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SUBJECT: Forwarding of Change 1 to Materiel Test Procedure 5-2-504

TO: SEE DISTRIBUTION

1. The new pages should be inserted in their proper place in MTP 5-2-504 and the replaced pages should be destroyed.

FOR THE COMMANDER

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U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

STRUCTURAL TESTING FOR NONOSCILLATING STEADY STATE AND TRANSIENT LOADS

1. OBJECTIVE

The objective of this MTP is to instruct personnel in the techniques of conducting realistic structural load environment testing in conjunction with other applicable materiel test procedures.

2. BACKGROUND

Nonoscillating steady state and transient loads occur throughout the life of a missile. These loads are created by prefiring environmental forces, thrust forces, and aerodynamic forces which affect the missile. Structural load testing of a test specimen is conducted to discover areas in which design changes might be necessary to ensure that structural limitations do not have a deleterious effect on the missile performance.

Certain procedures for subjecting a test specimen to structural load tests have been developed. These procedures, properly used, determine the degree of the test specimen's structural adequacy with all phases of a predicted environment.

3. REQUIRED EQUIPMENT

a. Tape Recorders
b. Oscillograph Records
c. Motion Picture Cameras and film
d. Multichannel Recorders
e. Load Cell
f. Strain Bar
g. Pressure Pickup Strain Gage
h. Photoelectric Cell
i. Stress Coating Displacement Transducer
j. Dial Gage Indicator
k. Precision Level
l. Structural Rigs (to include: Hydraulic pistons, turn buckels or weights, steel cables, and whippletrees)
m. Fabric Straps
n. Fabric Tabs
o. Laboratory (for room ambient conditions) (if applicable)
p. Missile manufactures and military instructions and/or specifications

4. REFERENCES

A. Static Test of Cantilevered Fin Mount XM-50 Rocket, The Emerson Electric Manufacturing Company, Report No. 912

B. Static Test of XM-50 Rocket, The Emerson Electric Manufacturing Company, Report No. 908
C. Niles, Alfred S., Airplane Structures, Volume 1, Fourth Edition, Joseph S. Mowelle, 1954
D. Testing Techniques for Full-Scale Missile Structures Under Simulated Re-Entry Environment, Experimental Mechanics, January 1961
E. MIL-E 5272 C (ASG), "Environmental Testing, Aeronautical and Associated Equipment, General Specification For"

5. SCOPE

5.1 SUMMARY

This materiel test procedure describes the following test procedures:

a. Preparation for structural load test - A study to determine the desired equipment and facility required for the test, and the test item's physical characteristics and physical condition.

b. Structural load test - This test procedure describes the necessary particulars to be performed when the test item is subjected to structural load tests.

5.2 LIMITATIONS

The procedures in this MTP deal with loads that occur during missile flight and recovery of the launch vehicle but are limited to loads that are nonoscillatory but not necessarily static. In most cases, each structural test to be conducted is a special case, so specific instructions are not generally appropriate. Theoretical coverage and mathematical development is limited to that required to understand the practical aspects of structural load testing.

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 Test Personnel

Prior to conducting structural load tests, test personnel shall perform the following:

a. Review all available pertinent manufacturer's and military instructions and/or specifications.

b. Review operating instructions pertaining to the test equipment and instrumentation.

c. Review and understand the symbols, and their meaning, listed in Table I.

d. Prepare log folders for each test specimen tested.

NOTE: Log folders will contain all test data, including the number of times and the date when the test was conducted. The log will be complete, accurate and up-to-date, as they may be used for future load distribution analyses.

6.1.2 Testing Facilities and Equipment

The appropriate test facilities and equipment to be used shall be determined by performing the following:

NOTE: Test facilities and equipment, which have proven effective through previous use, should be used. Equipment should be accurate to the magnitude ten greater than the function being measured. Various structural testing devices and structural rigs are required for conducting the structural load tests. Any kind of structural rig able to absorb and distribute loads as required by the test procedures can be regarded as a structural test facility.

a. Select the facility and equipment to be used during the conduct of structural load testing using the criteria of Appendix A.

b. Determine test equipment limitations, with regard to allowable tensile loads and maximum strain, in order to avoid possible damage.

c. Determine which test condition(s) will be required for the structural load tests:

1) Tests conducted at laboratory room ambient conditions
2) Tests conducted in a specified environment and then compared with the results of similar tests conducted at laboratory room ambient conditions
3) Tests conducted in a specified environment and then repeated at laboratory room ambient conditions

NOTE: Environmental tests generally are conducted in accordance with the latest revisions to military specification MIL-E-5272C (ASG), "Environmental Testing, Aeronautical and Associated Equipment, General Specification For", a variation of this specification, or the applicable MTP.

d. Determine the load environment to which the structure will be subjected (bending moments, shear, torsion) and the expected reaction from this environment in the form of strain and deflection using the following criteria:

1) Technical data obtained from design and structural analyses
2) Histories of previous failures under a particular environment
3) Contractor and military specifications

TABLE I. SYMBOLS USED

Symbol	Description	Unit (if any)
A, B, C, D	Discrete Forces	lb.
E	Modulus of Elasticity	psi
F	Area	in^2
G	Resultant Force	lb.
K	Strain Gage Sensitivity	-
L	Longitudinal Force	lb.
M	Bending Moment	in-lb.
P	Force	lb.
R	Resistance	ohm
AR	Change in Resistance	ohm
S	Shear	lb.
T	Torsion	in-lb.
V	Voltage	volt
o	Stress	psi
a, b, c	Moment Arms	in.
d	Length of Missile Structure	in.
f	Acceleration	in/sec^2
$\Delta\lambda/\lambda$	Strain	-
m	Mass	slug
n	Positive Integer	-
P	Pressure	$lb./in^2$
r	Moment Arm of Resultant Force	in.
w	Continuous Load	lb./in.
x	Abscissa Coincident with Missile Axis	in.
1, 2, 3	Missile Stations	
Subscripts:		
A	Aerodynamic	-
B	Active	-
C	Compensating	-
P	Parachute	-
α }	Assured Values	-
β }	Assured Values	-
γ }	Assured Values	-

Table I lists the symbols that will be maintained in subsequent illustrations, equations, and text. A thorough understanding of the symbols and their meaning is necessary before preceding with the material in this MTP.

6.1.3 Preparation of Test Specimen

a. Inspect the missile and record the following, if applicable:

1) Physical damage
2) Evidence of corrosion
3) Surface imperfections
4) Other deficiencies

b. Ascertain that the test specimen's physical characteristics are in accordance with its military specification and record the following:

1) Deviations from the test specimen's military specifications
2) Missile weight
3) Missile length
4) Missile maximum diameter
5) Location of center of gravity

6.1.4 Instrumentation

Instrument the test specimen using the criteria of Appendix B.

NOTE: Because of the test specimen's dead weight considerations, obtain zero load instrument readings prior to positioning the test specimen in its test configuration.

6.2 TEST CONDUCT

Place the test specimen in its test configuration and perform the following:

6.2.1 Structural Load Testing

a. Using the considerations of Appendix C, subject the test specimen to structural load testing.
b. Record the following for each test conducted:

1) Date of test
2) Test number
3) Environment being simulated
4) Load source being used
5) Load number being used
6) All test equipment settings at which the tests were conducted
7) Conditions being simulated:

   a) Loads applied
   b) Strains developed
   c) Deflections

8) Type or size of load failure
9) If whiffletrees are used, record the single forces that act on the test specimen

NOTE: The only direct load measurement is the main force that acts on the last member of the wiffletrees arrangement. The procedure described in Appendix A has to be reversed to obtain the single forces that act on the test specimen. This is done easily, since all forces within a whiffletree arrangement change in proportion to the main force. Referring to Figure A-3, Appendix A, and assuming that the main force changed from 850 lbs. to 1300 lbs., obtain the new single forces on the missile by multiplying each of them by $\frac{1300}{850} = 1.5294$.

