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MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

ATM ELECTRICAL INTERFACE

Augmentation Task No. 28

LMSC-A842320 5 September 1967

Prepared Under Contract No. NAS8-21003 by

LOCKHEED MISSILES & SPACE COMPANY
A Group Division of Lockheed Aircraft Corporation
Sunnyvale, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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ACKNOWLEDGEMENTS

The Experimental Test Program was carried out by the VE organization of the AAP of LMSC in the Engineering Labs of the R&D Division. The Task Leader, Mr. Frank Bischof, was responsible for project direction and test program organization. Actual testing apparatus and procedures were developed by Messrs. B. Fitchett, A. Wyman, J. Kindsvater, and M. Fronsdahl. Test runs and data reduction were done by J. Kindsvater, A. Wyman and M. Fronsdahl. This report was edited by B. Fitchett and F. Bischof.

CONTENTS

ILLUSTRATIONS

TABLES

Section 1
INTRODUCTION

The purpose of this extended test program was to conduct additional bending tests on several electrical cable harnesses using a modified test rig to better simulate the ATM geometry. This Task 28 work plan was an outgrowth of the Contract Period III Test Program (Task 20) documented in LMSC-A842260, 5 July 1967. It was verbally agreed during the 60-day contract extension with Marshall R-ASTR-EAA (task monitor) that more would be gained in this manner than by performing the design of a full-scale test fixture as originally considered. The possibility and nature of a revised task statement was being discussed at MSFC when it was announced on 27 July that Martin Denver was awarded the Phase D Contract. The decision was then made for Lockheed under Task 28 to gather additional ATM harness test data using modified Lockheed rigs from Task 20.

This report, an addendum to LMSC-A842316, presents the results of the additional harness test and the relationship of the data to the recommended design approaches contained in LMSC-A842239, 9 June 1967.

Lockheed performed other related minor tasks such as evaluation of MSFC tests, comparison of several types of round wire, etc., which are discussed in the Appendices of this report.

Section 2
HARNESS LOAD TESTS

Table 2-1 summarizes the bending tests conducted during the 60-day continuation contract and identifies the test rigs and test harnesses. Rigs 4 and 5 are new designs to simulate the ATM geometry for the end approach. Rigs 3A, 3B, and harnesses are as described in Ref. 2. Table 2-2 contains the wire count for each harness.

Table 2-1

TEST PROGRAM SUMMARY

Routing Approach	Type of Load	Test Rig No.	Cable Harness Tested	Angular Displacement (deg)
End	Bending	5–4B–4C–4D 4A	5 1-4A-5-6	±5 pitch, yaw ±2 pitch, yaw
Side	Bending at Gimbal Joint	3A 3B 3A 3B	3 – 4A 3 – 4A	±2 pitch, yaw ±5 pitch, yaw
End-Side No. 1	Bending at Gimbal Joint	3A – 3B	3	±2 pitch, yaw
End-Side No. 2	Bending at Gimbal	4A 3B	4A 4B	±2 pitch, yaw

2.1 BENDING TESTS, RIG 4

2.1.1 Description

The cable harness geometry of Rig 4 is equivalent to that of the ATM Spar/LM-A. Four modifications of Rig 4 were investigated: 4A, 4B, 4C, and D. These differed only in the way the test harness was installed for testing.

Table 2-2

DESCRIPTION OF CABLE HARNESSES

Harness No.	Flat Cable		Round Wire		Number of Coaxial Cables[b]	Number of Conductors
	Number of Conductors	Number of Flat Cables[a]	Gage No.	Number of Conductors		
1	418	12.6	26	773	15	1,206
2	145	4.4	26	387	7	539[c]
3	290	8.8	26	773	15	1,078
4A	0	0.0	—	645	15	660
4B	384	11.6	—	0	0	384
5	1,191	36.0[d]	—	0	0	1,191
6	1,204	37.0	—	0	0	1,204

NOTES:
a. Test used 2.9-in. flat cable with 37 conductors (0.004 × 0.040) to simulate 2.5-in. flat cable with 33 conductors.

b. Test used a special coaxial ribbon composed of 15 miniature coaxial cables (Raychem 32-179A) to simulate 13 required coaxial cables with RF-59/U.

c. Per side.

d. Test used 25 2.9-in. flat cables and 11 2-in. flat cables. Harness 6 used 12 2-in. cables.

In Rig 4 a cable harness was clamped rigidly to the end of a 62-in. pivoted beam which represented the Spar. The other end of the harness was also rigidly clamped to a fixture representing the LM-A. Figure 2-1 shows the four different ways the harnesses were installed, Force data required to rotate the beam (±2 deg to ±5 deg) were taken and converted into torques. All Rig 4 data were taken with the beam in a horizontal plane; in some runs the cable harness was supported at midpoint by a vertical string to reduce gravity effects.

Rig 4A has the cable harness flexing in the plane of least resistance (Fig. 2-2) while Rig 4B bends a sagging cable harness in the plane of maximum resistance (Fig. 2-3). All flat cables used mylar insulation.

The spiral harness configurations of Rigs 4C and 4D were attempts to produce the same bending loads in pitch and yaw. Rig 4C has the ends of the spiral along the beam axis (Fig. 2-1); Rig 4D offsets the ends of the harness in an attempt to center the spiral on the beam axis so that the effects of roll upon 2-deg pitch or yaw loads can be obtained by rotating the spiral from the null (0-deg) position (Fig. 2-5) to 90 deg clockwise (Fig. 2-6) or 90 deg counterclockwise (Fig. 2-7).

2.1.2 Observations

Harnesses 1, 5, and 6 were tested on Rig 4A for various amounts of sag. Harness 1, containing 773 round wires, was the heaviest harness and the most susceptible to sag effects (flopping back and forth). These effects tended to produce erratic torque data. As the amount of sag was increased, the required torque was noted to decrease. A midpoint string support was added in an attempt to reduce the tendency of the harness to flop during the tests.

Significant sliding between adjacent flat cables and between wire bundles was noticed for test runs made without harness ties. The addition of ties every 6 to 8 in. reduced the sliding but produced a stiffer cable harness.

