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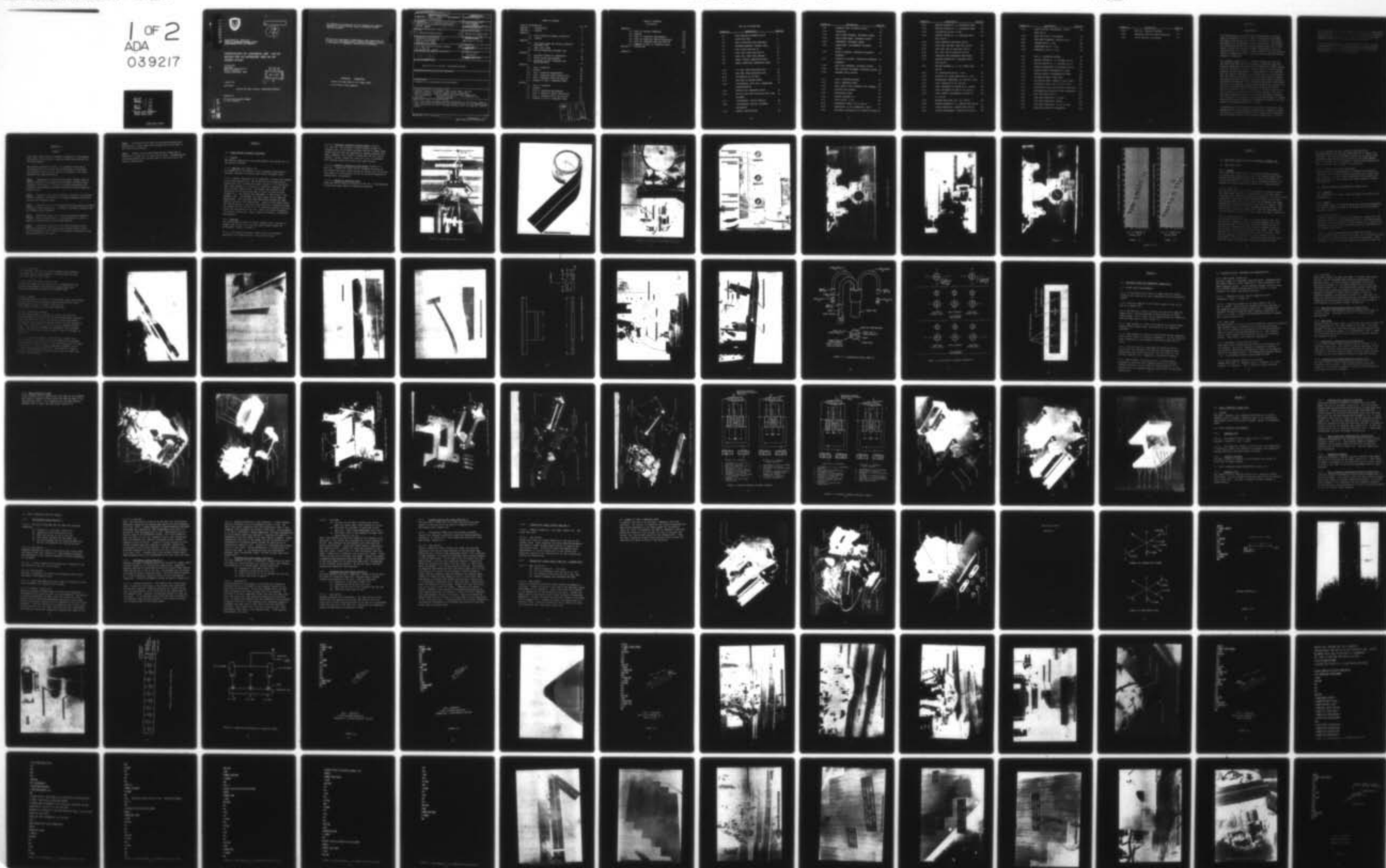

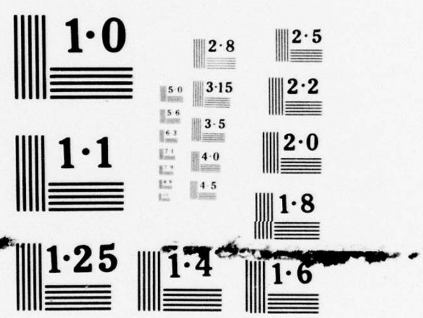

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PRODUCTION ENGINEERING MEASURES PROGRAM
MANUFACTURING METHODS AND TECHNOLOGY

INVESTIGATION OF COMPOSITE TAPE LAY-UP DEVICES FOR AN AUTOMATED TAPE LAY-UP SYSTEM (ATLAS)

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1 August 1975

Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This final report presents research information on the design, fabrication, and testing of composite tape-laying devices for the ATLAS Machine, which proved the ability to compact pre-preg tape to irregular compound shapes.

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TABLE OF CONTENTS

TABLE OF CONTENTS
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LIST OF ILLUSTRATIONS

SECTION 1

INTRODUCTION

The introduction of the ATLAS tape-laying machine, developed under the auspices of the U.S. Army Aviation Systems Command, provided a much-needed capability for continuing technological developments in the general field of tape-laying. The program to be described herein utilized the research potential of the ATLAS to carry out the first in-depth investigation into the characteristics of a number of generic devices for the precision-laying of prepreg tape onto or into surfaces possessing various degrees of curvature.

The urethane laydown roller originally produced for use with the ATLAS tape head was of the rotating, inflatable type and although possessing the capability to conform to surfaces having radii of curvature as low as 2 inches, was not viewed as being suitable for all applications. In particular, it was observed that the complex interaction of footprint pressure distribution with the elastic characteristics of the roller material caused distinctly periodic deviations from the laydown path defined by the machine's movements. This phenomenon manifested itself when laying on flat surfaces, becoming more acute as the curvature of the tooling surface became additionally complex and severe. Since the intention was to ultimately use the ATLAS Machine for the production of helicopter rotor blades (amongst other sophisticated composite structures) involving continually changing tool surfaces, it was evident that further development of laydown devices would be both necessary and generally worthwhile for the composite structures industry as a whole.

A consideration of the interaction phenomenon referred to above, suggested that a non-rotating laydown device, possessing either controllable or inherent pressure and footprint characteristics, may prove highly effective for specific applications. To this end, the program which is the subject of this report, established and evaluated designs which utilized rigid, semi-rigid, flex ble, inflatable non-rotating concepts and compared their basic performance to that of the rotating inflated cylinder.

It is considered that the data which was derived will provide a technology base for the rational choice of laydown devices for particular ranges of application and further expand the effectiveness of the tape-laying process.

SECTION 2

SUMMARY

This final report presents research information on the design, fabrication, and testing of composite tape-laying devices for the ATLAS Machine.

The program consisted of seven (7) progressive tasks which investigated for the optimal design of devices to precisely lay composite tape onto flat and curved surfaces. The tasks performed are summarized below:

TASK 1 Implemented an industry-wide survey between users of existing tape-laying equipment and Government representatives throughout the country, in order to collate experiences with different tape dispensing systems and provide further empirical research data.

TASK 2 Carried out an exacting optical inspection of the ATLAS Machine alignment, establishing an accurate reference system for ensuing tape alignment tests.

TASK 3 Designed six (6) tape compacting devices based on concepts displaying rigid, semi-rigid, flexible, inflatable, rotating, and non-rotating hybrid designs.

TASK 4 Fabricated three (3) of the most promising compactor designs, from an effectiveness vs. cost standpoint. Each is capable of being mounted on the ATLAS Machine.

TASK 5 Tests were conducted on the above mentioned lay-up devices to establish their tape-laying accuracy using 3-inch wide glass/prepreg tape, compacted at different pressures on tool profiles defined in Section 4.

TASK 6   An evaluation was made of the minimum concave and convex radii to which tape can accurately be laid by each of the three lay-up devices.

TASK 7   Results of the investigations were summarized in statistical, graphical, and quantitative form. Recommendations were made regarding the optimal type of lay-up device(s) for specific applications.

SECTION 3

3.0 ATLAS MACHINE ALIGNMENT INSPECTION

3.1 PURPOSE

An exacting inspection of the ATLAS Machine was carried out in two parts as follows:

3.1.1 Part One (See Figure 3-1)

An inspection of the machine's basic alignment established an accurate reference for ensuing tape lay-up alignment tests.

3.1.1.1 Before inspection of the tape-head, a transit was squared to the ATLAS Machine bed. The inspection was accomplished by installing a roll of digitizing tape, Figure 3-2, on the pay-off reel, then threading it through the tape-head, compactor, and onto the paper take-up reel. The transit was sighted to the centerline of the digitizing tape on top of the pay-off reel (Figure 3-3). By rotating the tape-head 'C' axis, first + 180 degrees, then - 180 degrees, the exact center of the tape was established. The digitizing tape was pulled through the tape-head by activating the take-up reel. Sighting the transit along the various points on the digitizing tape as it travelled through the compaction foot (Figure 3-3), the tape-head checked vertically within two thousandths of an inch (.008) true center throughout its vertical centerline. Thus, inspection showed no significant misalignment.

3.1.2 Part Two

The relationship between the actual pressure (psi) required to compact tape around a tool and the gauge reading (psig) was established, Figures 3-6 and 3-7.

3.1.2.1 Two separate pneumatic forces affect the pressure applied by the compacting foot. They are as follows:

3.1.2.1.1 Pneumatic Tape-Head Balance System (Figures 3-4, and 3-5). The pneumatic counter-balance system, an integral part of the ATLAS tape-head, serves to offset those forces incurred when the tape-head is lowered one-half inch after compaction foot contact is made with the tool lay-up surface. Optimal compaction force of 23 lbs. is obtained with eighteen pounds per square inch gauge reading.

3.1.2.1.2 Pneumatic Compaction Force System (Figures 3-4 and 3-5). Compaction forces can be increased from zero to one hundred and twenty eight pounds per square inch (0-128 psi). They require a manual preset and can be activated manually or automatically (programmed).

3.1.2.1.3 Compaction Pressures Chart
Using the set of values in Figures 3-8 and 3-9, it was possible to know and preset specific compaction pressures.