Old Values	70	110	40	70	50	130	150	60	120	50
New Values	107.0	168.2	61.3	107.0	76.5	198.8	229.4	91.8	183.5	76.5

The moment is then obtained by multiplying each of these forces by its active moment arm. A plot of the moments versus the missile station then yields the moment diagram. Similarly, the loads and deflection versus missile station can be plotted. A comparison between test requirements and test results will show whether the missile structure gives the expected performance or will reveal weak spots in the design of structural members.

10) Determined slippage

NOTE: Slippage between missile sections can be detected if a sufficient number of deflection readings are taken, i.e., at least three points on a missile section. Slippage can be a rather critical mode of failure, because it changes the aerodynamic configuration of the missile, which in turn leads to considerable error in the missile trajectory.

Another indication of slippage occurring in the structure is a sudden decrease of load, provided the response to an error signal in the closed loop system is slow enough. The force required to produce a certain amount of deflection is smaller after the slippage has occurred. Besides the moment, shear, and deflection diagrams, which have the missile axis as the independent variable, other useful relationships can be established. For a particular missile station, strain and deflection versus the bending moment can be plotted. This immediately reveals the manner in which changes in strain and deflection take place.

c. Obtain recordings of the following vs. time:

1) Applied loads
2) Developed strains
3) Developed deflections

6.3 TEST DATA

6.3.1 Preparation of Test Specimen

Record the following:

a. For missile inspection, as applicable:

1) Physical damage
2) Evidence of corrosion
3) Surface imperfections
4) Other deficiencies

b. Physical characteristics as prescribed by specific requirements and:

1) Deviations from these requirements
2) Weight in pounds
3) Length in feet
4) Maximum diameter in feet
5) Location of center of gravity

6.3.2 Structural Load Testing

a. Record the following for each test conducted:

1) Date of test in day, month and year
2) Test number (1, 3, 5, etc.)
3) Environment (ambient temperature, extreme low temperature)
4) Load source used (hydraulic cylinder, weights)
5) Load number being used (whiffletree, strain bar)
6) All test equipment settings at which the tests were conducted
7) Condition being simulated (prefiring handling; lateral thrust forces, etc.)
8) Type or size of load failure
9) Single forces that act on the test specimen, if whippletrees were used
10) Slippage

b. Retain the continuous recording of:

1) Applied loads
2) Resulting strains
3) Resulting deflections

6.4 DATA REDUCTION AND PRESENTATION

a. Data reduction and presentation will consist of reducing the data from instrument indications and physical measurements to tabular form which permits comprehensive analysis and evaluation.

b. Charts, graphs and conversion calculations will become a permanent record in the log folder.

c. Test evaluation reports shall contain the following:

1) Test requirements, i.e., the environment to which the specimen was subjected (bending moments, shear, torsion) and the expected reactions from this environment in the form of strain and deflection.
2) Test results, i.e., the information obtained from the actual test (bending moments, shear, torsion, strain and deflection)
3) Comparison between 1 and 2 above. In the case of deviations between test requirements and results, the reasons for the deviation shall be described and methods to improve the situation should be recommended.

GLOSSARY

1. Moment: The product of a quantity (as force) and a distance to a significant point or axis connected with that quantity.

2. Bending Moment: The external bending moment at any section in a beam or truss is equal to the algebraic sum of the moments about the gravity axis of the section, assuming that all of the external forces are acting in one plane.

3. Shear: A stress which displaces a plane of a solid body parallel to itself and relative to other parallel planes within the body. An extreme shearing stress would cause adjacent planes to slide over each other.

4. Torsion: A transverse load which does not intersect the elastic axis of the member on which it acts, subjects that member to torsion.

5. Whiffletree: A pivoted swinging bar to which cables or straps are attached, which in turn are connected to other whiffletrees or to a test specimen.

6. Missile Station: Location of moment in inches from a common reference point such as the nose of the missile.

7. Actual Structural Load Environment: A consideration describing the actual load conditions to which a missile structure is subjected during its service life.

8. Simulation of a Structural Load Environment: A consideration describing the requirements that are to be met when simulating structural load conditions.

APPENDIX A

TEST FACILITIES AND EQUIPMENT

This appendix describes the use of a facility and equipment available for performing structural load testing of the missile frame.

STRUCTURAL TEST RIG

The basic test frame is a space frame consisting of structural numbers (beam trusses) which supports the missile frame during the test. A typical structural test frame (including test specimen) is shown in Figure A-1.

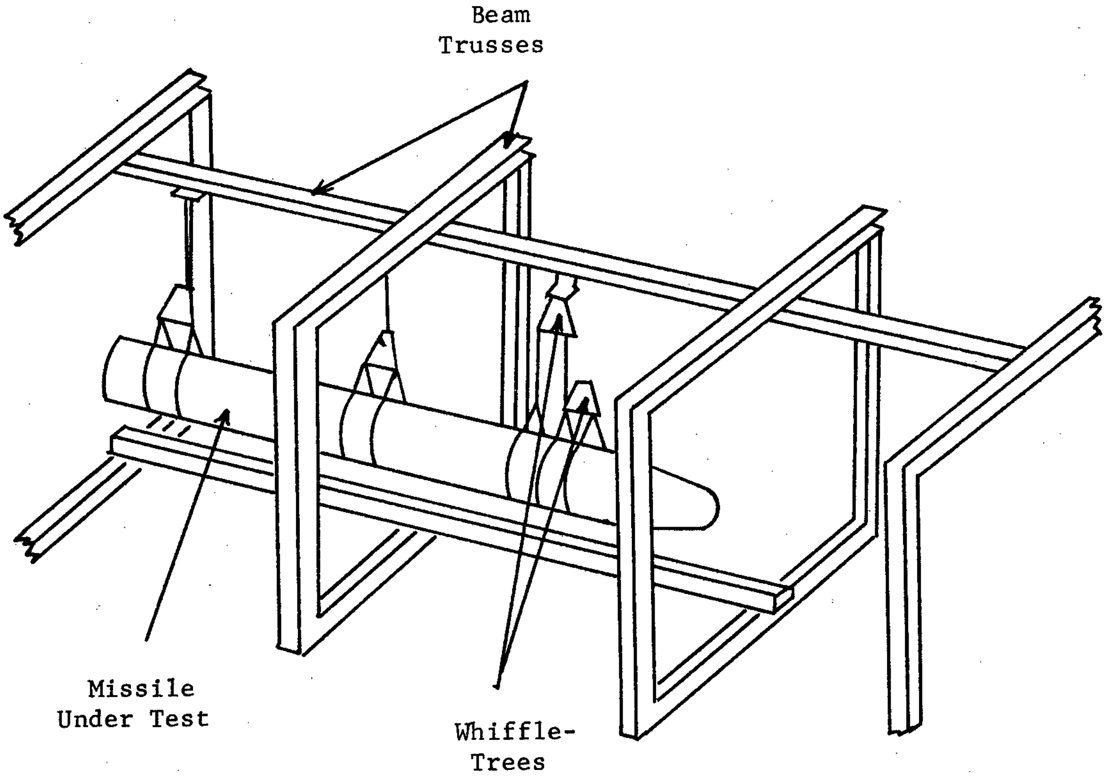

FIGURE A-1. Typical Structural Test Frame (with Test Specimen)

A number of attachment points are provided on the space frame for load members depending on the required load distribution. The location of these attachment points can be changed from test to test so that load paths may be provided as necessary to suit a particular test specimen.

