~~the~~ physical properties necessary for satisfactory functioning of an O-ring. Also included are details of a revised computer program for the study of aging characteristics of O-rings.

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INTRODUCTION

Since 1957, Rocketdyne has been actively engaged in studying the aging of elastomers and compliant materials from liquid-propellant propulsion systems. These studies have been directed toward determing and recommending the service-life of these "soft goods" as used in liquid-propellant rocket engines for weapon system applications.

The current requirement to remove the soft goods from a rocket engine system after a service life period of 42 months was established in 1957. This requirement resulted from the limited knowledge then available (Ref. 1) concerning the effect of aging on engine performance.

Consideration of the high reliability requirements of weapon system rocket engines and the time and costs involved in the dismantling of engine systems, primarily for the replacement of "aged" soft goods (after limited service life), provided impetus to determine the maximum service life of these goods. Previous studies to obtain fundamental practical O-ring aging information had not been performed, and several problem areas requiring further investigation had been uncovered during previous evaluations of soft goods.

The objective of the program summarized in this report was to complement the work performed in the O-ring aging characteristics study (Ref. 2) which was conducted to determine the service life of O-rings which must function in various engine components. Previous studies have produced data indicating degradation of the elastomer (as indicated by percentage reduction or percentage increase in a particular physical property), but this portion of the aging program was conducted to determine the critical degradation level that will affect the satisfactory functioning of an O-ring.

In addition, the computer program developed during the O-ring aging characteristics program (Ref. 2) was revised and modified to incorporate several factors not considered during the initial development of the program.

SUMMARY

Selected types of MS and AN O-rings have been functionally tested in Atlas propulsion system components following artificial aging at 212 F for periods up to 7 weeks. The MA-2 components tested (the lube tank pressurizing valve, the fuel disconnect assembly, and the main fuel valve) were chosen to provide various types of motion, sealing methods, O-ring sizes, and compounds.

Mechanical property tests on the aged rings showed that the hardness had changed as much as 28 points and the compressive stress at 10% deflection had changed as much as 330%. Despite these considerable changes in properties, there was no hydraulic oil or gaseous nitrogen leakage from any of the components in which aged O-rings had been installed.

Because of the satisfactory O-ring performance during the test program, O-ring property levels and O-ring functions could not be correlated.

Considering past evaluations of soft goods conducted by Rocketdyne on the Navaho, Redstone, Jupiter, Thor, and Atlas engine systems (Ref. 3), and from the general elastomer aging studies conducted by industrial and military organizations (Ref. 4 through 8), it appears that the service life of liquid-propellant rocket engine soft goods exceeds the present 42-month service limitation and may extend to at least 5 years.

The computer program for the storage and retrieval of test data from O-ring aging studies has been revised to improve the detail part identification, to incorporate all control values in the tape record, and to improve the printout format. Subroutines have been written to improve and expand the analysis of the stored data.

COMPUTER ANALYSIS PROGRAM

Rocketdyne has utilized the most modern mathematical tools available to improve the techniques and procedures used in aging studies of O-rings. Information retrieval and calculation programs have been prepared and used, and data accumulated from soft goods analyses have been recorded and stored on magnetic computer tape for use with Rocketdyne's IBM 7090 computer. Data from analyses performed prior to the inception of programs utilizing a computer in soft goods study will be transferred to the magnetic computer tape for permanent retention and comparison.

Experience with the present computer program revealed certain limitations, so a new program was set up to incorporate the changes outlined below.

IDENTIFICATION OF SOFT GOODS

Accurate identification of individual O-rings became a problem early during the engine soft-goods evaluation program. The original means of identifying and recording the O-ring was to shorten the AN or MS number according to a prearranged code, and to enter this code in the six spaces provided on a special analysis form. However, parts with up to 14 letters and digits began to appear and did not fit into the prearranged codes. Each of these parts was handled separately. These longer digit identification numbers began to appear with increasing frequency, so the method of identification was changed to utilize the entire identification number of the part, up to 14 letters or digits in length, without coding. The parts are further identified by the manufacturer so that values obtained from physical tests can be compared to the original test values for that particular manufacturer's part.

INCORPORATION OF CONTROL VALUES

It was also desired to incorporate all control values onto the tape record. This would result in less work for the technician recording the raw data (thereby reducing possibilities for error), and would shorten the card length and the time used to pack the data. The new program requires only one card for each O-ring, except when compressive modulus data is determined.

CLARIFICATION OF PRINTOUT FORMAT

The printout format was changed to show the derived information more clearly, and subroutines were written to compare and analyze data in different ways. Parts which exceed the specification limitations are grouped according to the amount of variance from specification tolerances. A "least squares" program is being formulated to fit the curves derived from compressive modulus testing.

REVISIONS TO INSTRUCTIONS

New instructions were written to enable technicians to accurately and effectively record data which will be transferred to key punch IBM cards and IBM magnetic tape. These instructions are presented in Appendix A. These instructions also provide a description of the new soft goods analysis program.

STUDY OF CRITICAL FUNCTIONAL PROPERTIES

O-RING SAMPLES

All O-rings used in this program were military specification (MS) rings supplied by the Parker Seal Company.

Three samples of each O-ring were exposed to each aging period and the properties were measured on these rings. Functional tests were performed on the rings prior to property testing.

All control values were obtained by averaging readings and measurements of at least five O-ring samples.

AGING AND EVALUATION OF PHYSICAL PROPERTIES

To determine the critical values of properties which affect the function of an O-ring, different property levels were obtained by accelerating the normal aging of the rings and then measuring the properties of the ring.

The accelerated aging was performed in a Konrad oven equipped with a recorder controller. The oven was calibrated prior to the test program; the temperature variation within the oven was less than ±5 F. An aging temperature of 212 F was used.

The properties evaluated included W-diameter, hardness, compressive stress, and compressive relaxation. The W-diameter value was required to provide an initial value for the calculation of deflections during the compressive tests. The hardness value provided a general indication of the degree of aging. Compressive stress and compressive stress relaxation are closely related to the mechanism of O-ring sealing. A detailed discussion of this matter is included in Rocketdyne report R-5253 (Ref. 2).

TEST PROCEDURES AND DESCRIPTION

Dimensions

The W-diameter of each O-ring was measured in at least five areas equally distributed around the circumference of the O-ring. A dead-weight instrument graduated in increments of 0.0010 inch was used. The inside diameter of each ring was determined by use of a stepped cone.

Hardness

The Shore-A hardness of each O-ring was measured in at least five areas equally spaced about the circumference of the O-ring. The hardness was recorded at ambient temperature (77 ±5 F) approximately 30 minutes after the O-rings were removed from the aging oven. A spring-actuated instrument was used. Values reported in Table 1 represent the average of all the readings on the three samples.

Compressive Stress

Compressive stress tests (compression-deflection) utilized an Instron universal testing machine to compress the O-rings up to 50% deflection. The rate of loading was 0.02 in./min.