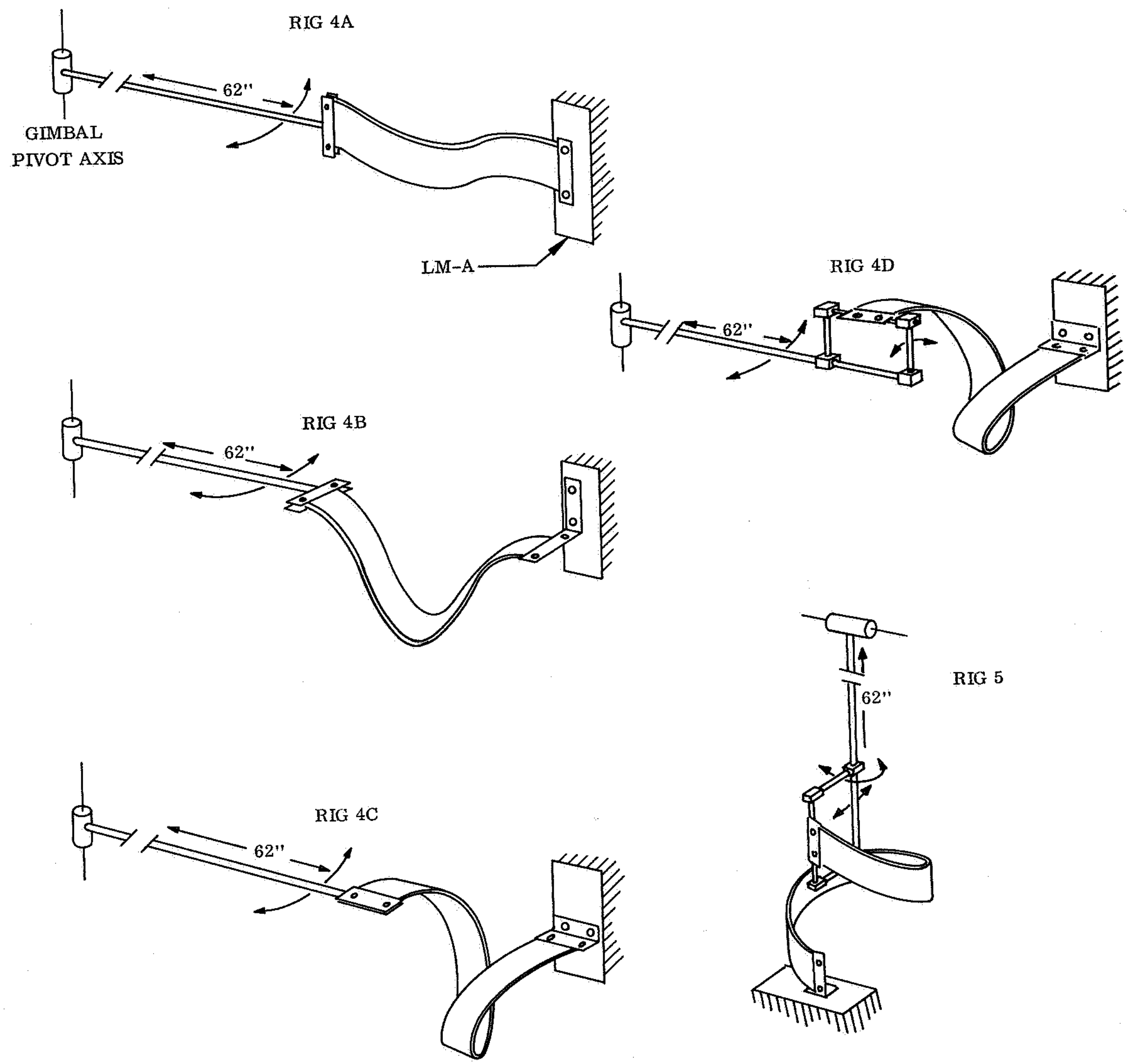

Fig. 2-1 Test Configurations

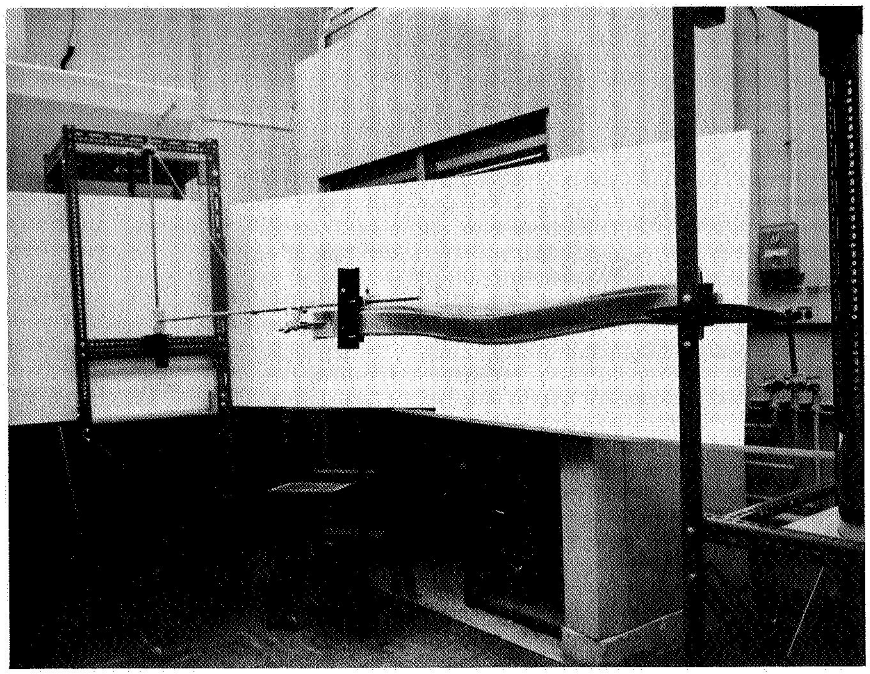

Fig. 2-2 Harness 5 in Rig 4A

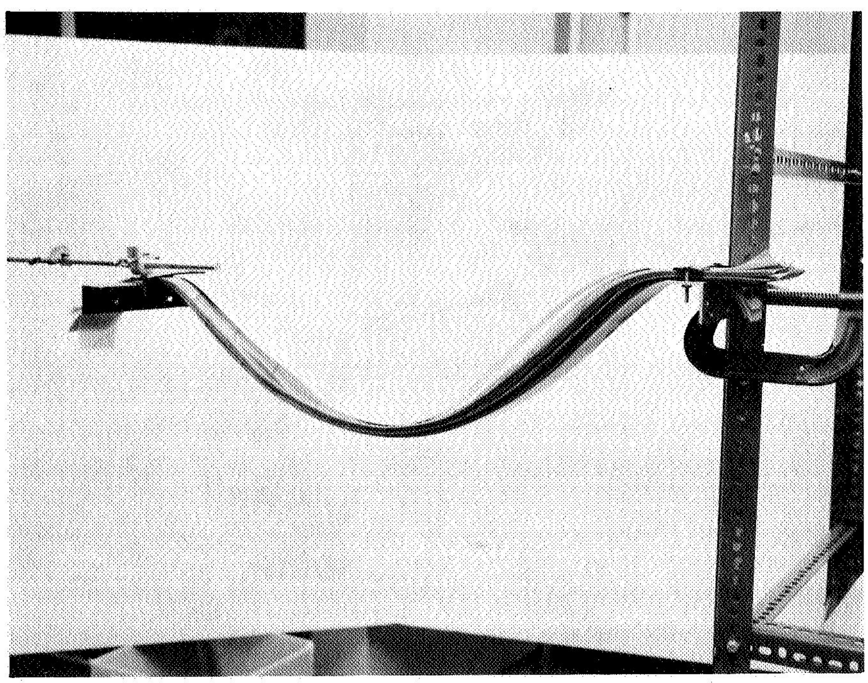

Fig. 2-3 Harness 5 in Rig 4B

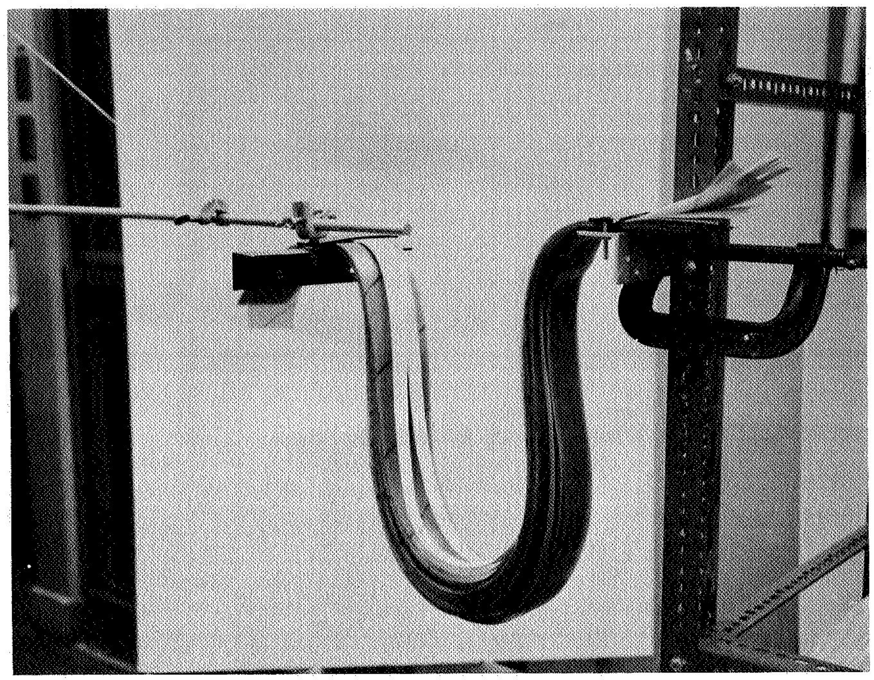

Fig. 2-4 Harness 5 in Rig 4C

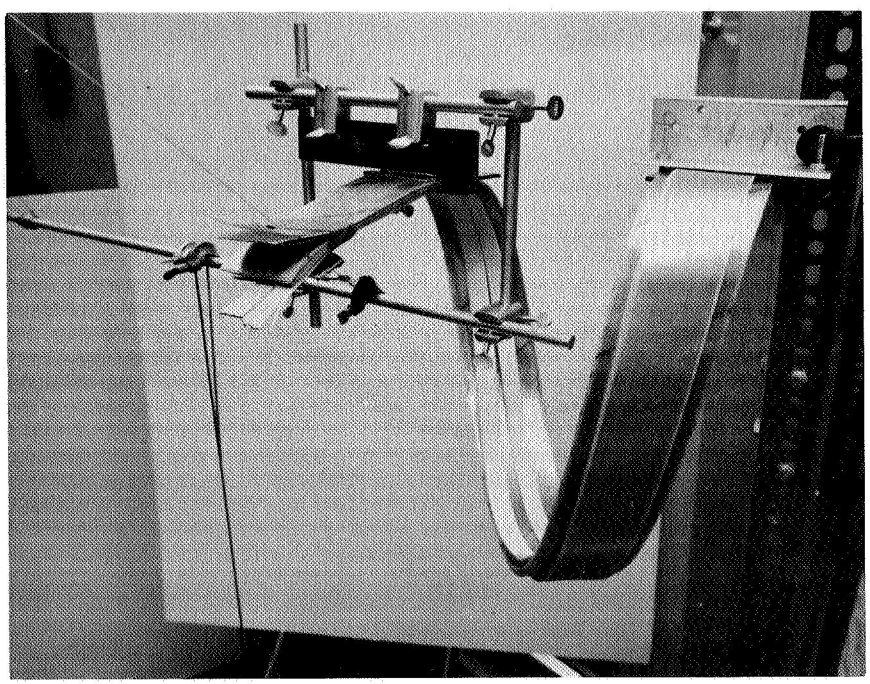

Fig. 2-5 Harness 5 in Rig 4D

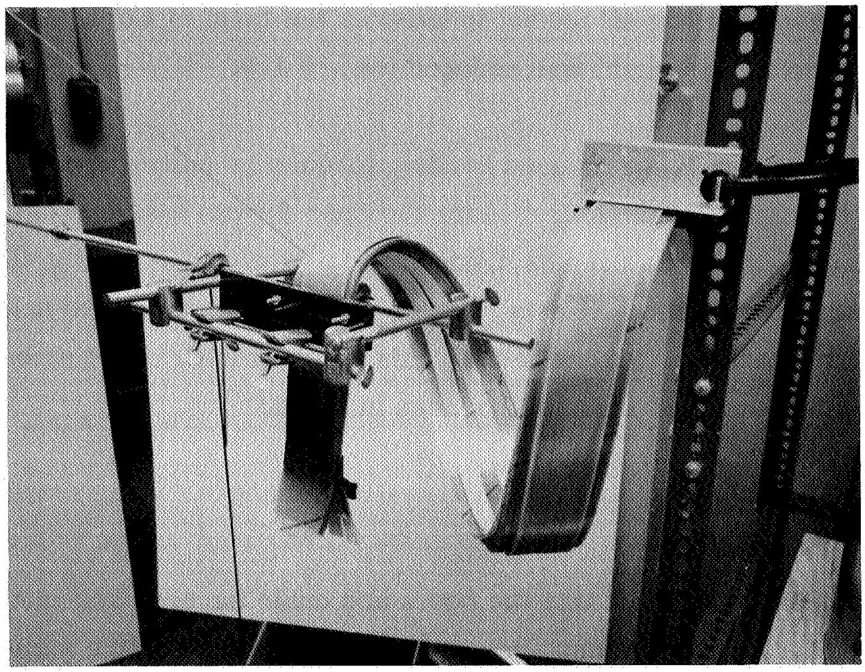

Fig. 2-6 Harness 5 in Rig 4D, 90-Deg Clockwise Position

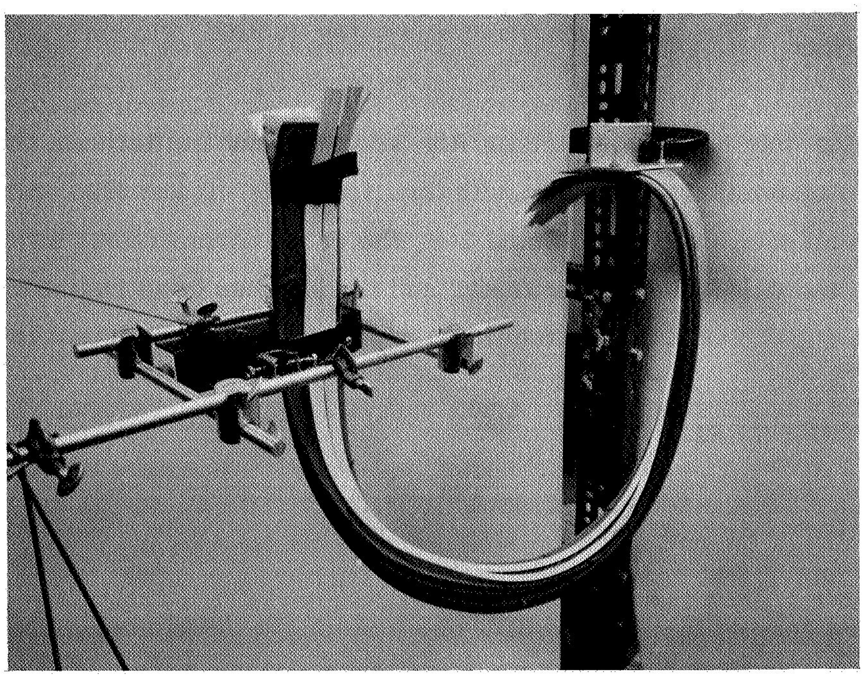

Fig. 2-7 Harness 5 in Rig 4D, 90-Deg Counterclockwise Position

Cable harnesses tested on Rig 4B tended to twist as the ratio of Lc/L (L_c = cable harness length, L = span length) was reduced toward 1.0.

Rig 4C was an attempt to obtain reduced bending torques by coiling the cable harness into a spiral with the ends of the spiral along the Spar (beam) axis. It did not produce equal torques in pitch and yaw and was dropped in favor of Rig 4D. Rig 4D, using a spiral harness centered on the roll axis, tended to produce a distorted spiral at the extreme positions (see Figs. 2-6 and 2-7). This configuration is not amenable to direct support at the midpoint as is the harness in Rig 4A.

2.2 BENDING TESTS, RIG 5

Rig 5 is similar to Rig 4D except that the boom and cable harness are mounted vertically (Fig. 2-1). The rig dimensions and angular boom travel are the same; the spiral cable harness is centered on an extension of the boom axis and can be rotated ± 90 deg. Figure 2-8 shows the entire rig; Fig. 2-9 is a closeup of Harness 5 in the null (0-deg) position.

2.2.1 Observations

Harness 5 was the only harness tested on Rig 5 due to time limitations. Data from this harness can be compared directly with data from Rig 4D and also with data from Ref. 2. As can be seen in Figs. 2-8 and 2-9, the cable harness sags away from a uniform spiral, the various plies separate, and the harness bend radius varies. These effects, seen in Figs. 2-8 and 2-9, tended to produce variations in test torque data.

2.3 GIMBAL JOINT TESTS

2.3.1 Description

These tests were run on Rigs 3A and 3B, which simulate the gimbal joint geometry and are depicted in Figs. 2-15 and 2-20 of Ref. 2. These tests were made using Harnesses

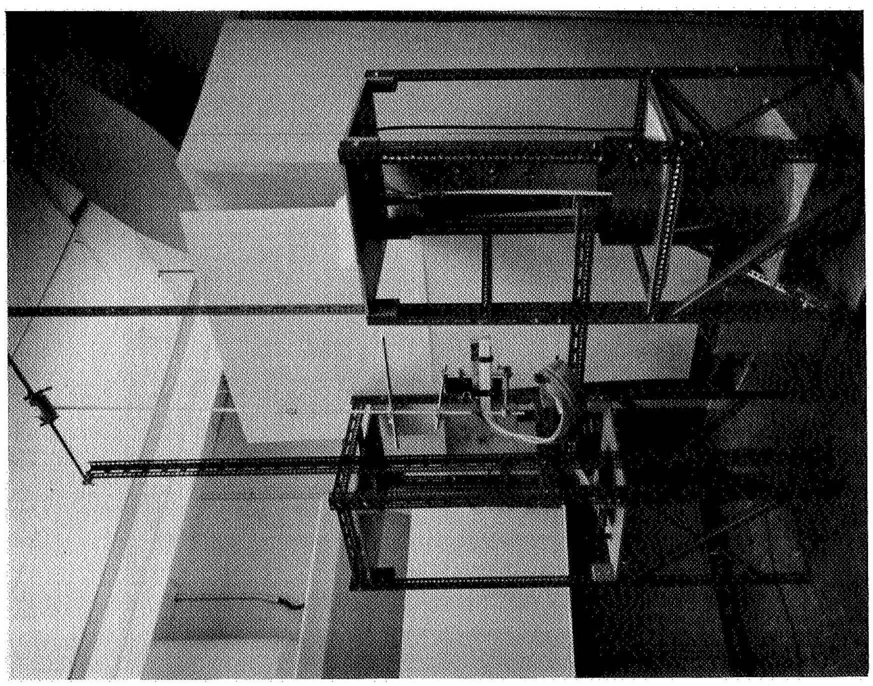

Fig. 2-8 Harness 5 in Rig 5

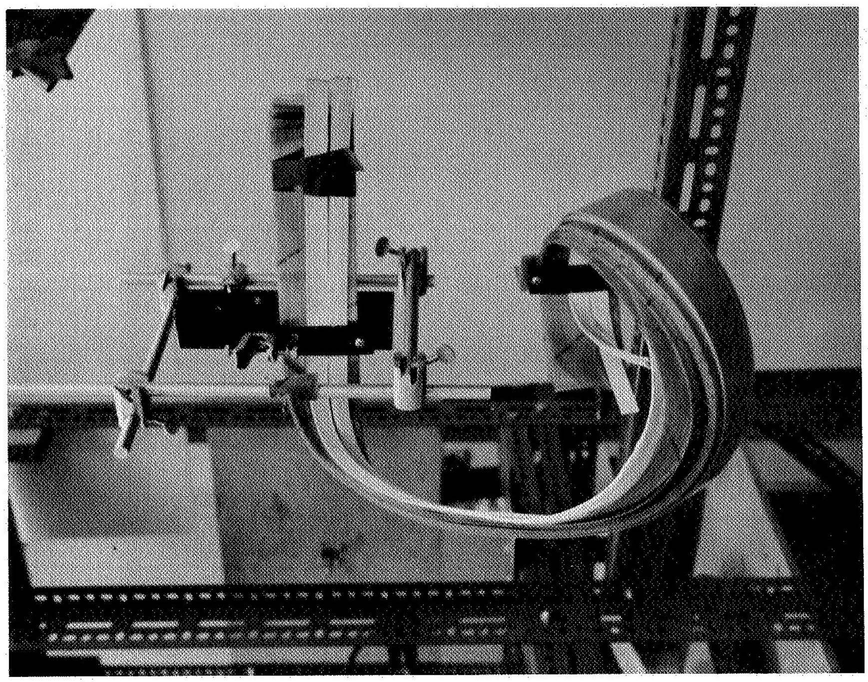

Fig. 2-9 Harness 5 in Rig 5,
0-Deg Position

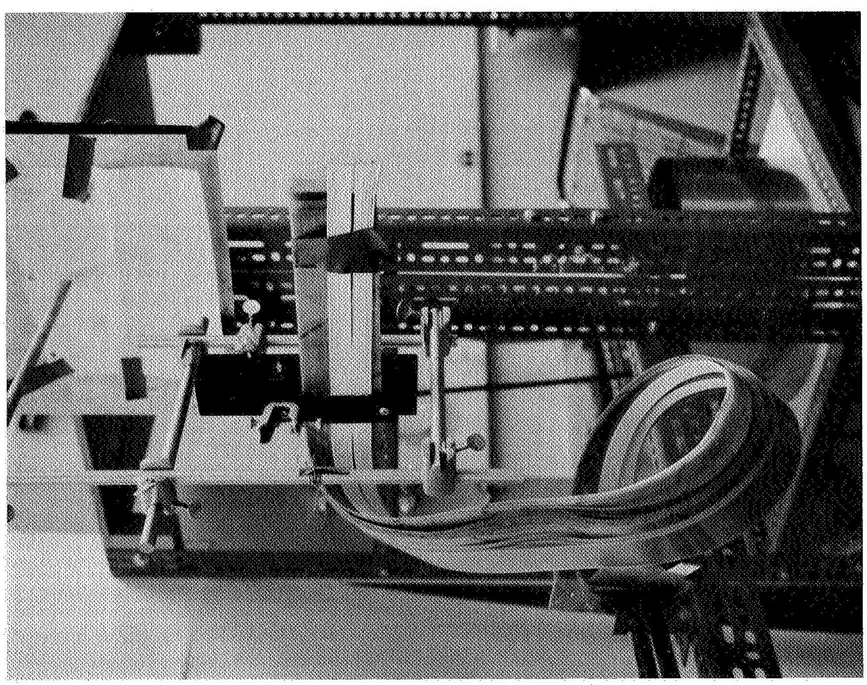

Fig. 2-10 Harness 5 in Rig 5, 90-Deg Clockwise Position

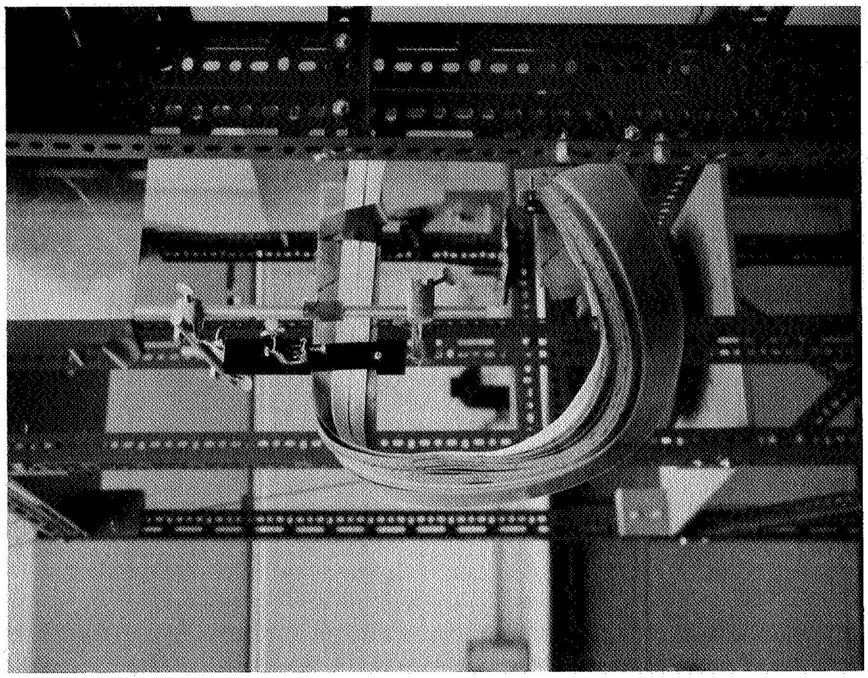

Fig. 2-11 Harness 5 in Rig 5, 90-Deg Counterclockwise Position

3 and 4A and are a repeat of runs cited in Ref. 2 with two modifications:

- The gimbal joint travel was limited to ± 2 deg.
- The load data were taken so as to obtain the typical hysteresis loop, i.e., force measurements were made through a complete cycle.

2.3.2 Observations

Harness behavior was similar to that reported in Ref. 2 except that the limited gimbal joint travel (± 2 deg) did not cause the harness to bind against the side of the simulated gimbal joint for Rig 3A.