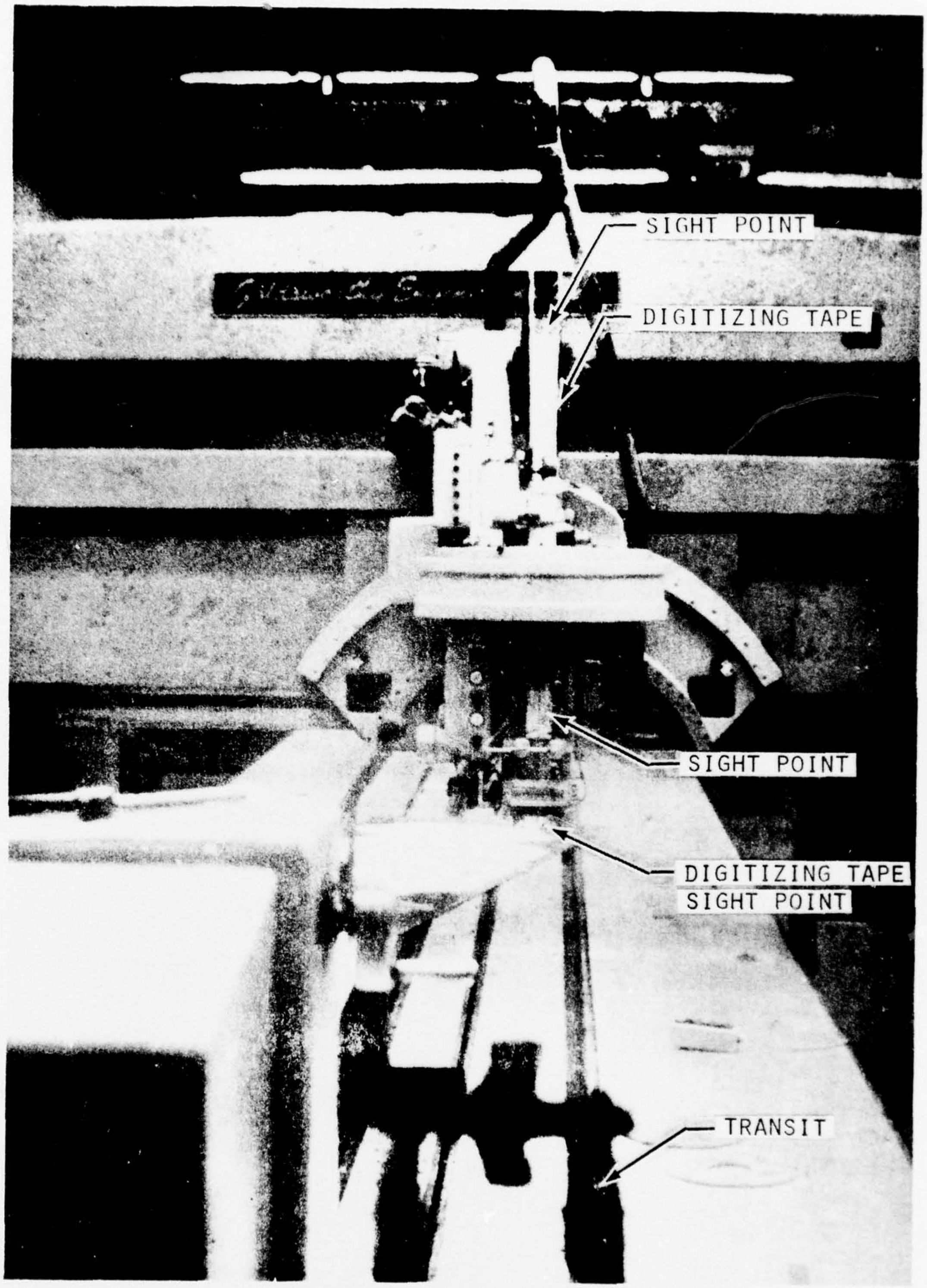


FIGURE 3-1 ATLAS MACH. ALIGN. SET-UP

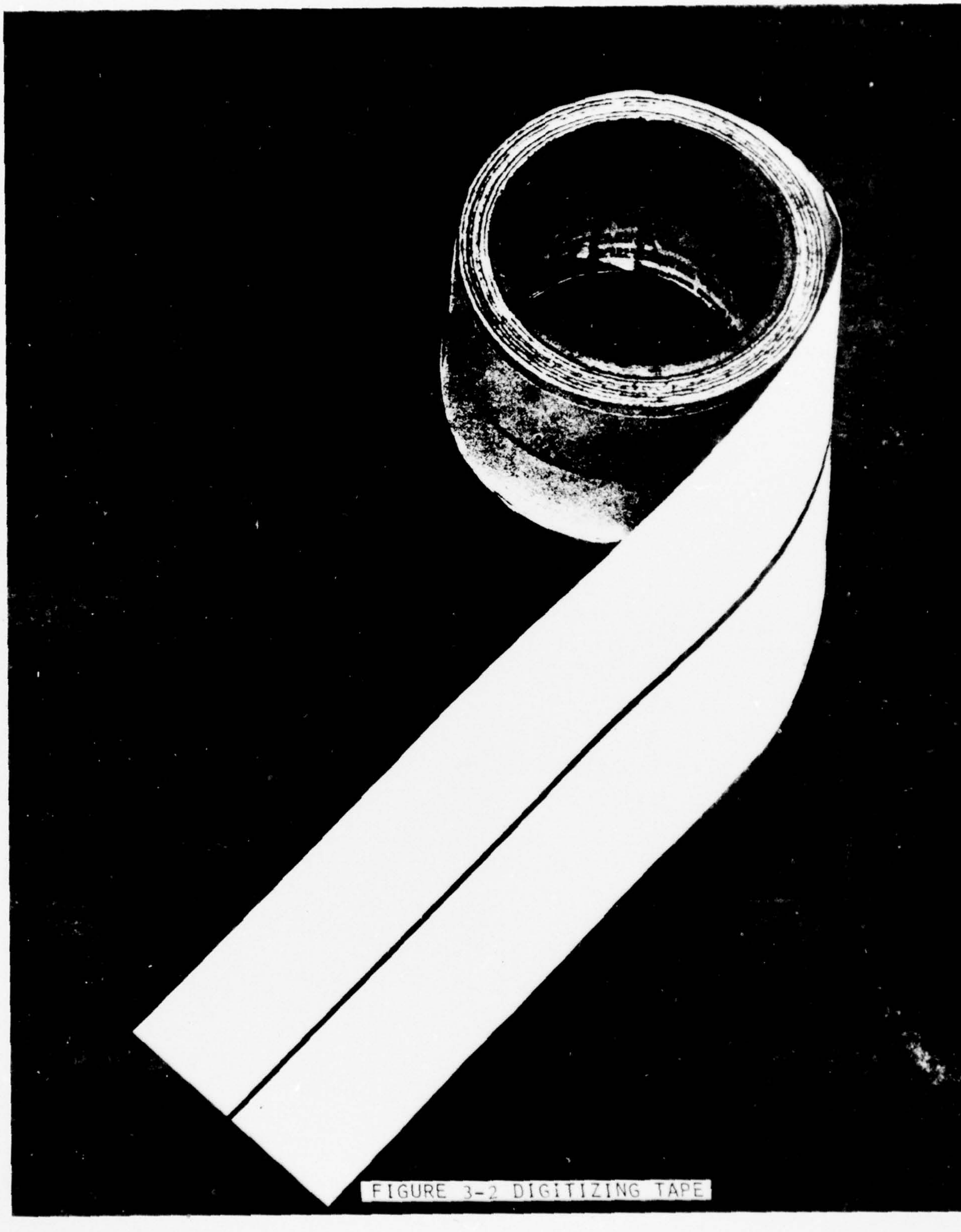


FIGURE 3-2 DIGITIZING TAPE

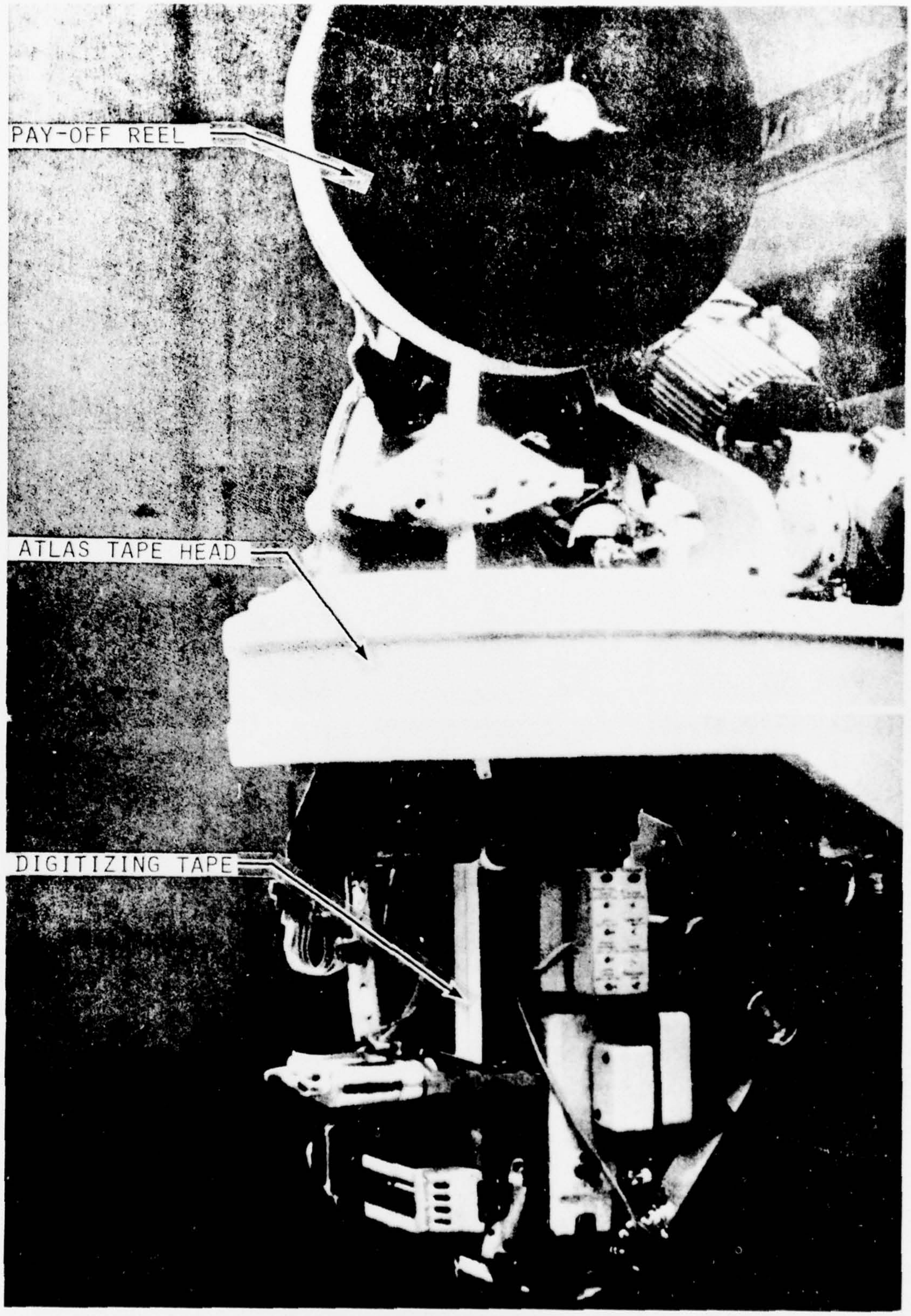


FIGURE 3-3 VIEW, DIGITIZING TAPE INSTALLED