LOAD SOURCES

Generally, there are three sources used to deliver the required forces to the test specimen:

a. Hydraulic cylinders with pistons
b. Turnbuckles
c. Weights

The turnbuckles and weights are simple mechanical devices and usually cannot be incorporated into an electronically controlled loading program. They are used in tests where the time sequence of events is not important, such as static checks of design or ultimate loads.

Hydraulic cylinders with pistons are the most widely used devices due to the ease with which they can be incorporated into an electronically controlled loading program. The hydraulic cylinder and piston device generally is used as an electronically controlled hydraulic servo-valve system. The system operates on a typical servo-mechanism principle and is described in Reference 4A. A curve follower generates a signal from a curve drawn on graph paper with conductive ink. This curve represents the desired load time history. The curve follower signal is compared electrically with a signal generated by a load cell connected in series with the load path. An error signal is produced proportional to the difference between the load cell and curve follower signal. This signal is used to control an electro-hydraulic servo valve which, in turn, regulates the hydraulic pressure in the cylinder to correct the error.

The response of such a system is extremely fast, permitting rapid recovery from errors and an accurate maintenance of load, in the event of yielding or deflection of any structure.

Depending on the number of individual load channels available and the different types of simultaneous loads required, a complete mission can be programmed and tested in the laboratory.

If it is desirable to control either stress or deflection, a signal from the strain gage or displacement transducer is compared with the signal from the curve follower signal. The resultant would then represent strain versus time or displacement versus time.

LOAD MEMBERS

The load members are used for distribution and transmission of loads. Typical load members are steel cables, beams, rods, fabric straps, and whiffletrees.

The nature of a particular test sometimes requires several load attachment points on the missile structure to simulate inertia or aerodynamic loads. If these loads were supplied from single independent sources, the same number of load sources would be required as there are force attachment points on the missile. Whiffletrees are used to circumvent this inconvenience.

These whiffletrees operate on the principle of lever action and their obvious advantage over single load source application is demonstrated by an example. Refer to the typical test load distribution diagram shown in Figure A-2.

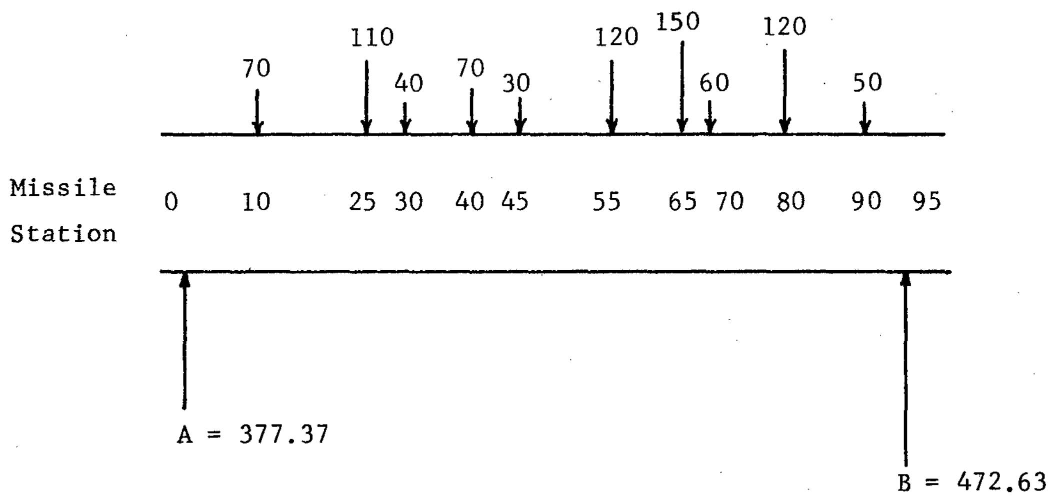

FIGURE A-2. Typical Test Load Distribution Diagram

Without the use of whiffletrees, 10 single, independent, load sources would be required, and depending on the space available between the two forces, it might be impossible to apply these loads because of space limitations on the structural frame.

The use of the resultant of each pair of forces in magnitude and location, would reduce the number of forces to five. The process of combining all the forces into a single force is shown in Figure A-3, and the physical arrangement would be as shown in Figure A-4.

The reaction force A is determined by taking moments about point B, and reaction force B is determined by taking moments about point A. The detailed determination of the reaction forces and the generation of the main resultant force is conducted by referring to Figures A-1 and A-2 and performing the following mathematic computations:

$$95\ B = 700 + 2750 + 1200 + 2800 + 2250 + 7150 + 9750 + 4200 + 9600 + 4500$$

$$= 44900 \text{ (in.-lb.)}$$

$$B = \frac{44900}{95} = 472.63 \text{ lb.}$$

$$95\ A = 250 = 1800 + 1500 + 4500 + 5200 + 2500 + 3850 + 2600 + 7700 + 5950$$

$$= 35850 \text{ (in.-lb.)}$$

$$A = \frac{35850}{95} = 377.37 \text{ lb.}$$

$$A + B = \underline{\underline{850}} \text{ (lb.)}$$

The moment arm (r) of the main resultant force G is determined by using the reaction force value of B as follows:

$$472.63 \times 95 = 850 \times r$$

$$r = \frac{472.63}{850} \times 95 = 52.82 \text{ (in.) from station zero}$$

The generation of the resultant forces can be determined, to check the moment arm value, as follows:

First generation of resultant forces:

$\Delta x_1 = \frac{15 \times 110}{180} = 9.17$	New location from 0: $10 + 9.17 = 19.17$
$\Delta x_2 = \frac{70 \times 10}{110} = 6.36$	$30 + 6.36 = 36.36$
$\Delta x_3 = \frac{130 \times 10}{180} = 7.22$	$45 + 7.22 = 52.22$
$\Delta x_4 = \frac{60 \times 5}{210} = 1.43$	$65 + 1.43 = 66.43$
$\Delta x_5 = \frac{50 \times 10}{170} = 2.94$	$80 + 2.94 = 82.94$

Second generation of resultant forces:

$\Delta x_1 = \frac{110(36.36 - 19.17}{290} = 6.52$	$19.17 + 6.52 = 25.69$
$\Delta x_2 = \frac{210(66.43 - 52.22)}{390} = 7.65$	$52.22 + 7.65 = 59.87$
$\Delta x_3 = 0$	$82.94 + 0 = 82.94$

