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Summary of LaRC 2-inch Erectable Joint Hardware Heritage Test Data

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Space Administration

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INTRODUCTION

As the National Space Transportation System (STS, also known as the Space Shuttle) was conceived in the early 1970's and went into service during the early 1980's, NASA envisioned many missions of exploration and discovery that could take advantage of the STS capabilities. In particular, the STS could transport significant payload mass and volume to Low Earth Orbit (LEO) while also providing astronauts available for extravehicular activity (EVA) operations. Many of those missions, such as large orbiting space stations, large space science telescopes and large spacecraft for manned missions to the Moon and Mars, required the use of low-mass, large-area space structures. Since these structures were significantly larger than the payload volume available on the STS (or any other available launch vehicle), the structures were designed to be launched disassembled (for compact packaging) and then assembled on orbit.

In parallel (during the early 1970's through the early 1990's), NASA Langley Research Center (LaRC) conducted studies to design and develop the technology needed to assemble the large space structures in LEO. One promising construction method extensively developed was referred to as erectable truss structures. Erectable truss structures, which would be assembled component-by-component on orbit, could be packaged very efficiently for launch (references 1 and 2). Once on orbit, the pieces would be assembled to form the truss structure by EVA astronauts using efficient assembly line-type techniques. Extensive studies were performed that addressed the truss structure design, launch payload packaging concepts, structural analysis, assembly concepts, structural tests and assembly tests. A complete summary of all of these activities is presented in Reference 3.

A typical erectable truss structure is comprised of repeating elements or bays, composed of two basic components; struts and connecting nodes. A critical feature for assembling erectable structures is the joint that connects the truss struts at the truss nodes. Methods for joining on Earth, such as welding, bolting and riveting, are not easily accomplished on orbit, where the connecting joint must be easily and efficiently assembled by astronauts in bulky space suits. For this reason, a quick-attachment, side entry joint that requires no tools for assembly was developed at LaRC (Reference 4), as shown in Figure 1. Key features of the joint included a spring-loaded latch which facilitated initial capture and secured the joint, a hand-operated collar which was rotated to lock and preload the joint, and linear axial structural performance.

The joint and associated truss struts were designed to have a 2-inch diameter to accommodate EVA handling. The space suits worn by EVA astronauts are bulky and the internal pressure causes the suits to be stiff. The stiffness induced in the spacesuit gloves limits the dexterity of the astronaut's hand operations and also requires the astronaut to exert force to open or close the glove from its neutral position. The erectable joint design and the 2-inch size were optimized to minimize astronaut hand fatigue (Reference 5).

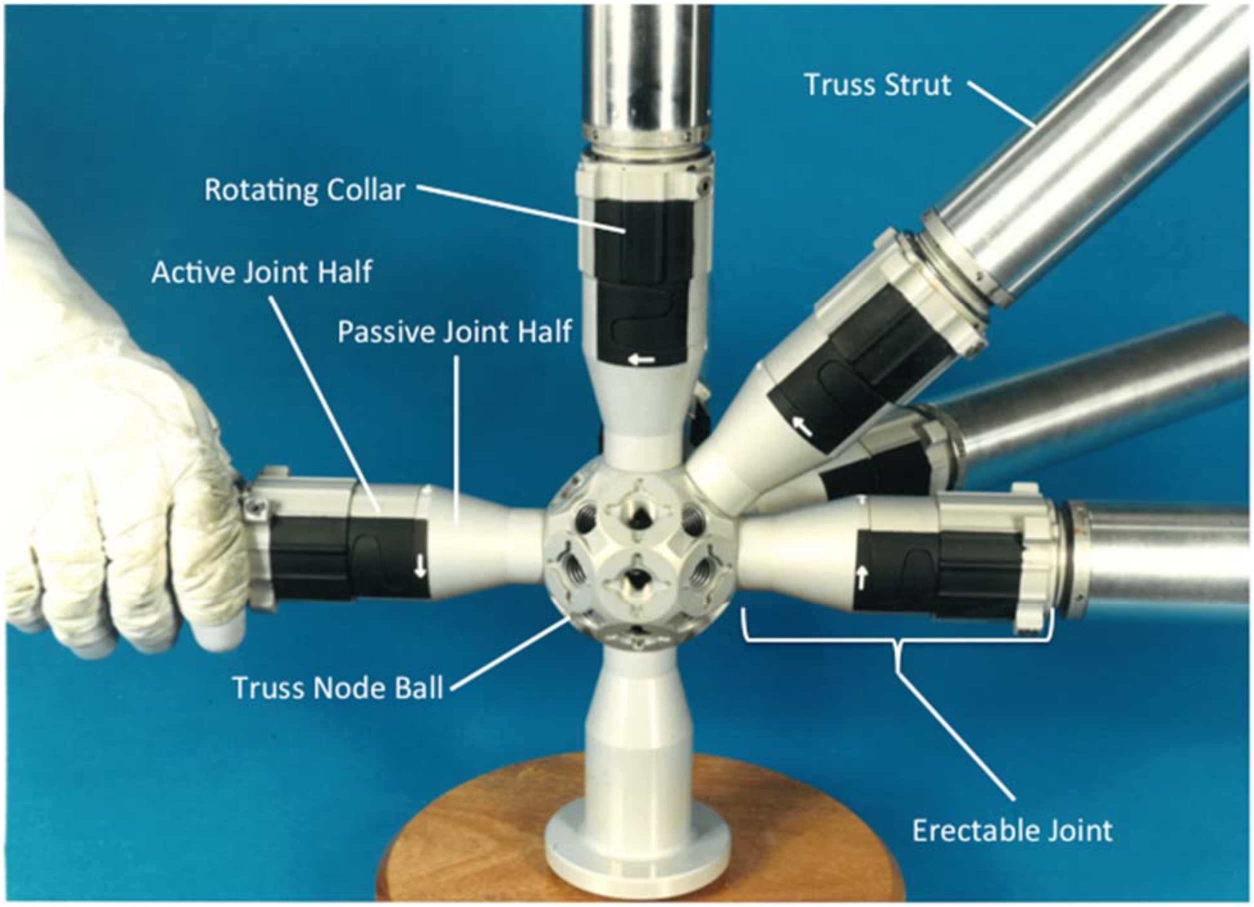

Figure 1. LaRC heritage 2-inch erectable joint.

When the NASA research in large erectable space structures ended in the early 1990's, a significant amount of structural testing had been performed on the LaRC 2-inch erectable joint that was never published. Recently, there has been renewed interest in on-orbit assembly, the erectable joint technology and the structural performance of the joints. This paper summarizes the results from reviewing 2-inch erectable joint heritage test data as well as the performance measurements obtained from these previous structural tests.

JOINT DATA EXECUTIVE SUMMARY

The 2-inch diameter LaRC Erectable Joint was developed during the late 1970's through the early 1990's. Many iterations of the joint were designed and fabricated, with the final version referred to as the "Type 6" joint. As part of the effort to compile data for this paper, all of the erectable joint drawings (only paper drawings existed) were retrieved from storage and design information compiled on the Type 3, 4, 5, and 6 designs. At the same time, all of the documentation on erectable joint testing was retrieved and reviewed. Information from an unpublished technical paper outline indicates that the main focus of the testing program was to perform axial tests in order to validate the joint manufacturing process; that is, to prove that joints with linear stiffness could be produced consistently and that the stiffness performance was also reproducible. Because axial forces are dominant in a truss structure, axial strength tests were also performed to assess the joint ultimate load and failure mode. The strength information was used to aid in margin-of-safety calculations for various mission applications of the erectable truss structures.

In addition to the axial stiffness and strength data, the bending and torsional stiffness of the LaRC 2-inch erectable joint was investigated (reference 6) as part of a design evaluation for an Astronaut Monorail System for the Space Station Freedom design. A limited number of 3-point bending and torsional tests were performed to assess the joint stiffness characteristics.

In 1992, on Space Shuttle flight STS-49, the LaRC 2-inch erectable joints were flown as part of the Assembly of Station by EVA Methods (ASEM) experiment, as shown in Figure 2. At the time, various approaches were being considered for how to assemble the International Space Station on orbit, including EVA methods to assemble an erectable truss. A portion of the 5-meter erectable truss was assembled in the cargo bay of the Space Shuttle during the flight. During the EVA assembly, there were times when truss struts would be cantilevered and/or not fully supported and the astronauts could exert bending or torsion forces on the joints. Although the erectable joints were never explicitly designed and structurally sized for these load conditions, a limited number of additional 3-point bending stiffness, cantilevered bending strength and torsional stiffness tests were performed to assess the joint capability for these off-nominal load cases. While the joint was tested to failure during the cantilever bending test, the joint was not tested to failure in the single torsion test that was performed. A minimum torsional strength is inferred from the maximum torque applied during the heritage test program and is also reported.

A summary of all available test results for axial stiffness, axial strength, bending stiffness, bending strength and, torsional stiffness and torsional strength are contained in Table 1. Details of the test set ups, applied loads, joints tested, and examples of test results and data are contained in the appendices; Appendix A summarizes axial stiffness, Appendix B summarizes axial strength, Appendix C summarizes bending stiffness, Appendix D summarizes bending strength, and Appendix E summarizes torsion stiffness and the inferred torsional strength.

Table 1. Summary of results from 2-inch erectable heritage joint tests.

Joint Parameter	**Detailed Summary**	**Heritage Data Summary Value**
Axial Stiffness	Appendix A	8.88×10^5 lbf/in (Average of 5 tests): (EA= 6.77×10^6 lb)
Axial Strength	Appendix B	20,267 lbf (Average of 3 tests)
Bending Stiffness (Major Axis)	Appendix C	2.32×10^6 lb-in^2 (Average of 4 tests)
Bending Stiffness (Minor Axis)	Appendix C	1.92×10^6 lb-in^2 (Average of 4 tests)
Bending Strength (Major Axis)	Appendix D	1244 ft-lb (14,928 in-lb)
Bending Strength (Minor Axis)	Appendix D	1360 ft-lb (16,320 in-lb)
Torsional Stiffness	Appendix E	0.6198×10^6 lb-in^2
Torsional Strength		> ±1200 in-lb