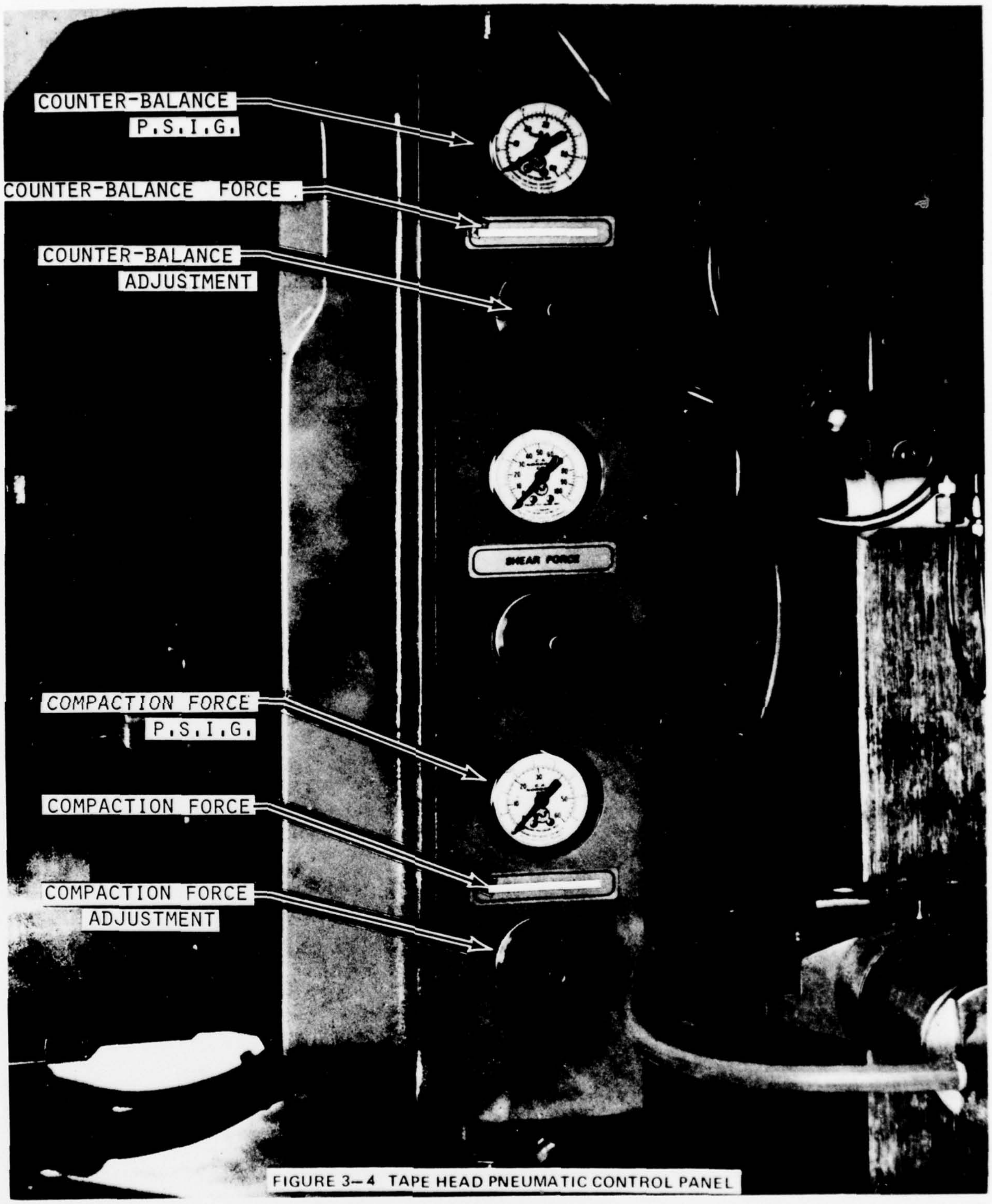


FIGURE 3—4 TAPE HEAD PNEUMATIC CONTROL PANEL

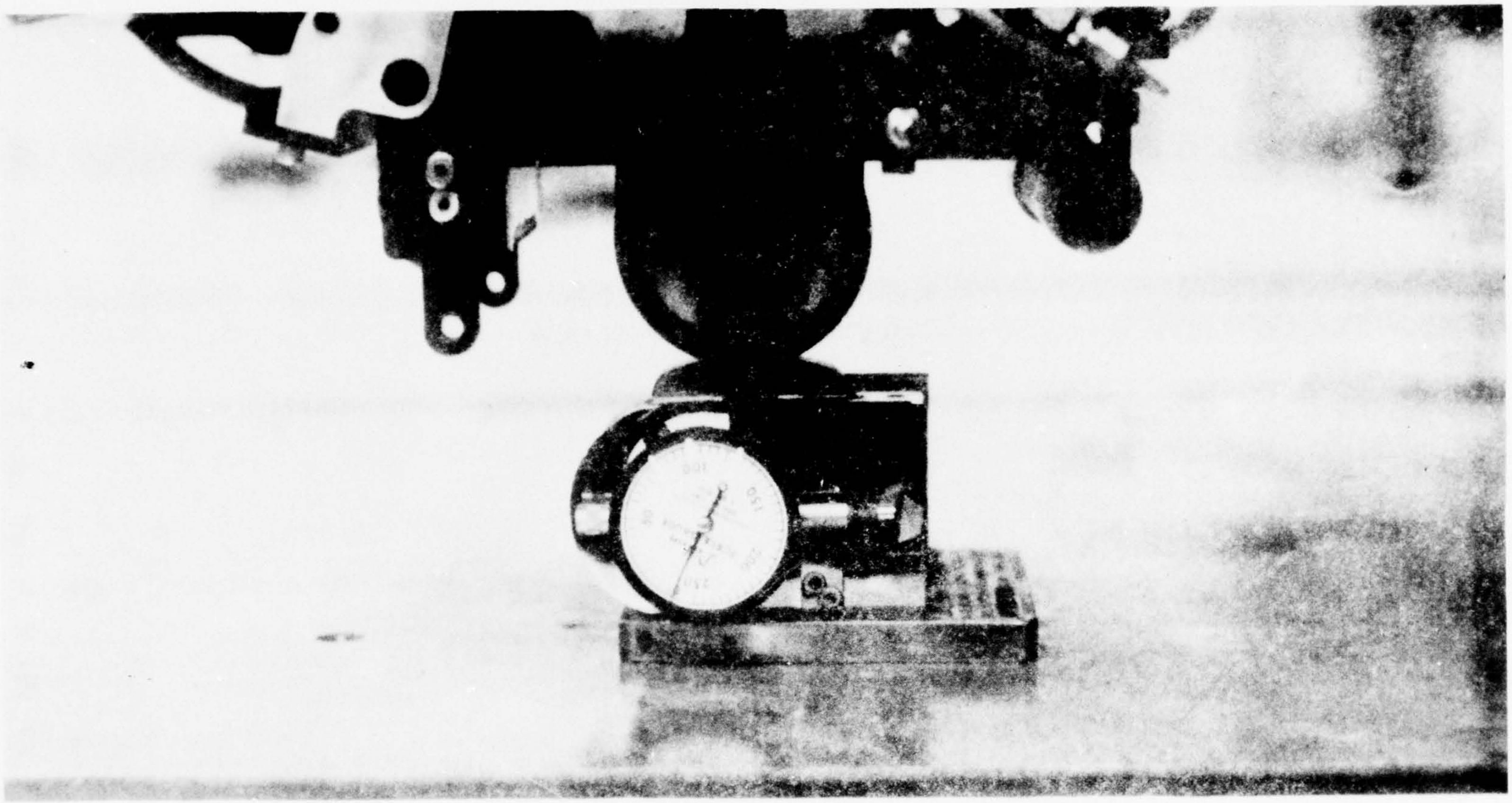


FIGURE 3-5 FORCE GAUGE SET-UP

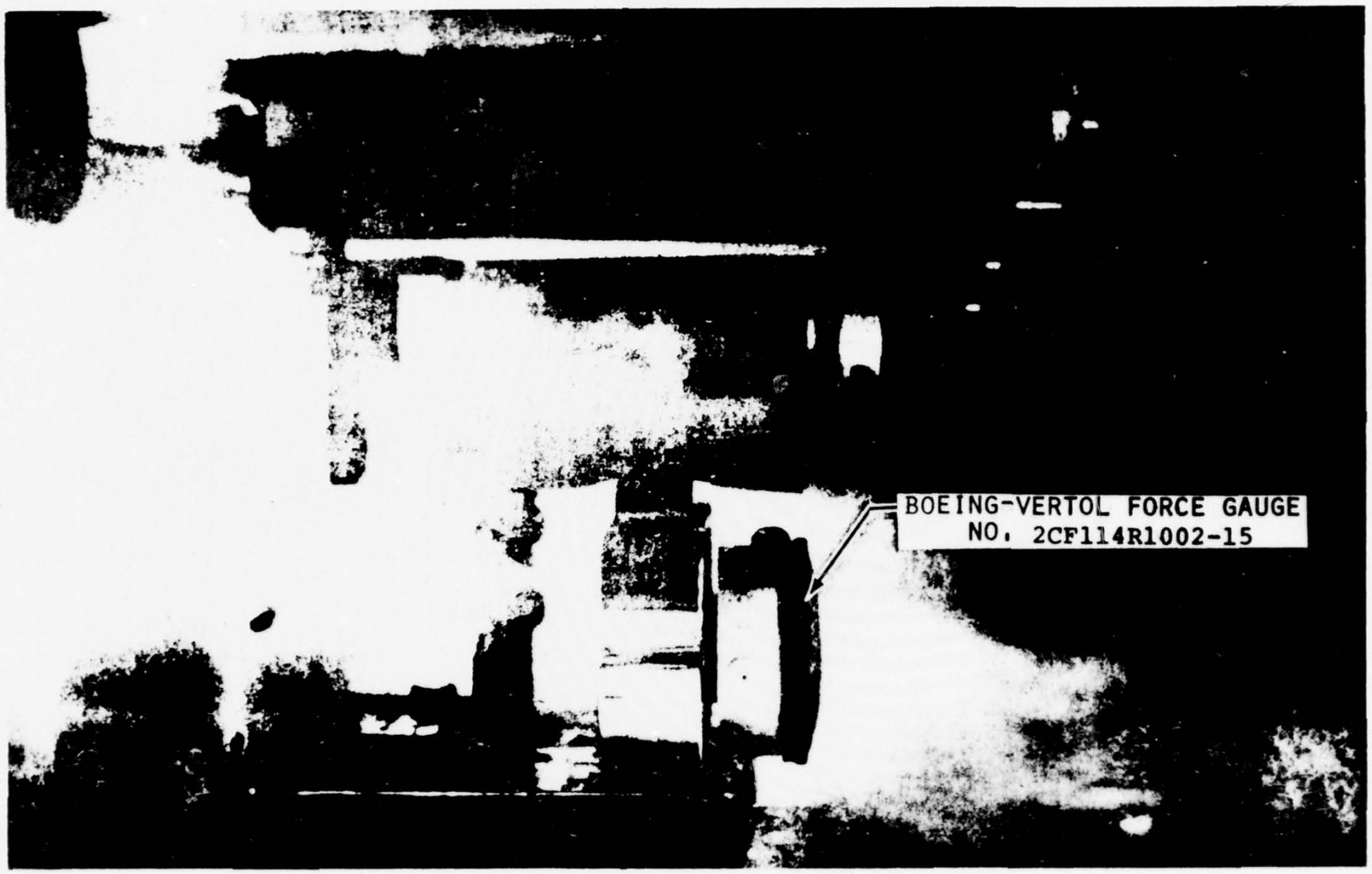


FIGURE 3-6 SIDE VIEW FORCE GAU[redacted]