Section 3
TEST RESULTS AND RELATIONSHIP TO DESIGN APPROACHES

The four basic routing approaches for providing electrical power and signals to the ATM Spar experiments, PCS equipment, and torque motors are the end approach (Fig. 3-1), the side approach (Figs. 3-2 and 3-3), and two combined (end-side) approaches (Figs. 3-4 and 3-5).

Test rigs and test harnesses have been designed to duplicate the actual ATM geometry insofar as critical interface dimensions and Spar movements are concerned. Test methods have been aimed at obtaining torque data for one harness at a time flexed in pitch (or yaw) or in roll in order to use simple, inexpensive test fixtures.

3.1 ROUTING APPROACHES/HARNESS CONFIGURATIONS

The relation between the various routing approaches (for crossing the interface between the LM-A/Rack and the Spar) and their associated cable harnesses is shown in schematic form in Fig. 3-6. All harnesses for the end approach can be seen to cross the Spar/Rack roll interface (± 95 deg) with the majority of their conductors; only a small minority of flat conductors are required to cross the pitch-yaw interface (± 2 deg) to power the yaw torque motors.

The side approach requires a split harness with two takeup reels (or equivalent) for the roll interface. The split harness must then cross both the pitch and yaw interfaces before it reaches the spar.

Both end-side approaches No. 1 and No. 2 use a rigid conduit to route the major portion of the wires from the end of the Spar down to the roll ring. Both must then cross the pitch and yaw interfaces to reach the Spar. The difference between these two