TABLE 1

AGING DATA FOR FUNCTIONALLY TESTED O-RINGS

O-Ring	Aging Period, days	W-Diameter, inch	Shore-A Hardness, points	Compressive Force (pounds)/Circumference (inches) At Indicated Percentage Compression					Negative Compressive Relaxation Slope*
				10%	20%	30%	40%	50%	
MS 29512-10 (2.38-inch circumference)	0	0.095	61	3.86	9.34	18.5	40.2	91.2	0.0334
	7	0.094	65	4.54	11.15	22.5	45.4	97.3	0.0319
	14	0.095	66	4.81	12.2	24.2	46.6	91.7	0.0461
	21	0.096	67	5.42	13.2	27	52.6	108	0.0500
	28	0.095	77	8.45	21.5	46	93.0	191	0.057
	35	0.095	81	9.10	24.2	49.7	95.1	176	0.0581
	42	0.095	83	11.3	30.2	64.3	127	245	0.0558
	49	0.094	84	11.3	30.8	65.0	127	247	0.0557
MS 29512-12 (2.91-inch circumference)	0	0.113	63	4.84	11.85	23.6	50.4	114	0.0358
	7	0.113	80	--	--	--	--	--	--
	14	0.112	81	--	--	--	--	--	--
	21	0.112	84						
	28	0.111	86	12.2	32.4	68.0	135	236	C.0483
	35	--		--	--	--	--	--	--
	42	--		--	--	--	--	--	--
	49	0.111		15.0	41.5	85.5	155	282	0.0527
MS 29512-16 (3.7-inch circumference)	0	0.112	65	5.21	13.3	26.9	65.1	197	0.044
	7	0.112	68	5.20	13.4	26.9	53.8	113	0.0362
	14	0.112	70	6.3	16.0	32.8	66.5	142	0.0404
	21	0.112	71	6.2	15.6	30.7	58	111	--
	28	0.112	79	9.2	23.6	49.8	103	194	0.0553
	35	0.112	83	9.98	27.6	58.4	115	221	0.0519
	42	0.111	85	10.5	31.2	68.3	133	257	0.590
	49	0.112	87	13.1	39.8	82.6	167	329	0.590
MS 29513-116 (2.32-inch circumference)	0	0.101	62	4.52	10.5	20.4	42.7	96.5	0.052
	7	0.100	66	5.56	13.3	26.4	53.8	131.5	0.0346
	14	0.100	67	5.73	14.5	28.8	58	130.5	0.0425
	21	0.100	69	6.41	15.7	31.4	60.9	123	0.0323
	28	0.100	80	8.93	23.3	47.0	89.2	169	0.0528
	35	0.100	81	8.85	25.2	53.2	103	206	0.0623
	42	0.100	84	11.0	30.3	63.4	127	255	0.0564
	49	0.100	85	15.6	41.4	88.5	176	358	0.0621
MS 29513-117 (2.52-inch circumference)	0	0.101	60	4.5	10.4	20.4	43.5	90.8	0.0413
	7	0.101	63	4.17	10.75	20.6	43.0	105	0.0355
	14	0.101	66	5.87	14.05	28.2	56.9	118.5	0.0494

	35	0.112	83	9.98	27.6	58.4	115	221	0.0519
	42	0.111	85	10.5	31.2	68.3	133	257	0.590
	49	0.112	87	13.1	39.8	82.6	167	329	0.590
MS 29513-116 (2.52-inch circumference)	0	0.101	62	4.52	10.5	20.4	42.7	96.5	0.052
	7	0.100	66	5.56	13.3	26.4	53.8	131.5	0.0346
	14	0.100	67	5.73	14.5	28.8	58	130.5	0.0425
	21	0.100	69	6.41	15.7	31.4	60.9	123	0.0323
	28	0.100	80	8.93	23.3	47.0	89.2	169	0.0528
	35	0.100	81	8.85	25.2	53.2	103	206	0.0623
	42	0.100	84	11.0	30.3	63.4	127	255	0.0564
	49	0.100	85	15.6	41.4	88.5	176	358	0.0621
MS 29513-117 (2.52-inch circumference)	0	0.101	60	4.5	10.4	20.4	43.5	90.8	0.0413
	7	0.101	63	4.17	10.75	20.6	43.0	105	0.0355
	14	0.101	66	5.87	14.05	28.2	56.9	118.5	0.0494
	21	0.101	69	6.05	14.7	29.2	55.6	108	0.0283
	28	0.101	81	11.35	28.6	58.8	119	255	0.0376
	35	0.101	86	14.6	37.4	75.5	144	271	0.0670
	42	0.101	87	15.4	40.6	79.3	147	278	0.0729
	49	0.101	88	18.3	47.7	100	178	352	0.0675
MS 29513-123 (3.7-inch circumference)	0	0.101	62	4.11	9.73	18.85	38.4	84.5	0.0295
	7	0.101	66	4.35	11.4	25.1	46.1	104	0.0289
	14	0.101	68	5.61	15.4	32.6	66.1	146.5	0.0272
	21	0.101	70	5.24	15.7	28	50.7	113.5	0.0402
	28	0.101	80	8.4	23.1	50	102	215	0.0600
	35	0.101	82	10.4	28.6	63.7	145	271	0.0484
	42	0.101	83	11.6	32.6	72.0	150	297	0.0588
	49	0.101	87	14.6	42.1	93.5	195	368	--
MS 29513-124 (3.9-inch circumference)	0	0.101	61	3.9	9.6	19.7	40.6	92.6	0.0231
	7	0.101	65	4.47	10.75	22.6	45.9	104	0.0293
	14	0.100	66	4.59	12.0	24.6	49.0	102	0.0589
	21	0.100	70	4.8	12.3	26.1	48.2	96.9	0.0359
	28	0.100	77	6.16	17.6	36.7	70.6	135	0.0482
	35	0.100	80	8.0	22.7	48.3	93.5	180	0.0460
	42	0.100	83	8.65	27.2	58.6	117	224	0.0486
	49	0.100	85	9.45	31.0	67.5	132	250	0.0541

$$* \; \frac{\text{stress ratio at 30 seconds} - \text{stress ratio at 300 seconds}}{\log 30 \; - \; \log 300}$$

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TABLE 1

(Continued)