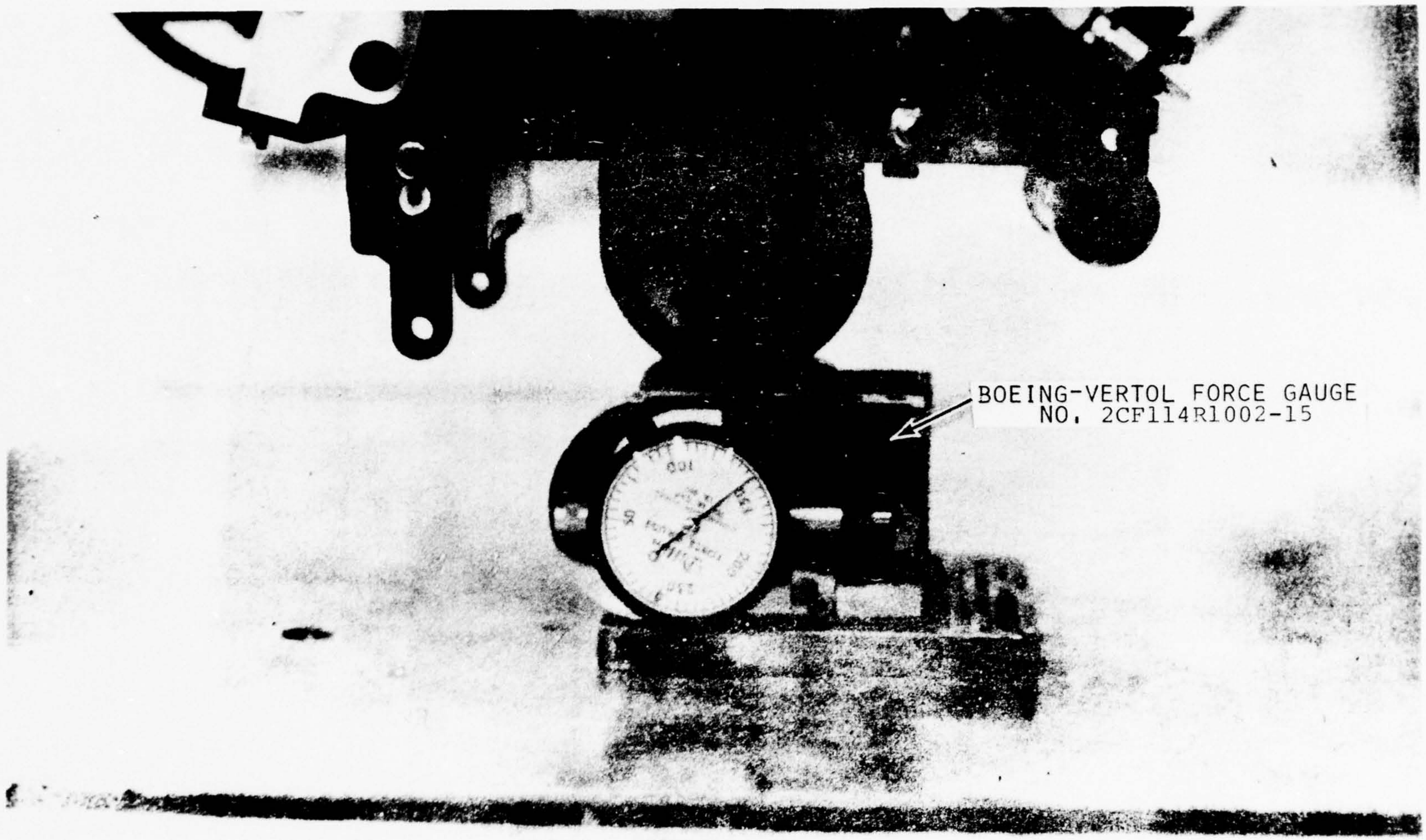


FIGURE 3-7 VIEW MAXIMUM DOWN FORCE READING

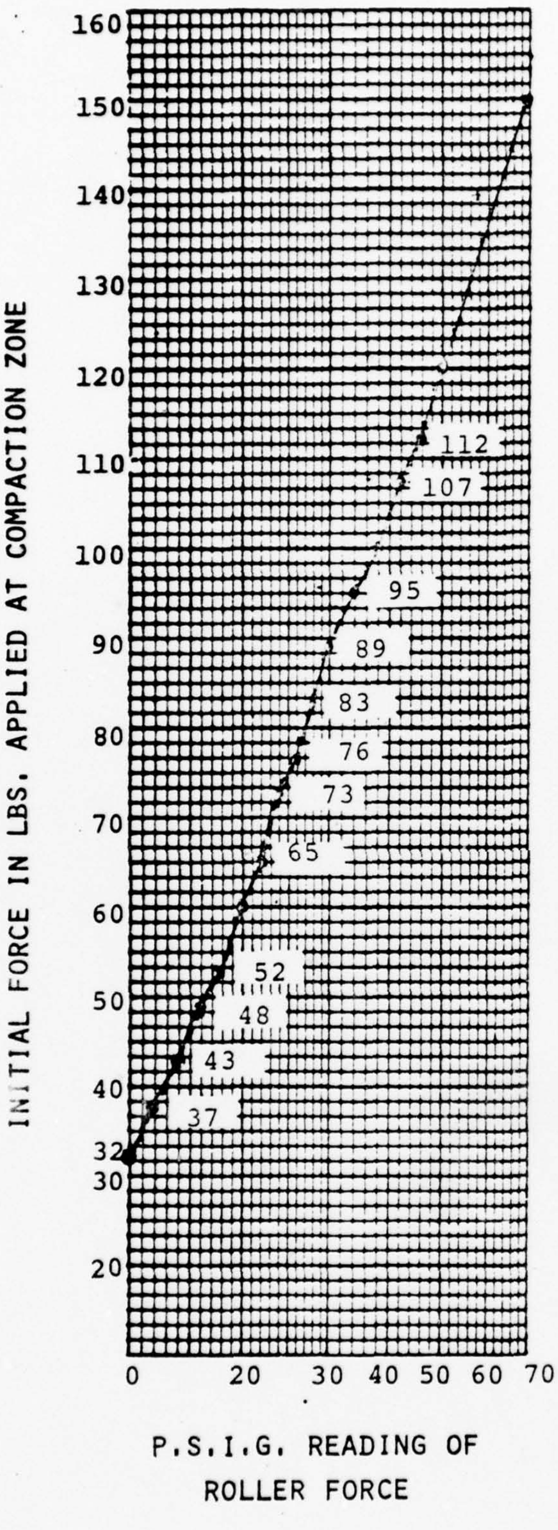


FIGURE 3-8

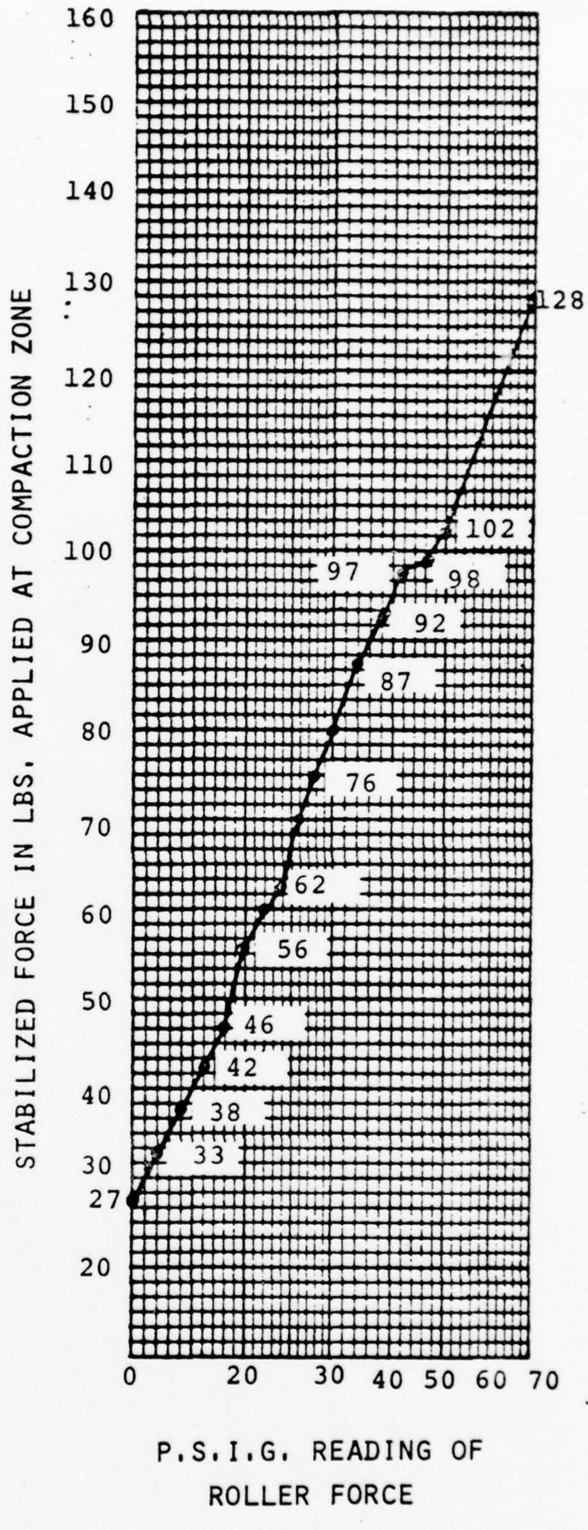


FIGURE 3-9

SECTION 4

4.0 TEST LAYUP FORMS AND OPTICAL WORKPIECE ALIGNMENT TOOL

4.1 TEST LAYUP FORMS

4.1.1 Purpose

The layup tools offered various contoured surfaces analagous to manufacturing applications. The three shapes choosen demonstrated the ATLAS Machine's ability to lay up contoured unidirectional shapes (e.g. spar straps), cylindrical shapes (e.g. shafts), and concave and convex shapes (e.g. fuselage skins).

4.1.1.1 Spar Tool

The form shown in Figure 4-10 was designed to simulate a section of a spar strap layup and is considered to be the most severe configuration in regard to compaction uniformity. The face is fifty inches (50") long and three and one-half inches (3-1/2") wide. Its contour varies from a flat surface to an asymmetrical shape consisting of a raised crown with a one inch (1") radius, offset one-quarter inches (1/4") from its mean linear centerline. The crown height is one-half inches (1/2") from the tool edges and sloping surfaces run from the crown to the tool edges, Figure 4-11.

4.1.1.2 Cylindrical Form

The cylindrical form in Figure 4-12 was designed to test the ability of a compactor to wrap a forty-five degree (45°) angle using three inch (3") wide tape. Analysis determined that a six inch (6") diameter tool, presenting a curvature radius of three inches (3") would be the most severe shape. This tube is ten feet (10') long with a one-quarter inch (1/4") wall. The outside diameter was machined to a true roundness of one-thousandths (.001) of an inch. Epoxy white paint was applied to seal the surface and provide an excellent compaction area.

4.1.1.2.1 Cylindrical Form, Mounting Characteristics

The ATLAS Machine has a powered headstock with a simple, live tailstock. The tailstock weldment consists of an upright with a flat base that can be held by T-Bolts in the ATLAS Machine bed. To minimize set-up alignment, a self-aligning bearing was used to assemble the cylinder to the tailstock.

4.1.1.3 Concave and Convex Layup Forms

During a visit to Boeing-Vertol by a Goldsworthy Engineering representative, various existing concave and convex layup tools were reviewed. The tool chosen presented a flat surface with good transitions to both concave and convex surfaces, Figures 4-13 and 4-14.