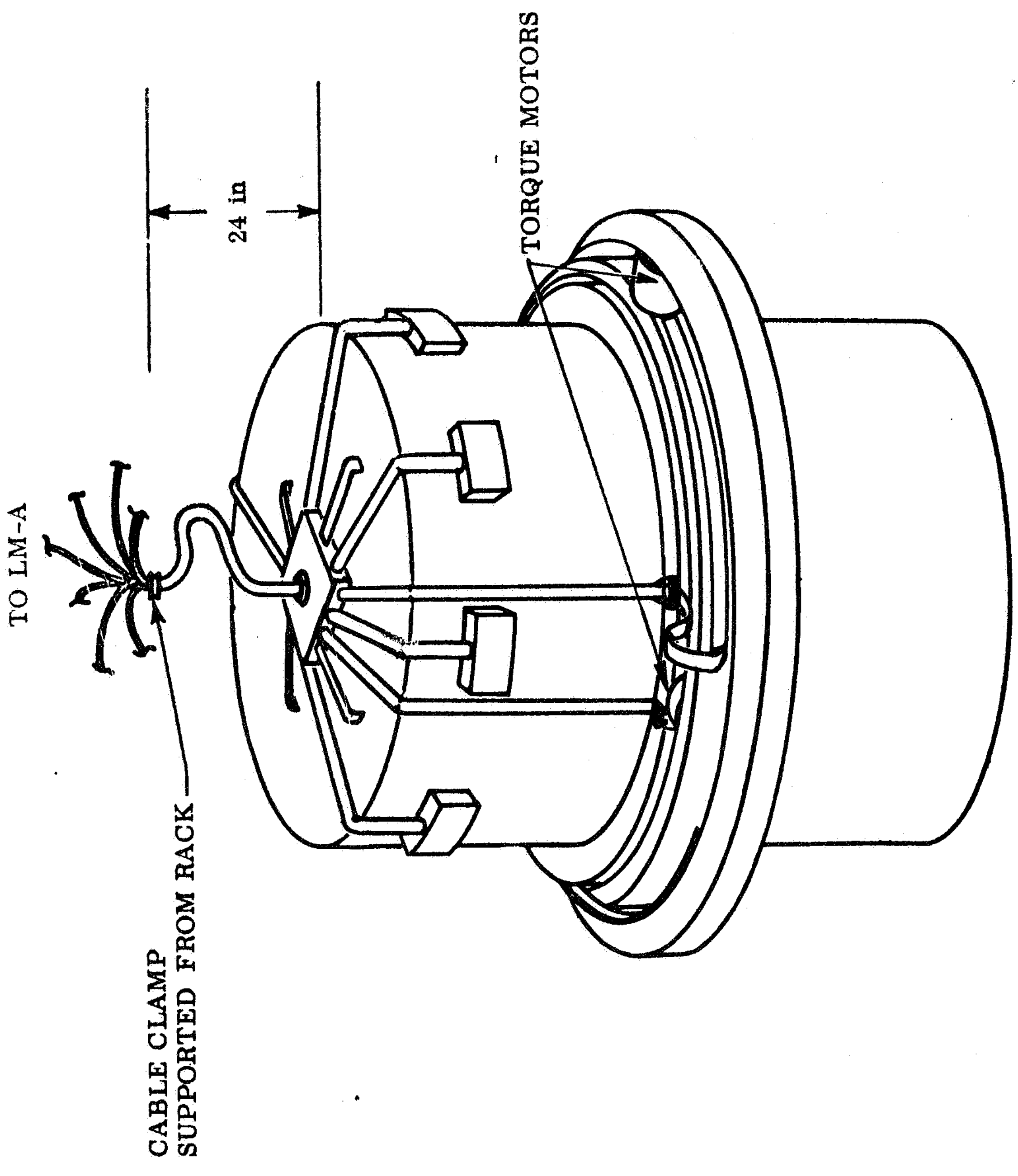

Fig. 3-1 End Approach

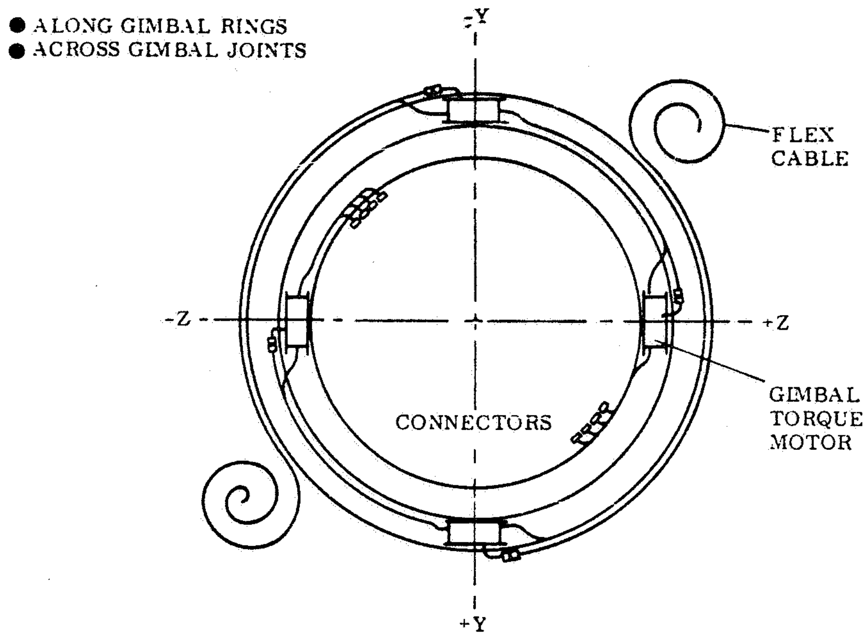

Fig. 3-2 Side Flex Cable Approach

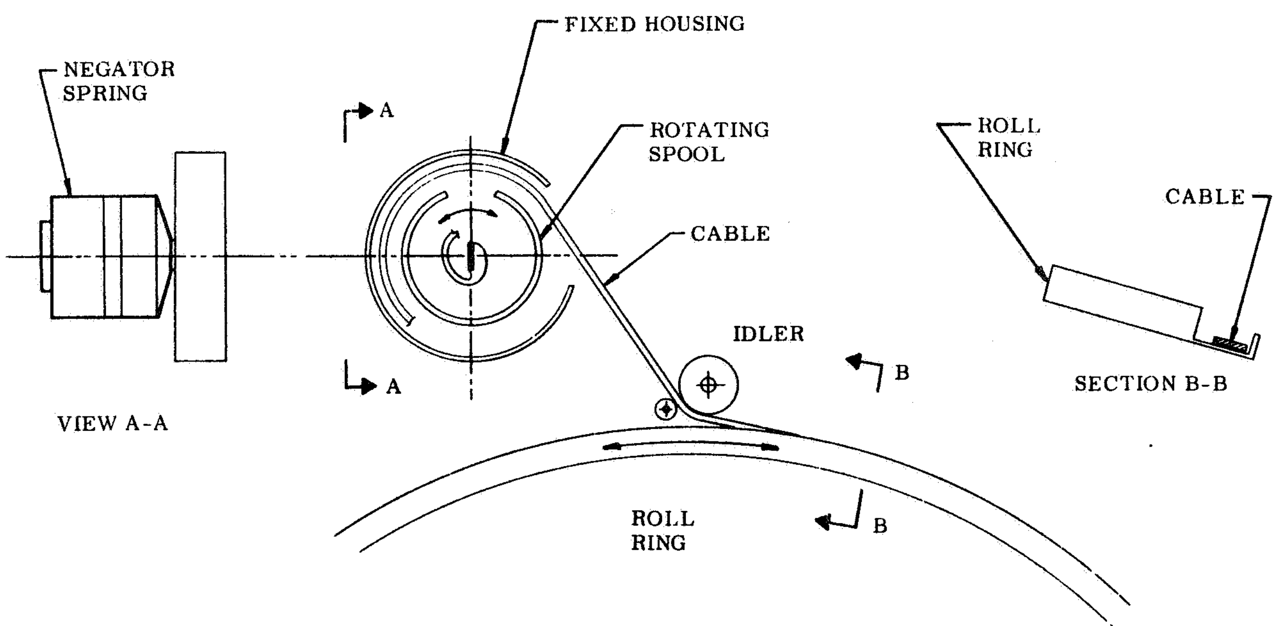

Fig. 3-3 Flex Cable Takeup Reel

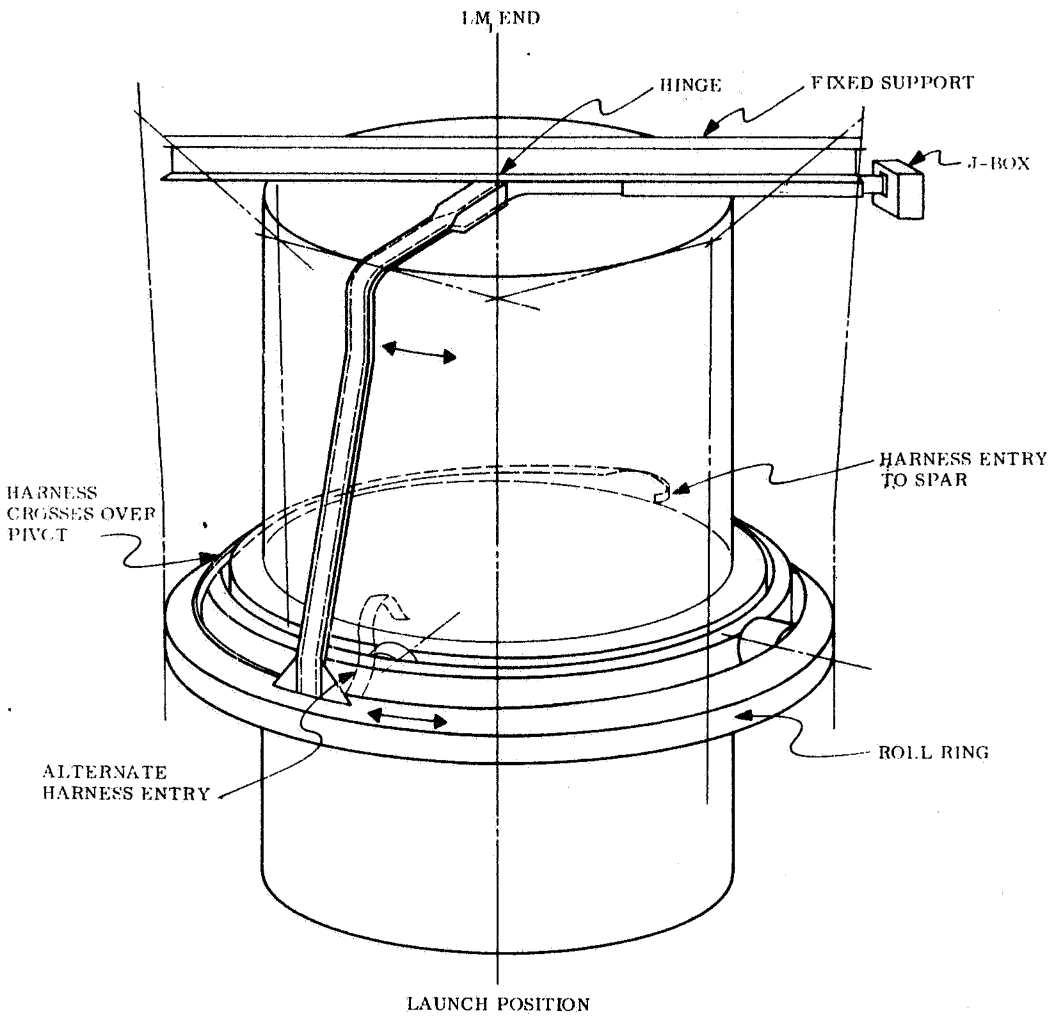

Fig. 3-4 End and Side Approach No. 1

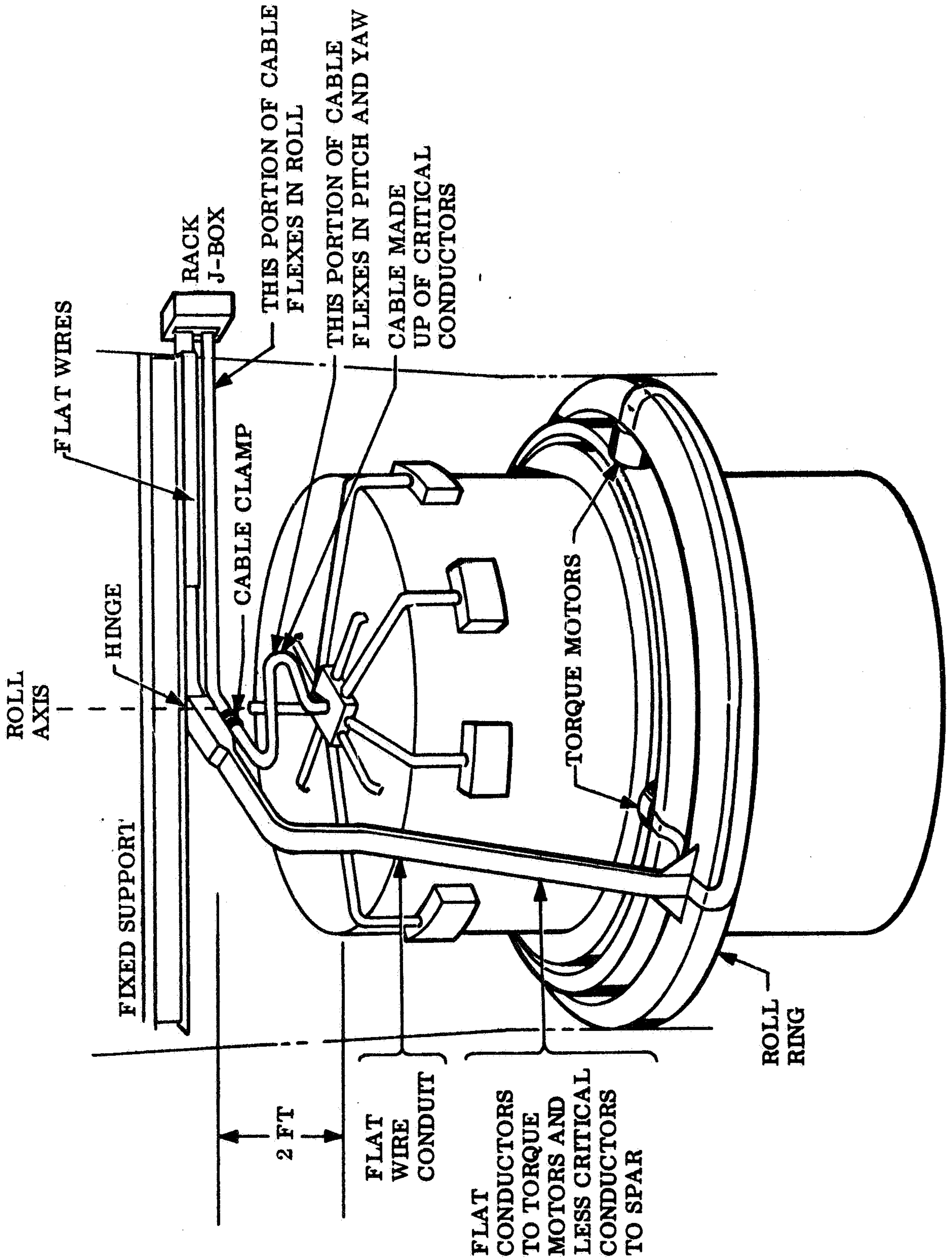

Fig. 3-5 End-Side Design Approach No. 2

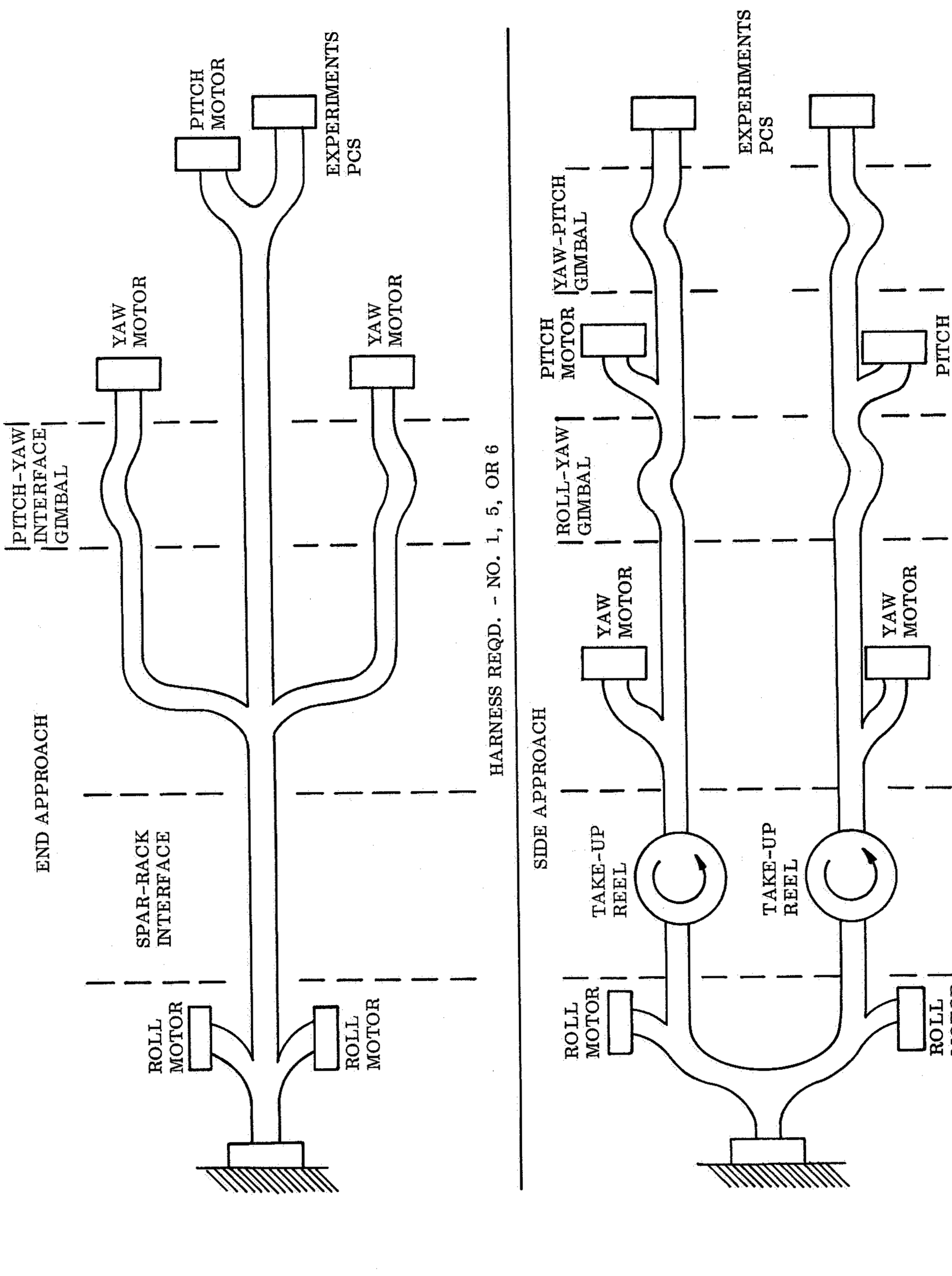

Fig. 3-6 Harness Schematics for ATM Interfaces

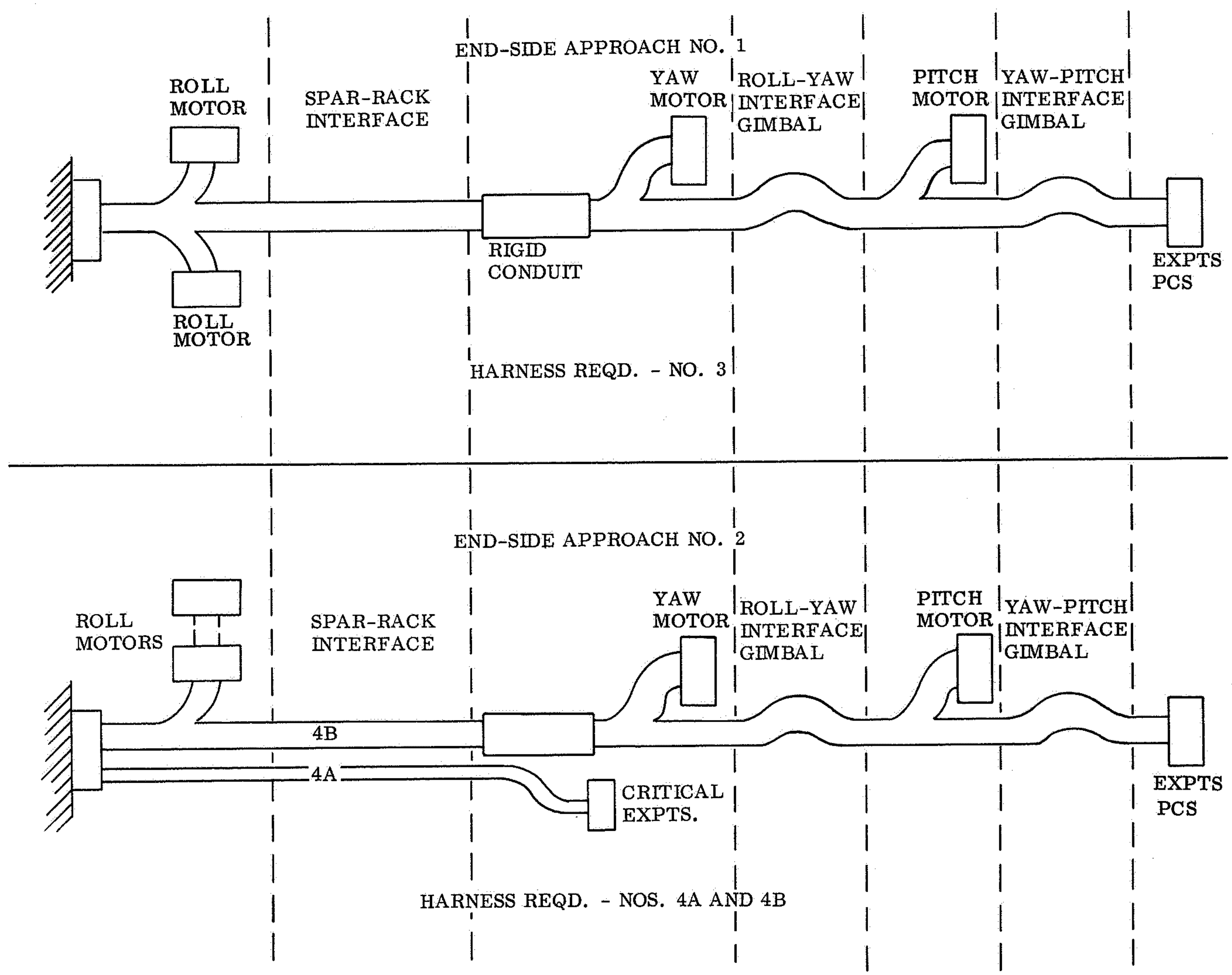

Fig. 3-6 Harness Schematics for ATM Interfaces (Cont.)

approaches lies in the way wires for critical experiments are routed. The latter approach routes them in a separate bundle whose pitch and yaw torques must be added to the torques imposed by the other section of the harness at the gimbal joints.

3.2 TORQUE DATA

Table 3-1 is similar to Table 5-1 of Ref. 2 and is intended to compare the test results obtained from Rigs 4, 3A, and 3B with the new allowable 2-deg torque based on a cable harness spring rate of 80 $\frac{\text{in.-lb}}{\text{rad}}$ per pivot axis instead of 50.

Inspection of Table 3-1 reveals that no combination of routing approach and cable harness can meet the required torque based on 80 $\frac{\text{in.-lb}}{\text{rad}}$ per pivot axis. Data for this table were based upon maximum observed test data; Figs. 3-7, 3-8, 3-9, and 3-10 show the range of test data obtained for various span lengths and harness lengths and, at first glance, indicate that some combinations did exhibit acceptable torque values. However, two factors must be kept in mind for these four bar-graph figures:

- Harness 4A torques must be added to Harness 4B torques obtained from either Rig 3A or 3B.
- Torque data shown as a narrow band or line do not mean that no spread was found from run to run; it means that only one run was made due to time limitations.

The influence of the ratio of the harness length L_c to the span length L upon the torque is shown in Fig. 3-11 for several harnesses. The curves indicate that values of L_c/L between 4 and 5 will reduce torques to the desired value. These curves are based upon a cable harness length of less than 40 in. To obtain the desired torque for the end approach with a span of 24 in., harness would be approximately 100 in. long, based upon these data.

An inspection of Fig. 3-7 shows that Harness 1 torque values tend to exceed the design allowable value by an order of magnitude for the range of harness lengths and

Table 3-1

REVISED RESULTS FOR VARIOUS ROUTING APPROACHES

Routing Approach	Test Rig No.	Cable Harness No.	Bend or Twist (deg)	Cable Length (in.)	Span Length (in.)	Measured Torque (in.-lb)	Design Torque (in.-lb)	Cable Harness Acceptable	Comments
End	1	1	95	40	40	3.2	N/A	--	No roll torque limits have been established
		5	95	40	40	3.2	N/A	--	
		6	95	40	40	3.2	N/A	--	
	4A	1	2	37	34	28.3	2.79	No	No ties, no support
		5	2	37	36	9.5	2.79	No	
		6	2	37	36	10.5	2.79	No	
Side	3A	2	2	40	--	1.7	1.40	No	
	3B	2	2	20	--	2.5	1.40	No	
End-Side No. 1	3A	3	2	42	36	4.2	2.79	No	Only one run made
	3B	3	2	24	6	11.2	2.79	No	Limited number of runs
End-Side No. 2	3A	4B	2	37.5	35.5	1.0	2.79	No	Total torque for end-side No. 2 is sum of harness 4A torque (on Rig 4A) plus Harness 4B (on Rig 3A or 3B)
		5	2	37	--	6.5	2.79	No	
		6	2	37	--	5.5	2.79	No	
	3B	4B	2	20	6	0.5	2.79	No	See above note
		5	2	20	6	5.0	2.79	No	
		6	2	20	6	3.5	2.79	No	
	4A	4A	2	37	34	18.8		No	