O-Ring	Aging Period, days	W-Diameter, inch	Shore-A Hardness, points	Compressive Force (pounds)/Circumference (inches) At Indicated Percentage Compression 10%	20%	30%	40%	50%	Negative Compressive Relaxation Slope*
MS 29513-130 (5.09-inch circumference)	0	0.100	62	3.77	9.44	18.85	37.7	80.4	0.0407
	7	0.100	65	4.25	11.15	23.1	50.5	129.5	0.0337
	14	0.100	67	4.11	10.4	20.5	40.0	85.4	0.0245
	21	0.101	70	3.71	13.8	27.5	51.6	106	0.0338
	28	0.099	81	7.05	21.2	46.2	94.5	197	
	35	0.099	84	8.82	27.7	61.5	128	274	0.0527
	42	0.099	86	10.8	30.5	65.3	133	302	0.0667
	49	0.099	87	14.4	42.0	97.0	205	438	0.0598
MS 29513-134 (5.87-inch circumference)	0	0.101	62	3.69	9.51	19.0	37.8	81.0	0.0222
	7	0.101	66	3.72	9.85	20.0	41.3	95.0	0.0342
	14	0.101	69	4.17	11.25	22.8	45.6	101	0.0365
	21	0.101	72	4.84	12.5	25.4	50.4	107	0.0389
	28	0.100	78	5.61	16.8	36.8	80.4	185	0.0520
	35	0.100	82	7.94	23.0	53.5	122	271	0.0505
	42	0.100	85	8.8	26.0	60.4	133	296	0.0556
	49	0.100	86	10.3	31.6	71.8	162	318	0.0570
AN 6227-12 (1.95-inch circumference)	0	0.101	71	6.29	15.5	33.2	78.4	284	0.0413
	7	0.101	72	7.0	17.9	37.2	74.6	160.5	0.0290
	14	0.100	76	9.28	23.4	47.7	92.5	187	0.0421
	21	0.101	77	9.59	23.2	46.7	87.7	161	0.0325
	28	0.100	87	17.3	44.7	90.3	165	319	0.0546
	35	0.101	88	22.3	57.3	112	208	451	0.0721
	42	0.101	92	30.9	79.4	157	302	603	0.0679
	49	0.100	91	32.3	84.3	171	344	710	0.0618
AN 6227-15 (2.32-inch circumference)	0	0.136	67	7.64	19.7	42.8	104	314	0.0344
	7	0.136	68	7.55	19.8	40.9	70.6	188	0.0314
	14	0.136	72	9.55	24.6	50.6	103	197	0.0366
	21	0.136	76	10.3	26.2	54.1	109	225	0.0343
	28	0.136	84	18.3	47	97.5	190	387	0.0536
	35	0.135	86	20.8	58.4	124	232	509	0.0416
	42	0.136	90	26.5	72.9	157	321	685	0.0556
	49	0.135	91	28.0	73.7	159	328	705	0.575
AN 6227-33 (6.61-inch circumference)	0	0.207	71	12.35	32.5	70.6	167	451	0.0270
	7	0.207	72	10.7	31.3	74.0	--	474	0.0264
	14	0.207	75	--	--	--	--	--	0.0257
	21	0.207	76	11.4	33.9	75.4	164	365	0.0271

	49	0.100	91	32.3	84.3	171	344	710	0.0618
AN 6227-15 (2.32-inch circumference)	0	0.136	67	7.64	19.7	42.8	104	314	0.0344
	7	0.136	68	7.55	19.8	40.9	70.6	188	0.0314
	14	0.136	72	9.55	24.6	50.6	103	197	0.0366
	21	0.136	76	10.3	26.2	54.1	109	225	0.0343
	28	0.136	84	18.3	47	97.5	190	387	0.0536
	35	0.135	86	20.8	58.4	124	232	509	0.0416
	42	0.136	90	26.5	72.9	157	321	685	0.0556
	49	0.135	91	28.0	73.7	159	328	705	0.575
AN 6227-33 (6.61-inch circumference)	0	0.207	71	12.35	32.5	70.6	167	451	0.0270
	7	0.207	72	10.7	31.3	74.0	--	474	0.0264
	14	0.207	75	--	--	--	--	--	0.0257
	21	0.207	76	11.4	33.9	75.4	164	365	0.0271
	28	0.207	85	16.2	49.4	110	234	460	0.0442
	35	0.207	86	21.7	63.9	133	264	543	0.0515
	42	0.207	89	31.6	93.5	188	347	675	0.0521
	49	0.206	91	37.7	101	198	378	725	0.0507
AN 6227-45 (11.35-inch circumference)	0	0.208	72	10.1	26.9	57.4	128	305	0.0362
	7	0.208	75	10.4	29.8	64.9	138.5	322	0.0260
	14	0.208	77	13.0	33.6	73.0	159	337	0.0326
	21	0.207	80	12.7	34.7	73.6	154	336	0.0320
	28	0.207	86	14.1	44.8	95.7	190	356	0.0473
	35	0.207	88	20.1	59.4	125	247	488	0.0573
	42	0.207	90	30.9	85.0	167	315	598	0.0513
	49	0.207	92	33.2	93.8	194	367	710	0.0621
AN 6230-6 (7.05-inch circumference)	0	0.137	72	7.36	19.15	41.5	99.0	267	0.0400
	7	0.137	73	7.40	20.6	44.4	94.0	208	0.0307
	14	0.136	75	8.8	23.7	49.1	101	229	0.0315
	21	0.137	78	8.45	23.0	45.9	87.6	176	0.0243
	28	0.136	87	14.3	43.4	91.0	177	301	0.0540
	35	0.136	90	21.3	61.2	127	238	415	0.0473
	42	0.136	91	25.2	74.0	150	276	507	0.0662
	49	0.135	92	28.4	78.8	162	292	526	0.0571

$$* \ \frac{\text{stress ratio at 30 seconds} - \text{stress ratio at 300 seconds}}{\log 30 \quad - \quad \log 300}$$

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Compressive Relaxation

Compressive relaxation tests were performed by using the Instron machine to compress the O-rings used during the compressive stress tests to a fixed 20% deflection. The change in load over a predetermined time interval was recorded on an Instron strip recorder chart. The compression relaxation values reported represent the slope of the stress decay curve, and were calculated from the following equation:

$$\text{Slope} = \frac{(S_t/S_o)_{30} - (S_t/S_o)_{300}}{\log\,(t)_{30} - \log\,(t)_{300}}$$

where

$(S_t/S_o)_{30}$ = ratio of stress at 30 seconds to initial stress

$(S_t/S_o)_{300}$ = ratio of stress at 300 seconds to initial stress

$(t)_{30}$ = 30 seconds

$(t)_{300}$ = 300 seconds

All the compressive test measurements were made at 77 ±5 F. The stress and relaxation tests were performed no earlier than 1 hour after removal from the aging oven.

EXTENT OF AGING

O-rings were aged for varying periods up to 7 weeks. The results of the property tests (Table 1) reveal that all the rings experienced considerable changes in their original properties at the end of the 7 weeks. For example, changes in hardness values generally ranged from about 20 to 28 points, and the compressive stress at 10% deflection changed by as much as 330%.