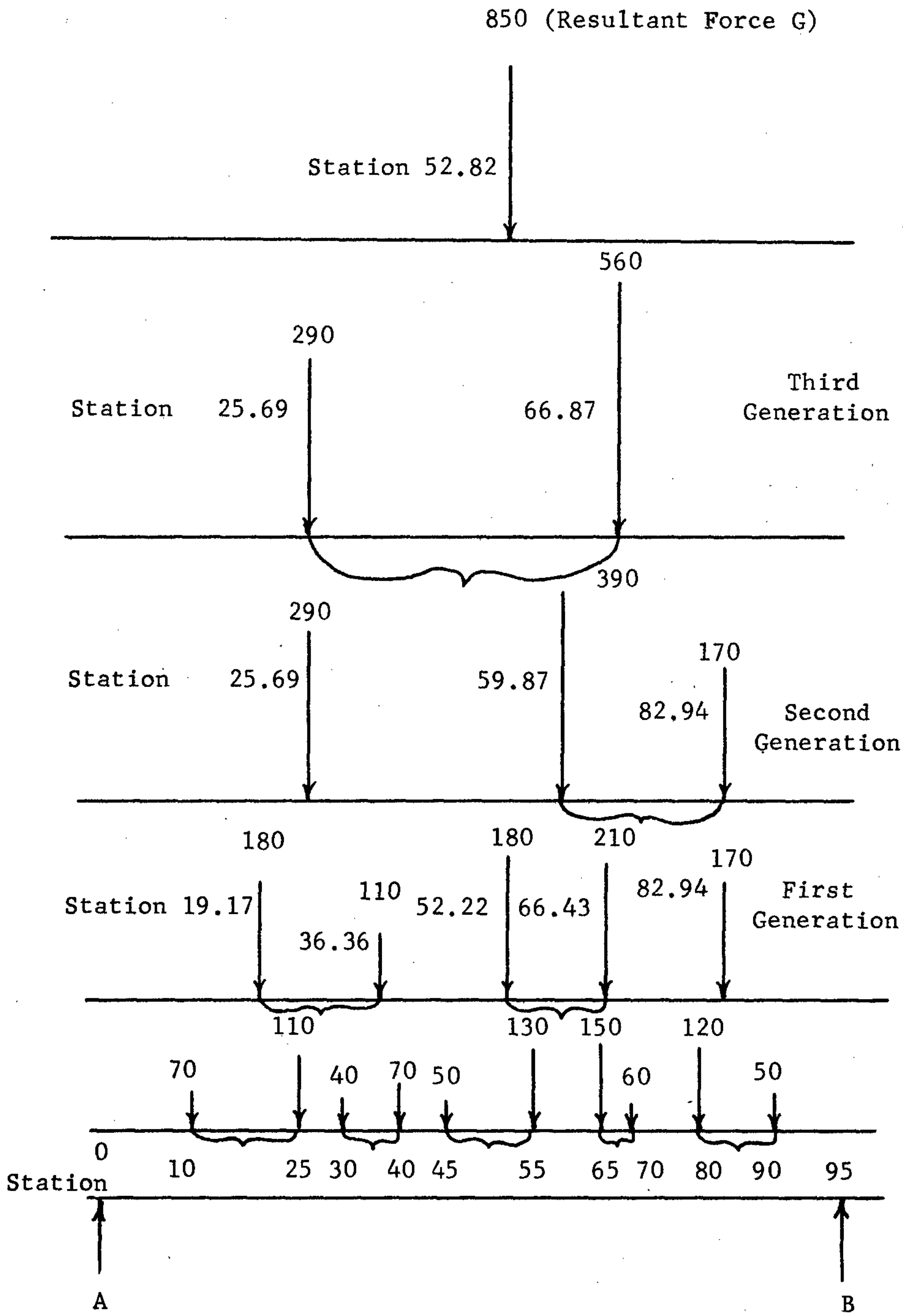

FIGURE A-3. Whiffletree Load Distribution

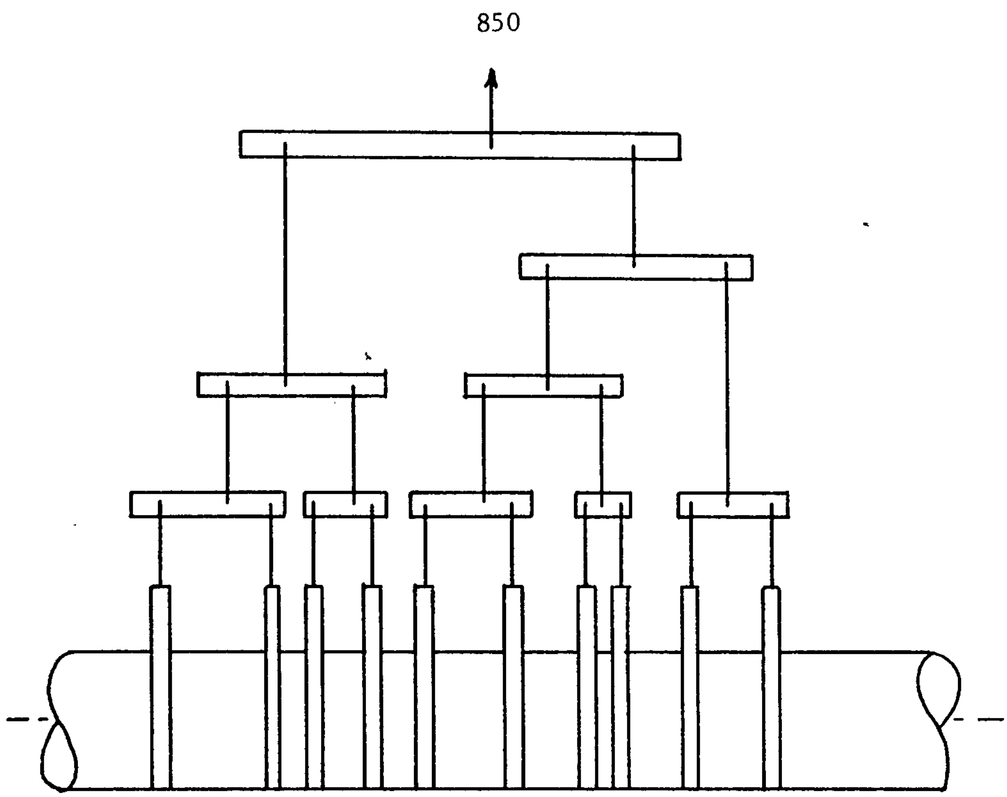

FIGURE A-4. Physical Arrangement of Whiffletree

Third generation of resultant forces:

$\Delta x_1 = 0$ $\qquad 25.69 + 0 = 25.69$

$\Delta x_2 = \dfrac{170(82.94) - 59.87)}{560} = 7.00$ $\qquad 59.87 + 7 = 66.87$

Main resultant force:

$\Delta x_1 = \dfrac{560(66.87 - 25.69)}{850} = 27.13$ $\qquad 25.69 + 27.13 = 52.82$

This agrees with the moment arm value previously obtained.

The pivoting points of the whiffletree arrangement should be well lubricated to prevent friction forces from introducing undesirable loads.

In the whiffletree method of load distribution, the forces on the missile are amplified linearly by increasing the single resultant force on top of the arrangement. For example, to increase the inertia loads by 10 percent, it is only necessary to increase the resultant force by 10 percent, which generally corresponds with the actual physical situation.

To apply inertia forces to a test specimen, split the forces and apply them at convenient and structurally safe positions along the test specimen body. This may be done by attaching tabs on both sides of the test specimen as shown in Figure A-5. The desired load distribution can be monitored and adjusted with strain bars and turnbuckles or hydraulic cylinders. The force that has to be applied through the individual cable at station 1, for instance, is equal in the difference of the forces at station 0 and 1 divided by 2, i.e., if the difference at station 1 is 100 lbs, then each cable at station 1 has to carry 50 lbs.

The angle between the missile axis and the cable should be as small as the physical arrangement will allow. If this angle is 10° or less, and cosine components are not considered, then the error introduced is less than 1½ percent. A small angle also reduces the magnitude of the transverse forces which are inherent with this type of loading scheme.