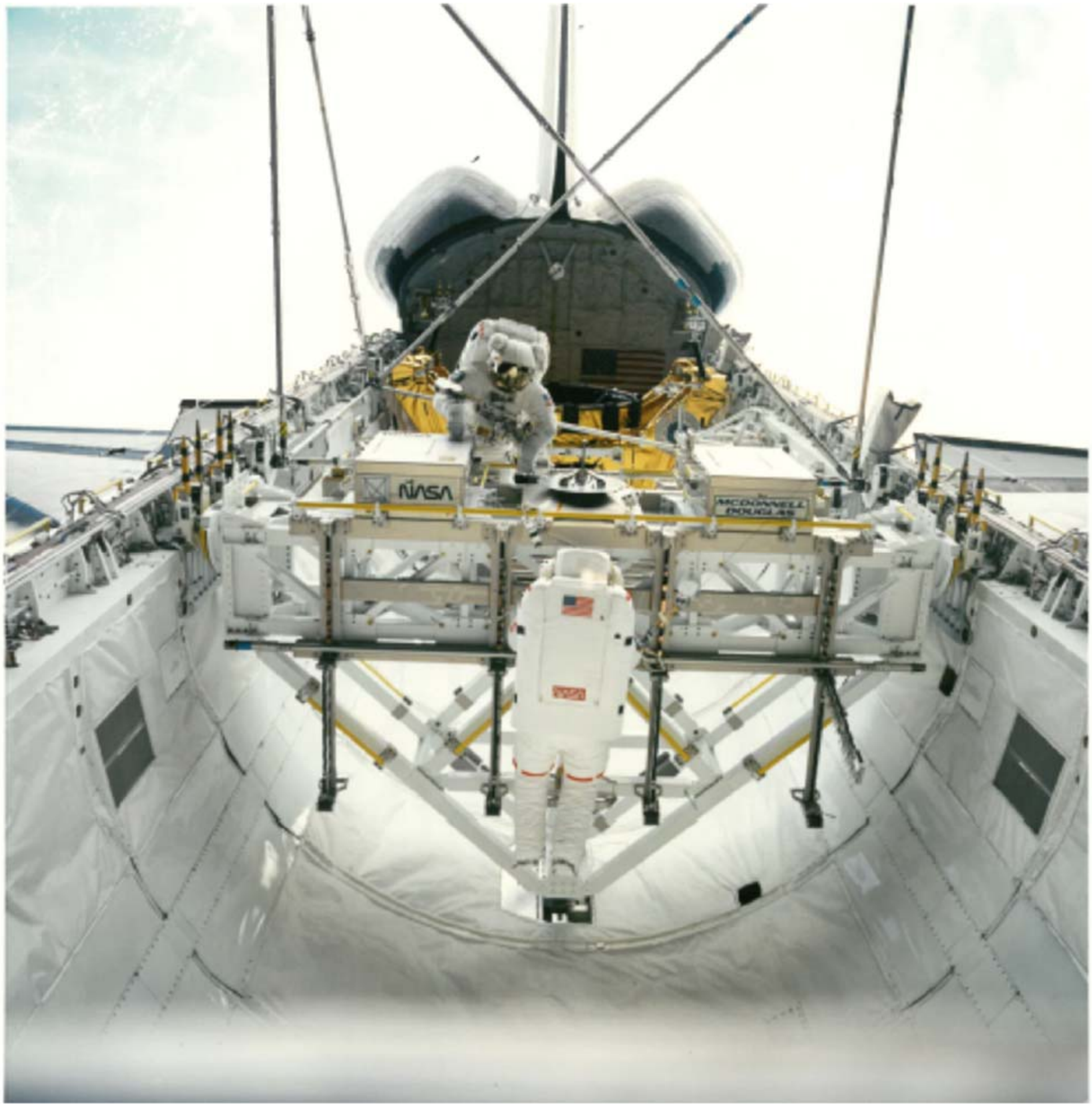

Figure 2. ASEM experiment flown on STS 49.

CONCLUDING REMARKS

The heritage LaRC 2-inch erectable joint is receiving renewed interest as the point of departure for a joint that can be robotically assembled in space. An extensive set of historical information and data were reviewed and previous results of heritage joint structural testing were compiled and summarized in this report. The heritage data suggest that the LaRC 2-inch erectable joint can meet the strength and stiffness requirements for many on-orbit assembly applications.

ACKNOWLEDGEMENTS:

Many people (see list of authors for references 1 – 6) participated on the teams that designed, analyzed, manufactured, and tested the 2-inch erectable joints and developed the many mission applications that included in-space assembly. The work reported here is a very short summary of their substantial achievements.

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4. Bush, Harold G., Mikulas, Martin M., and, Wallsom, Richard E., "Mechanical End Joint System for Connecting Structural Column Elements," United States Patent Number: 4,963,052, Date of Patent: October 16, 1990.
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6. Watson, Judith J., "Design Considerations for an Astronaut Monorail System for Large Space Structures and the Structural Characterization of its Positioning Arm," (Master's thesis), Old Dominion University, Norfolk, VA, 1992.

Appendix A. Axial Stiffness

Data have been located on axial stiffness testing of Type 2, 3, and 4 joints. Representative axial stiffness values for Joint Types 2, 3, and 4 are summarized in Table A1. Information from an unpublished technical paper outline indicates that the main purpose of performing the axial tests was to validate the joint manufacturing process; that is, to prove that joints with linear stiffness could be manufactured consistently and that the stiffness performance was also reproducible. In a typical test, the 2-inch joints were loaded between ± 1000 lbf and three load cycles were run.

Data from Type 2

The data found from Type 2 joint axial stiffness testing are terse; it is not clear how many joints were tested. What has been reported is data from a single test, with the data from that test incorporated into a presentation chart; Figure A1. The emphasis for this test was to generate data that would allow the equivalent stiffness for an erectable joint residing in a large truss structure to be calculated in order to support accurate finite element modeling of large space structures built with the erectable technology.

In a normal linear finite element truss model, a stiffness value would be input for the truss struts while the truss joints would not be explicitly modeled. If the joints (actual hardware) have a linear stiffness, then it is straight forward to derive a modified stiffness value to input into the analysis model that combines the truss strut and truss joint stiffnesses. Thus, a great deal of effort was put into developing joint hardware with linear axial stiffness behavior.

The test set up for the 2-inch joint is shown in Figure A1, while Reference A1 describes in detail a similar test set up for a 1-inch joint. Note that the stiffness is measured for what is considered the entire joint in a truss analysis model: it includes a central node ball and the two complete joints on the opposite faces of the node ball. Thus, the measured stiffness is for this entire chain of structural elements and connections, it is not the stiffness of a single erectable joint.

The relationship between the value of axial stiffness in the joint; $k = F/\Delta L$ and the stiffness of a strut; EA/L are:

$$F = k \cdot \Delta L \tag{1}$$

where F would be the force measured in the test, ΔL is the displacement and k the derived stiffness.

For the truss strut, the stress can be expressed as

$$\sigma = F/A = E \cdot \varepsilon \tag{2}$$

where A is the strut area, E is the strut modulus and ε is the strain in the strut. The strain is also represented by

$$\varepsilon = \Delta L/L \tag{3}$$

After appropriate substitution, one gets

$$k \cdot L = E \cdot A \tag{4}$$

The measured joint stiffness multiplied by the length of the test article (L) gives an equivalent extensional stiffness, modulus multiplied by the area, that can be combined with the extensional stiffness, EA, of a strut to derive a combined value for the analysis model. Thus, much of the data are reported as the extensional stiffness, EA, in the archives. The axial stiffness can be calculated by dividing the EA values listed in Table A1 by the appropriate value of L from each test. Note that since there are two joints in the Type 2 test setup (see Figure A1), one on each side of the node ball, the stiffness value represents the average of the 2 joints, not that of a single joint.

Data from Type 3

The most extensive set of heritage data found is associated with the Type 3 joint; information could be found for a total of 23 different joints that were tested for axial stiffness, with load deflection summary data and plots existing for all 23 tests. The test data from test/joint #44 are shown in Figure A2 and represents the largest value of EA measured. The most linear data came from test/joint #42, shown in Figure A3. The joints averaged in the 5 linear cases were test/joint #'s 44, 42, 32, 29, and 23. In the Type 3 tests, the setup was changed and the deflection was measured from the node ball center across one erectable joint (two halves locked together) so the values now represent that particular joint. The test length, L, is approximately half of the value for the Type 2 test (see Table A1).

Data from Type 4

On Space Shuttle flight STS-37, LaRC erectable joints were flown in the cargo bay and included in an experiment called Crew Loads Instruments Pallet Experiment (CLIP). It has not been confirmed, but from photographs of the experiment taken at Johnson Space Center (JSC) before the flight, it appears that a Type 4 joint was flown. Four joints were tested for axial stiffness behavior and the data prepared and sent to JSC. Each joint was tested twice; in the first test some joints had a higher degree of nonlinear performance than desired. Based on observations after the first series of tests, a pin was installed to keep the Belleville washers centered and each joint tested a second time. For all joints, the nonlinear behavior was reduced in the second tests, with the most dramatic improvement occurring for Specimen D, as shown in Figures A4 and A5. As in the Type 3 test set up, the deflection was measured from the node ball center across one complete erectable joint, giving a test length of approximately 7.62 inches. The Belleville washer alignment pin, that also enabled the Belleville washer preload to be adjusted without taking the joint apart, was incorporated into the Type 6 joint, as described in Figure A6.

Table A1. Erectable Joint Axial Stiffness Data Summary.

Joint Type	Data Description	Equivalent Axial Stiffness (EA), lb	Comments
Type 2	Single Joint tested?	7.75×10^6	L = 15.5 inches Tested in 1986
Type 3	Most linear case	7.38×10^6	L = 7.62 inches Tested in 1988
	Average of 5 (best?) linear cases	6.77×10^6	L = 7.62 inches Tested in 1988
	Average of all (23) cases	6.14×10^6	L = 7.62 inches Tested in 1988
CLIP: Type 4	Specimen A, Test 2	6.22×10^6, mild nonlinearity through 0	L = 7.62 inches Tested in 1990
	Specimen B, Test 2	6.71×10^6	L = 7.62 inches Tested in 1990
	Specimen C, Test 2	Not calculated; moderate nonlinearity through 0	L = 7.62 inches Tested in 1990
	Specimen D, Test 2 (see Figure 5)	7.51×10^6	L = 7.62 inches Tested in 1990

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A1. Bush, Harold G., Herstrom, Catherine L., Heard, Walter L., Collins, Timothy J., Fichter, W.B., Wallsom, Richard E., Phelps, James E., "Design and Fabrication of an Erectable Truss for Precision Segmented Reflector Application," Journal of Spacecraft, Volume 28, No. 2, March–April 1991, pg. 251.