FUNCTIONAL TESTING

COMPONENT SELECTION

To obtain suitable and representative components containing O-rings used in various applications within the Atlas propulsion system, the following components were selected at random:

1. The lube tank pressurizing valve assembly (P/N 551730). This assembly has linear-motion pistons. The unit contains MS 29512-10, -12, -16 and MS 29513-116, -117 O-rings.
2. The fuel disconnect valve assembly (P/N 400566 booster half, P/N 400565 sustainer half). This assembly incorporates a unique sealing method consisting of a dynamic poppet sealing within a bore. The unit contains MS 29513-123, -130, and -134 O-rings.
3. The main fuel valve assembly (P/N 402660). This assembly has rotary and linear motion, diametrically sealing static seals, and conventional AND 10050 boss seals. The unit contains AN 6227-12, -15, -33, -45; AN 6230-6, and MS 29513-116 and -124 O-rings.

These valves were chosen for three reasons:

1. The components are used on MA-2 engines and represent actual weapon system applications.
2. The valves represent various types of motion, sealing method, O-ring sizes, and O-ring materials.
3. The valves were available for this program, and special test fixtures which would result in additonal hardware cost were not necessary.

TEST PROCEDURES

Lube Tank Pressurizing Valve Assembly

MIL-H-5606 oil was used as the pressurizing media for O-rings aged the first 3 weeks. The pressure was applied to the regulator pressurizing inlet port, and leakage was measured past the dynamic seals on the pistons and static seals on the four caps. Pressures of 1, 5, 50, 100, 750, and 1500 psig were applied.

Leakage tests on the remaining four sets of aged O-rings were conducted with gaseous nitrogen. Pressure was applied to the same ports used during the hydraulic oil tests and at the same pressures.

Gaseous nitrogen leakage tests were also conducted with a valve which had been aged at 212 F for 7 weeks with all the O-rings installed. Gaseous leakage was detected at low pressures, so leakage was measured at various intermediate pressures to determine the maximum quantity. After leakage tests, the valve was disassembled and the O-rings were photographed (Fig. 1) to show the condition of the static seals.

Fuel Disconnect Valve Assembly

Leakage tests were conducted on the sustainer half of the pullaway disconnect to test the static and piston seals. The two halves of the disconnect were then clamped together to test the dynamic seal located on the booster half.

IBL65-6/27/63-Ca

Figure 1. Condition of O-Rings After 7 Weeks of Aging (At 212 F) in Lube Tank Pressurizing Valve

Main Fuel Valve Assembly

Hydraulic and gaseous nitrogen pressures of 1 to 20, 1 to 100, 1 to 500, or 1 to 750 psig were applied to the shaft, cap, piston rod, actuator piston, piston cylinder, switch box shaft, and switch box cover, depending on the maximum limitation at each location.

TEST RESULTS

The functional tests were conducted on the aged O-rings within 3 to 5 days after they were removed from the aging oven.

Initially MIL-H-5606 hydraulic oil was used as the pressurizing medium for all three valves. A liquid medium was selected because the three components basically are liquid valves. Because essentially no hydraulic oil leakage was observed when aged O-rings exposed 1 to 3 weeks at 212 F were installed in the valves, the remaining aged O-rings were tested with gaseous nitrogen (a pressurizing medium against which sealing is more difficult).

Lube Tank Pressurizing Valve Assembly

O-Rings Aged Outside of Valve. No hydraulic oil leakage occurred with the first three sets of aged O-rings at pressures of 1, 5, 50, 100, 750, and 1500 psig, and no gaseous nitrogen leakage occurred with the remaining four sets of aged O-rings at the same pressures.

O-Rings Aged in Valve. The static gasket MS 29512-12 displayed audible leakage when the pressure was first increased. At a pressure of approximately 700 psig, the leakage stopped and did not recur. The MS 29513-116 piston O-ring leaked at an increasing rate up to 0.5 cfm at 14 psig, but reduced to zero at 18 psig. The MS 29513-117 O-ring leaked at an increasing rate up to 0.9 cfm at 15 psig, but reduced to 0.5 cfm at 50 psig, and to zero leakage at 75 psig. These leakage rates would not cause valve rejection because leakage tests are not conducted at these low pressures. Normal operating conditions for this valve is about 1500 psig.

The valve was disassembled, and the O-rings were found to be severely deformed (Fig. 1). This may be attributed to a combination of factors, including the differential coefficient of expansion between the metal valve parts and the elastomer, and the effects of long-term high-temperature environment which can contribute to appreciable compression set of the O-rings. The high pressures during leak checks were sufficient to seat the deformed rings and enable them to perform their designed function.

Fuel Disconnect Valve Assembly

The first three sets of O-rings were cycled 100 times, and no leakage occurred when pressurized with hydraulic oil at pressures of 1/2, 5, 50, 100, and 750 psig.

The remaining four sets of aged O-rings were used with gaseous nitrogen at the same pressures. No leakage was obtained from the static seal in the sustainer half or the dynamic seal in the booster half.

At 750 psig, the O-ring on the sustainer half piston showed a slight leakage of approximately 1 scim from the fourth through the seventh set of O-rings. Zero leakage was obtained at pressures up to 100 psig. The amount of leakage remained constant from the fourth to the seventh set of aged O-rings, and did not reduce appreciably after 100 actuation cycles. The component permits 1 scim of gaseous nitrogen leakage at 50 psig, so the leakage rates obtained would not cause rejection of the part.

Main Fuel Valve Assembly

No hydraulic oil leaked past any of the O-rings. When gaseous nitrogen was used, fuzz leakage occurred past the piston cyclinder actuator O-ring (aged 5 weeks) at 750 psig. The leakage was not evident on the sixth or seventh sets of O-rings. The slight leakage recorded would not cause rejection of the component. The aged condition (hard and brittle) of the O-rings made installation of the rings difficult, and one ring broke during assembly.

CONCLUSIONS AND RECOMMENDATIONS

Other than acceptable fuzz leakage, no hydraulic oil or gaseous nitrogen leaked past the Atlas lube tank pressurizing valve, fuel disconnect valve, or main fuel valve ~~as a result~~ of installing aged O-rings in the valves. No correlation between O-ring property levels and functions was attempted because of the satisfactory performance demonstrated by the O-rings during component leakage checks, but ~~it is recommended~~ that further studies be conducted to obtain these correlations. ~~To fully explore the problem and benefit from the knowledge gained in this study~~, special test fixtures should be designed and built to permit the best utilization of test time and available funding. To simplify the program, testing should be limited to simulation of the most severe service and applications encountered by Atlas O-rings. In rocket engine systems such as Atlas, Thor, and Jupiter, O-rings are exposed to one or more of the 11 different fluids listed below.