4.2 OPTICAL WORKPIECE ALIGNMENT TOOL (Figure 4-15)

4.2.1 Purpose

The optical tool was used to align the layup form tools on the ATLAS Machine.

4.2.2 Method

An accurate system for aligning layup form tools was established by relating reference points on the form tools with the ATLAS Machine's readouts.

4.2.2.1 Fiber-Optics

A sensing head with a "Bow Tie" configuration, Figure 4-17, was developed during the line-follower portion of the ATLAS program. With this "Bow-Tie" sensor in surface contact with a target area, differential outputs of the two photo cells were indicated by a null meter, Figure 4-18.

4.2.2.1.1 Design Characteristics of Fiber-Optic Sensor

Two triangular shapes touching at the apex of the triangles formed the "Bow-Tie" configuration at one end of a brass body. Three bundles of fibers were brought together and epoxied within this

4.2.2.1.1 continued

brass housing. The fibers in each triangle were arranged so that there was an equal dispersion of fibers going to each photo-cell and the light source.

4.2.2.2 "Bow-Tie" Target (Figure 4-19)

A "Bow-Tie" target for the photo-cells to differentiate was made of black opaque lines printed on translucent mylar. Self-stick adhesive was used on the opposite side.

4.2.2.3 Holder

A removeable holder to mount in the universal holder was provided for the "Bow-Tie" and associated lamps and photo-cells. This holder slides on the 'Y' plane to achieve the true center of rotation on the ATLAS tape-head.

4.2.2.4 Electrical Hardware

All electrical hardware necessary to convert the "Bow-Tie" optical sensing to an electrical signal was completely contained within the "Bow-Tie" holder. Electrical connections between the "Bow-Tie" and a portable machine control box were through an eight foot, six conductor cord to a six pin threaded internal socket. The "Bow-Tie" assembly was attached to the universal holder by the same method used for Type I, Type II and Type III compactors.

4.2.2.5 Fiber-Optics Sensor, Assembled Unit (Figure 4-15)

Cross-sliding of the holder between two hardened gibs provided true centering of the "Bow-Tie" to the tape-head in the 'X' plane (Figure 4- 15). Using a locking thumbscrew, movement in the 'Y' plane was accurately controlled. The "Bow-Tie" location on the 'Y' plane centerline was accurately fixed by dowels and therefore non adjustable.