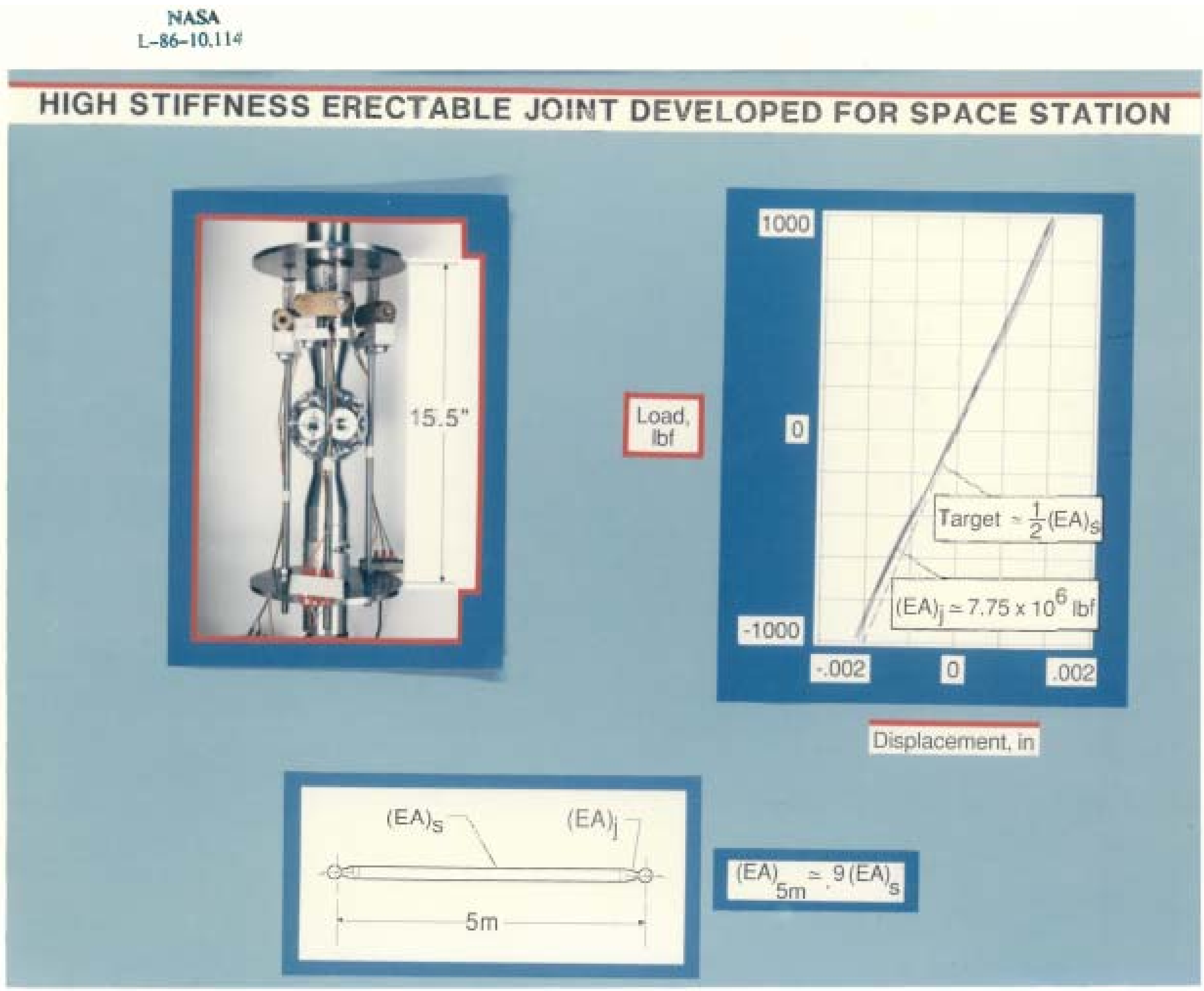

Figure A1. Type 2 Erectable joint test setup and axial stiffness data.

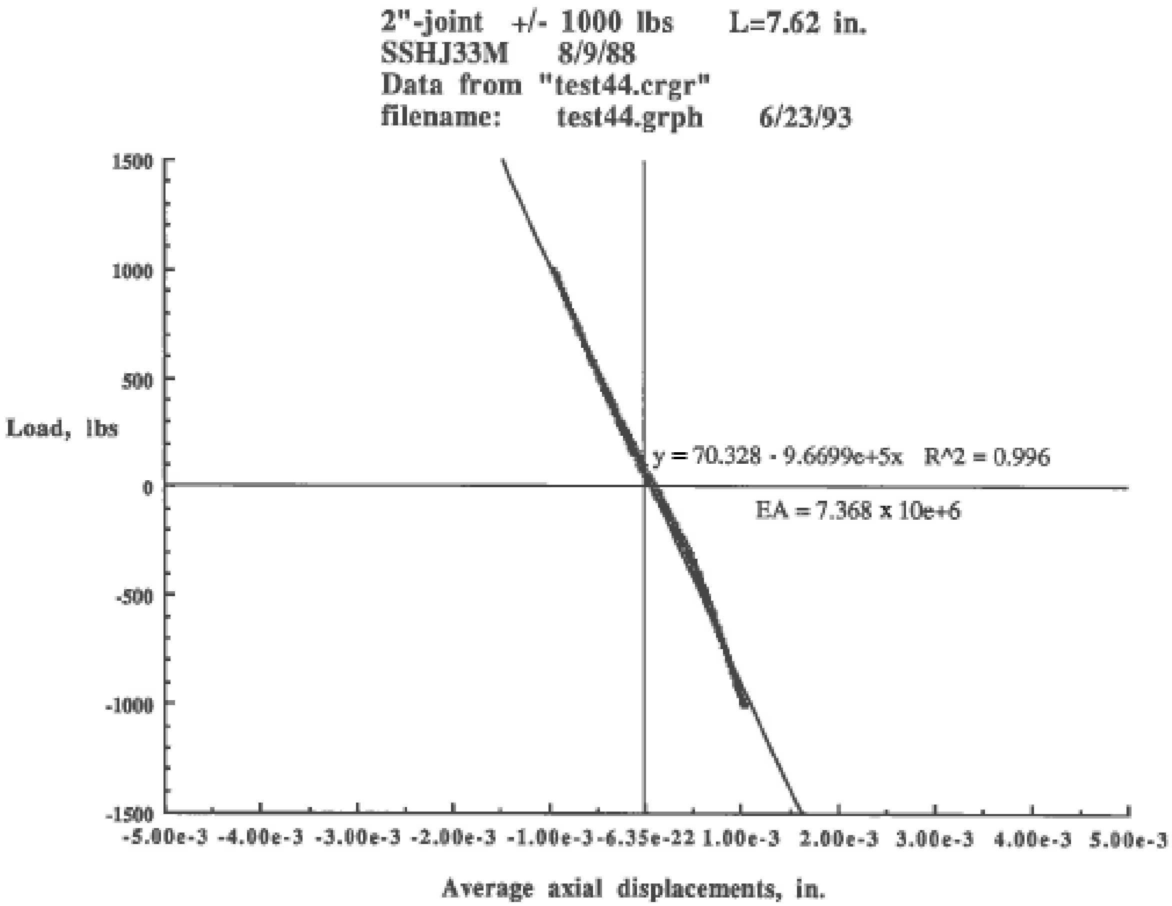

Figure A2. Representative data from Type 3 axial stiffness test.

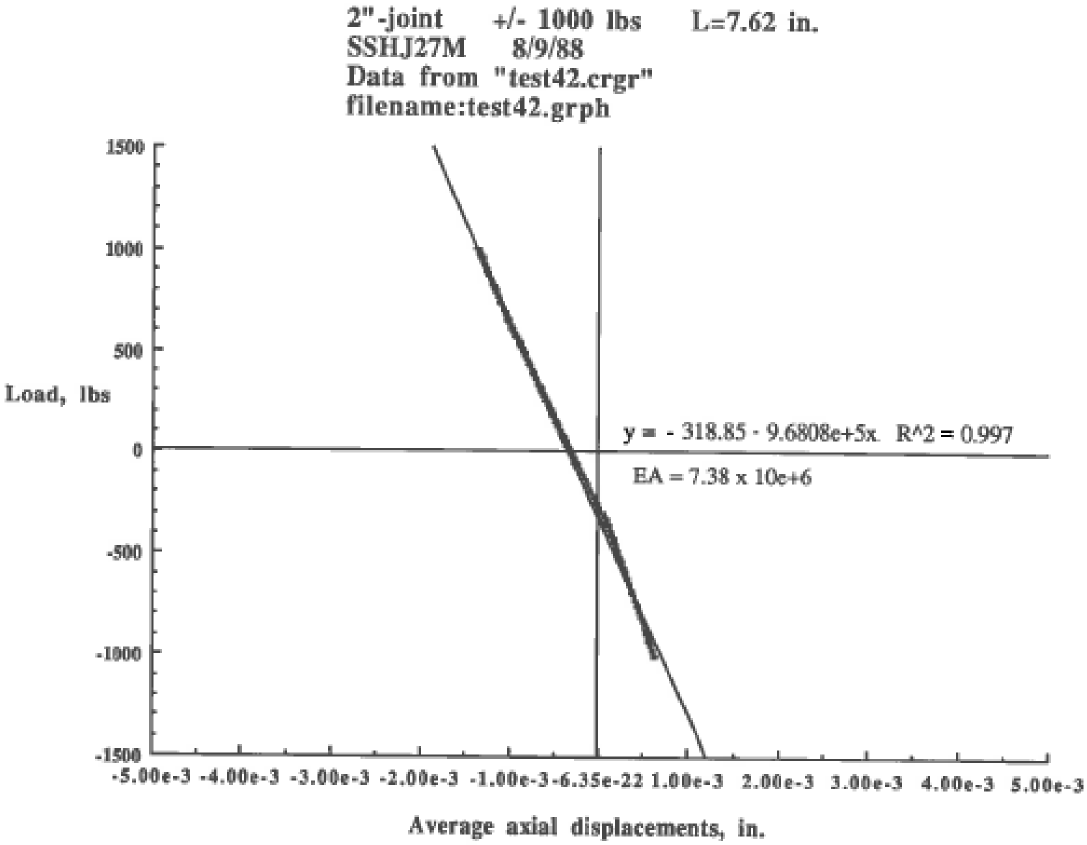

Figure A3. “Most linear” type 3 test data case.