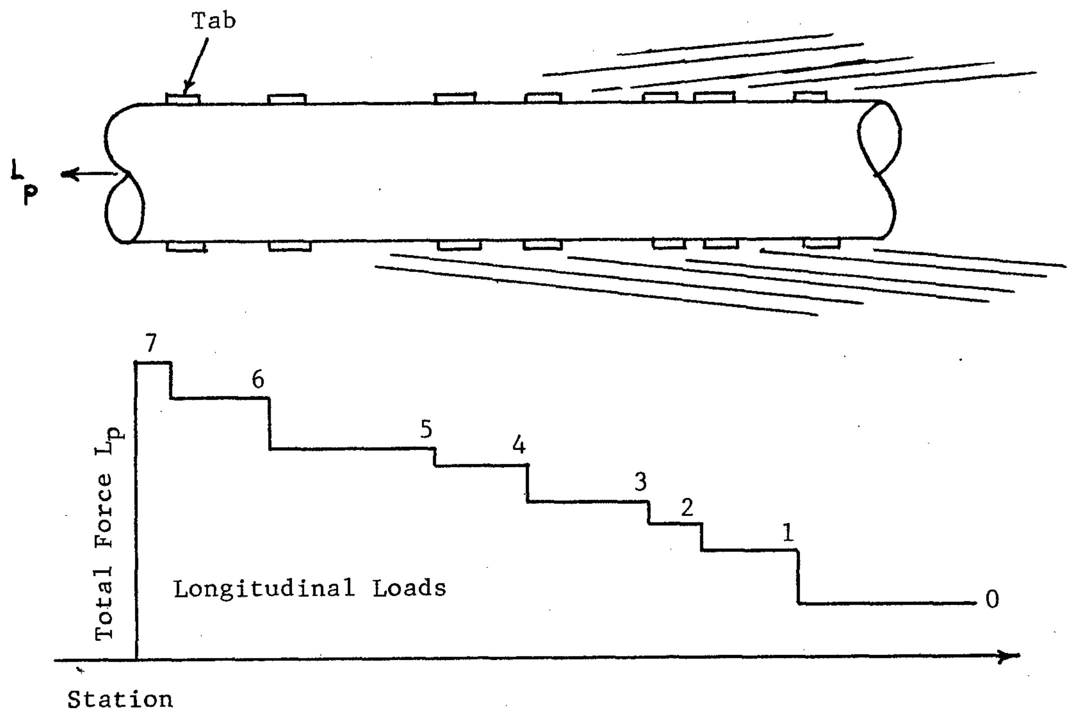

FIGURE A-5. Typical Application of Inertia Forces

A typical Monitoring and adjusting arrangement for the cables is shown in Figure A-6.

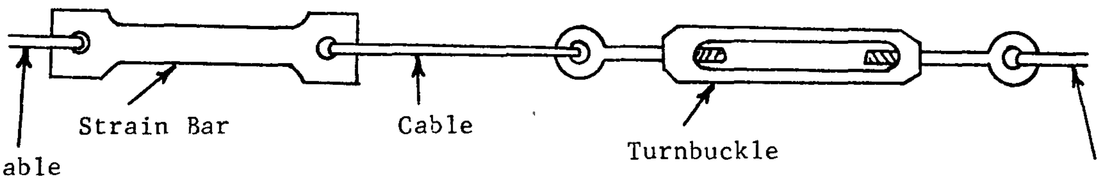

FIGURE A-6. Typical Load Monitoring and Adjusting Arrangement

The strain bar is described in Appendix B. This method of distributing the load and the monitoring and adjusting arrangement described provides a realistic environment, but has the disadvantage of being a laborious undertaking. In practice, for each change in longitudinal force, the forces in the cables shift disproportionately due to misalignment or slippage of test specimen sections. In addition, the method is not accurate when a continuously changing environment is programmed. Nonetheless, it simulates the actual conditions better than the application of a single force through the longitudinal axis. When the change in load is performed manually on each turnbuckle, the individual turnbuckles are easily adjusted and accurate load distribution is obtained without difficulty.

APPENDIX B

STRUCTURAL LOAD MEASURING AND RECORDING EQUIPMENT

This appendix describes the measuring and recording equipment that is generally required for structural load tests. Recording equipment includes tape recorders, oscillograph recorders, motion picture cameras and multi-channel recorders. For transient loads, it is essential to establish an accurate time reference in the recording equipment so that inputs can be compared with the corresponding outputs. The response of the system under test is measured as deflection, strain, and type or size of failure. The type of measurements involved in structural load tests and the associated measuring equipment are listed in Table Bl.

Table Bl. Load Measurements and Equipment Used

Type of Measurement	Equipment Used
Force	Load cell, Strainbar, Pressure pickup
Strain	Strain gage, Photoelectric cell, Stress coating
Deflection	Displacement transducer, Dial gage indicator, Precision level

If an electronically controlled load programmer is used to produce a desired load pattern and this pattern is such that it changes continuously, displacement transducers should be used so that continuous recordings can be made.

For purely static load conditions, a precision level is an appropriate instrument to use. Its advantage lies in that it is physically disconnected from the test specimen and only one instrument on each side of the specimen is needed to make any desired number of measurements. The test specimen has to be marked clearly at the locations where its deflection is to be measured. A fixed reference point is needed on the structural rig to supply null readings for periodic checks. The use of two instruments (one on each side of the test specimen) is desired to detect any angular displacement around the longitudinal axis of the missile frame.

The dial gage indicator is a mechanical measuring device. Its application is restricted to static load deflection measurements unless these measurements can be recorded by motion picture cameras and a common time base between camera data, load, and strain data is established.

Strain bars can be manufactured when there is a need to obtain rough load data and space for bulky load cells is not available, as in longitudinal loading. A typical strain bar design is shown in Figure B-1.

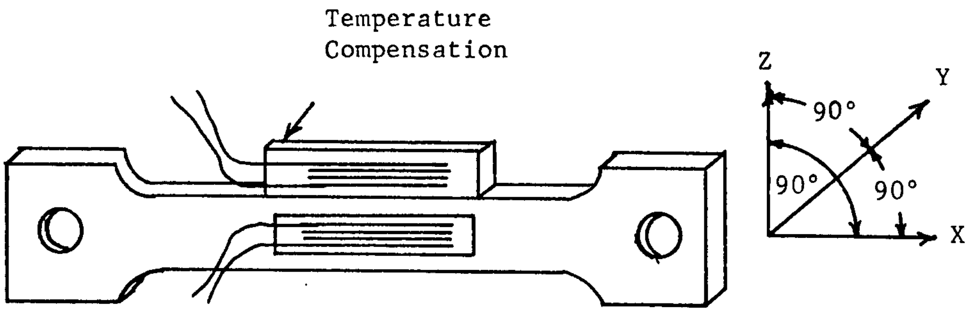

FIGURE B-1. Typical Strain Bar Design

An active strain gage is mounted on either side of the metal bar to compensate for bending in the y-direction. Two or more gages are glued to the piece of metal that is loosely connected to the main body. These two gages serve as temperature compensators. The strain bar as well as the temperature compensating block should be manufactured from the same kind of material. The four strain gages may be connected in a bridge circuit similar to that shown in Figure B-2.

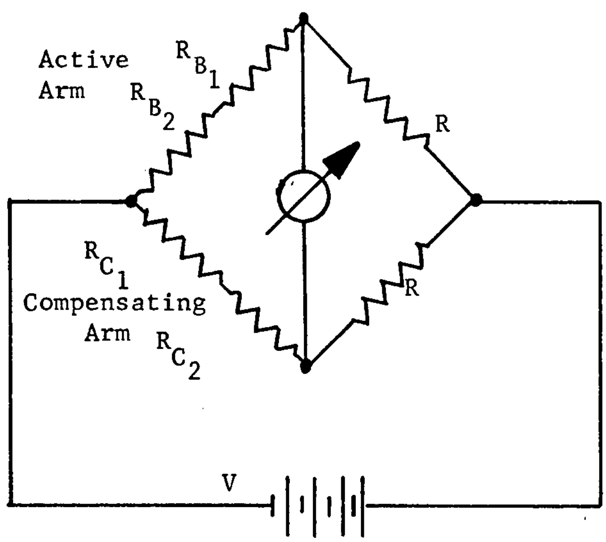

FIGURE B-2. Typical Strain Gage Bridge Circuit

A choice of dimensions for the strain bar has to be made for a particular application to obtain reasonable output from the strain gages. The maximum force that will be applied to the strain bar should be determined and a strain chosen, that lies within the elastic range of the test specimen material. The required cross sectional area of the strain and resistance changes per unit force can be determined by using the following equations:

$$\text{Strain } (\epsilon) = \frac{\Delta\lambda}{\lambda} = \frac{\sigma}{E}$$

$$\sigma = \frac{P\text{max}}{F}$$

$$\epsilon = \frac{P\text{max}}{EF}$$

The change in resistance that is expected per unit force can be determined using the following equations:

$$K = \frac{\Delta R/_R}{\Delta\lambda/\lambda} \text{ or } \frac{\Delta R}{R} = K \frac{\Delta\lambda}{\lambda} \text{ or,}$$

$$\frac{\Delta\lambda}{\lambda} = K \frac{P}{FE}$$

Then, to obtain the result in ohms per pound,

$$\frac{\Delta R}{P} = K \frac{R}{FE}$$

The preceding equation can also be used to determine the approximate dimensions and output range of the strain bar. However, the manufactured product has to be calibrated to determine the actual relationship of ΔR and P, which generally is different from the theoretical one, due to production inaccuracies.