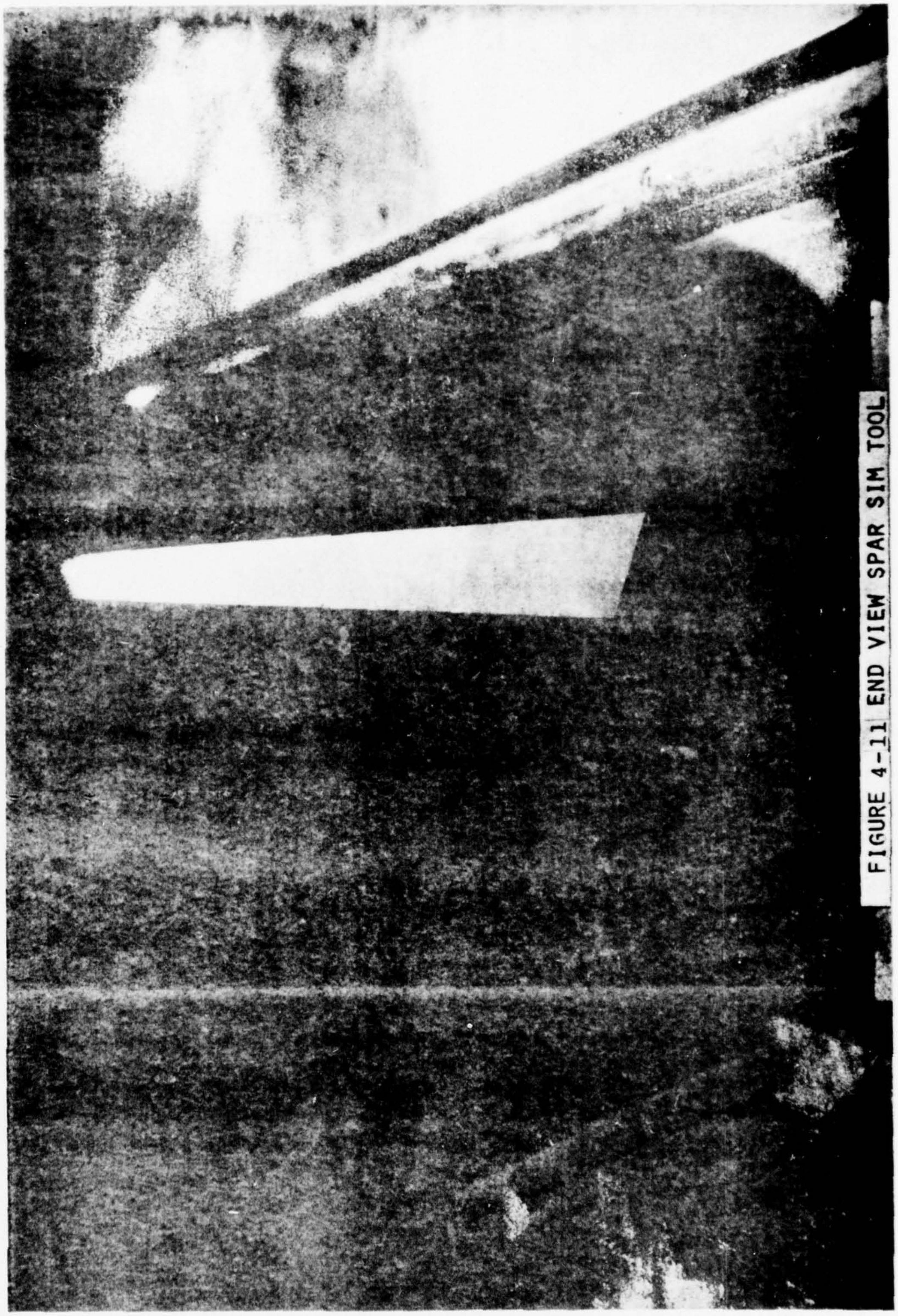


FIGURE 4-11 END VIEW SPAR SIM TOOL

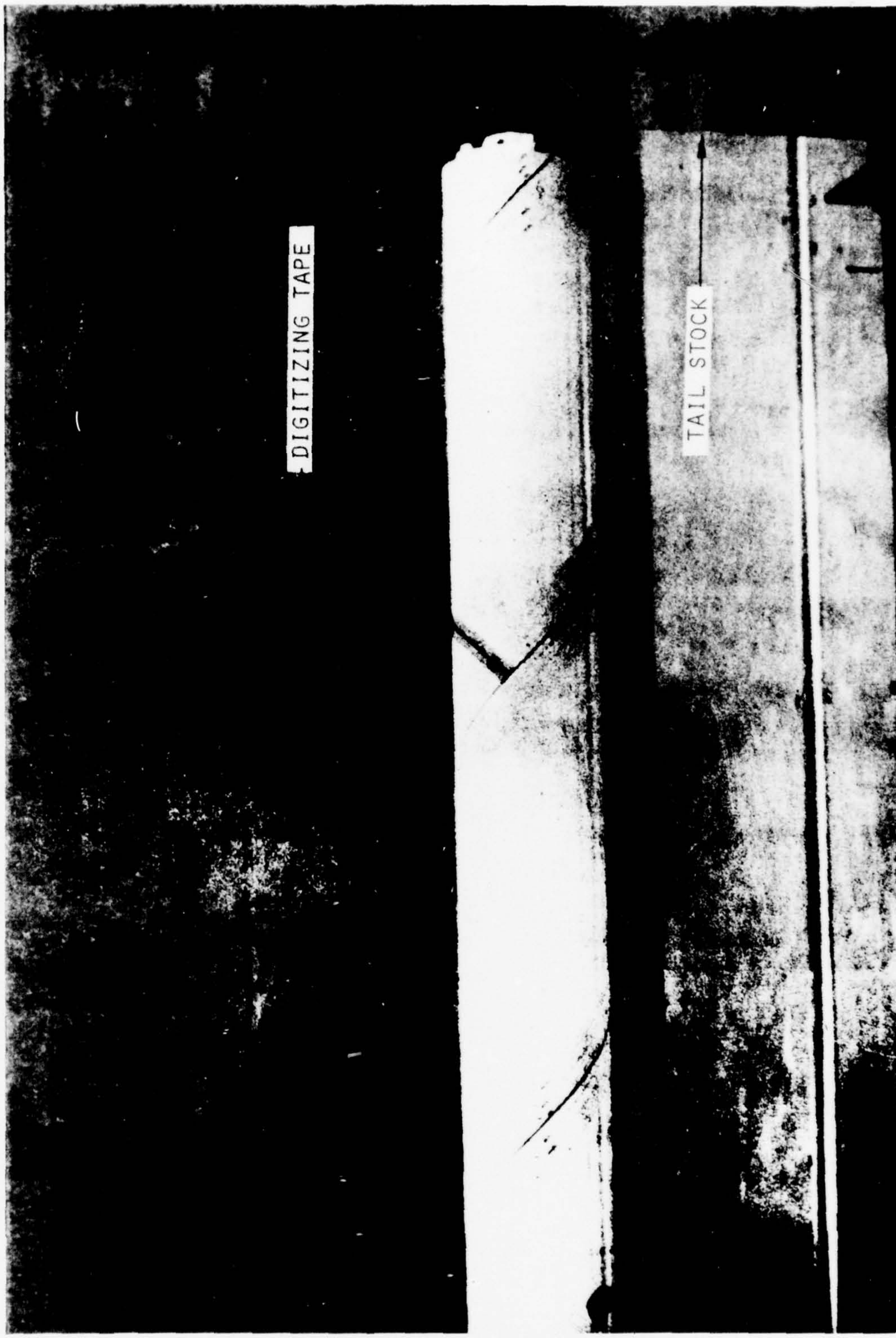


FIGURE 4-12 CYLINDER LAY-UP TOOL

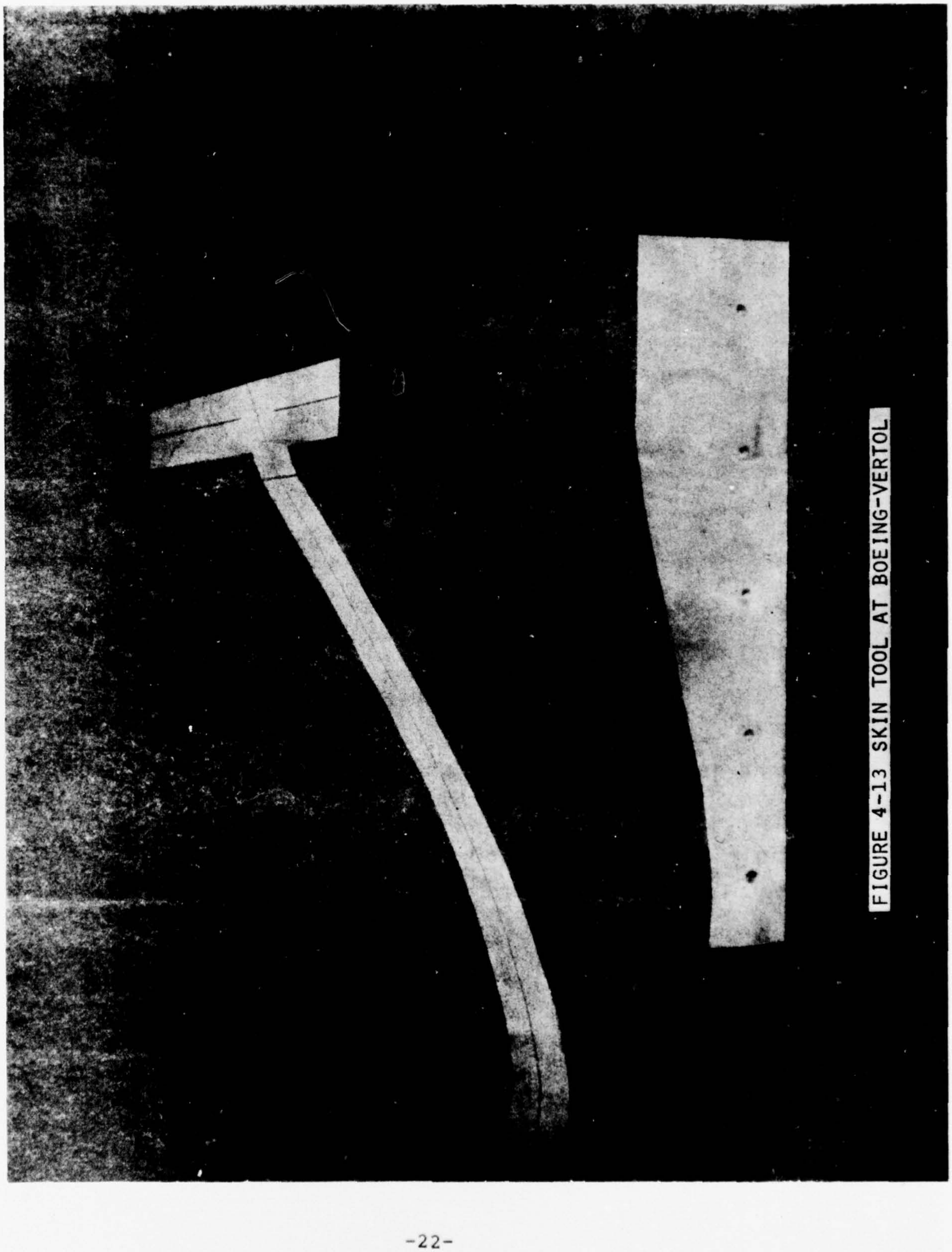


FIGURE 4-13 SKIN TOOL AT BOEING-VERTOL

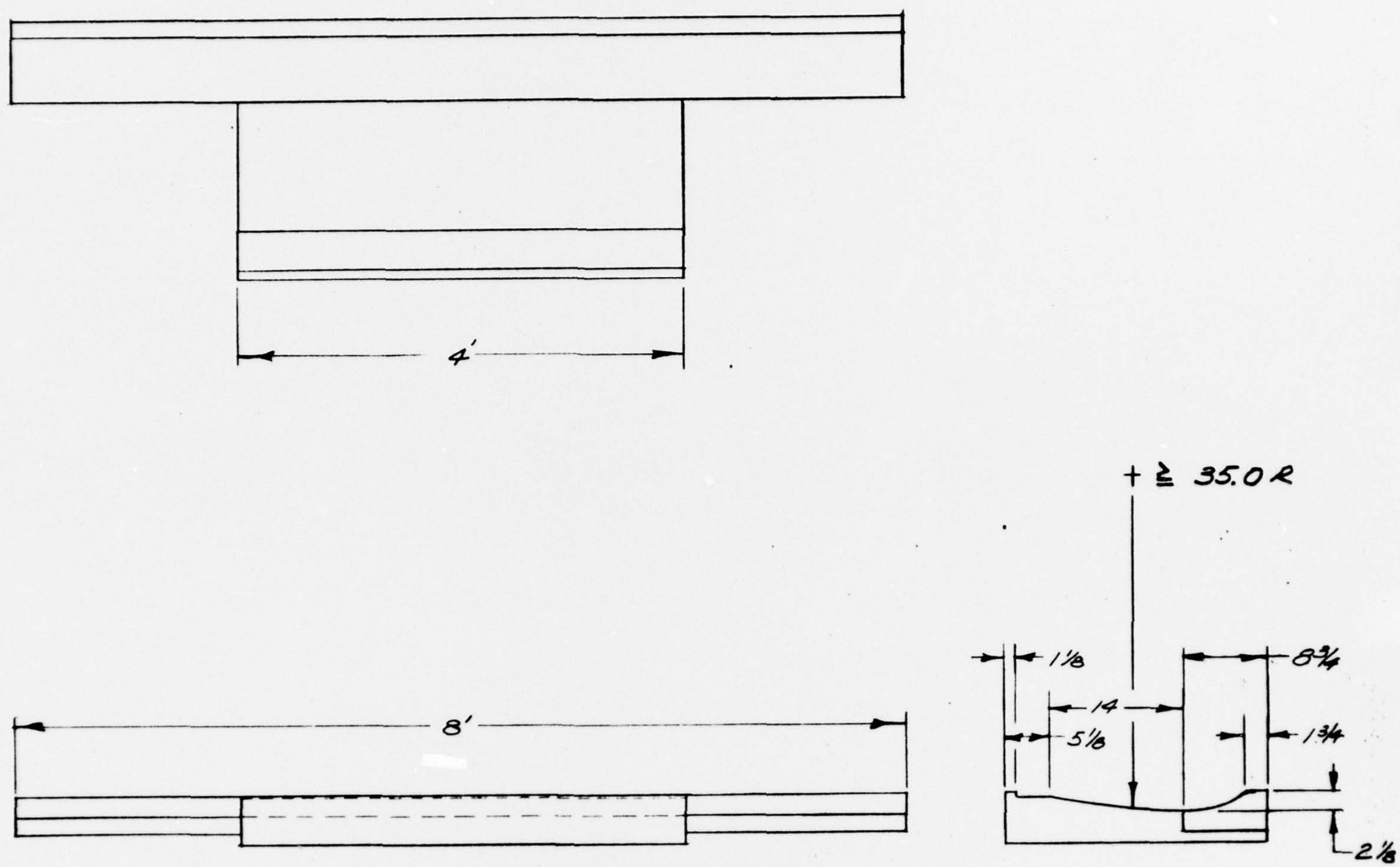


FIGURE 4-14 ILLUS SKIN-TOOL DIM CHARACTERISTICS

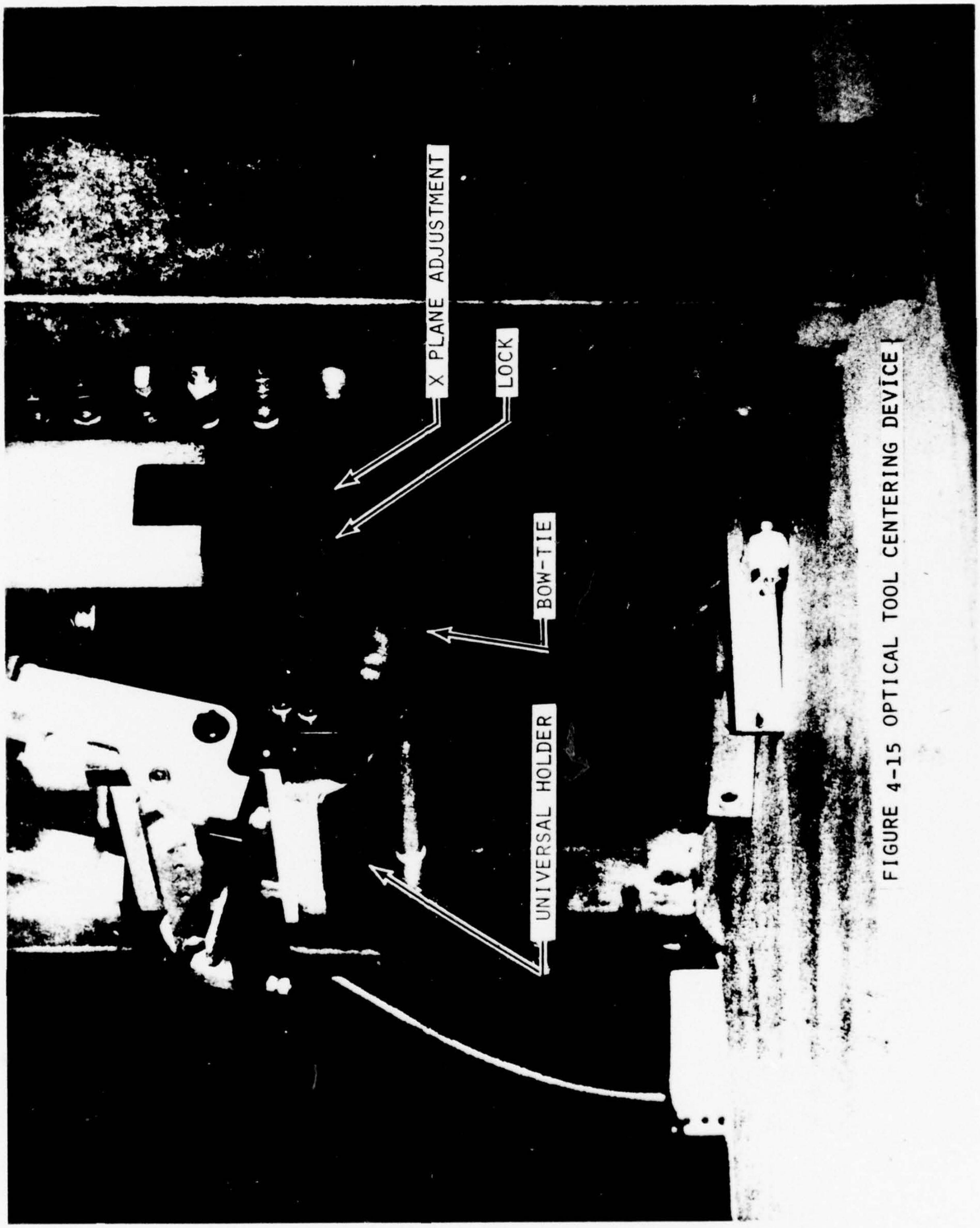


FIGURE 4-15 OPTICAL TOOL CENTERING DEVICE

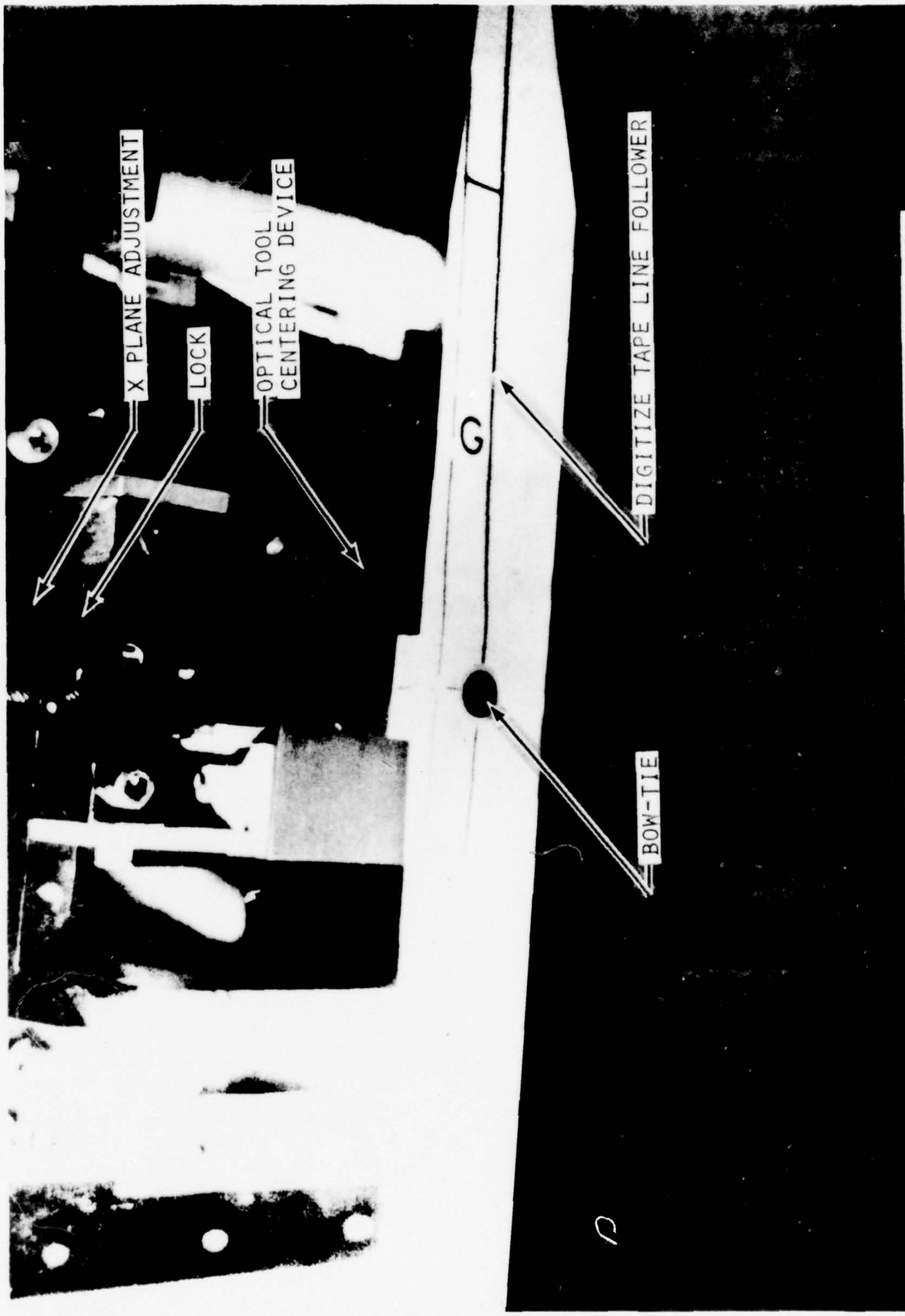


FIGURE 4-16 OPTICAL TOOL, W/DIGITIZE TAPE LINE FOLLOWER

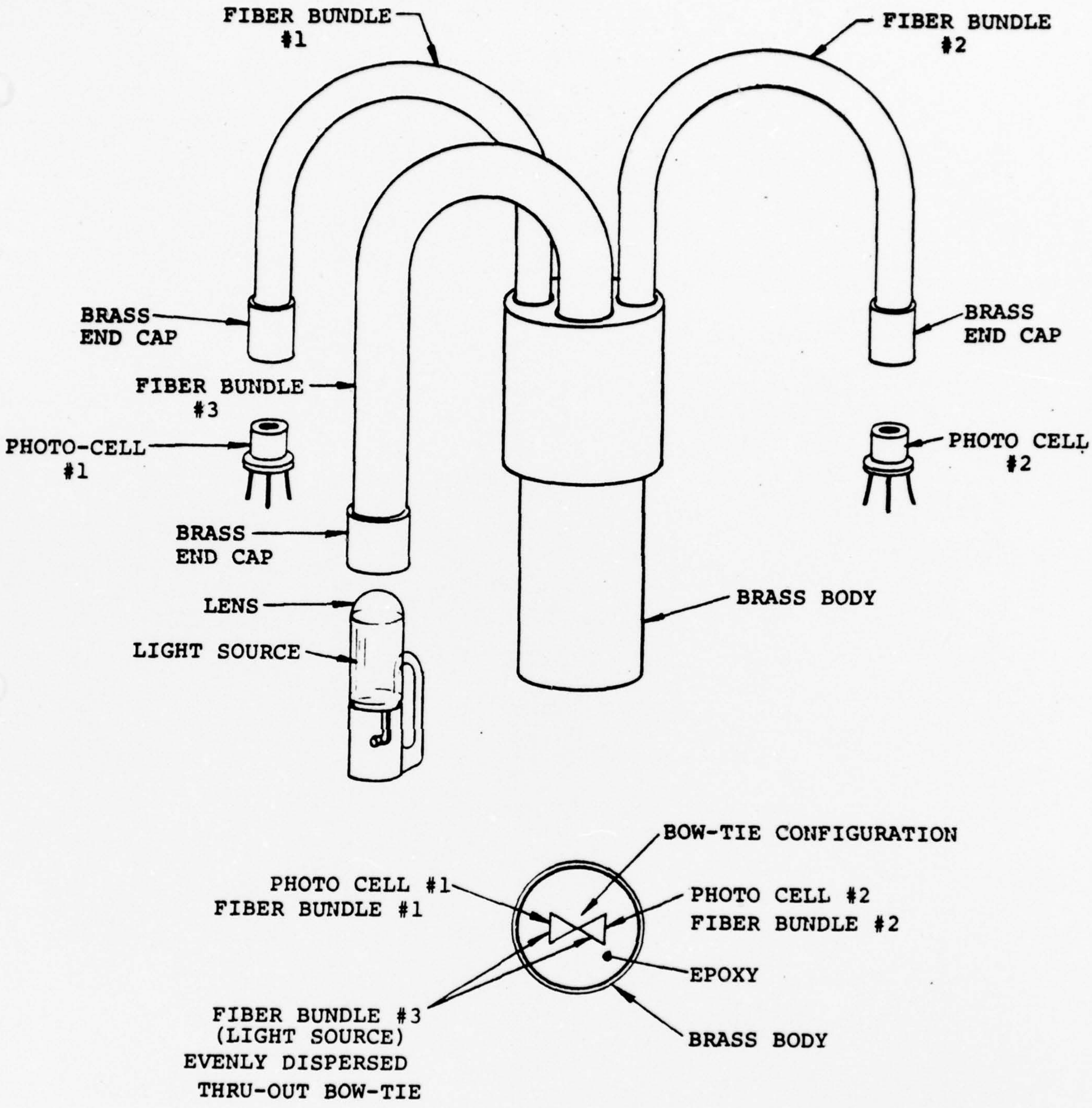


FIGURE 4-17 ILLUSTRATION OPTICAL BOW-TIE

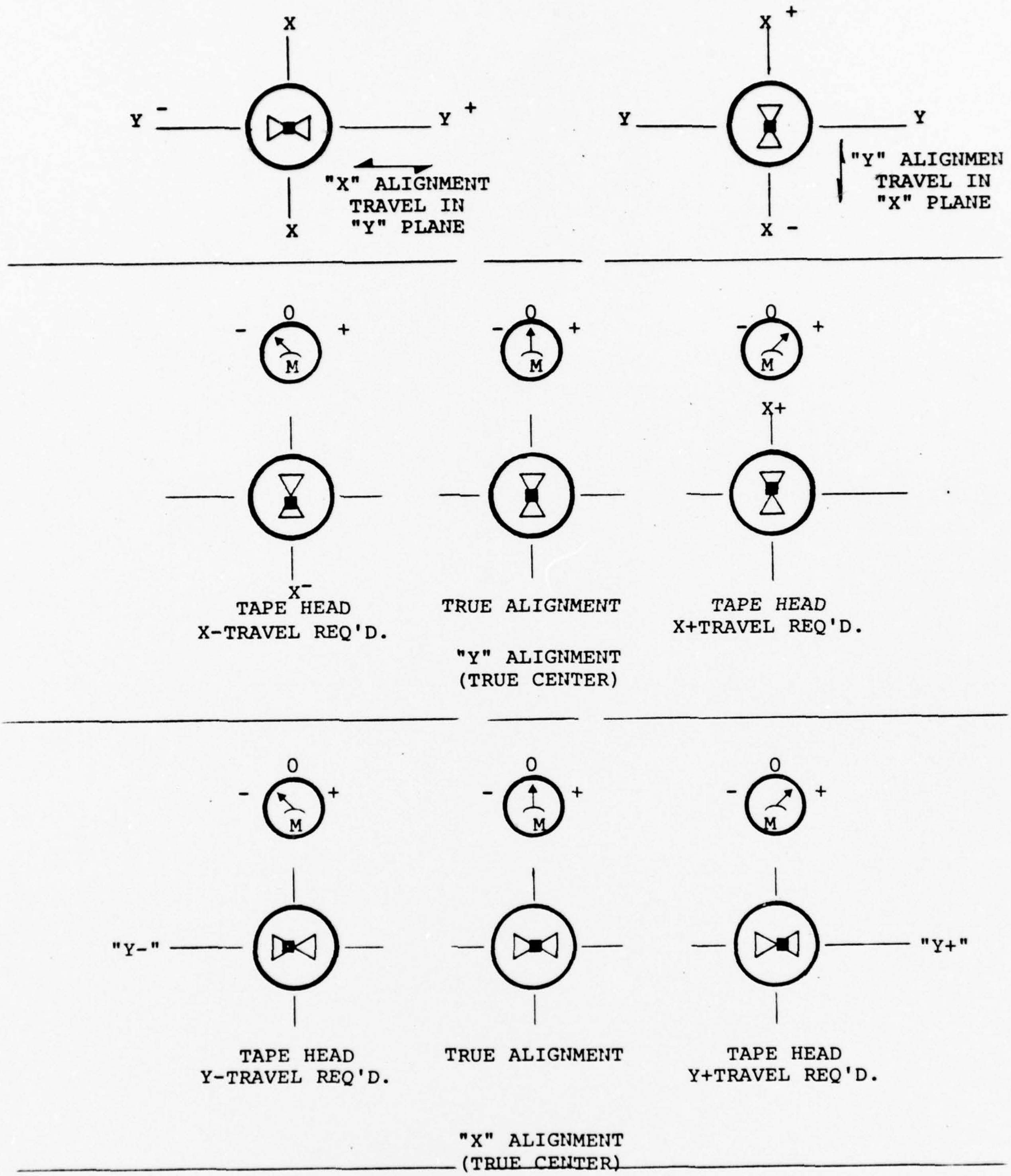


FIGURE 4-18 ILLUS BOW-TIE ALIGNMENT ORIENTATION

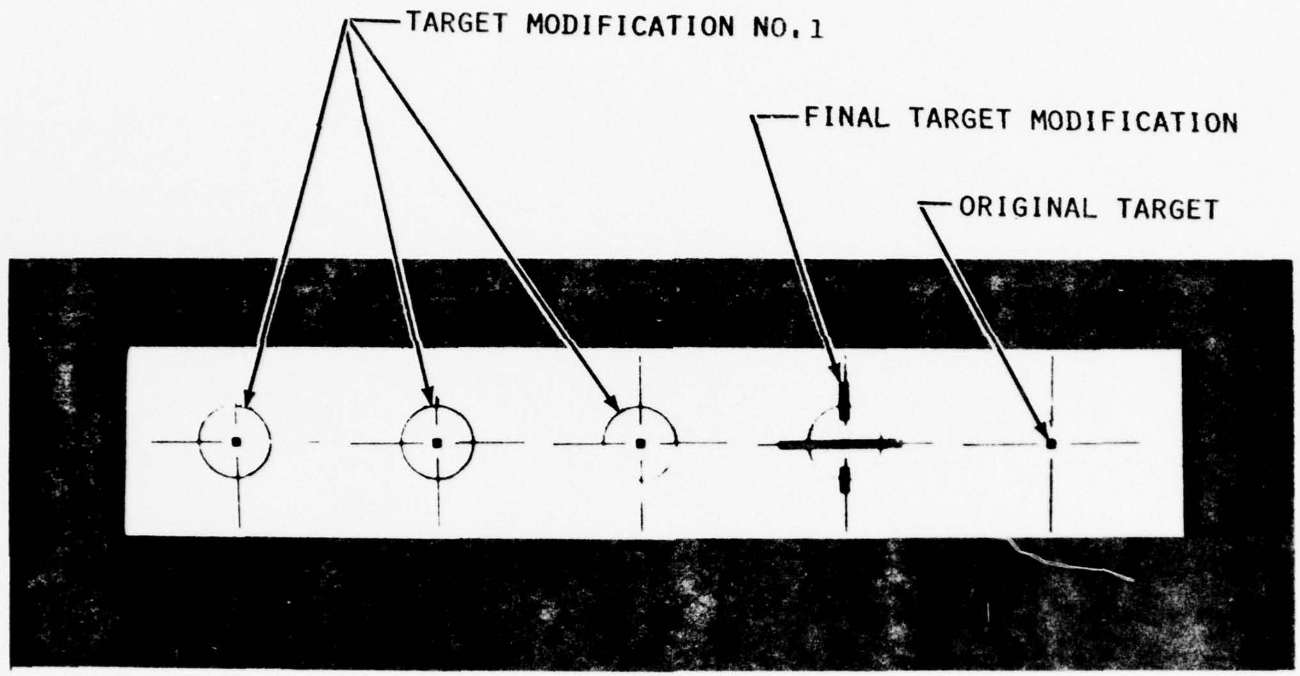


FIGURE 4-19 TARGET,MODIFICATIONS

SECTION 5

5.0 UNIVERSAL HOLDER FOR COMPACTORS (Figure 5-20)

5.1 HOLDER DESIGN REQUIREMENTS;

5.1.1 A rigid structure to act as a common base for readily attaching and removing the three compactors and other mechanisms tested.

5.1.2 Positive clamping of multi-fiber composite tape at the end of a laydown pass.

5.1.3 The ability to shear a variety of multi-fiber composite tapes within a limited time span without breaking the tape's backing paper, and to lower the cut-length between the compaction zone and shear point to five inches (5").

5.1.4 Tape guidance to insure a high degree of tracking repeatability during laydown pass, particularly at low compaction pressures.

5.1.5 Tape guidance to insure an accurate lead during transition from vertical travel to horizontal compaction. At this transition point, separation of the composite and backing paper must not occur.

5.1.6 A rolling device to elminiate the excessive tension occurring at the outermost side areas of the compactor foot's leading edge when transfering from a flat horizontal or flat vertical condition (e.g. compacting a cylindrical surface).

5.1.7 Tape guidance, both fore and aft, to insure proper alignment of the multi-fiber composite during the pin-wrap flipping operation, and to guide the backing paper as it is stripped from the compacted composite and rolled onto the paper take-up reel.