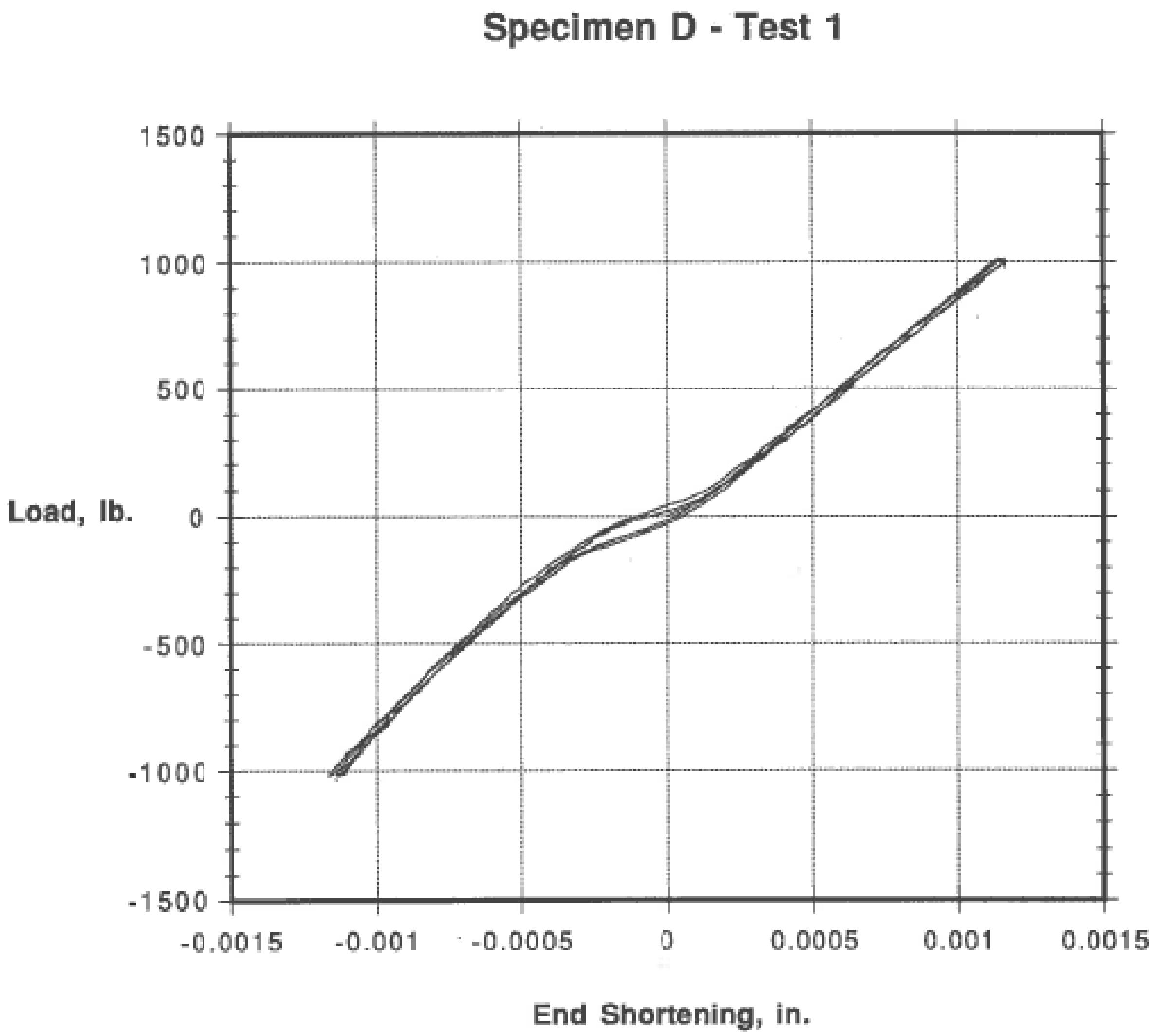

Figure A4. CLIP test data for joint Specimen D, Test 1.

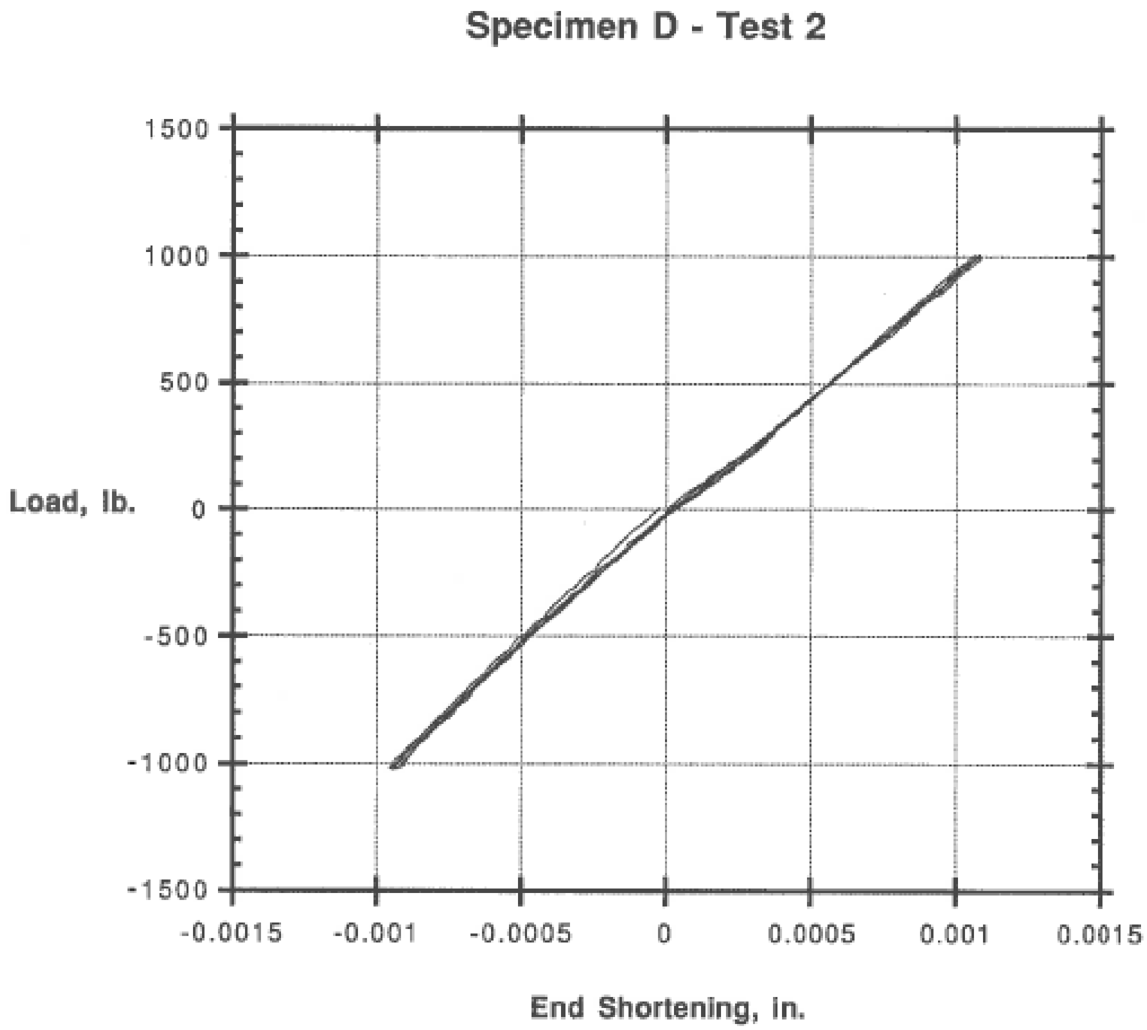

Figure A5. CLIP test data for joint Specimen D, Test 2.

Adjustable-Torque Truss-Joint Mechanism

A threaded pin is tightened or loosened; a tedious trial-and-error procedure is shortened.

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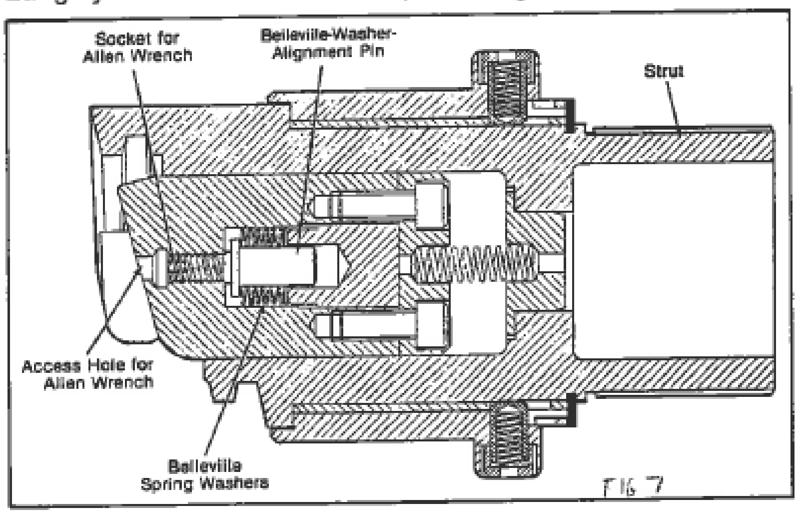

The Threaded Belleville-Washer-Alignment Pin is turned, by use of an allen wrench, to adjust the compression preload on the Belleville washers and thereby adjust the joint-operating torque.

A mechanism that joins a strut and a node in a truss structure can be preloaded to a desired stress to ensure a tight, compressive fit that prevents motion of the strut during loading or vibration. The preload stress on a stack of Belleville spring washers is adjusted by tightening or loosening a threaded Belleville-washer-alignment pin. Previously, in a tedious trial-and-error procedure, the joint was assembled, tested, and disassembled if the compression of the washers did not yield the specified joint-operating torque. Belleville washers were then added or removed, and the joint was reassembled. As many as six iterations were needed to obtain the correct preload.

The mechanism includes mating conical surfaces at the end of the strut and on the node. At full engagement, an internal latch mechanism is activated, locking the parts together. The latch mechanism comprises a latch bolt, the Bel-

For

leville washers stacked on the threaded alignment pin (see figure), a latch plunger, and a latch retainer. Latch-retainer screws hold the latch mechanism together.

The outer end of the Belleville-washer-alignment pin contains an allen socket. The installer can insert the allen wrench in the socket through an access port. To increase or decrease the compression of the Belleville washers, the installer tightens or loosens the pin, respectively. The washer-compression force is applied through the latch mechanism to the mating surfaces of the strut and the node.

By use of the allen wrench, the operating torque on the joint can readily be adjusted (via adjustment of the compression) to 45 lb•in. (5.1 N•m). Previously, the torque was measured after the joint had been assembled. If it did not fall within 43 to 47 lb•in. (4.9 to 5.3 N•m), the joint was disassembled and a different stack of Belleville washers was installed in the latch mechanism. This procedure was not only tedious and time consuming but also potentially damaging to parts of the joint.

This work was done by Harold G. Bush of **Langley Research Center** *and Richard E. Wallsom of Lockheed Engineering & Sciences Co. For further information,* ***write in 10*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 24]. Refer to LAR-14899.

Figure A6. Copy of article describing type 6 joint with updated Belleville washer alignment pin.

Appendix B. Axial Strength

Currently, data have been located on axial strength testing of what is likely to be either Type 3 or 4 joints, with a total of 3 joints tested to failure (ultimate load). The test set up is shown in Figure B1; steel rods were threaded into the ends of two joint halves, the joints were assembled and locked and then, tension (axial) load applied by the test machine. Load was applied to each joint until failure occurred. The failure mode for all three joints was identical; shear failure of the tongues, as illustrated in Figure B2. The ultimate axial failure loads for the 3 joints tested are summarized in Table B1. Since deflections were also measured during the test (using a set of 3 Direct Current Differential Transducers (DCDTs) spaced circumferentially at 120-degree increments), the joint stiffness value (tension only) can also be derived, and those values are also shown in the table. The load/deflection test data for test number 1 is shown in Figure B3.

Table B1. Erectable Joint Axial Strength Data Summary.