1. RP-1 fuel
2. MIL-H-5606/MIL-H-6083 hydraulic oil
3. Gaseous oxygen
4. Liquid oxygen (static seals only)
5. Gaseous nitrogen
6. Liquid nitrogen (functional tests)
7. Helium
8. MIL-C-14201 preservative oil

9. MIL-L-25336/MIL-L-6086 lube oil
10. DC-55 lubricant
11. FS-1280 lubricant

Application of O-rings in various design configurations can be reduced to six fundamentally different categories, as follows:

1. Dynamic seal; reciprocating
2. Dynamic seal; rotary
3. Dynamic seal; compression (valve seat)
4. Static seal; face type
5. Static seal, AND 10050 port
6. Static seal; diametral type

Intermittent exposure to RP-1 is the most severe fluid service experienced by the Atlas O-rings. The most severe design application is assumed to occur with the use of compression-type dynamic seals which are used as valve seats and are the most susceptible to age deterioration.

A properly designed test fixture will allow various applications to be tested simultaneously, so all six of the categories can be evaluated. Because the effect of size also must be considered, it is suggested that two similar fixtures be utilized for the tests. One fixture will contain O-rings less then 3/4-inch in diameter; the second fixture will contain O-rings between 2 and 3 inches in diameter.

To minimize variation in results due to physical differences between O-rings, a standardized inspection procedure should be prepared. All test specimens should be subjected to the inspection.

One suggested test program, outlined below, is divided into three phases:

Phase 1:	New O-rings will be subjected to leakage and cycling tests at ambient temperature, -65 F, and +160 F. These tests will be repeated a sufficient number of times to establish normal values.
Phase 2:	O-rings taken from engines returned from service with considerable accumulated life will be tested and results compared with results obtained during Phase 1. This will establish deterioration that occurs with natural aging of a known duration.
Phase 3:	O-rings which have been subjected to accelerated aging procedures will be tested and results correlated with results obtained during the first two phases. Quantitative deterioration values for critical properties will be established.

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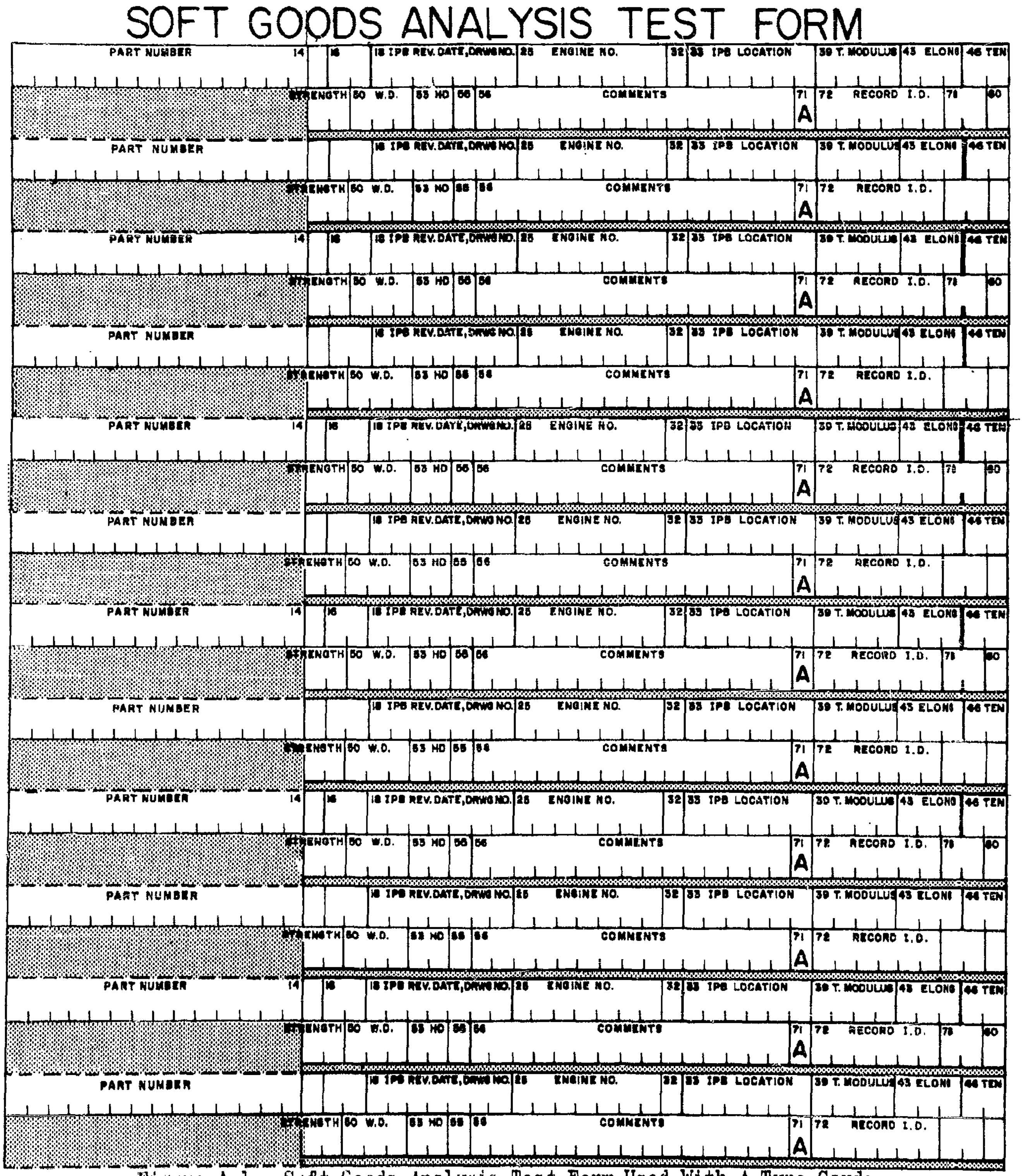
APPENDIX A

INSTRUCTIONS FOR COMPLETION OF SOFT GOODS ANALYSIS TEST FORMS

For convenience when entering data and to avoid needless writing, two types of soft goods analysis test forms (Fig. A-1 and A-2) and one type of control values form (Fig. A-3) are used. The soft goods analysis test form shown in Fig. A-1 is used for all data except compressive modulus data and consists only of A-type cards ("A" in column 71). The soft goods analysis test form presented in Fig. A-2 consists of alternate A- and B- type cards. This form is used for all data concerning a part, and includes compressive modulus data. The control values form (Fig. A-3) consists of alternate 1- and 2- type cards. These cards are used to list all control, specification, and nominal values obtained for the part.

Letters and numbers are printed clearly and neatly within the applicable column spaces. Only upper-case letters are used, and each character or punctuation mark accounts for one space. All characters are printed slightly above the bottom line to avoid the possibility of error if the bottom of the character (E, F., etc) should interfere with the bottom line. Only the punctuation and symbols listed below are used

1. Upper-case letters A through Z. To prevent confusion between letters and numbers, special letter forms Ȼ, I, Φ, $, U, Ƶ are used
2. Numbers 0 through 9
3. Dash: -
4. Period .



SOFT GOODS ANALYSIS TEST FORM

PART NUMBER 14 16 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D. 78 80

PART NUMBER 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D.

PART NUMBER 14 16 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D. 78 80

PART NUMBER 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D.