5.2 UNIVERSAL HOLDER, COMPONENTS AND CHARACTERISTICS

5.2.1 Basic Frame, Figure 5-22

The basic frame is a one piece, rigid structure. Retained within this basic frame is a yoke, Figure 5-23 , which attaches to the ATLAS tapehead casting. As an interface between the basic frame and the ATLAS tapehead casting and also to achieve 'X' plane alignment, two prime requirements were met:

5.2.1.1 Clearance to mount various compactors and/or mechanisms, Figure 5- 21 and 4-15.

5.2.1.2 Positive alignment of the basic frame in the 'X' and 'Z' planes. Dowel pins and threaded holes were provided on the compactor mounting surface, Figure 5-29 . Attachment and alignment accuracy between the basic frame and compactors in the 'X', 'Y', and 'Z' planes was established by using a hardened drill fixture, Figure 5-30.

5.2.2 Tape Clamp

The tape clamp is a positive, non-slip mechanism, Figure 5-24 and 5-25. Tape clamping force is exerted by two (2) one-and-one eighth inch (1-1/8") diameter air cylinders pulling through mechanical levers to obtain a mechanical advantage $\geqq$ 3:1. The clamping side is teflon coated; the stationary side is a soft urethane surface. Both sides of the clamp are replaceable.

5.2.3 Tape Shear (Figure 5-25 and 5-28)

Tape shear force is exerted by the same two air cylinders used for clamping. The action, however, is caused by extending the cylinders and pushing the mechanical levers in the opposite direction to clamping travel. The mechanical advantage remains $\geqq$ 3:1. A previously developed shear blade was used.

5.2.4 Shear Clamping (Figure 5-25 and 5-28)

Between positions 'A' (shearing) and 'B' (clamping) is a third positon, 'C' (neutral). The 'C' position allows continuous

5.2.4 continued