Test Number	**Failure Load, lbf**	**Axial Stiffness, lb/in**	**Comments**
1	20,125	1.43×10^6	For initial linear portion of curve; up to ~7000 lbf
2	20,500	1.33×10^6	For initial linear portion of curve; up to ~8000 lbf
3	20,175	1.38×10^6	For initial linear portion of curve; up to ~8250 lbf
Average of 3 cases	20,267	1.38×10^6	

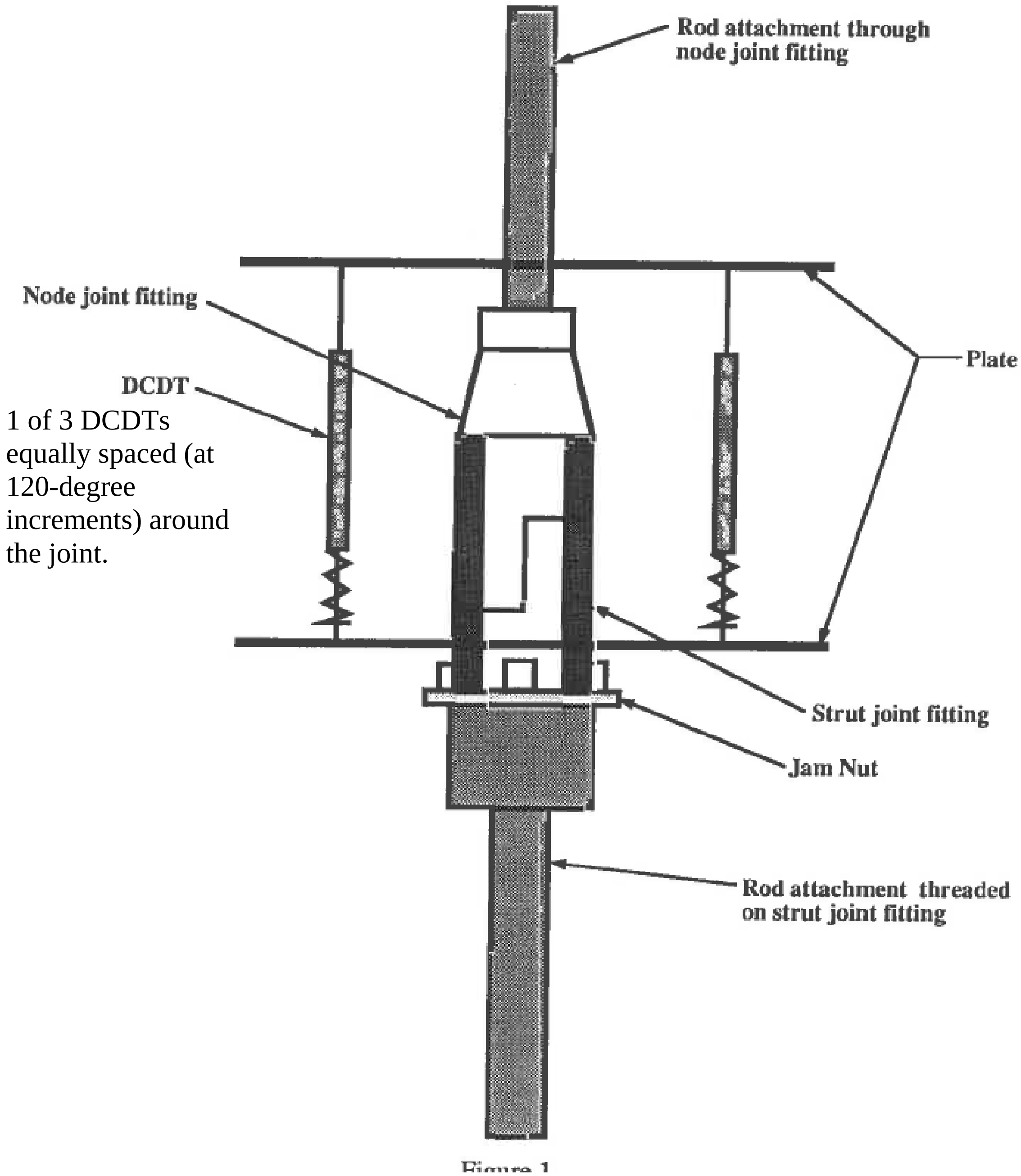

Figure B1. Test set-up to determine ultimate axial load of 2-inch erectable joint.

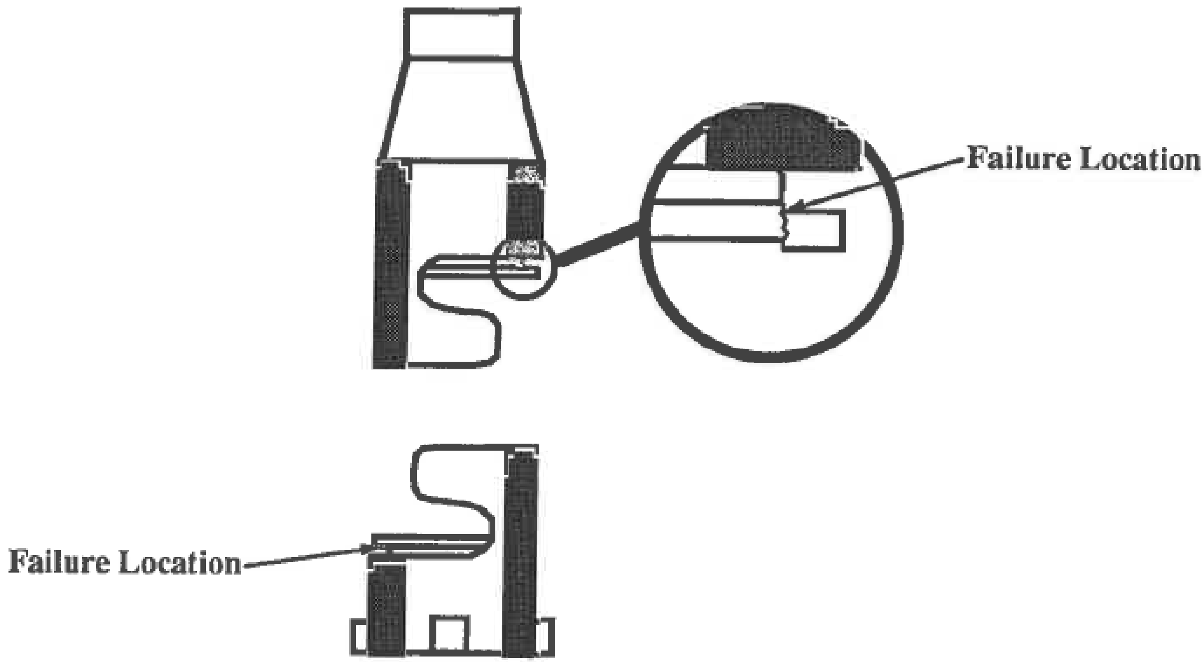

Figure B2. Axial joint failure mode: shear failure of material in the tongues.

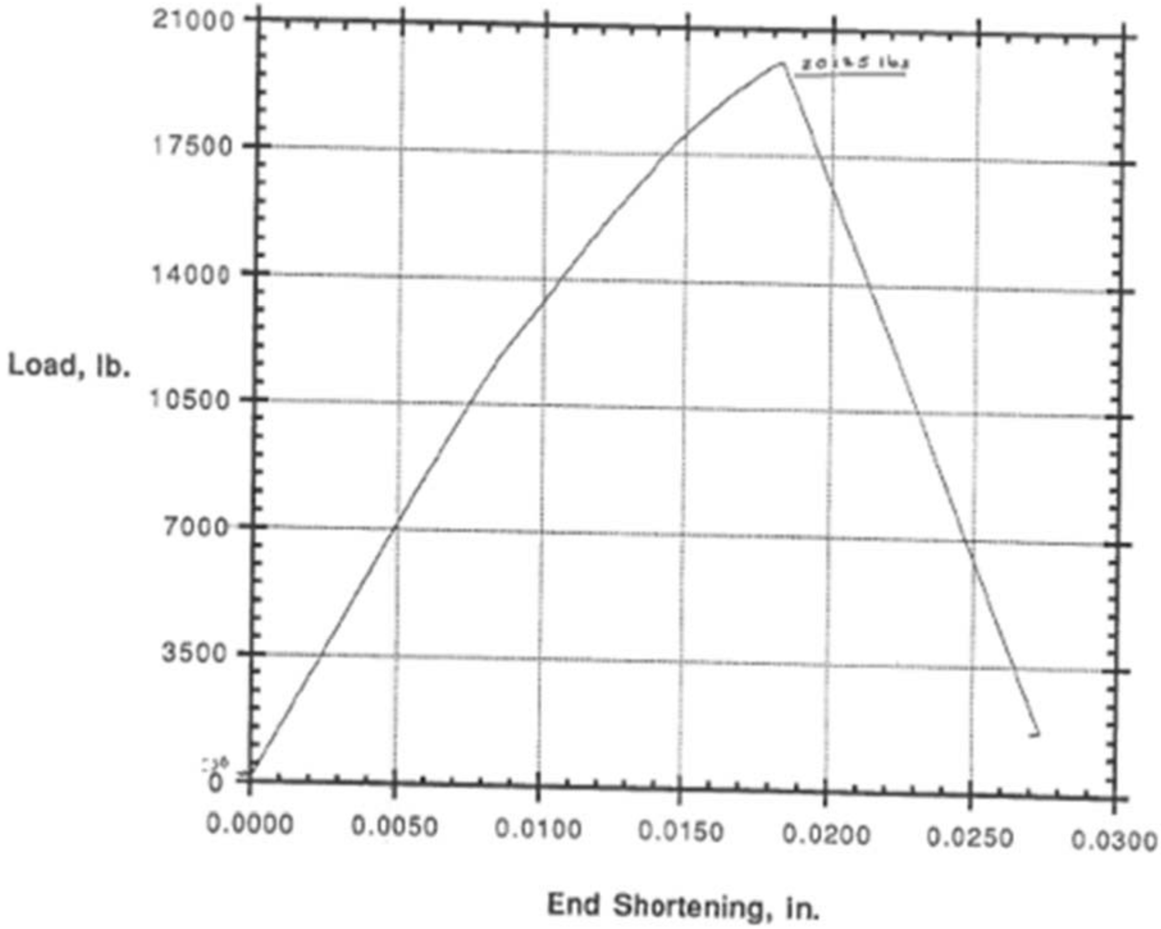

Figure B3. Data from ultimate load test of joint specimen 1.

Appendix C. Bending Stiffness

Data have been located on bending stiffness testing of the Type 4 joints. A test program was executed at LaRC to quantify the erectable joint bending stiffness. The test set up is shown in Figure C1; a truss node ball is at the center of the test article and to the left and right a passive joint half is bolted to the node (180 degrees apart), active joint halves are attached to each passive joint half and locked. A short section of tube is attached to each active joint half. The ends of the tubes are simply supported in fixtures and a force is applied to the node resulting in a 3-point bending test that achieves a pure moment along the entire test length. Since the erectable joint is designed for side insertion into a truss structure, there are two major orientations, each having a different path for transferring load across the joint, and each orientation was characterized. The joint in the major-axis orientation, shown in Figure C2, resolves the applied moment into tension and compression loads across the top and bottom of the joint. The minor-axis orientation resolves the applied moment across the joint ears (which serve as assembly alignment features).

Two different sets of tests were performed in 1990; the first tested a single joint to validate the test procedure and set up, and then a second set where four different joints were tested. In the tests, the load was varied between -100 lbf and +100 lbf and deflections measured at various locations along the test article (DCDTs used to measure deflection can be seen in Figure C2). The joint bending stiffness was derived using the methods developed in Reference C1. The bending stiffness of the aluminum tube section used in the test set up was also required in order to derive the joint stiffness and was also measured using the test setup shown in Figure C1. The values of joint bending stiffness measured from the tests are summarized in Table C1.

Table C1. Erectable Joint Bending Stiffness Data Summary.