PART NUMBER 14 16 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D. 78 80

PART NUMBER 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D.

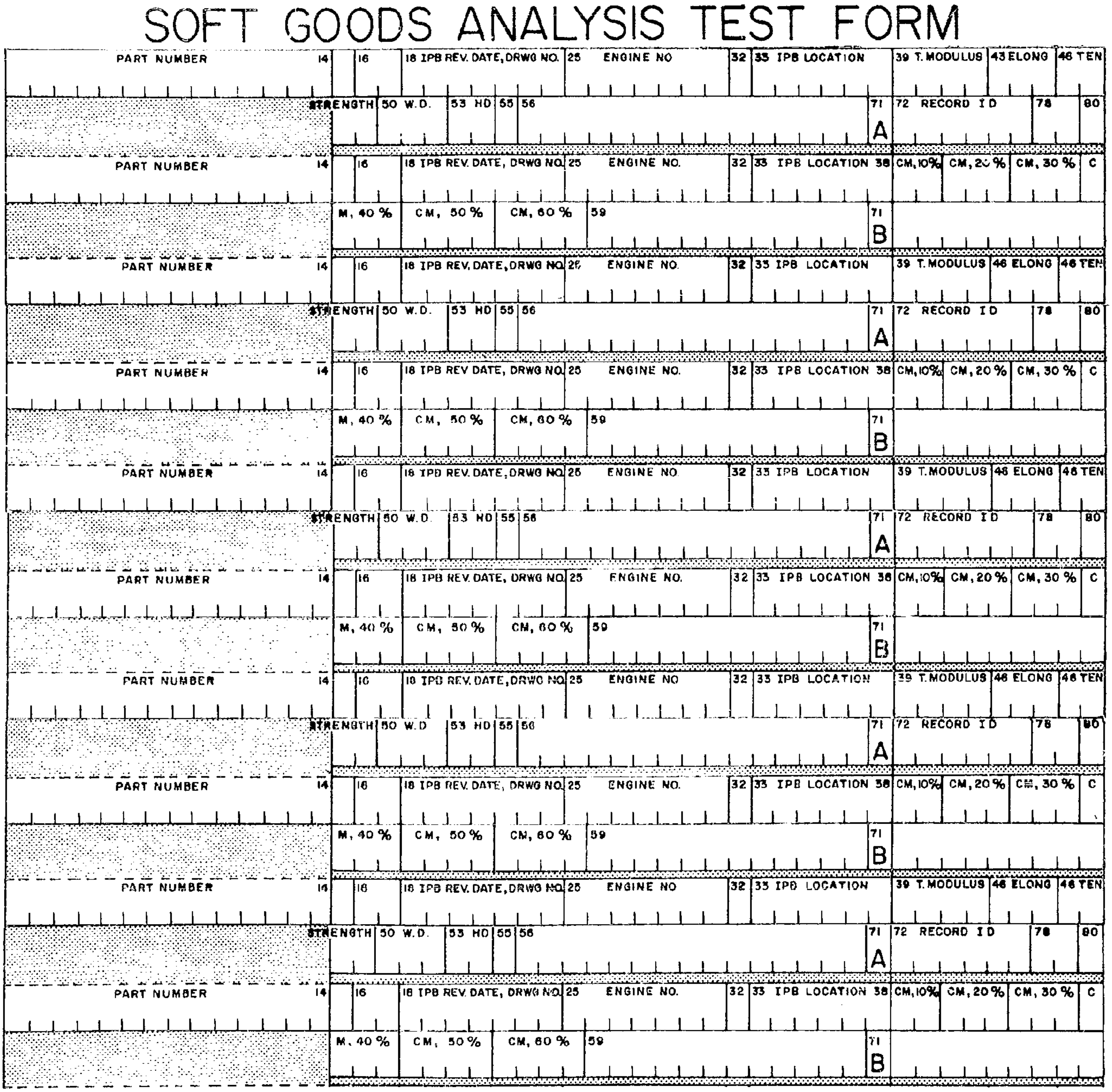
PART NUMBER 14 16 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D. 78 80

PART NUMBER 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D.

PART NUMBER 14 16 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D. 78 80

PART NUMBER 18 IPB REV. DATE, DRWG NO. 25 ENGINE NO. 32 33 IPB LOCATION 39 T. MODULUS 43 ELONG 46 TEN
STRENGTH 50 W.D. 53 HD 55 56 COMMENTS 71 A 72 RECORD I.D.

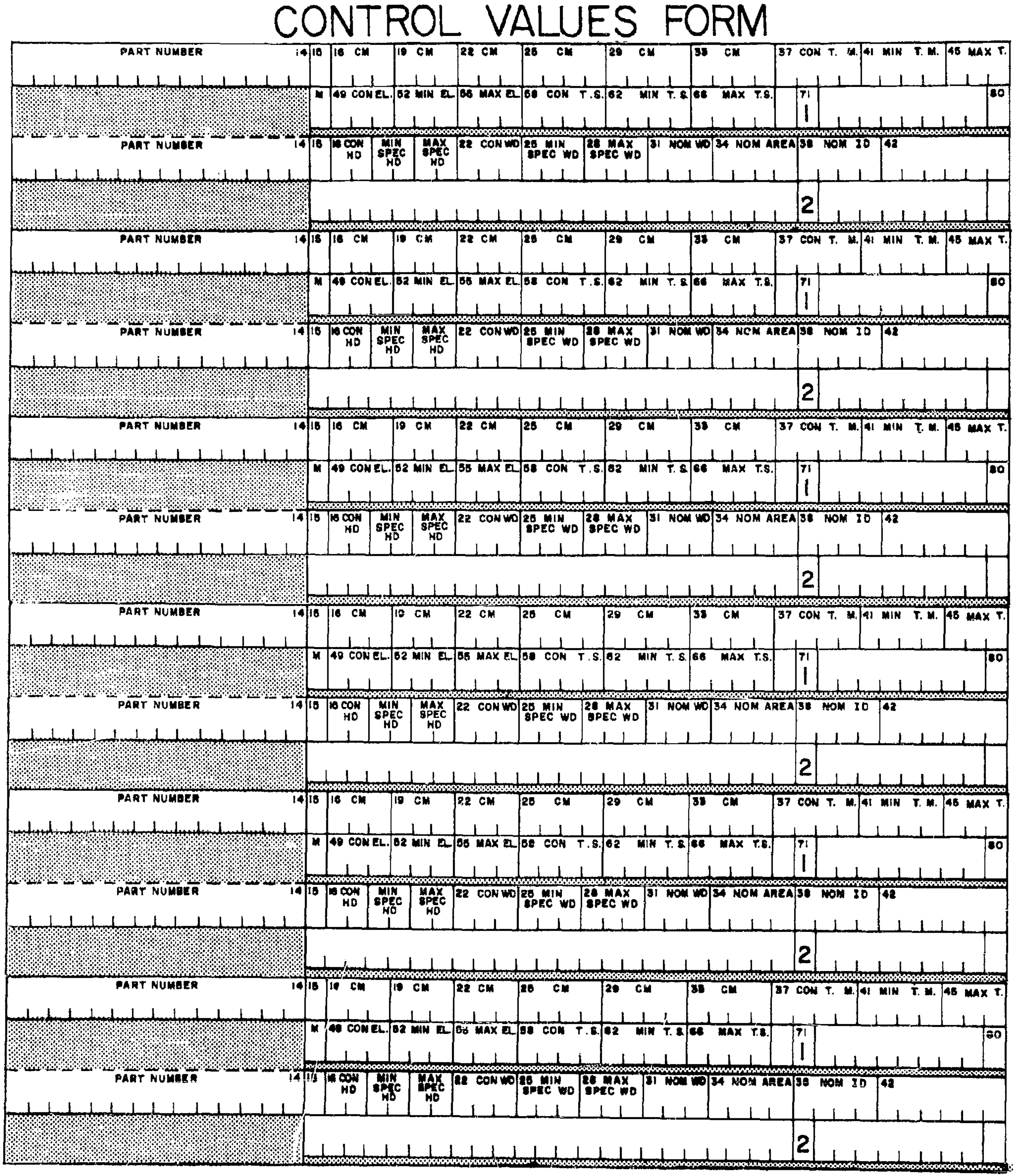
Figure A-1. Soft Goods Analysis Test Form Used With A-Type Cards