The techniques of mounting strain gages for strain measurements on the test specimen are discussed in the applicable MTP. When choosing locations on the missile structure, make a thorough investigation of the stresses that are to be expected in the particular area. If the area under the strain gage is subjected to nonuniform stresses, the gage senses only the average value of these stresses and local values might be considerably greater. Therefore, take care in selecting appropriate locations for strain measurements.

Pressure pickups are mentioned in connection with force measurement. They should not be used as a sole source of load information but only as a backup for load cell readings. The conversion from pressure to force is established by multiplying the pressure by the cross sectional area of the strain bar. Errors inherent with this type of measurement due to friction between piston and cylinder wall and drive rod and seals can be considerable at small loads.

APPENDIX C

TEST CONSIDERATIONS

This appendix describes the actual structural load environment (steady state or transient) to which a missile structure is subjected during its service life and the simulation of this environment in the laboratory.

ACTUAL STRUCTURAL LOAD ENVIRONMENT

To describe actual load environment, consider a missile that is launched with a booster where a transient load is caused by booster ignition and the subsequent thrust buildup. Steady state load conditions follow when the missile attains operating speed, during which the applied forces can be progressive, neutral, or regressive. Another transient condition follows when the booster burns out. Soon after, the ramjet engine takes over and a condition exists, similar to the launch condition but of less severity. When the vehicle goes through maneuvers, a condition of both steady state and transient loads exists. Upon completion of the mission, parachute deployment takes place and shortly before impact, with the missile in a horizontal position, retrorockets fire to allow a soft landing.

In addition the loads may occur (on both the missile structure and associated equipment such as launcher, trailer, etc.) during the prefiring stage. All these load conditions are created by various forces which may be classified as follows:

a. Prefiring environmental forces:

(1) Handling
(2) Transportation
(3) Field operation

b. Thrust forces:

(1) Longitudinal from main power plant or retrorockets
(2) Circumferential from spin rockets
(3) Lateral from yaw or pitch correction rockets
(4) Any combination of the above

c. Aerodynamic forces:

(1) Lift and drag
(2) Maneuver
(3) Airbrake
(4) Parachute
(5) Wind gusts
(6) Any combination of the above

Category a. applies to ground equipment as well as to the launch vehicle, while the forces under b. and c. usually occur on the missile structure itself.

SIMULATION OF A STRUCTURAL LOAD ENVIRONMENT

A prime consideration in the simulation of a load environment is the analysis of the loading, shear, bending moment, and torsional moment diagrams from the structural analysis and design of the missile system. These diagrams should cover all possible phases of maximum stresses to which the vehicle or part of the equipment is subjected during service (see Reference 4C for details).

A method of recording variations in loading, shear, and bending moment along the length of beams is shown in Figure C-1. Positive values are pointed upwards and negative values downwards. Bending moments with a clockwise direction are positive. Shear can also be expressed mathematically, as the integral of the transverse loading with respect to the distance along the beam as follows:

$$S = \int_0^x w \, dx$$

Similarly, bending moments can be expressed as the integral of shear with respect to the distance along the beam by the equation:

$$M = \int_0^x S \, dx = \int_0^x \int_0^x w \, dx \, dx$$

As loading is the second derivative of the moment with respect to x, it then follows that:

$$w = \frac{dS}{dx} = \frac{d^2M}{dx^2}$$

Usually, it is not possible to duplicate the exact aerodynamic or inertia loads because w(x) is some arbitrary function of x, i.e., the loads are distributed along the body axis in a nonlinear, continuous manner. To duplicate exact loads, an infinite number of point loads would be required, which is not practical. In practice, the closest approximation to continuous loads is achieved by using fabric straps which are attached around the test specimen (see Figure C-2). Thus, the continuous load can be broken up into step loads of constant magnitude and a relatively good agreement with actual loads can be obtained.

In some cases, the configuration of the test specimen may not allow the application of fabric straps. In addition, because of structural considerations, the test engineer may be bound by the test specimen design to use only certain points to attach the forces. On a missile body that is not fitted for the application of fabric straps, it is necessary to use reinforced stations to apply the forces, because the structure skin alone will not support the load.