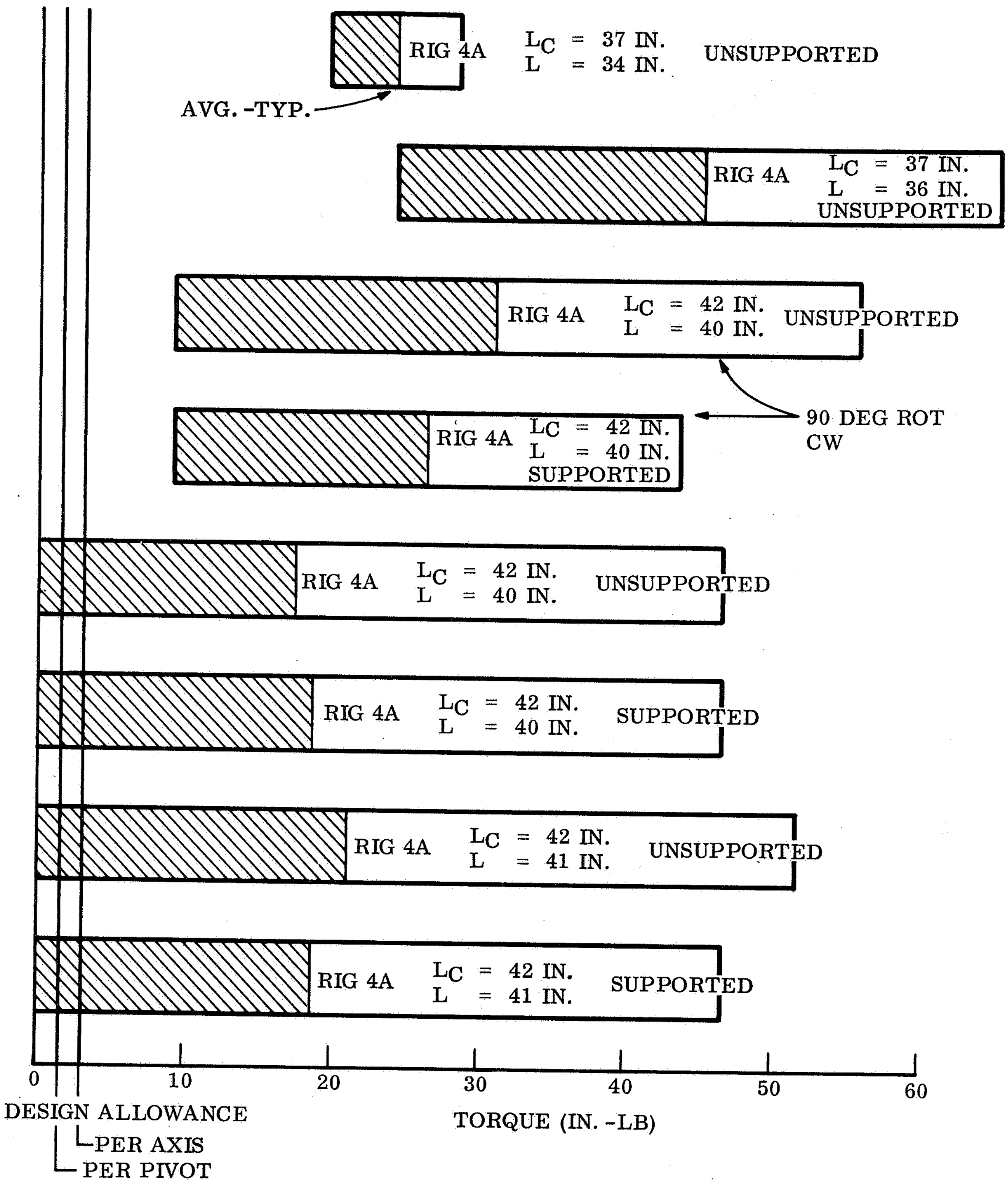

Fig. 3-7 Test Torque Limits at 2 Deg, Harness 1

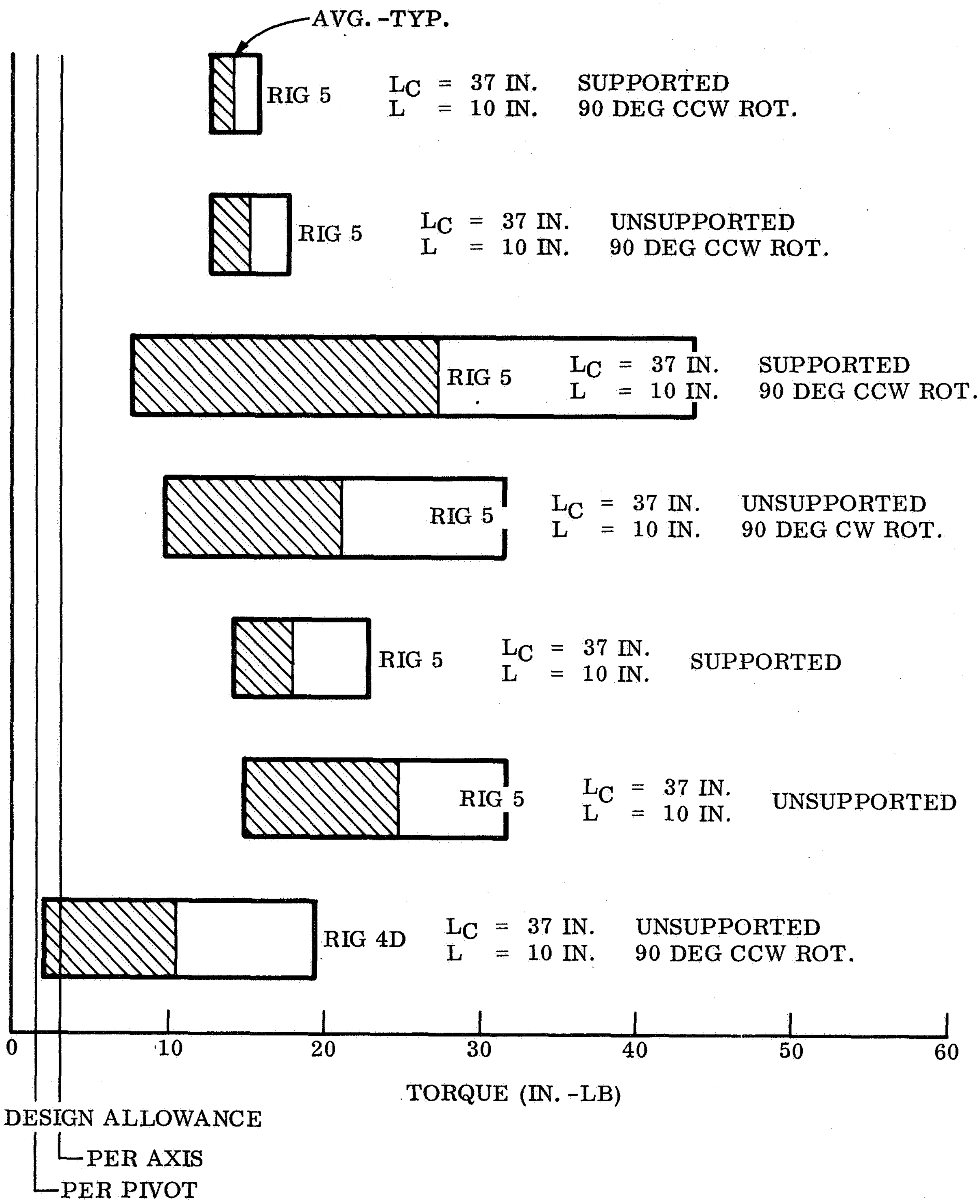

Fig. 3-8 Test Torque Limits at 2 Deg, Harness 5, Rigs 4D and 5

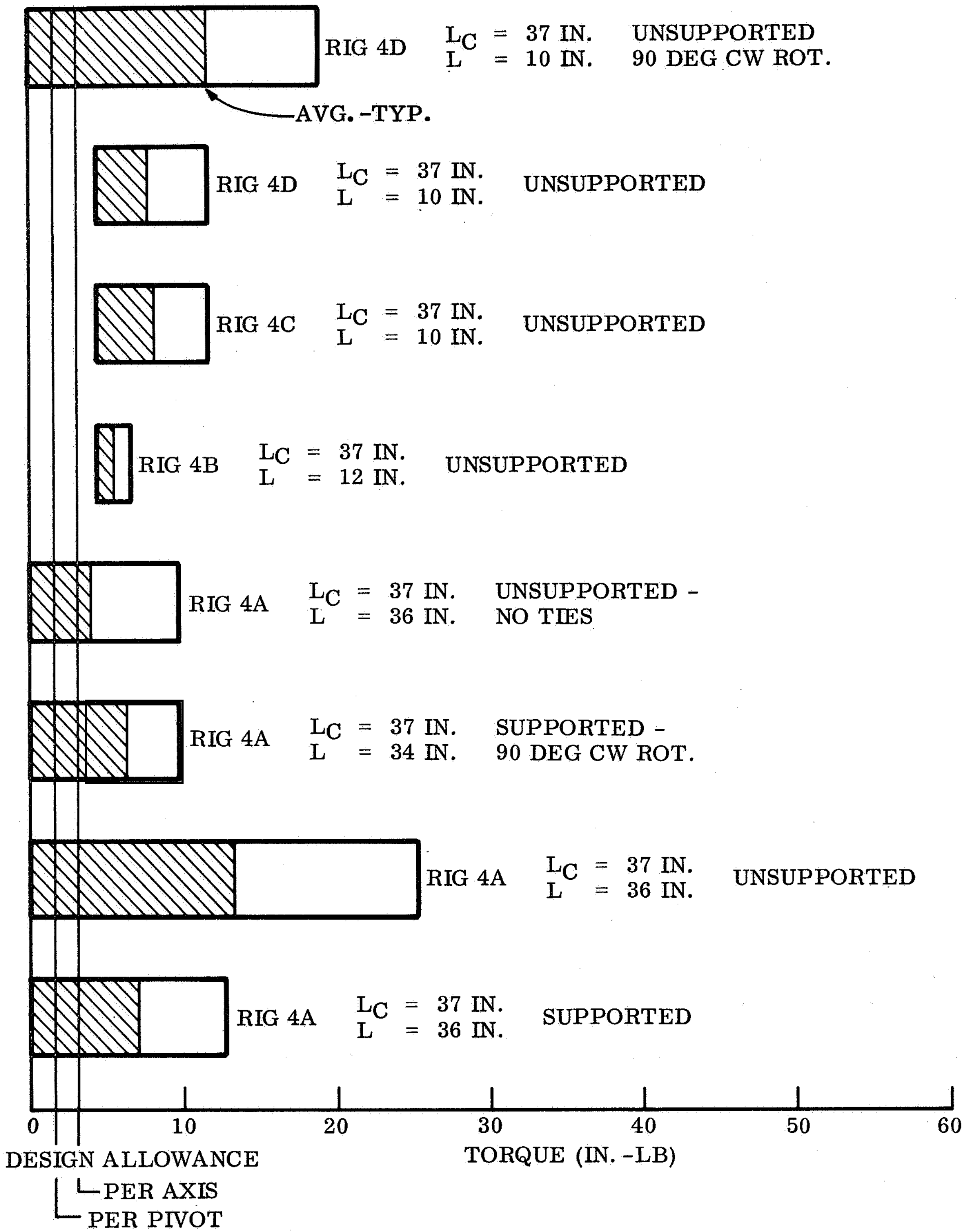

Fig. 3-9 Test Torque Limits at 2 Deg, Harness 5, Rigs 4A, 4B, 4C, and 4D

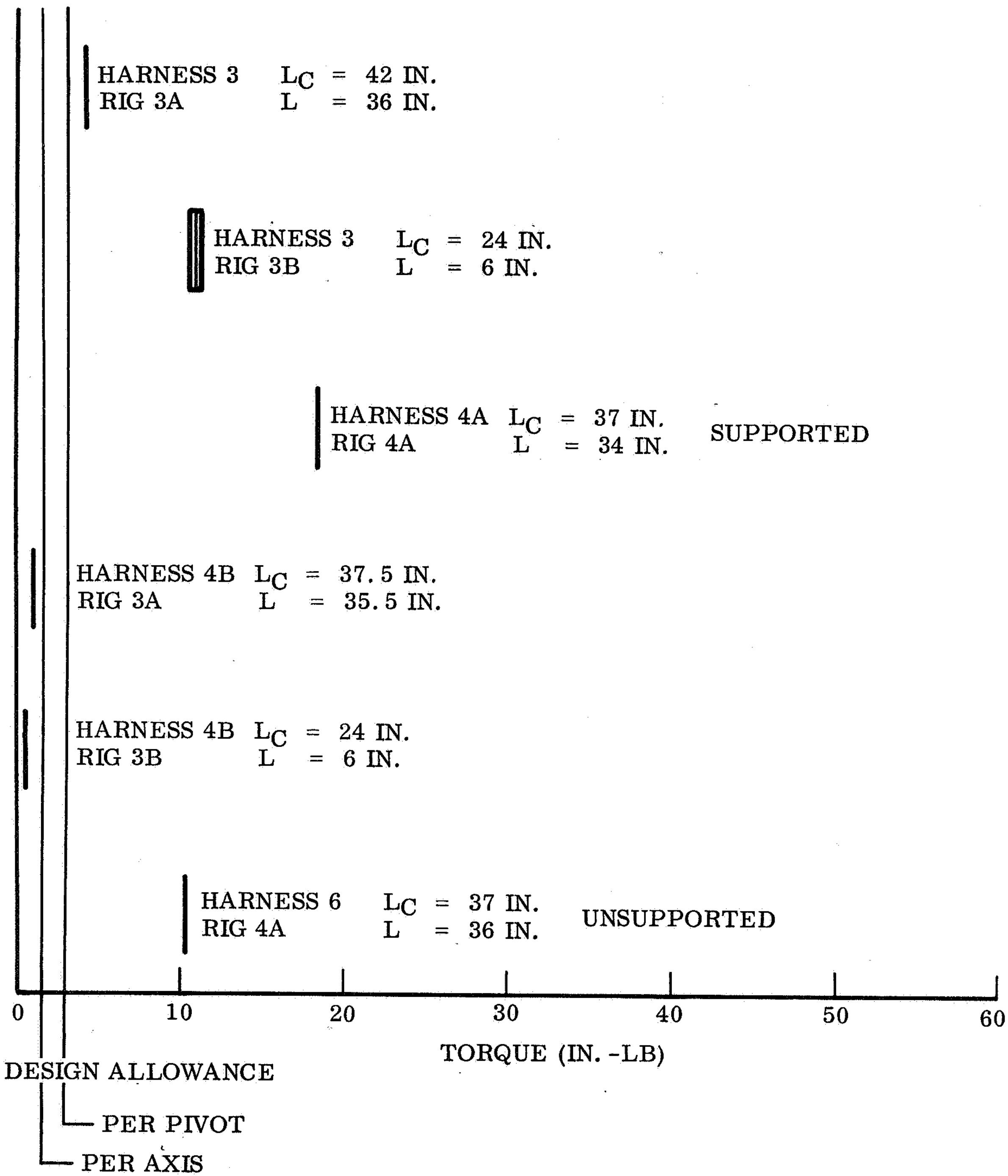

Fig. 3-10 Test Torque Limits at 2 Deg, Harnesses 3, 4A, 4B, and 6

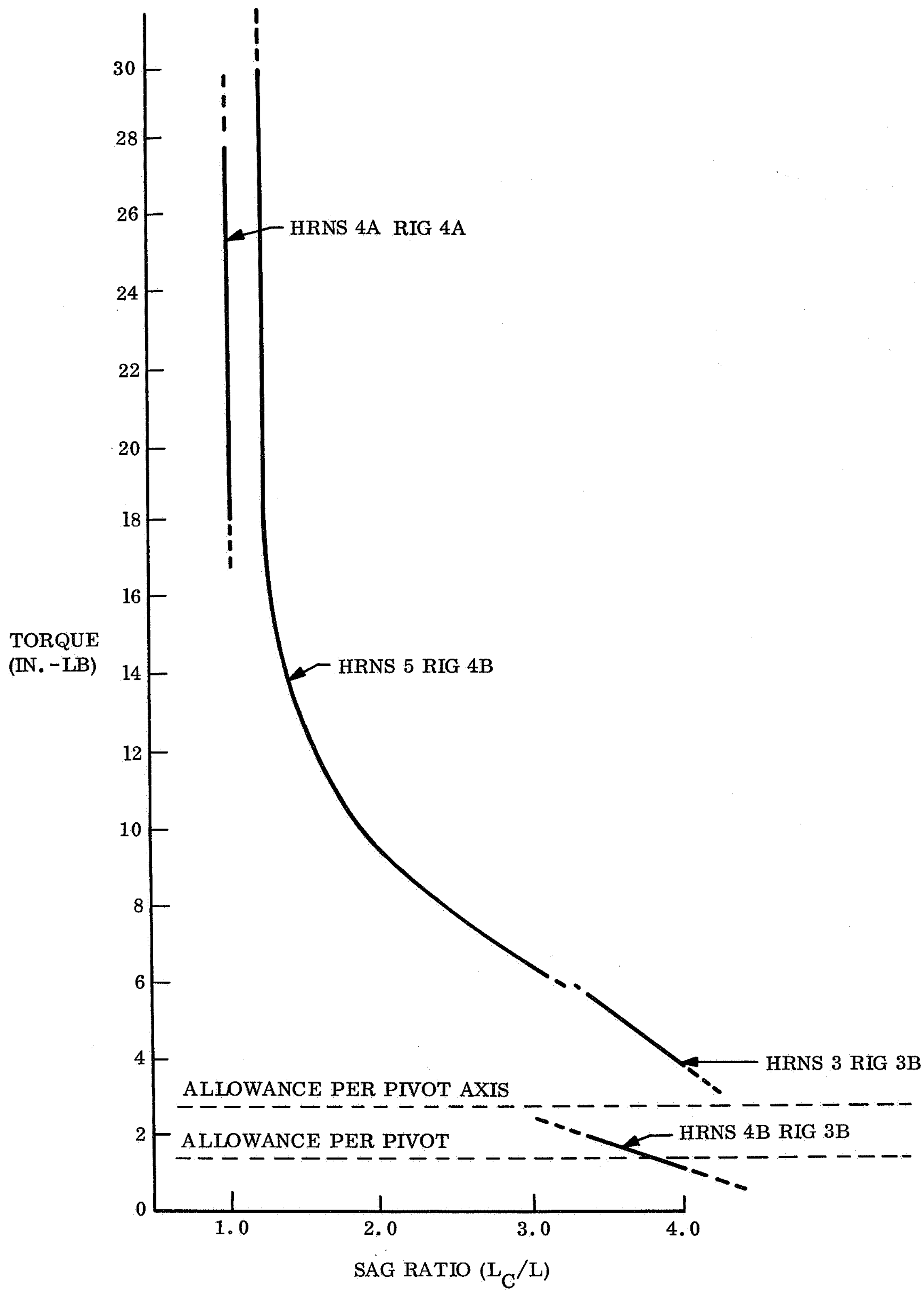

Fig. 3-11 Cable Torque vs. Sag Ratio

span lengths tested on Rig 4A. The design allowable value is based upon one of the two torque motors at each pivot axis having failed. With no failure, both motors can move the Spar in pitch (or yaw), and the allowable torque is doubled as shown in Table 3-2.

Torque data for Harness 5, shown in Figs. 3-8 and 3-9, are significantly lower than data for Harness 1. This is attributed to the large number of round wires used in Harness 1; Harness 5 consists of flat cables plus a split 15-coax ribbon cable. More runs were made using Harness 5 than with Harness 1 in the expectation that Harness 5 offered a better chance of meeting the design torque.

Figure 3-10 shows the results of a number of quick tests to obtain sample 2-deg test data for Harnesses 3, 4A, 4B, and 6 before time ran out. As such, the data are too sparse to warrant lengthy analysis.