SOFT GOODS ANALYSIS TEST FORM

PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO	32	33 IPB LOCATION	39 T. MODULUS	43 ELONG	46 TEN	
STRENGTH	50 W.D.	53 HD	55	56	71 A	72 RECORD ID	78	80	
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO.	32	33 IPB LOCATION 38	CM, 10%	CM, 20 %	CM, 30 %	C
M, 40 %	CM, 50 %	CM, 60 %	59	71 B					
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO.	32	33 IPB LOCATION	39 T. MODULUS	46 ELONG	46 TEN	
STRENGTH	50 W.D.	53 HD	55	56	71 A	72 RECORD ID	78	80	
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO.	32	33 IPB LOCATION 38	CM, 10%	CM, 20 %	CM, 30 %	C
M, 40 %	CM, 50 %	CM, 60 %	59	71 B					
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO	32	33 IPB LOCATION	39 T. MODULUS	46 ELONG	46 TEN	
STRENGTH	50 W.D.	53 HD	55	56	71 A	72 RECORD ID	78	80	
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO.	32	33 IPB LOCATION 38	CM, 10%	CM, 20 %	CM, 30 %	C
M, 40 %	CM, 50 %	CM, 60 %	59	71 B					
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO	32	33 IPB LOCATION	39 T. MODULUS	46 ELONG	46 TEN	
STRENGTH	50 W.D.	53 HD	55	56	71 A	72 RECORD ID	78	80	
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO.	32	33 IPB LOCATION 38	CM, 10%	CM, 20 %	CM, 30 %	C
M, 40 %	CM, 50 %	CM, 60 %	59	71 B					
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO	32	33 IPB LOCATION	39 T. MODULUS	46 ELONG	46 TEN	
STRENGTH	50 W.D.	53 HD	55	56	71 A	72 RECORD ID	78	80	
PART NUMBER 14	16	18 IPB REV. DATE, DRWG NO.	25 ENGINE NO.	32	33 IPB LOCATION 38	CM, 10%	CM, 20 %	CM, 30 %	C
M, 40 %	CM, 50 %	CM, 60 %	59	71 B					

Figure A-2. Soft Goods Analysis Test Form Used With A- and B-Type Cards



CONTROL VALUES FORM

PART NUMBER	14	15	16 CM	19 CM	22 CM	25 CM	29 CM	33 CM	37 CON T. M.	41 MIN T. M.	45 MAX T.	
		M	49 CON EL.	52 MIN EL.	55 MAX EL.	58 CON T.S.	62 MIN T.S.	66 MAX T.S.	71 1			80
PART NUMBER	14	15	16 CON HD	MIN SPEC HD	MAX SPEC HD	22 CON WD	25 MIN SPEC WD	28 MAX SPEC WD	31 NOM WD	34 NOM AREA	38 NOM ID	42
											2	
PART NUMBER	14	15	16 CM	19 CM	22 CM	25 CM	29 CM	33 CM	37 CON T. M.	41 MIN T. M.	45 MAX T.	
		M	49 CON EL.	52 MIN EL.	55 MAX EL.	58 CON T.S.	62 MIN T.S.	66 MAX T.S.	71 1			80
PART NUMBER	14	15	16 CON HD	MIN SPEC HD	MAX SPEC HD	22 CON WD	25 MIN SPEC WD	28 MAX SPEC WD	31 NOM WD	34 NOM AREA	38 NOM ID	42
											2	
PART NUMBER	14	15	16 CM	19 CM	22 CM	25 CM	29 CM	33 CM	37 CON T. M.	41 MIN T. M.	45 MAX T.	
		M	49 CON EL.	52 MIN EL.	55 MAX EL.	58 CON T.S.	62 MIN T.S.	66 MAX T.S.	71 1			80
PART NUMBER	14	15	16 CON HD	MIN SPEC HD	MAX SPEC HD	22 CON WD	25 MIN SPEC WD	28 MAX SPEC WD	31 NOM WD	34 NOM AREA	38 NOM ID	42
											2	
PART NUMBER	14	15	16 CM	19 CM	22 CM	25 CM	29 CM	33 CM	37 CON T. M.	41 MIN T. M.	45 MAX T.	
		M	49 CON EL.	52 MIN EL.	55 MAX EL.	58 CON T.S.	62 MIN T.S.	66 MAX T.S.	71 1			80
PART NUMBER	14	15	16 CON HD	MIN SPEC HD	MAX SPEC HD	22 CON WD	25 MIN SPEC WD	28 MAX SPEC WD	31 NOM WD	34 NOM AREA	38 NOM ID	42
											2	
PART NUMBER	14	15	16 CM	19 CM	22 CM	25 CM	29 CM	33 CM	37 CON T. M.	41 MIN T. M.	45 MAX T.	
		M	49 CON EL.	52 MIN EL.	55 MAX EL.	58 CON T.S.	62 MIN T.S.	66 MAX T.S.	71 1			80
PART NUMBER	14	15	16 CON HD	MIN SPEC HD	MAX SPEC HD	22 CON WD	25 MIN SPEC WD	28 MAX SPEC WD	31 NOM WD	34 NOM AREA	38 NOM ID	42
											2	
PART NUMBER	14	15	16 CM	19 CM	22 CM	25 CM	29 CM	33 CM	37 CON T. M.	41 MIN T. M.	45 MAX T.	
		M	49 CON EL.	52 MIN EL.	55 MAX EL.	58 CON T.S.	62 MIN T.S.	66 MAX T.S.	71 1			80
PART NUMBER	14	15	16 CON HD	MIN SPEC HD	MAX SPEC HD	22 CON WD	25 MIN SPEC WD	28 MAX SPEC WD	31 NOM WD	34 NOM AREA	38 NOM ID	42
											2	

Figure A-3. Control Values Form Used With 1- and 2-Type Cards

A dark, sharp pencil, preferably No. 2 or HB, is used. No type of ink or ballpoint pen is used.