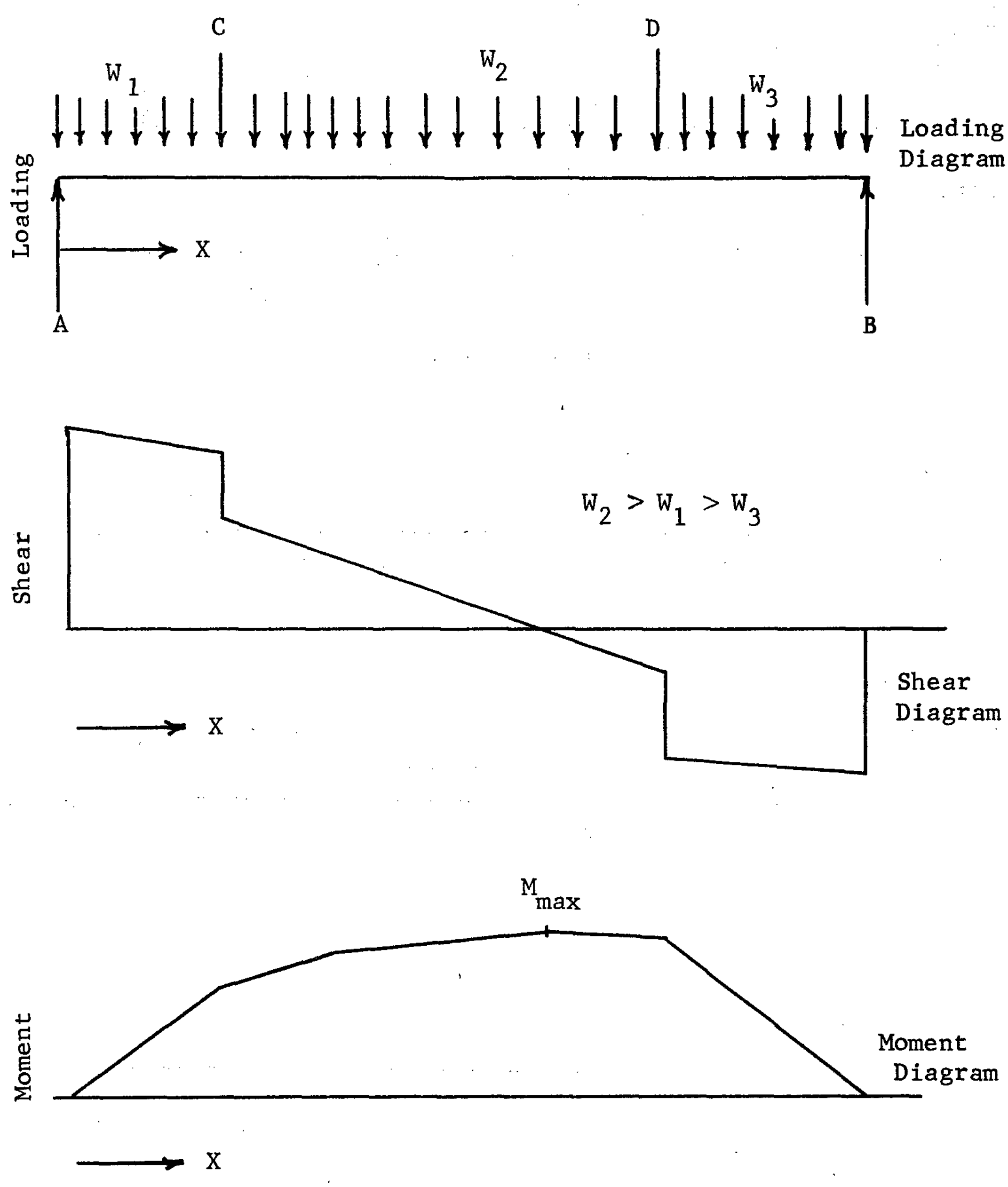

FIGURE C-1. Typical Loading, Shear, and Moment Diagrams

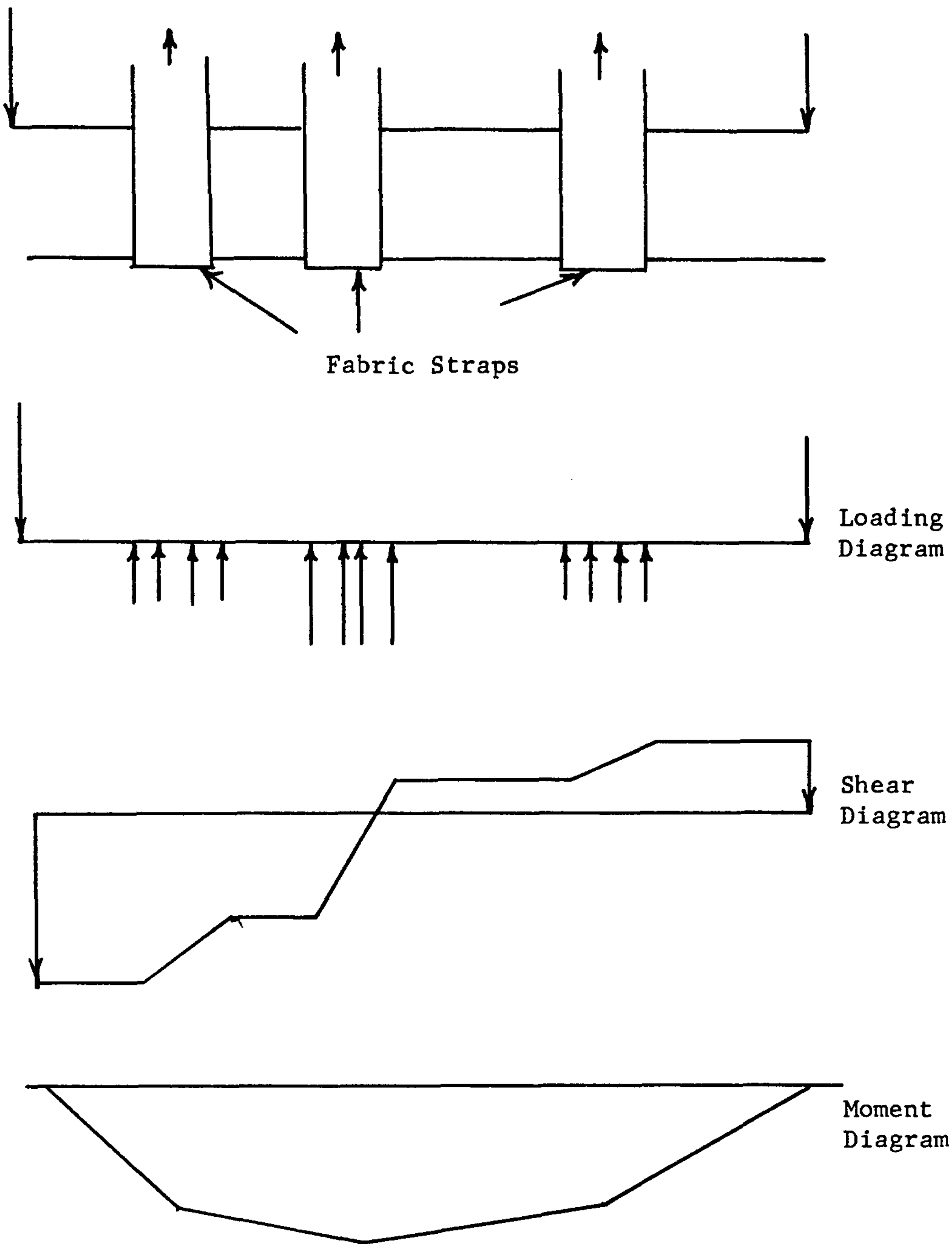

FIGURE C-2. Fabric Straps on Test Specimen and Resultant Diagrams

Thus, the test engineer has to consider several factors in determining the best way to rearrange the loading diagram and still be as close to the actual conditions as possible. For example, consider the simplified case of a wing load and assume that the loading is a linear function of the wing span (see Figure C-3). Then the shear distribution is quadratic and the moment distribution cubic. Further assume that the load can be applied to only three points of the fin, at stations 1, 2, and 3.

Equilibrium conditions require that the sum of all forces and the sum of all moments should be zero. This may be represented as follows:

$$G = A + B + C$$

$$M = a.A + b.B + c.C$$

A situation exists in the equations that has no analytical solution, as there are three unknowns with only two equations. However, a third nonexact boundary condition offers the suggestion to solve A, B, and C by trial and error, i.e., to approach the moment diagram as closely as possible. This is performed by connecting stations 0, 1, 2, and 3 by straight lines as shown in Figure C-3. Now the magnitude of the force C can be determined since $M\beta$ and the moment arm c known using the following equation:

$$C = \frac{M\beta}{c}$$

The determination of C reduces the number of unknown forces to two and A and B can be solved analytically. The moment at station 1 is then calculated and compared with the actual value. If the approximation is not too good, the procedure has to be repeated with a new value for $M\beta$ and, therefore, C, until reasonable agreement exists between test values and the actual condition.

This process gets more complicated with an increasing number of attachment points; however, the solutions become more accurate.