3.3 HYSTERESIS DATA

Hysteresis data were obtained by recording force measurements as the test beam (simulating the Spar) was moved continuously from 0 deg to 2 deg, back to 0 deg, to -2 deg, and back to 0 deg. The data show that, in general, the cable harnesses using round wire bundles (Harnesses 1 and 3) exhibited larger hysteresis loops than harnesses composed of flat cables. Different rigs produced hysteresis curves of varying shapes. Figure 3-12 shows four typical curves produced by several rigs with different harnesses and is included to show the variation obtained.

Figure 3-13 has four curves for the same harness. Curves A, B, and C are directly comparable, all being on the same rig. These curves show that increasing the amount the harness is twisted, i.e., rotated in a clockwise direction, tends to both increase the torque and widen the hysteresis loop. Curve D is included to show a very small hysteresis loop obtained for a flat cable harness deflected ± 2 deg in a horizontal plane.

Table 3-2

DESIGN TORQUES

Status	Allowable Cable Harness Spring Rate (Single Failure)*		2 Deg Allowable Torque Per Axis (in. -lb)	
	In. -Lb/Rad Per Pivot Axis	In. -Lb/Deg	(Single Failure)	(No Failure)
Original	50.0	0.873	1.75	3.50
Modified on July 25, 1967	80.0	1.395	2.80	5.40
Estimated But Not Official	100.0	1.745	3.50	7.00

*Single Failure Means That One of Two Torque Motors Per Pivot Axis has Failed.

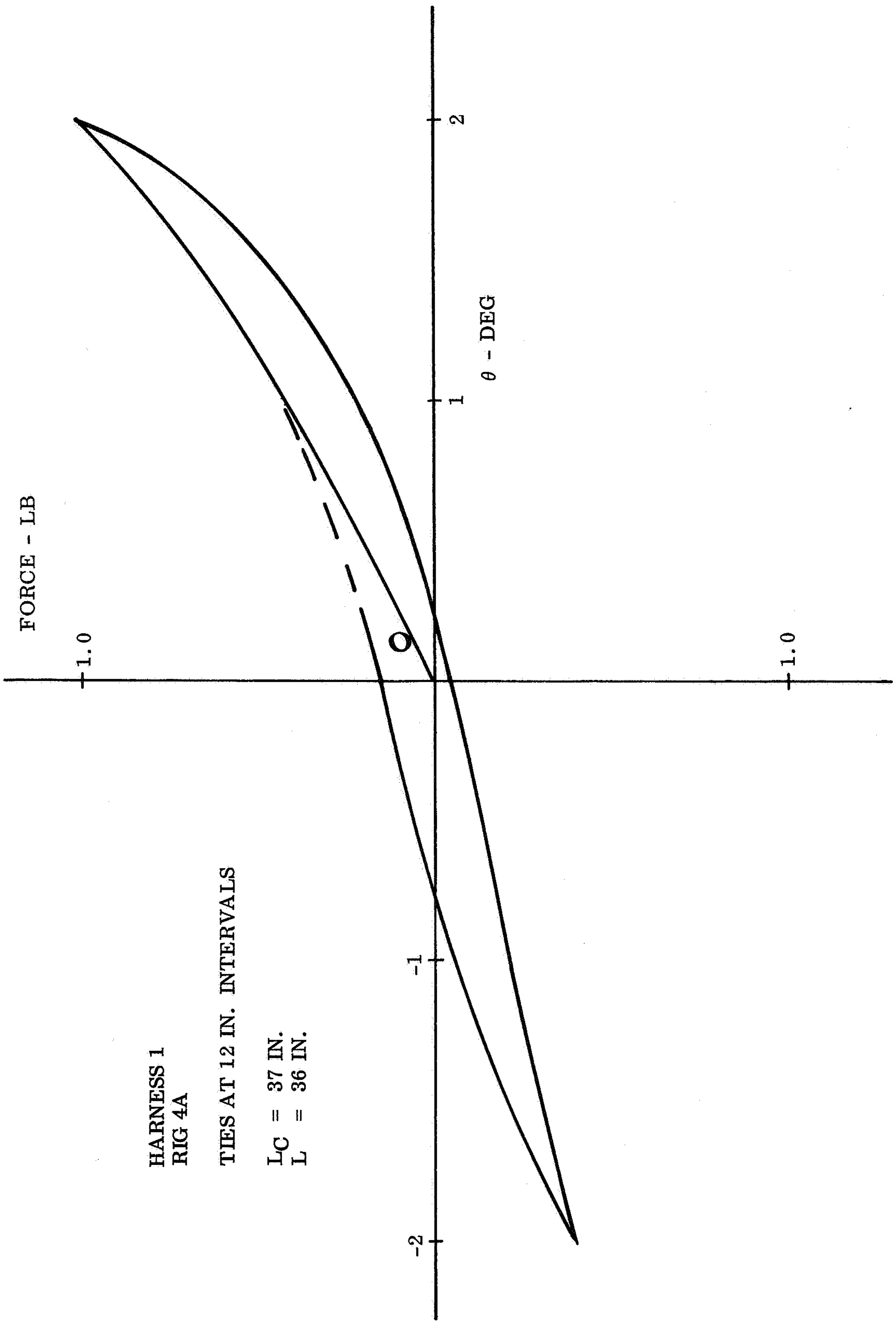

Fig. 3-12 Representative Hysteresis Curves, Harnesses 1, 3, and 4B

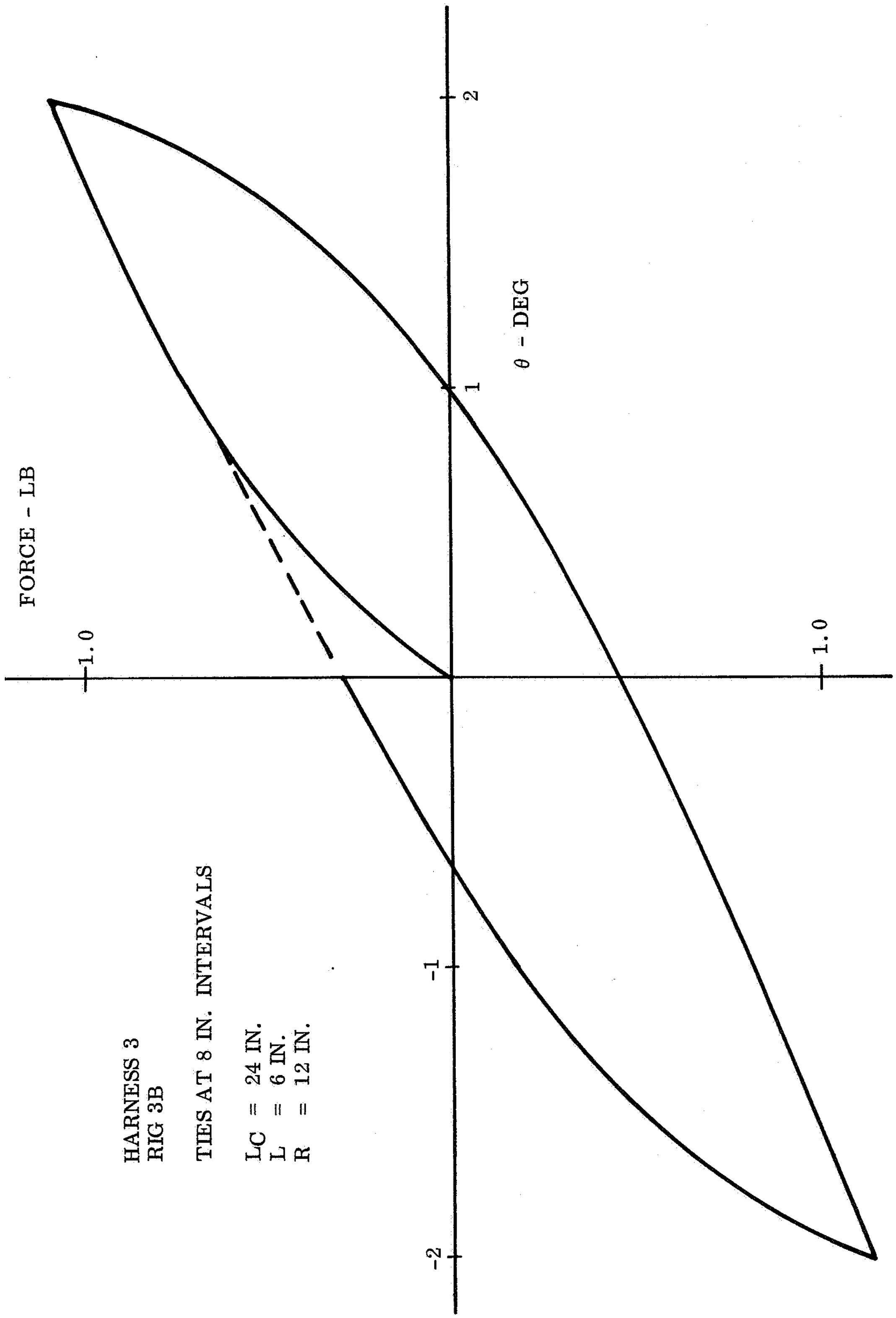

Fig. 3-12 Representative Hysteresis Curves, Harnesses 1, 3, and 4B (Cont.)

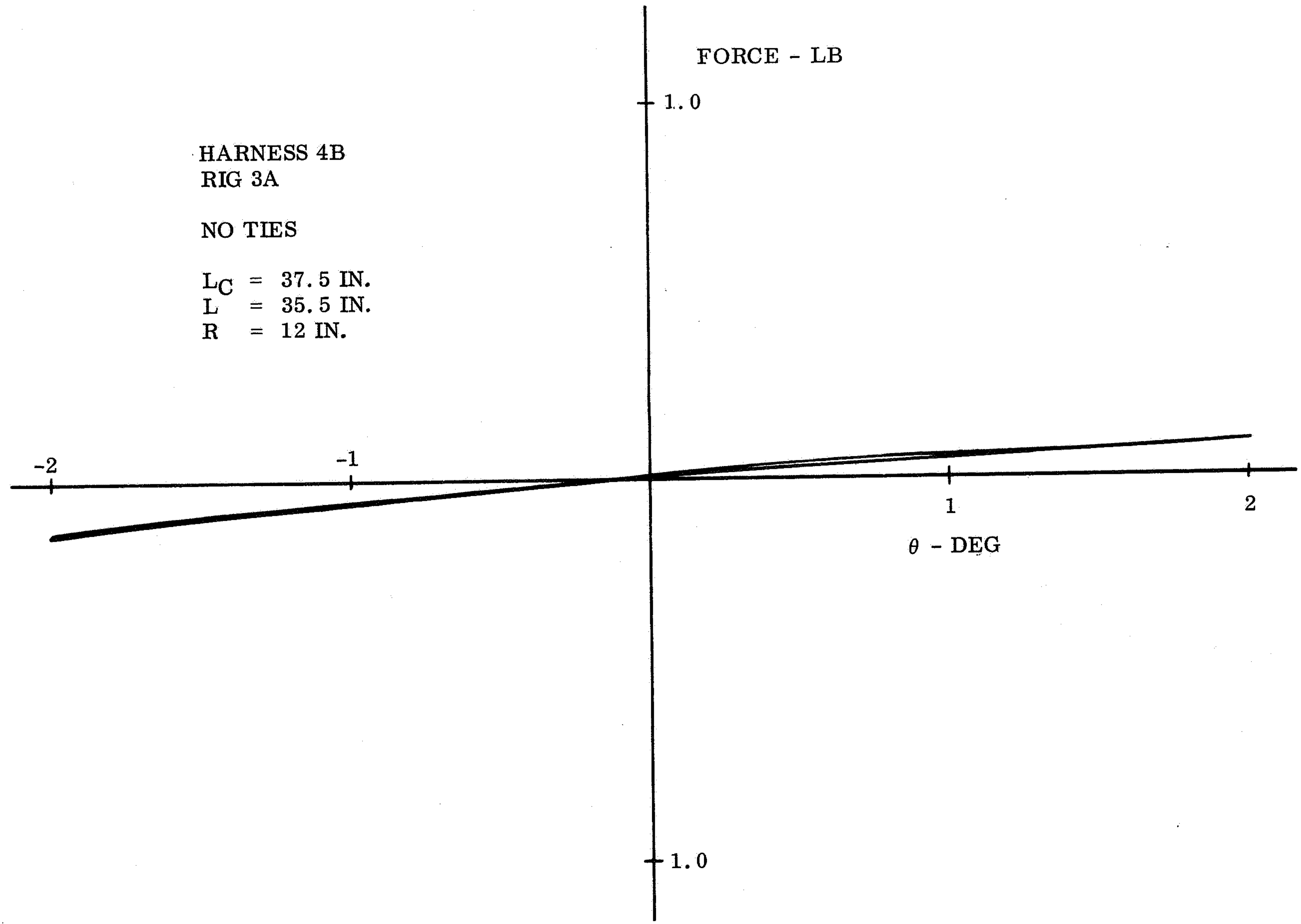

Fig. 3-12 Representative Hysteresis Curves, Harnesses 1,3, and 4B (Cont.)

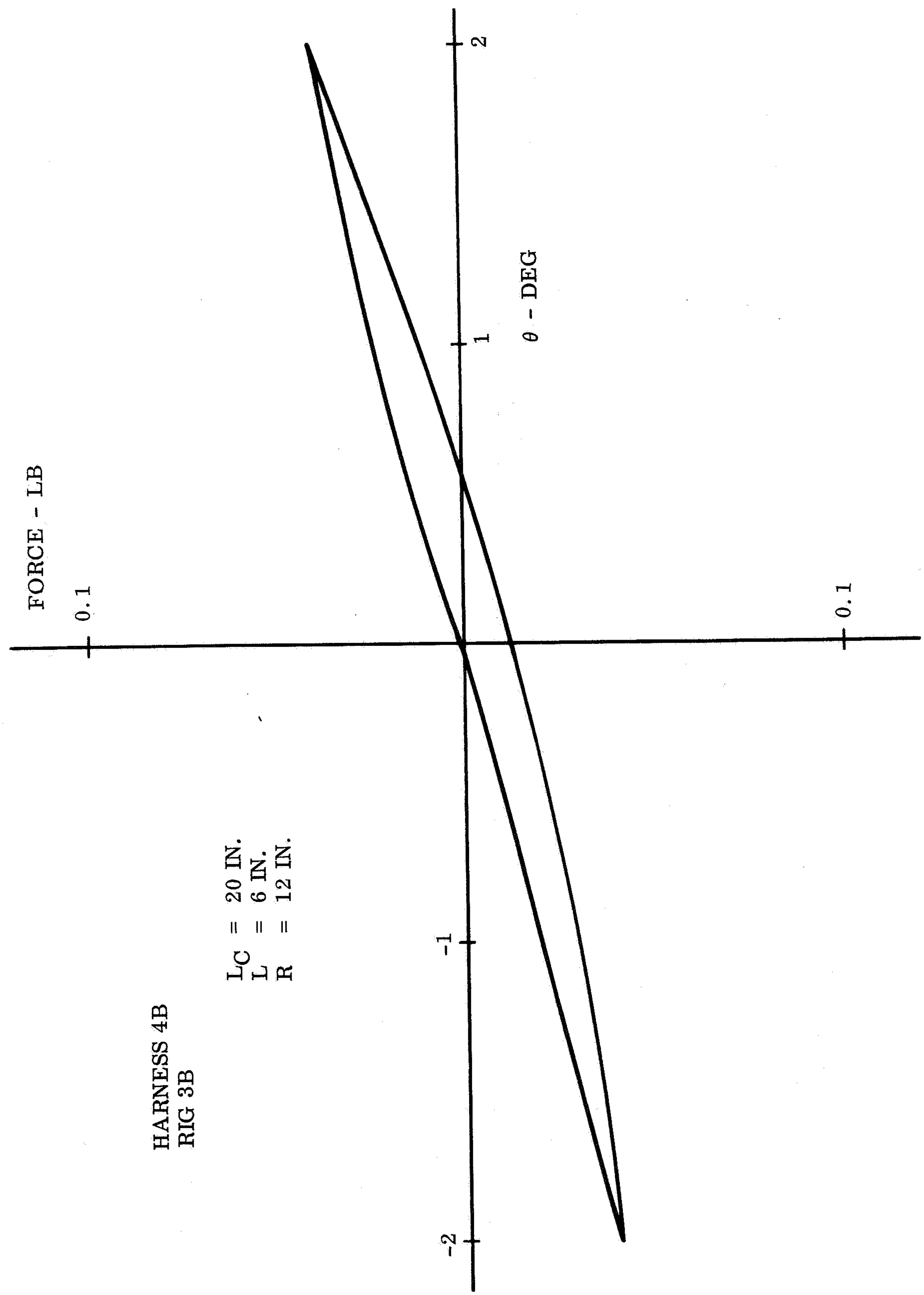

Fig. 3-12 Representative Hysteresis Curves, Harnesses 1, 3, and 4B (Cont.)