Test Series	**Bending Stiffness - Major, 10^6 lb-in^2**	**Bending Stiffness - Minor, 10^6 lb-in^2**	**Comments**
Aluminum Tube	2.11		Theoretical value = 2.094 x 10^6 lb-in^2
1	2.14	1.90	
2	2.23	1.77	Joint 1
2	2.37	2.05	Joint 2
2	2.35	1.94	Joint 3
2	2.32	1.92	Joint 4
Average Series 2	2.32	1.92	

REFERENCES

C1. Wu, K. Chauncey, “Characterization of the Bending Stiffness of Large Space Structure Joints,” NASA Technical Memorandum 101565, NASA Langley Research Center, Hampton, VA, May 1989.

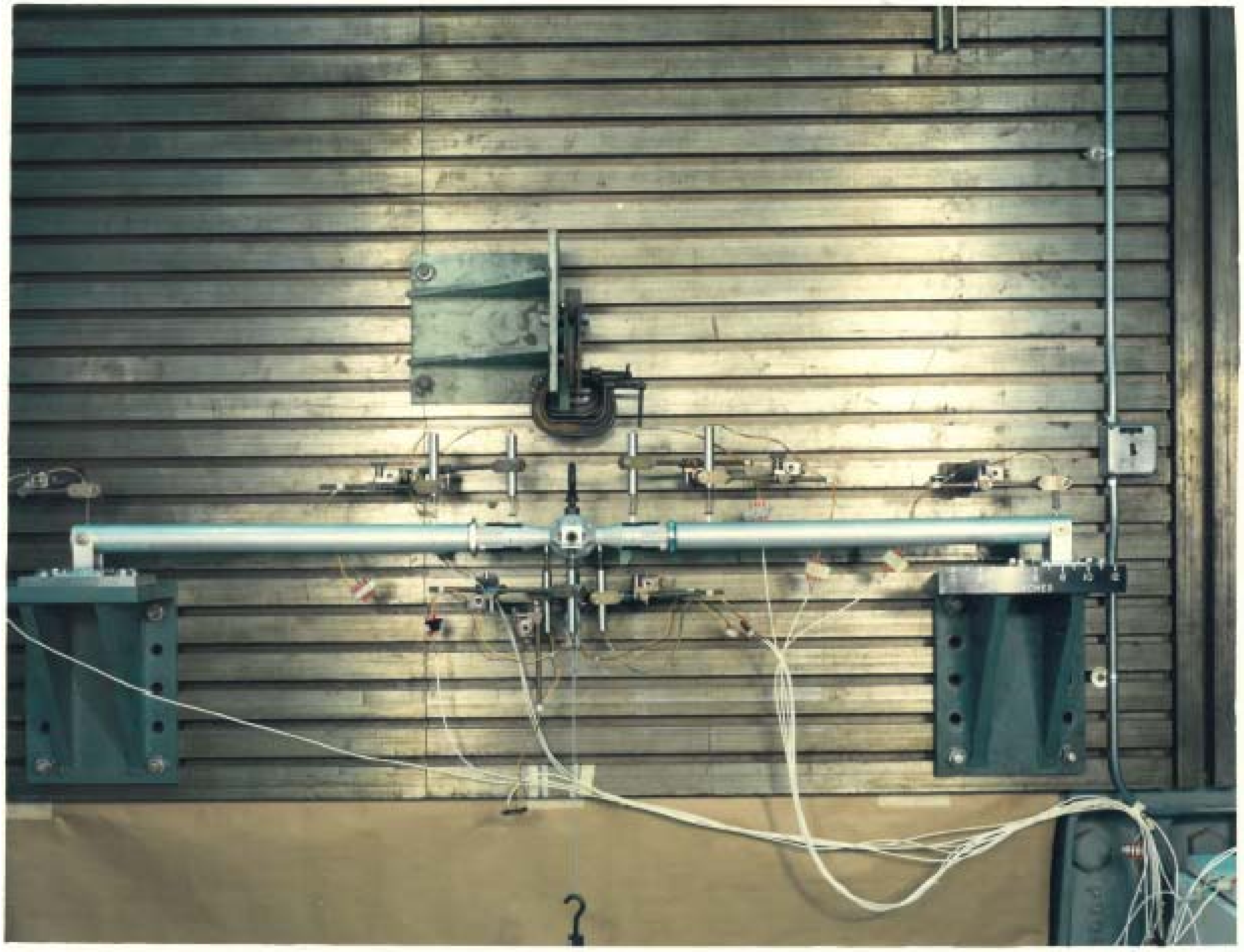

Figure C1. Test set-up to determine bending stiffness of 2-inch erectable joint.

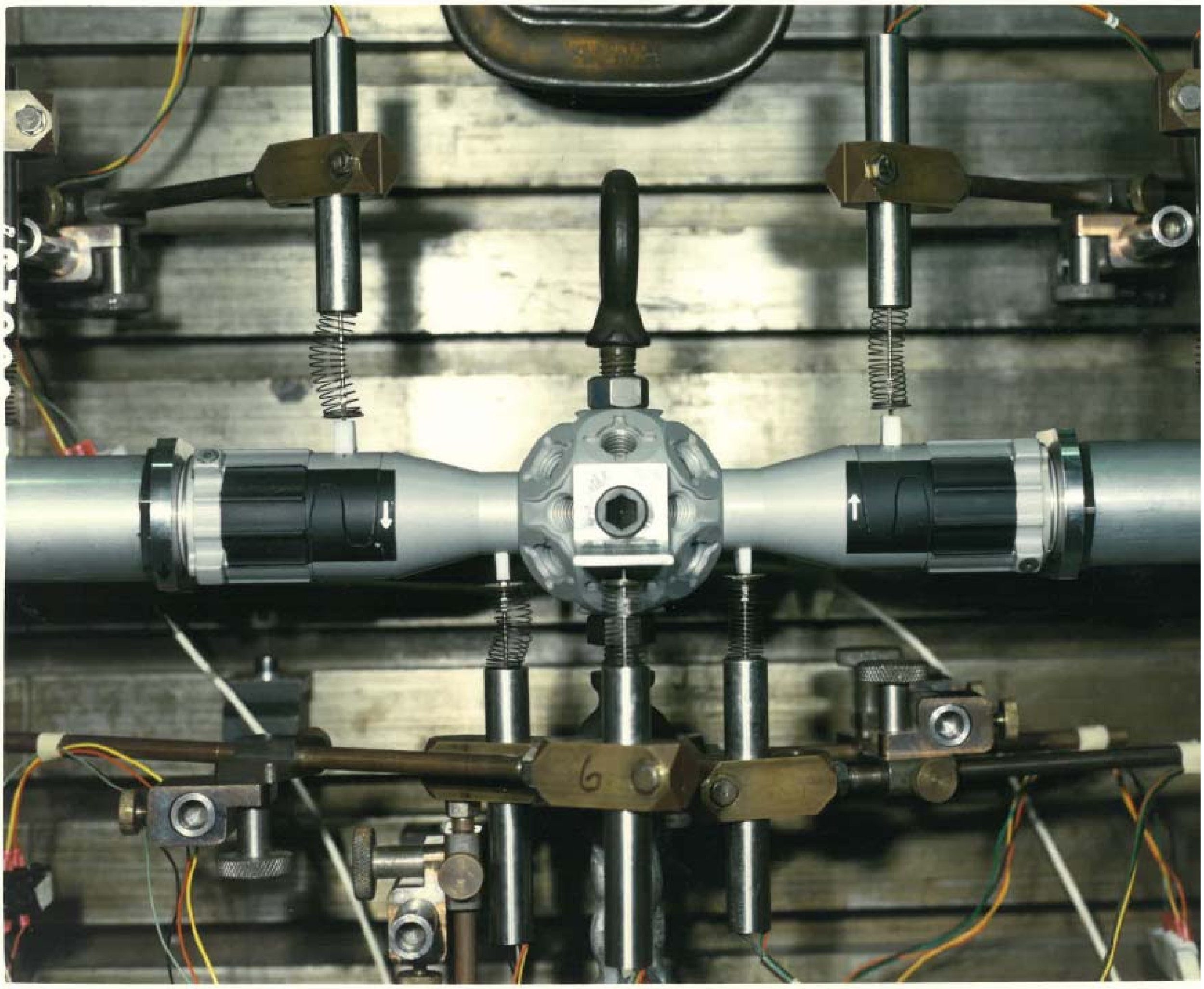

Figure C2. Bending test setup showing stiffness in major-axis direction being tested.

Appendix D. Bending Strength

Data have been located on bending strength testing of what is likely to be either Type 3 or 4 joints. A test program was executed at LaRC to quantify the erectable joint ultimate load (bending moment) capability and the results used to qualify the structure for flight without any modification. The test set up is shown in Figure D1; a truss node ball was attached to a structural backstop, a passive joint half was bolted to the node ball, the active joint half was inserted and locked into the passive joint half, and a short section of tube attached to the active joint half. A force was applied near the end of the tube, which created a moment across the joint. Since the erectable joint is designed for side insertion into a truss structure, there are two major orientations, each having a different path for transferring load across the joint, and each orientation was characterized. In the top of Figure D1, the major-axis orientation resolves the applied moment into tension and compression loads across the top and bottom of the joint. In the bottom of Figure D1, the minor-axis orientation resolves the applied moment across the joint ears (which serve as assembly alignment features).

In initial tests, a low-strength bolt (80 ksi ultimate strength, 30 ksi yield strength), was used to attach the passive joint half to the node ball. In the four tests performed, two each in the major and minor-axis orientation, bolt yielding was the failure mode. In the next sequence of tests, the low strength bolt was replaced with a high strength bolt (190 ksi ultimate strength, 170 ksi yield strength). A small number of failure tests with the high strength bolt were completed and the results are summarized in Table D1 with failure locations illustrated in Figure D2. Note that for the major axis, the level of preload in the bolt influenced the joint failure load. Joints bending in the major-axis orientation failed by shearing a joint tongue (on the tension side). The failure was detected by a drop in the load cell reading occurring when a distinct popping sound was heard. However, the joint did not separate. Two initial tests were run for the minor axis, but in both tests there was no failure and the tests were stopped when the DCDTs went out of range. The maximum moments across the joint, achieved at the time the tests were stopped, were 1407 ft-lb and 1393 ft-lb. A third test was run for the minor axis and load applied until the joint failed. The failure was detected by a drop in the load cell reading and by separation of the joint when both tongues and two ears were sheared from the joint, as shown in Figure D3.

Table D1. Erectable Joint Bending Strength Data Summary.