In the case of longitudinal loading as it occurs under parachute deployment, similar methods have to be used. The parachute is attached to the aft end of the test specimen and its direction of force is aligned with the body axis. In this state of equilibrium, it can be said that the sum of all longitudinal force in the system components is zero. This condition is represented by the following equation:

$$L_p + \int_o^1 dL_A = f \int_o^1 dm\text{, or,}$$

$$L_p = f \int_o^1 dm \quad \int_o^1 dL_A$$

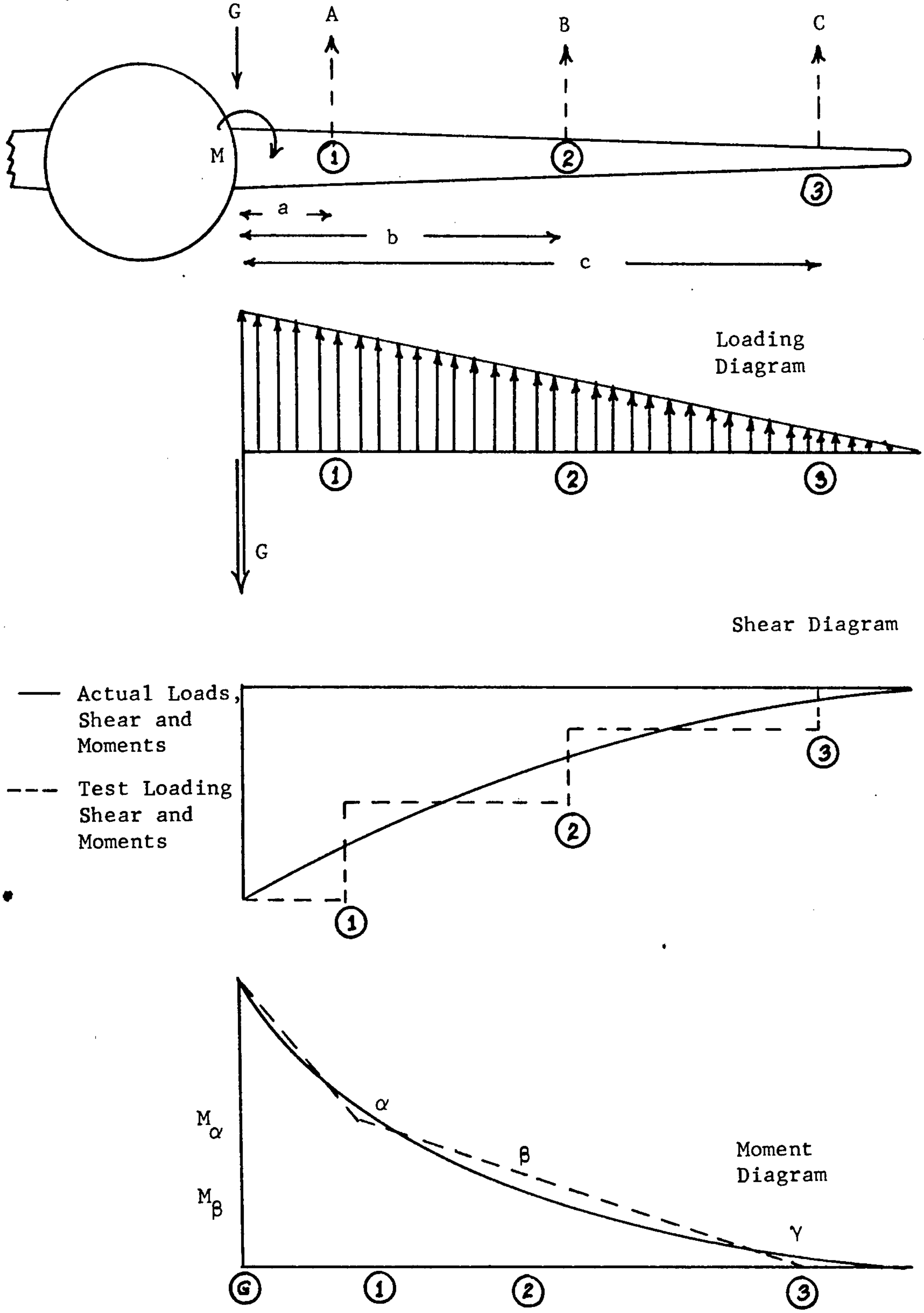

FIGURE C-3. Typical Wing Load Distribution

That is, the parachute longitudinal force is equal to the total mass of the body multiplied by its acceleration minus the sum of all longitudinal aerodynamic forces. However, this represents a pull on both ends of the test specimen with a force L_p, which would subject the greatest part of the specimen to a load that it actually never sees. True load distribution is that longitudinal load which acts on the cross section X of the test specimen as represented by the diagram shown in Figure C-4.

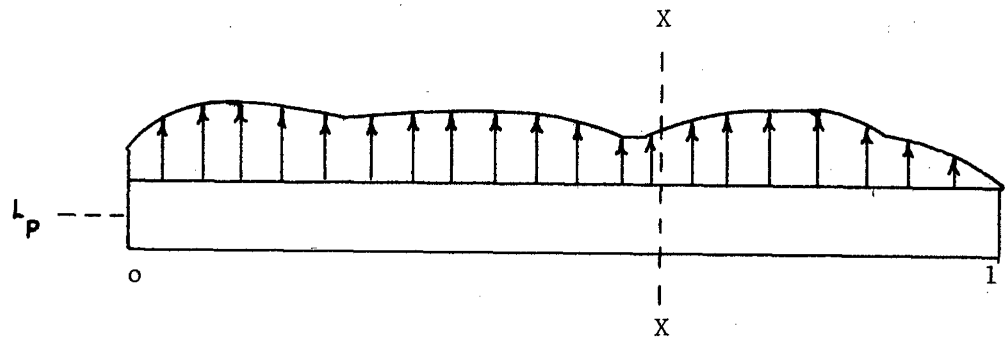

FIGURE C-4. Longitudinal Load Distribution Diagram

This load distribution can be represented by the following equation:

$$L_x = f \int_x^{\lambda} dm - \int_x^{\lambda} dL_A$$

Refer to Figure C-4 and assume a longitudinal load distribution along the missile axis as shown in the figure, where the curve represents the sum of aerodynamic and inertia forces. Then, Lp is equal to the area under the curve. To determine the longitudinal force at some cross section x, the curve is integrated between x and λ . In practice, this can be closely simulated by resolving the continuous load into discrete forces, which can be applied to the body at appropriate locations. For example, assume that a test specimen section has a longitudinal load distribution as shown in Figure C-5.

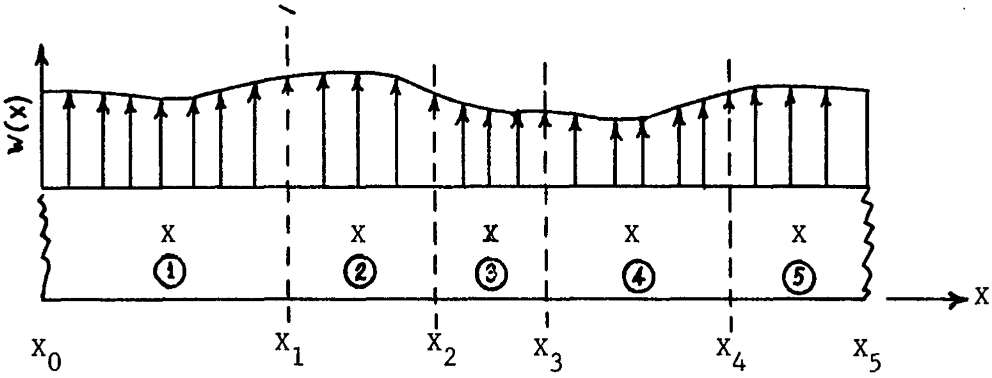

FIGURE C-5. Missile Station Load Application

Also, assume that the particular design requires a load application at stations 1 through 5. If an analytical expression for w(x) is available, then the force acting at station 1 is given by the following equation:

$$L_1 = \int_{xo}^{x1} w(x)\, dx$$

or, in general form,

$$L_{n+1} = \int_{x_n}^{n+1} w(x)\, dx \quad n = 0, 1, 2, \ldots$$

In most cases, this analytical form will not be readily available and it is necessary to replace the area under the curve between the station x_n and x_{n+1} by a rectangle of approximately the same area. The height of this rectangle now is $\overline{w}(x)$, the length $(x_{n+1} - x_n)$, and the expression for the force becomes:

$$L_{n+1} = \overline{w}_{n+1}(x)\, [(x_{n+1} - x_n)]$$