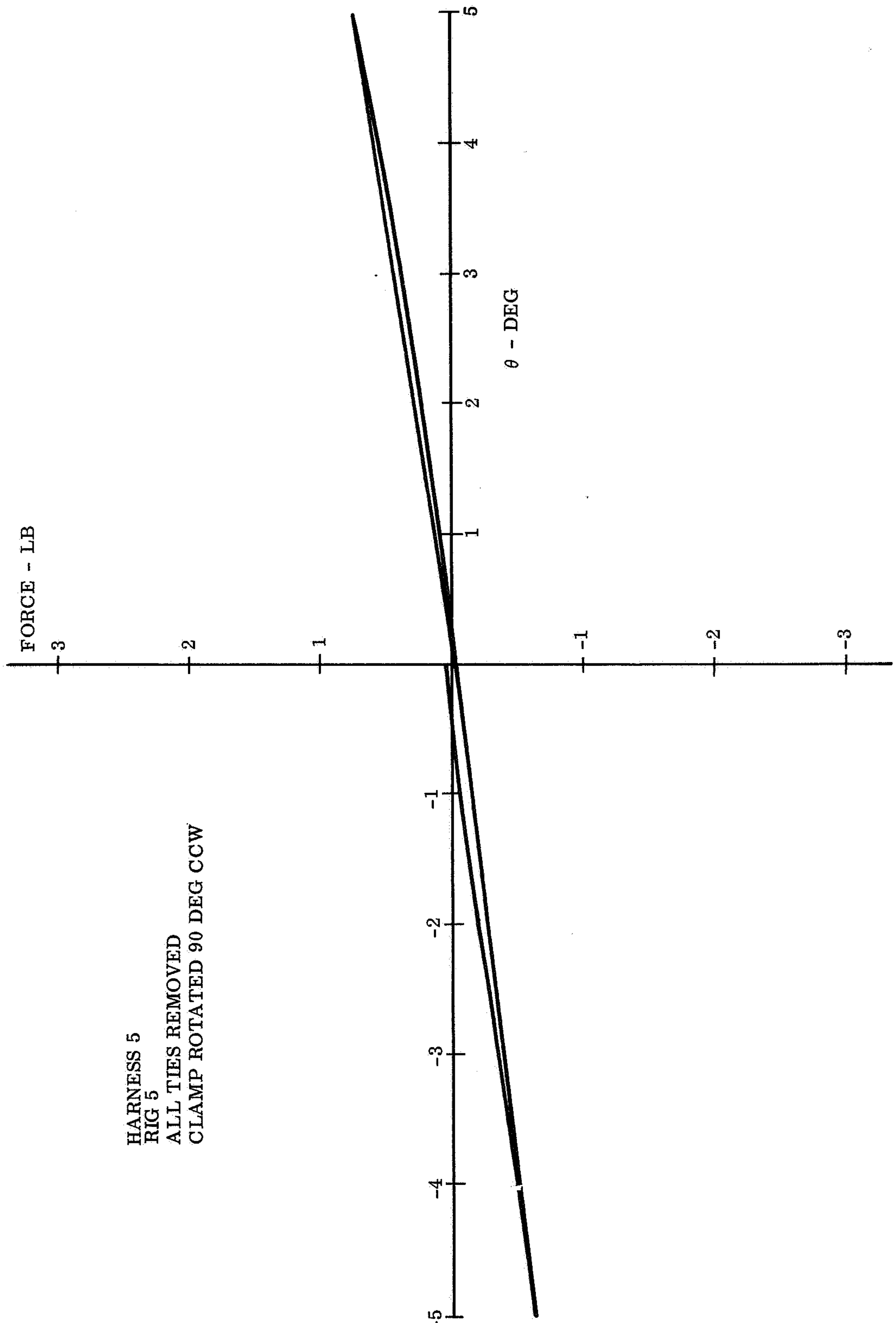

Fig. 3-13 Representative Hysteresis Curves, Harness 5

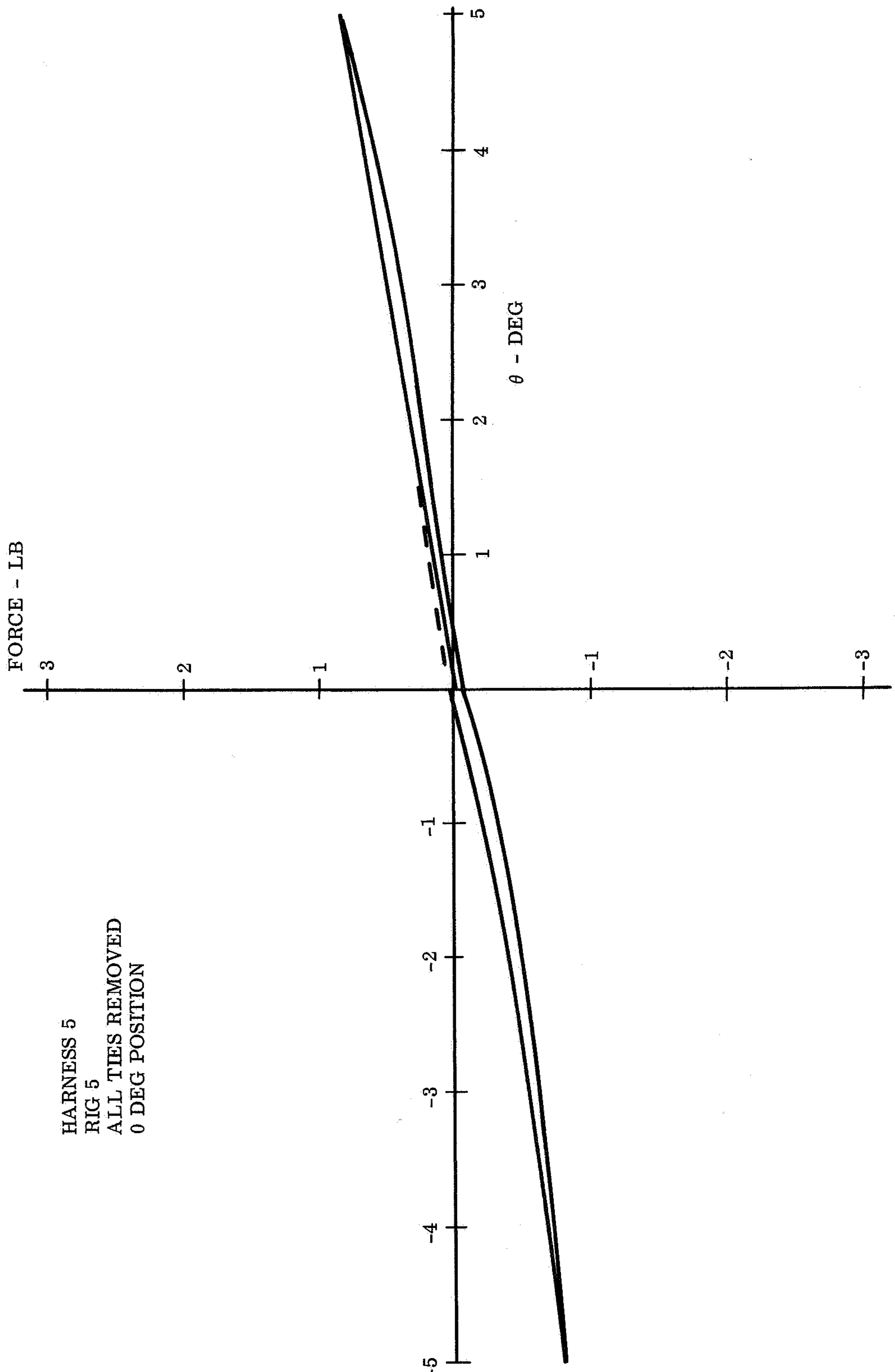

Fig. 3-13 Representative Hysteresis Curves, Harness 5 (Cont.)

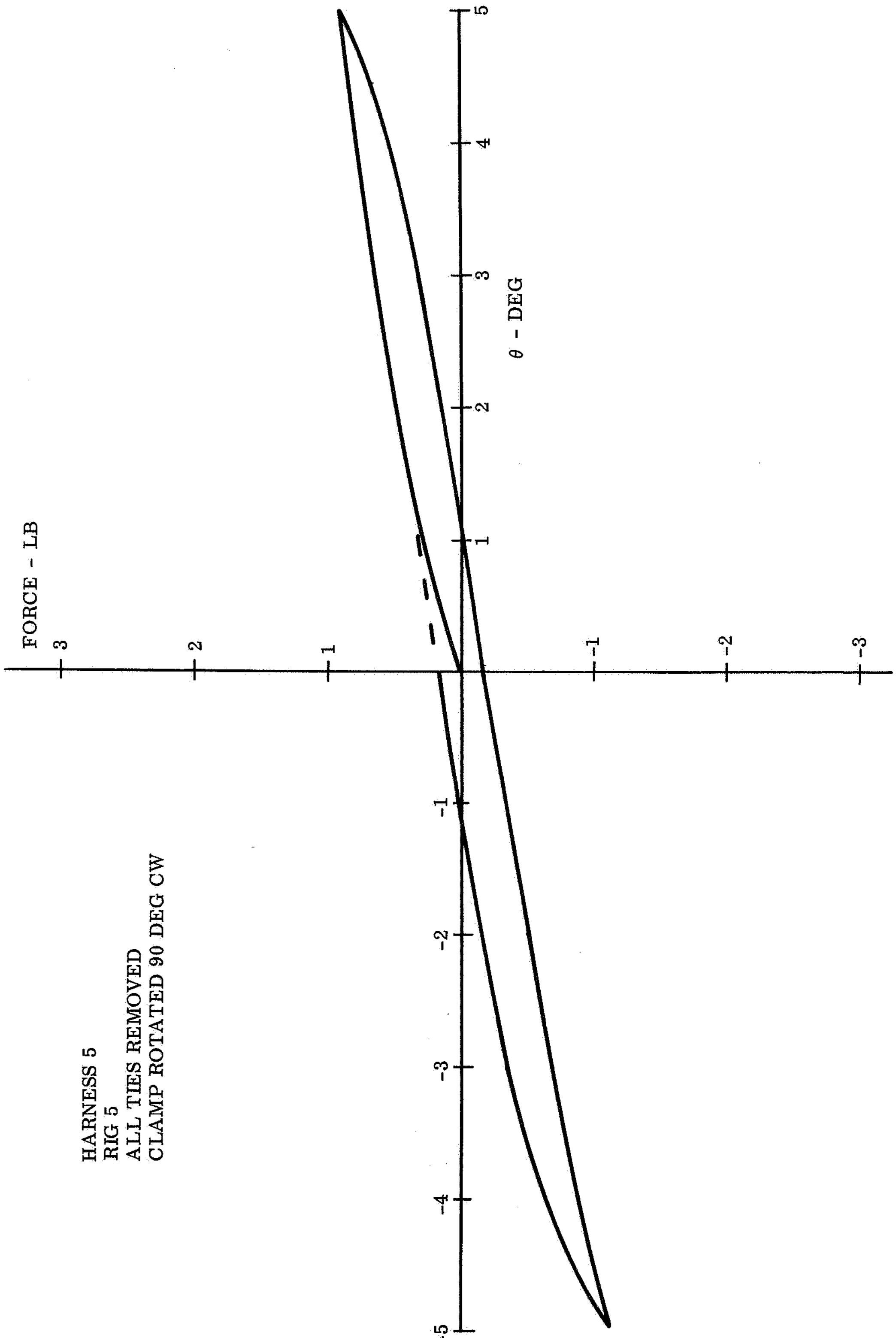

Fig. 3-13 Representative Hysteresis Curves, Harness 5 (Cont.)

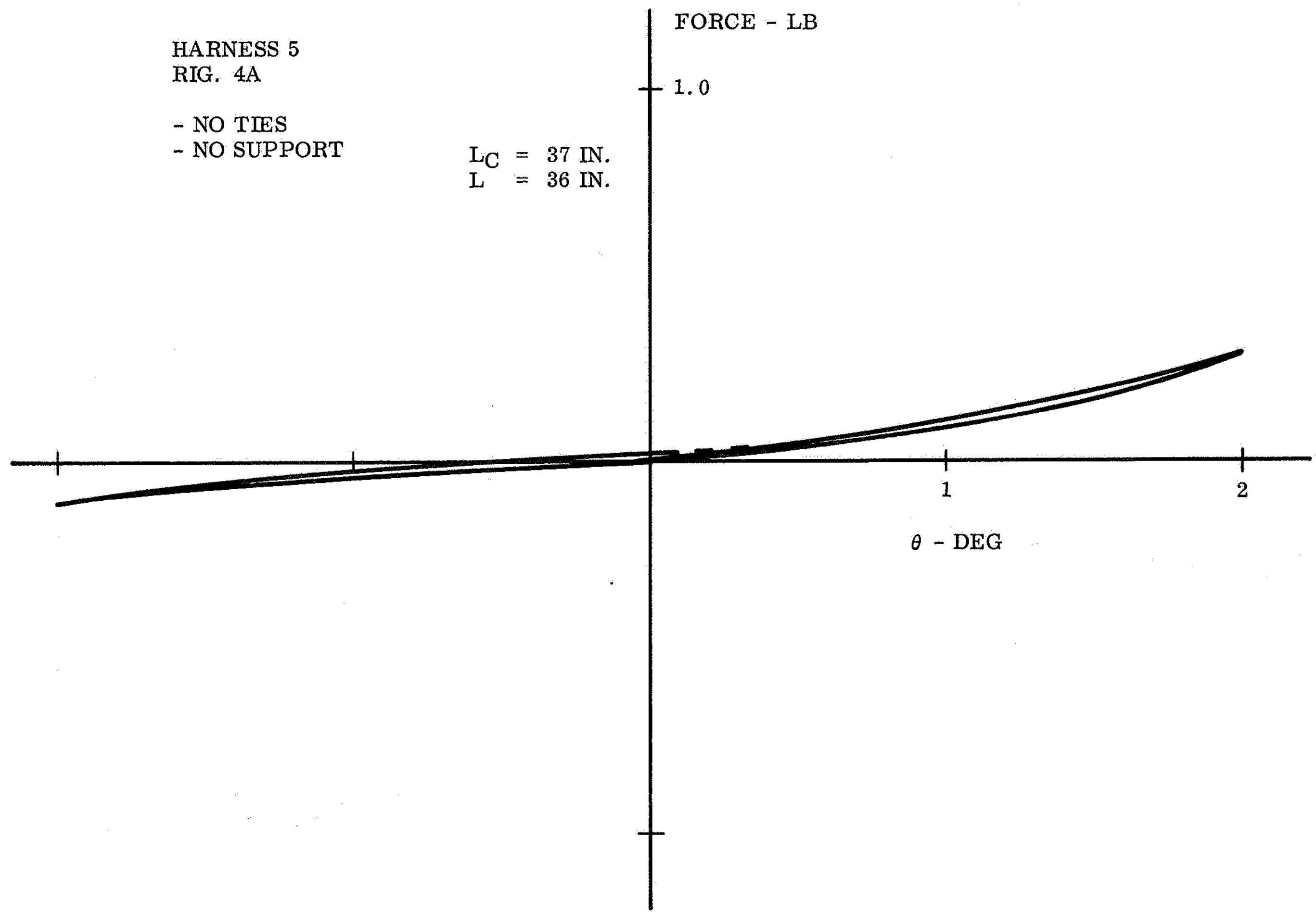

Fig. 3-13 Representative Hysteresis Curves, Harness 5 (Cont.)