Joint Orientation: Axis	**Failure Moment, ft-lb**	**Failure Mode**	**Comments**
Major	1244	Tongue Sheared	High-Strength Bolt; Bolt preload was 120 ft-lb
Major	1024	Tongue Sheared	High-Strength Bolt; Bolt preload was 190 ft-lb
Minor	1360	Failure of Tongues and Ears	High-Strength Bolt; Bolt preload was 120 ft-lb

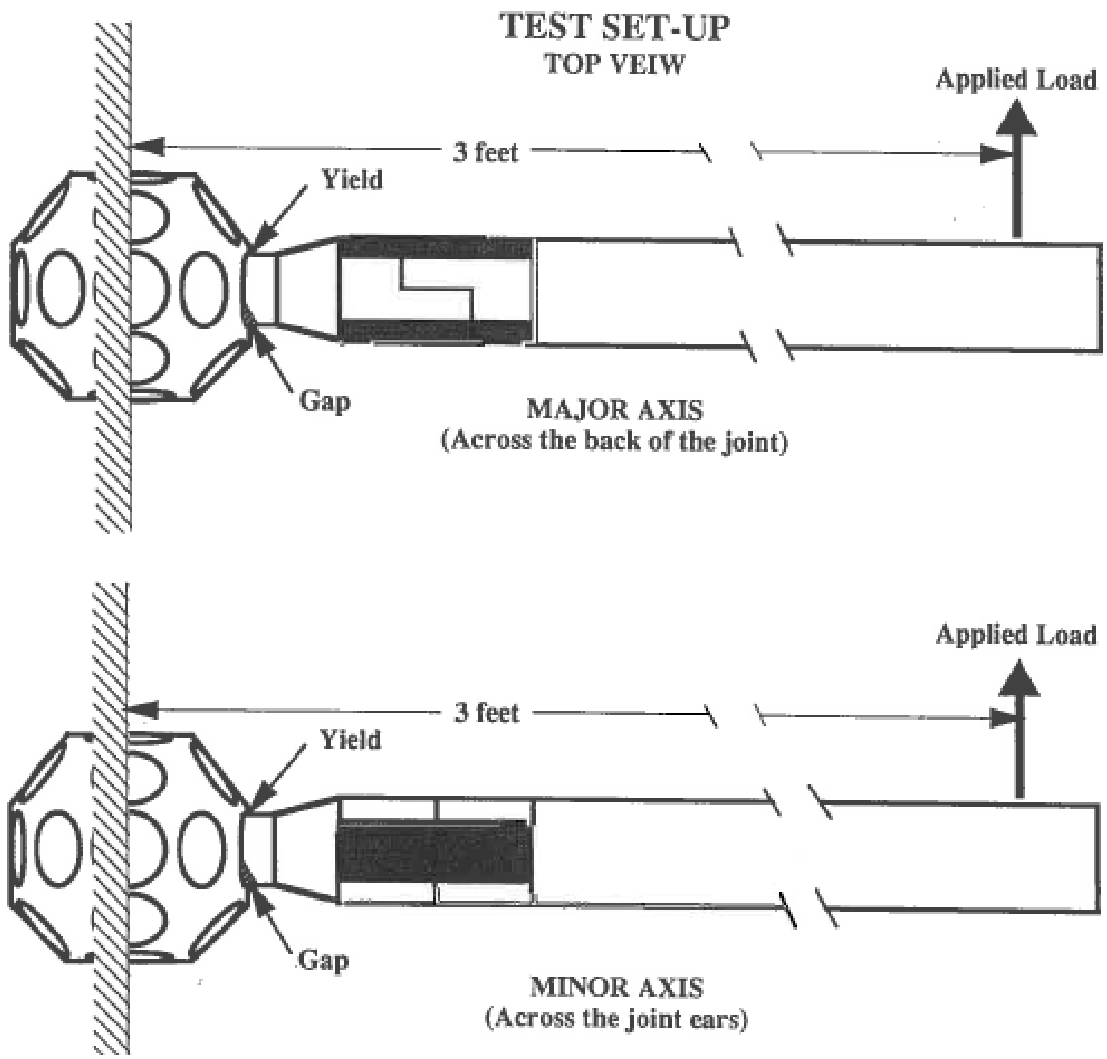

Figure D1. Test set-up to determine ultimate bending load of 2-inch erectable joint: areas of yield and gap refer to tests using low-strength bolt.

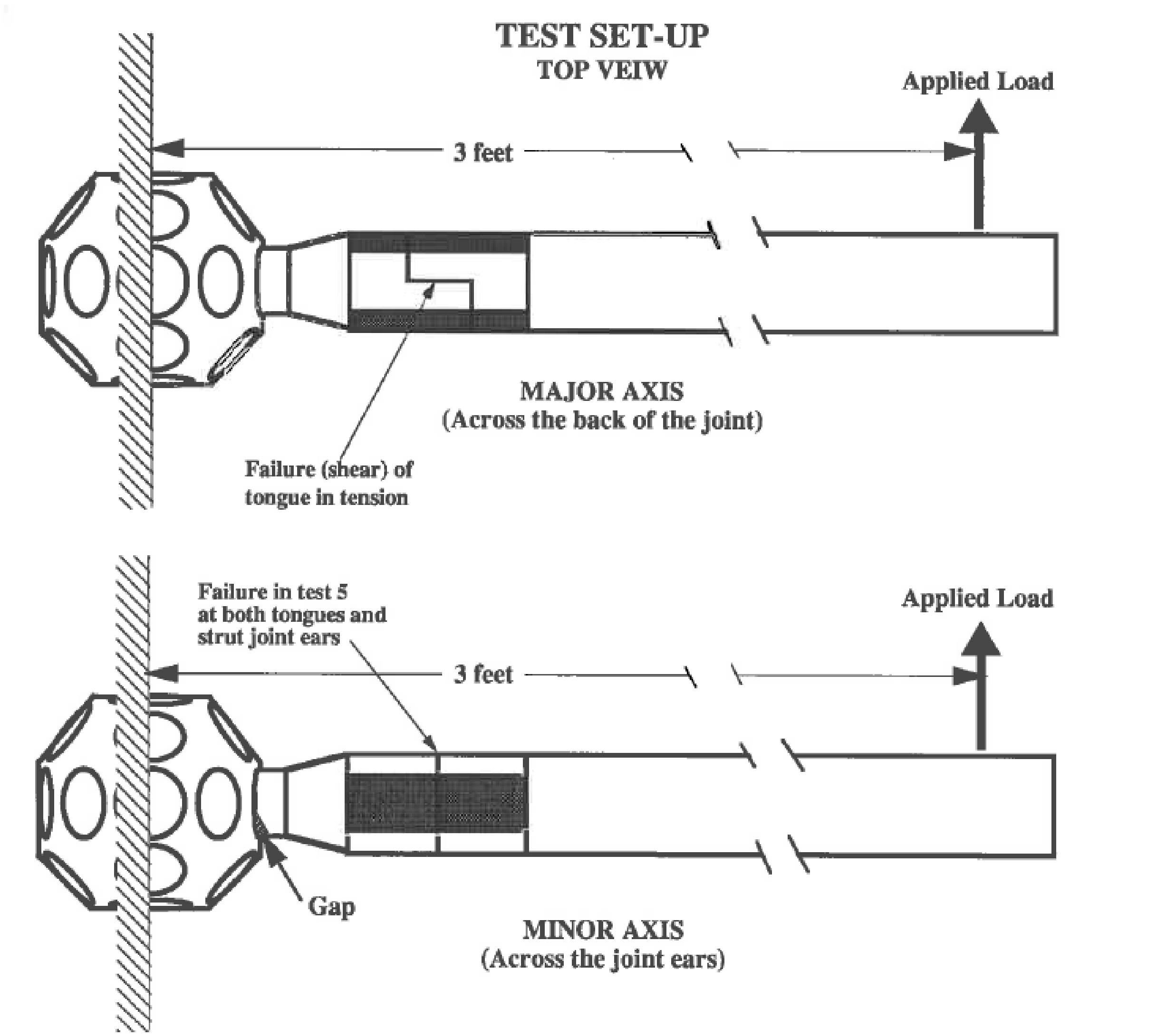

Figure D2. Bending joint failure modes for major-axis and minor-axis orientations; high-strength bolt.

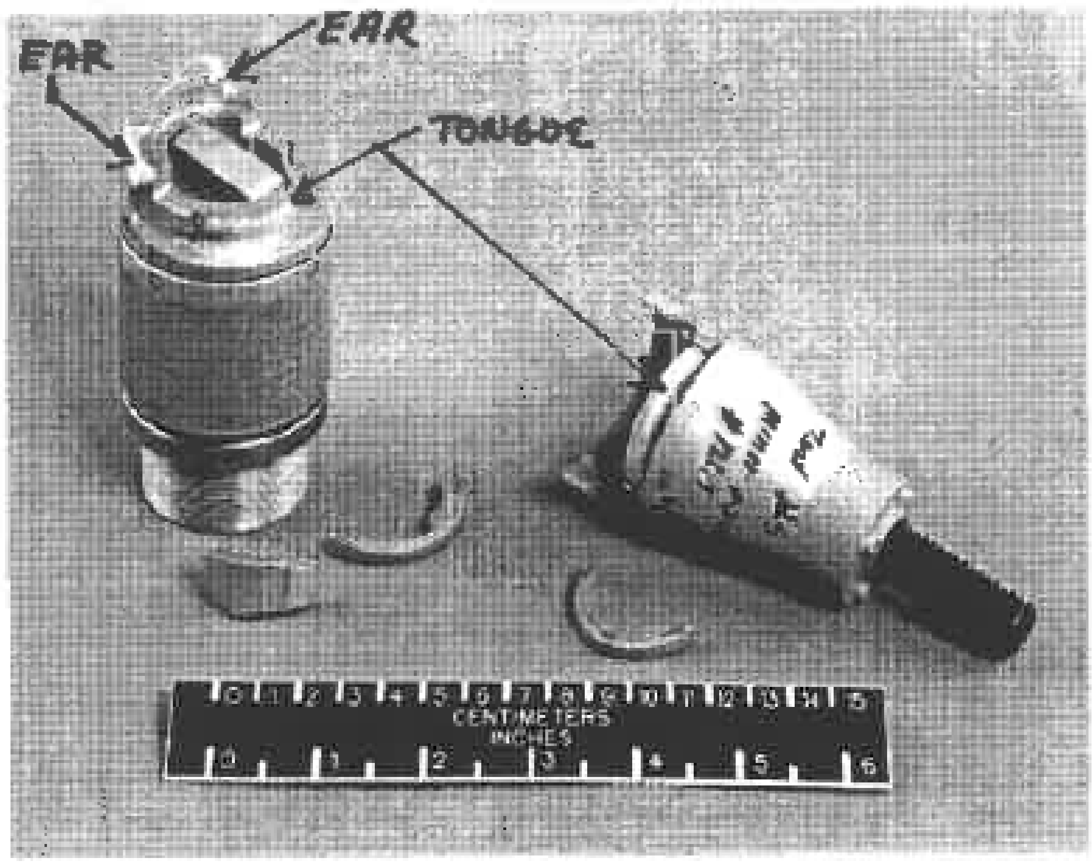

Figure D3. Failure locations for minor-axis bending test.