All words or series of integers are placed as far to the left as possible, except where a decimal point occurs within the number. When a decimal is used, the decimal point is preplaced on the form and the number is written around it.

All spaces or multiples of spaces are identified by a column number at start and finish. Eighty columns appear on each of the four cards used. As previously explained, card A is used for general test data, card B is used for compressive modulus data, and cards 1 and 2 are used for control values. The card type is designated by a letter or numeral in column 71. Information to be placed in the individual columns of each card is summarized below:

Card	Column	Description
A	1 through 14	The part number of the O-ring or other soft good tested
A	15	Code for the producer of the tested part*
A	16 and 17	Code for the component in which the tested part functioned**
A	18 through 24	The revision date of the applicable Illustrated Parts Breakdown. This item is written as year, month, day (i.e., 620202 is 1962 February 2), or the drawing number, or an arbitrarily assigned number for identification.

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*Explained on page 33
**Explained on page 34

Card	Column	Description
A	25 through 31	The engine number of the engine from which the part came
A	32	Code for part description*
A	33 through 38	Location of the part in the applicable Illustrated Parts Breakdown. The figure number followed by a dash and the number of the part on the figure
A	39 through 42	Tensile load expressed in pounds at 100% elongation (100% tensile modulus)
A	43 through 45	Elongation expressed in percent at break. If less than 100%, the last space to the right is left blank
A	46 through 49	Tensile load expressed in pounds at break (ultimate tensile strength)
A	50 through 52	W-Diameter
A	53 and 54	Hardness measured with a Shore-A Durometer
A	55	Code for part condition**
A	56 through 70	Comments (any unusual condition worthy of comment)
A	71	Card type
A	72 through 80	Left blank
B	1 through 14	Part number; same as card A

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*Explained on page 35
**Explained on page 36

Card	Column	Description
B	15	Producer code; same as card A
B	16 and 17	Component in which the part functioned; same as card A
B	18 through 24	Illustrated Parts Breakdown revision date; same as card A
B	25 through 31	Engine number; same as card A
B	32	Part description; same as card A
B	33 through 38	Part location; same as card A
B	39 and 40	Compressive load expressed in pounds at 10% deflection (10% compressive modulus)
B	41 through 43	Compressive load expressed in pounds at 20% deflection
B	44 through 46	Compressive load expressed in pounds at 30% deflection
B	47 through 50	Compressive load expressed in pounds at 40% deflection
B	51 through 54	Compressive load expressed in pounds at 50% deflection
B	55 through 58	Compressive load expressed in pounds at 60% deflection
B	59 through 70	Left blank
B	71	Card type
B	72 through 80	Left blank

Card	Column	Description
1	1 through 14	Part number; same as cards A and B
1	15	Producer code; same as cards A and B
1	16 through 18	Compressive load expressed in pound/mean in. of circumference at 10% deflection of control O-rings (control 10% modulus)
1	19 through 21	Compressive load expressed in lb/mean in. of circumference at 20% deflection of control O-rings
1	22 through 24	Compressive load expressed in lb/mean in. of circumference at 30% deflection of control O-rings
1	25 through 28	Compressive load expressed in lb/mean in. of circumference at 40% deflection of control O-rings
1	29 through 32	Compressive load expressed in lb/mean in. of circumference at 50% deflection of control O-rings
1	33 through 36	Compressive load expressed in lb/mean in. of circumference at 60% deflection of control O-rings
1	37 through 40	Tensile strength at 100% elongation of control O-rings (control 100% tensile modulus)
1	41 through 44	Tensile strength at 100% elongation. Minimum value by specification or an arbitrarily chosen limit

Card	Column	Description
1	49 through 51	Elongation expressed in percent at break of control O-rings
1	52 through 54	Elongation expressed in percent at break. Minimum value by specification or an arbitrarily chosen limit
1	55 through 57	Elongation expressed in percent at break. Maximum value by specification or an arbitrarily chosen limit
1	58 through 61	Tensile strength expressed in pounds at break of control O-rings
1	62 through 65	Minimum tensile strength expressed in pounds at break. A specification value or an arbitrarily assigned limit
1	66 through 69	Maximum tensile strength expressed in pounds at break. A specification value or an arbitrarily assigned limit
1	70	Not used
1	71	Card type
1	72 through 80	Left blank
2	1 through 14	Part number; same as cards A, B, and 1
2	15	Producer code, same as cards A, B, and 1
2	16 and 17	Control hardness in Shore-A units.
2	18 and 19	Minimum specification hardness

Card	Column	Description
2	20 and 21	Maximum specification hardness
2	22 through 24	Control W-diameter
2	25 through 27	Minimum specification W-diameter
2	28 through 30	Maximum specification W-diameter
2	31 through 33	Nominal W-diameter from specification
2	34 through 37	Nominal cross-sectional area from specification
2	38 through 41	Nominal inside diameter from specification
2	41 through 70	Left blank
2	71	Card type
2	72 through 80	Left blank

The following codes are used in the appropriate columns:

Item	Column	Code	Code Text	Card Type
Part Location	16 and 17	MC	Major Components System	A and B
		PC	Pneumatic Control System	A and B
		LS	Lubrication System	A and B
		GG	Gas Generator System	A and B
		SS	Start System	A and B
		HS	Hydraulic System	A and B
		PF	Propellant Feed System	A and B
		ES	Exhaust System	A and B
		U	Unknown	A and B

Item	Column	Code	Code Text	Card Type
Part Description	32	T	Backup Teflon	A and B
		P	Packing	A and B
		R	Ring	A and B
		A	Accumulator	A and B
		G	Gasket	A and B
		W	Washer	A and B
		S	Seal	A and B
		L	Lipseal	A and B
		B	Backup, Leather	A and B
		F	Flexitallic Gasket	A and B
		I	Injector Seal	A and B
		X	See body of report	A and B
Producer	15	L	Linear, Inc.	All cards
		I	Precision Rubber Products	All cards
		S	Stillman Rubber Co.	All cards
		P	Parker Seal Co.	All cards
		U	Unknown	All cards
		X	See body of report	All cards

Item	Column	Code	Code Text	Card Type
Part Condition	55	A	Undistorted; OK	A
		B	Distorted By Normal Use	A
		E	Delaminated	A
		F	Stress Cracks	A
		G	Twisted	A
		X	See body of report	A