Section 4
CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

A cable harness for the end approach can be designed to meet the allowable spring rate under 1-g conditions by using flat cable and a sag ratio (L_c/L) of 4 to 5. The flat cable harness will require a type of harness tie that permits considerable slippage between adjacent flat cables. The use of teflon in lieu of mylar for flat cable insulation will also reduce the required load.

Cable harnesses containing a large percentage of round wires are relatively heavy and stiff. Test torques do not indicate that an increase in the sag coefficient will provide a method of meeting the design spring rate.

Cable harnesses for the side approach are constrained by gimbal ring geometry, i.e., their lengths cannot be extended as freely as can harnesses for the end approach. Test data for both flat and round wire harnesses produced torques above the design limit for all approaches that involve bringing a major portion of the 1200 Spar conductors across an interface at a gimbal joint.

The design spring rate for the pitch or yaw torque motors, originally established for a smaller number of conductors at $50 \frac{\text{in.-lb}}{\text{rad}}$ per pivot axis has risen to $80 \frac{\text{in.-lb}}{\text{rad}}$ and may go even higher. In addition, this design value is based upon the pessimistic assumption that one of the two torque motors at each pivot axis has failed. It is unrealistic to require that a flight design be required to function during a ground test with one failed motor; such a test is more severe than on-orbit operation. Both torque motors should be assumed to be functional, thus doubling the allowable harness spring rate. In short, the design spring rate is not firmly established; consequently, a routing approach and harness design should be selected on a broader basis than a single quantitative criterion.

Hysteresis effects can be minimized by the same methods used to reduce torque: increased sag ratio and non-binding cable ties.

4.2 RECOMMENDATIONS

The simpler end approach should be made the subject of additional tests using full-scale test fixtures (or prototype flight hardware) together with a flat cable harness of sufficient length to achieve a ratio of L_c/L of 4 or greater for a span distance of up to 56 in. (maximum span dimension cited in para. 6.1 of Ref. 1).

Essential coaxial cables should be fabricated in ribbon configuration to facilitate incorporation into a flat cable harness. All flat cables should have teflon insulation (see Appendix A).

The only conductors to be routed across or near the gimbal joints should be those required for the center gimbal ring torque motors. These conductors should be flat cable.

Cable harness ties should be further investigated to determine the minimum number and type required to restrain the flat cables during operation.

Launch and ascent loads should be considered in the design and testing of any cable harness. Any launch restraint system should not interfere with on-orbit harness motion.

Hysteresis effects have been found to vary widely for different harnesses and test rigs. The impact upon the performance of the PCS should be analyzed.

Section 5
REFERENCES

1. Lockheed Missiles & Space Co., Final Report for ATM/Rack Flex Cable Interconnect Wiring Study, Augmentation Task No. 4, LMSC-A842239, Sunnyvale, Calif., 9 Jun 1967
2. -----, Final Report for Spar/Rack Harness Development Tests, Augmentation Task No. 20, LMSC-A842260, 5 Jul 1967

Appendix A
WIRE COMPARISON

LMSC harnesses for gimbal joint tests (Rigs 3A and 3B) are described in Table 2-2. Mylar insulation was used on all flat cables; the No. 26 AWG round wires were insulated with polyalkene. A special ribbon coax was used as noted in the above table. The mechanical properties of a given wire (flat or round) are highly dependent upon the type of insulation. For example, the torque required to deflect a flat cable is directly related to the tensile strength of the insulation. Table A-1 compares tensile strengths of 4 insulations. From this table it can be seen that a flat cable with teflon insulation could be expected to exhibit lower bending torque than one with mylar or kapton (H-film) insulation.

Table A-1

WIRE INSULATION CHARACTERISTICS

Property	Mylar	Kapton	Teflon (FEP)	PVC
Tensile Strength (psi)	20,000	20,000	3,000	3,000
Service Temp. °F Max.	303	752	392	185
Service Temp. °F Min.	-76	-454	-364	-40
	Flat Wire	Flat Wire	Flat Wire	Round Wire

MSFC gimbal joint test harnesses used different types and number of wires from LMSC test harnesses. Consequently, torque data would not be expected to be the same. Table A-2 presents data for MSFC wire harnesses. This table may be compared with Table 2-2. It is seen that the MSFC harnesses used shielded wire bundles and twisted pairs. These types would naturally exhibit greater torques than single wires in a loose bundle.

Table A-2

MSFC WIRE HARNESSES

Sample No.	Wire Count					MSFC Testing Rig
	Flat	Round	Round, Overall Shield	Twisted Pairs	Coax	
1	209	264	63	16	7	Gimbal Joint
2	209	328	67	16	7	Gimbal Joint

Wire Specs:
Round – ITT Supranaut C2BZZN
Coax – RG179B

Appendix B
COAX LIFE TESTS

As reported in Ref. 2, the ribbon coax cable used for torque tests was subjected to repeated flexing to determine if any mechanical or electrical degradation would occur; no degradation was discovered at the end of 2000 cycles.

An additional series of runs were made using a powered version of Rig 3B to cycle the ribbon coax. The test description, Fig. B-1, is as follows.

The harness was constructed of 15-wire coax identical to harness used in previous endurance tests. The cable length was 20 in. The harness was cycled through a 9-deg deflection counterclockwise from the 0-deg position angle at 4 cycles per min. The majority of the flexing was limited to 3-1/2 in. measured from the stationary clamp on the rig frame. After approximately 20,000 cycles with no physical or electrical deterioration, the cable length was decreased to 15 in. After 34,000 cycles, no electrical deterioration was noted. However, the harness became stiffer from the flexing encountered during cycling. At the $L_c = 15$ position the harness was cycled 50 percent of the time in the clockwise position from the 0-deg position. No change in harness condition was noted. The L_c was then decreased to 10 in. At this position, sharp bending of the harness was noted at the movable gimbal arm.

Figure B-2 shows a typical plot of center conductor and shield resistance vs. test time for Coax #1. Data for other coax cables were similar.

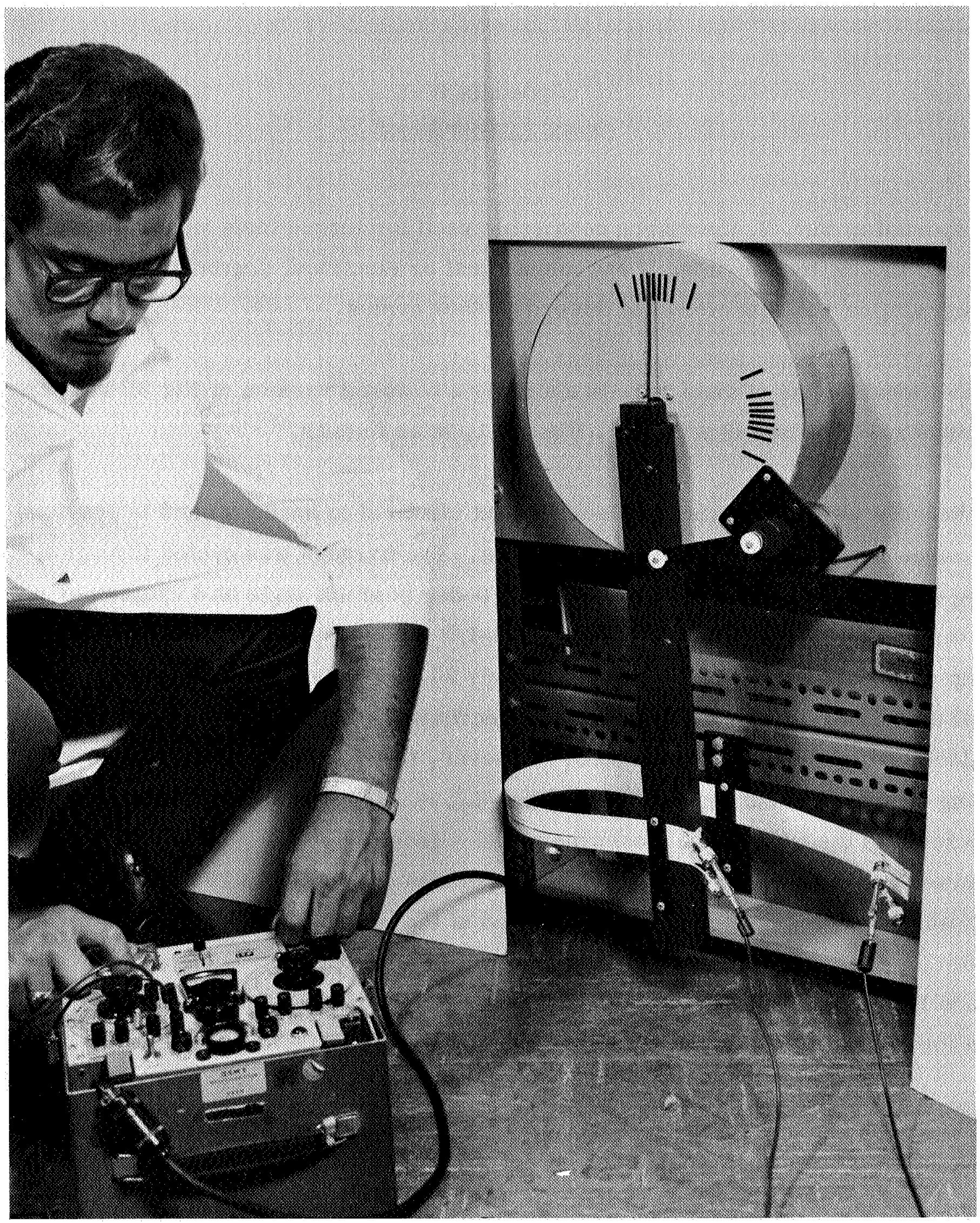

Fig. B-1 Coax Life Tests

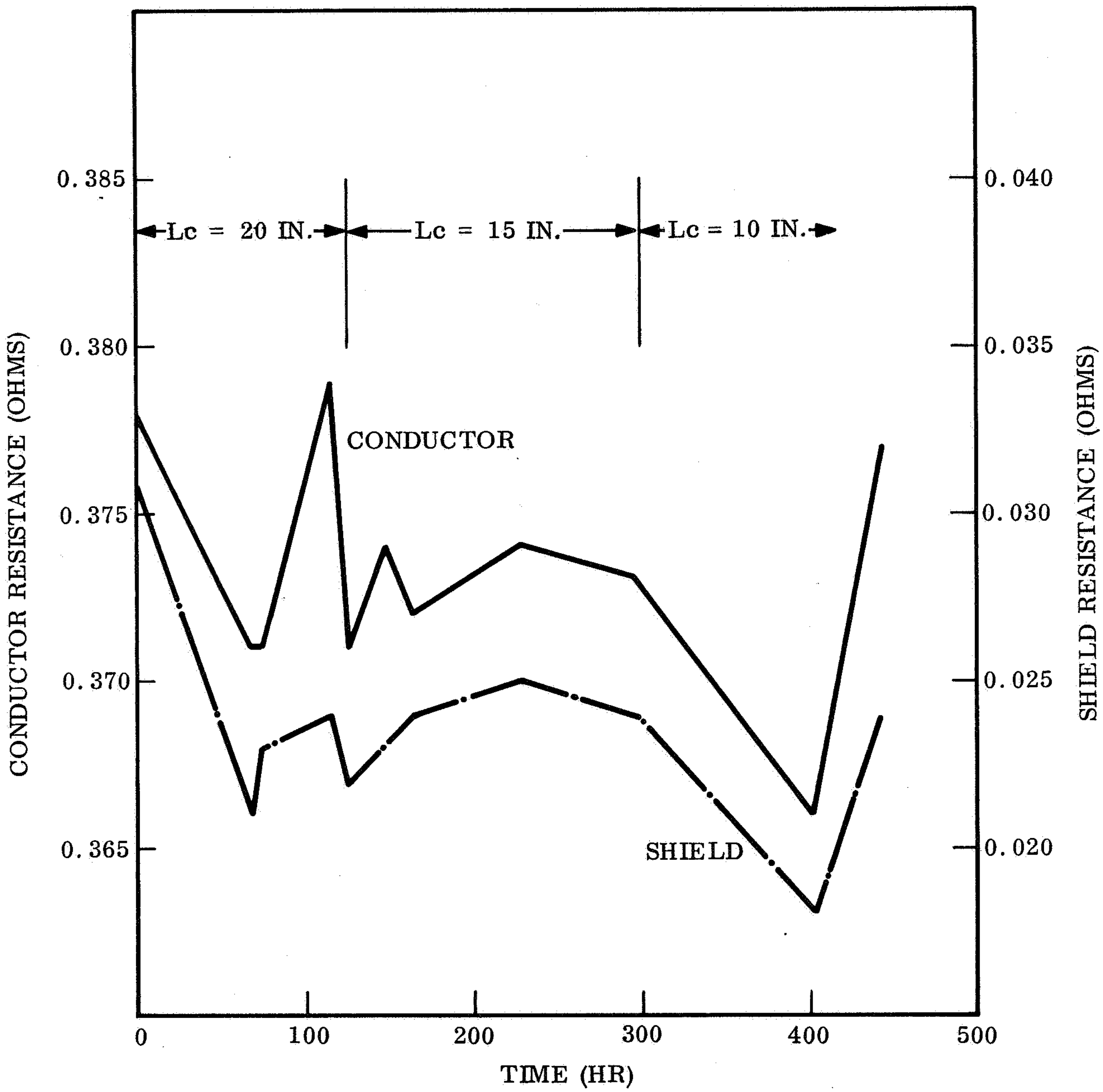

Fig. B-2 Endurance Test Data

Appendix C
ANALYSIS OF MSFC CABLE HARNESS

C.1 FLOTATION TESTS

MSFC-ASTR personnel performed a cable harness deflection test in a flotation tank in an attempt to obtain torque data without gravity effects. The test rig, intended to simulate the end approach shown in Fig. 3-1, floated a 36-in. cable harness clamped at one end and free to rotate at the other. The free end was displaced 12 in. horizontally and the required bending load recorded.

Several factors of the MSFC test combine to produce data which are below values that would be produced using flight hardware:

- One end of the MSFC harness was free to rotate; a flight harness for the end approach would be rigidly clamped at both ends and thus produce higher torque.
- A semi-analytical method was used to obtain torque data for 600 #26 AWG wires: test torques for 118 #26 AWG wires were multiplied by the ratio of $\frac{600}{118}$ to obtain a torque for 600 wires. This method ignores the nonlinear increase in harness stiffness due to friction between wires, harness ties, etc.
- The total wire count for the MSFC test was lower than the wire count cited in Ref. 2. Torque data calculated as discussed above were added to test data for 2 RG 59/U and 8 RG 174/U coaxial cables.

One factor for the MSFC test was more severe than necessary. The 12-in. lateral deflection is equivalent to a Spar travel of 11 deg, well above the current pitch and yaw value of 2 deg.

Table C-1 compares the MSFC test data and LMSC data for Harness 5 in Rig 4A. The conclusion reached by LMSC is that the MSFC data are not applicable.

Table C-1

COMPARISON OF MSFC AND LMSC TESTS

MSFC Flotation Test Data	LMSC Rig 4A
3.35 in.-lb	6.2 in.-lb
For: 600 #26 RW + 2 RF 69/u + 8 RG 174/u	For: 1191 flat conductors + 13 RF 179/u
$L = 24$ in.	$L = 40$ in.
$L_c = 36$ in.	$L_c = 42$ in.
Clamped at one end, pinned at other end	Clamped at both ends
Flotation tank	Supported at midpoint
11.5-deg deflection of Spar	2-deg deflection of Spar