Appendix E. Torsion Stiffness

Data have been located on torsional stiffness testing of the Type 4 joints. A test program was executed at LaRC to quantify the erectable joint torsional stiffness. The test set up is shown in Figure E1; a truss node ball is at the center of the test article and to the left and right a passive joint half is bolted to the node (180 degrees apart), active joint halves are attached to each passive joint half and locked and short sections of tube attached to each active joint half. A torsion machine key fitting was attached to each of the tubes on their free ends and interfaced with the torsion machine on the other end. When inserted into the machine shown in Figure E1, one end of the test assembly was fixed and the other end was subjected to a pure torque, as represented in Figure E2. DCDTs were used to measure the twist angle at ten locations along the test assembly.

Six tests were performed on a single Type 4 joint/node/joint specimen in 1990. An aluminum tube was also tested. In each test, the torque was varied from 0 to either -1200 in-lbs or +1200 in-lbs, with the results summarized in Figure E3. In general, the torsional stiffness was highly nonlinear between 0 in-lb and ±300 in-lb of torque; during this time the gap (which is between 0.05 inches and 0.075 inches) between the ears on the two joint halves is being closed. Once the ears make contact, the slope/stiffness increases and tends to become more linear. Of the six tests performed, the results from two (9 and C indicated in Figure E3) were not used because of the anomalies in the tests listed in the Figure. The results of the other four tests are summarized in Table E1. Since the torsional stiffness testing applied torques of ± 1200 in-lbf with no failure occurring, it is inferred that the torsional strength of the joint is > ± 1200 in-lbf.

Table 1. Erectable Joint Torsion Stiffness Data Summary.

Test Series	**Load Range, in-lbf**	**Torsional Stiffness (GJ), 10^6 lb-in^2**	**Comments**
Aluminum Tube	0 to 1200, 1200 to 0	1.59, 1.59	Theoretical value = 1.61 x 10^6 lb-in^2
7	0 to -1200	0.612	Clockwise Direction
7	-1200 to 0	0.704	
8	300 to 1200	0.380	Counter Clockwise Direction
8	1200 to 300	0.842	
A	0 to -1200	0.639	Clockwise Direction
A	-1200 to 0	0.666	
B	300 to 1200	0.427	Counter Clockwise Direction
B	1200 to 300	0.818	
Average		0.6198	

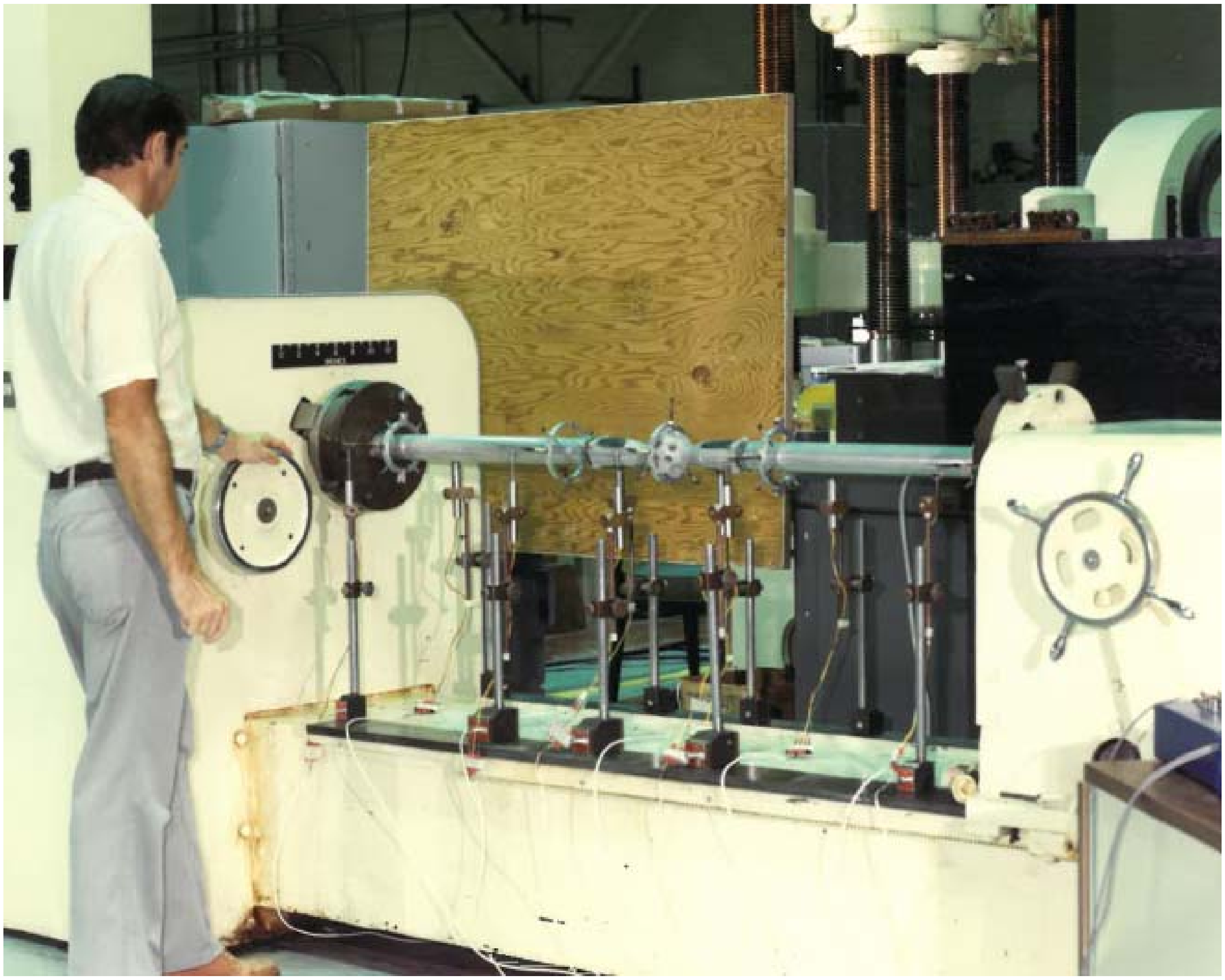

Figure E1. Test set-up to determine torsion stiffness of 2-inch erectable joint.

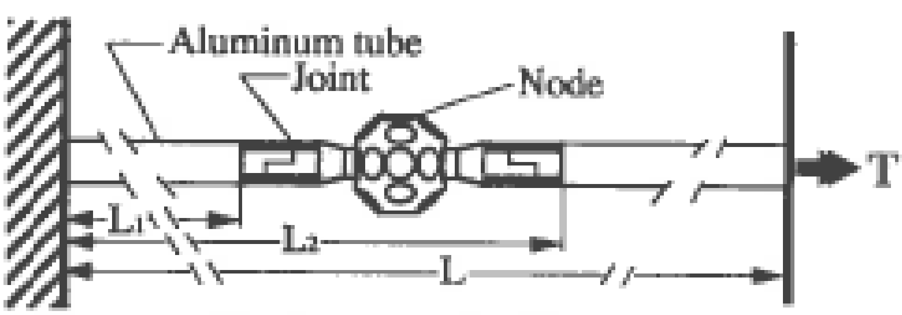

Figure E2. Torsion test set up representation showing boundary conditions.

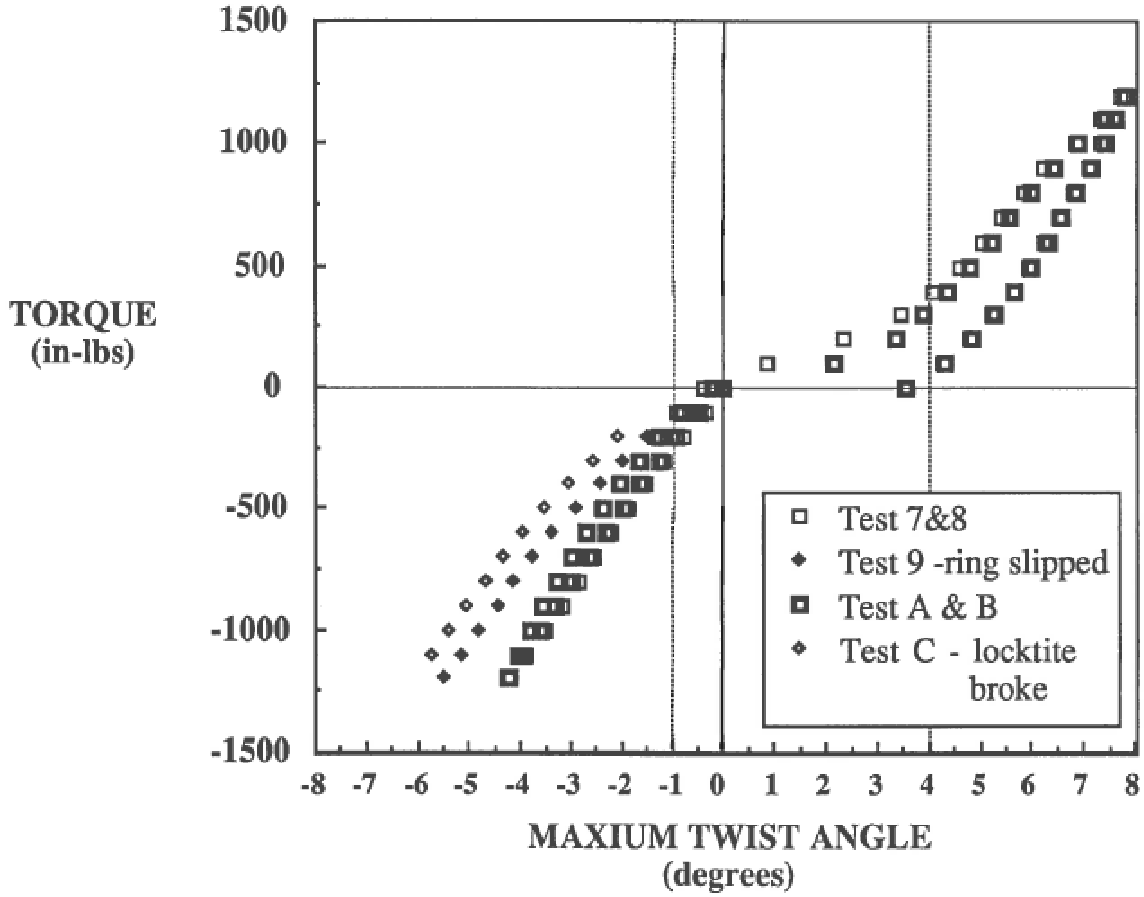

Figure E3. Torsion test results.

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14. ABSTRACT

As the National Space Transportation System (STS, also known as the Space Shuttle) went into service during the early 1980's, NASA envisioned many missions of exploration and discovery that could take advantage of the STS capabilities. These missions included: large orbiting space stations, large space science telescopes and large spacecraft for manned missions to the Moon and Mars. The missions required structures that were significantly larger than the payload volume available on the STS. NASA Langley Research Center (LaRC) conducted studies to design and develop the technology needed to assemble the large space structures in orbit. LaRC focused on technology for erectable truss structures, in particular, the joint that connects the truss struts at the truss nodes. When the NASA research in large erectable space structures ended in the early 1990's, a significant amount of structural testing had been performed on the LaRC 2-inch erectable joint that was never published. An extensive set of historical information and data has been reviewed and the joint structural testing results from this historical data are compiled and summarized in this report.

15. SUBJECT TERMS

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