tape travel through the shear and clamp. To obtain this neutral position, the air cylinders were positioned approximately in midrange stroke. A third cylinder, hereinafter known as the positioning cylinder "c", is located between the two large air cylinders, Figure 5-25 . This positioning cylinder incorporates a sliding piston, Mechanical Schematic Illustration 5-26. The sequential interface of these three cylinders is shown in Pneumatic Schematic Illustrations 5-26 and 5-27. The shear cut depth was controlled by positioning the air cylinders, Figure 5-25 . Clamping force was adjusted by stops located on the rod ends of the actuating air cylinders, Figure 5-25 and 5-20.

5.2.5 Tape Guide Backing-Paper Take-Up (Figure 5-28)

A teflon coated, free-wheeling roller was mounted to the rear of the basic frame. Adjustment for the 'Z', or vertical, plane was provided.

5.2.6 Tape Guide

Retained within the basic frame, a stationary tape guide (Figure 5-28) was incorporated to limit side movement of the tape. The guide directed the tape thru the clamp and shear during transition from vertical to horizontal planes. It is adjustable in the 'Z' plane so the required cut length of five inches (5") does not restrict the compactor's design.

5.2.7 Tape Guide - Prevention of Tape Separation

An outer tape retainer guide (Figure 5-24) was attached to the stationary tape guide. This retainer prevents separation of the tape from the backing paper during transition from vertical to horizontal. The inner working surface is teflon coated in order to lower friction and eliminate build-up of composite residue.

5.2.8 Cylindrical Conformance Mechanism (Figure 5-28)

Two free turning, clevis mounted rollers (Figure 5-28), were attached to air cylinders and prevented from rotating by a guide pin. The rollers' pressure is variable through regulation of air flow to the air cylinders.

5.2.9 Tape Guidance Pin Wrap

A free turning, teflon coated roller was used for pin wrapping. The roller is mounted directly below the trailing edge of the tape retainer guide. It is attached with the same mounting hardware used to retain the tape guide, Figure 5-28 .

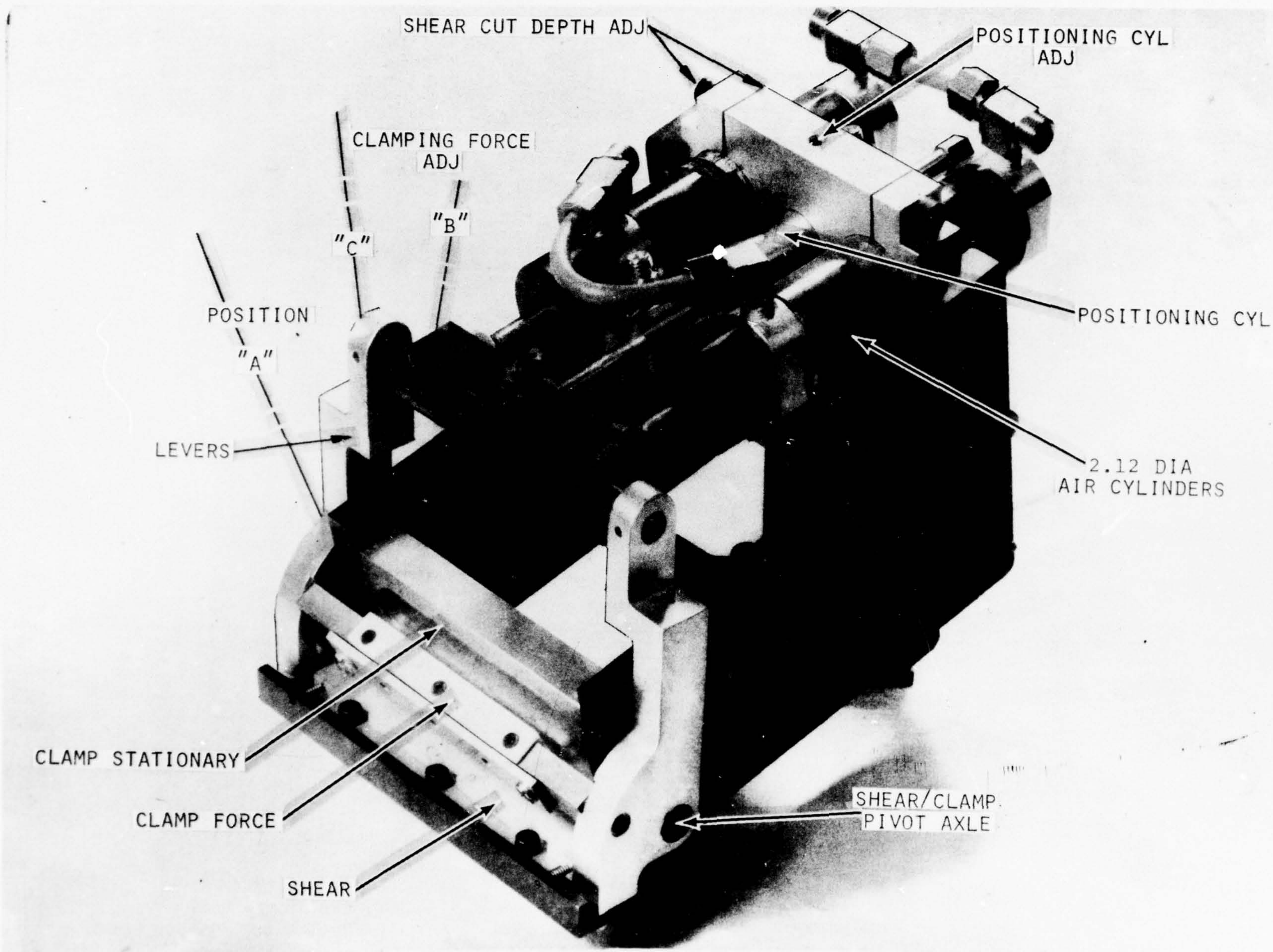


FIGURE 5-20 ASSY VIEW, UNIVERSAL HOLDER

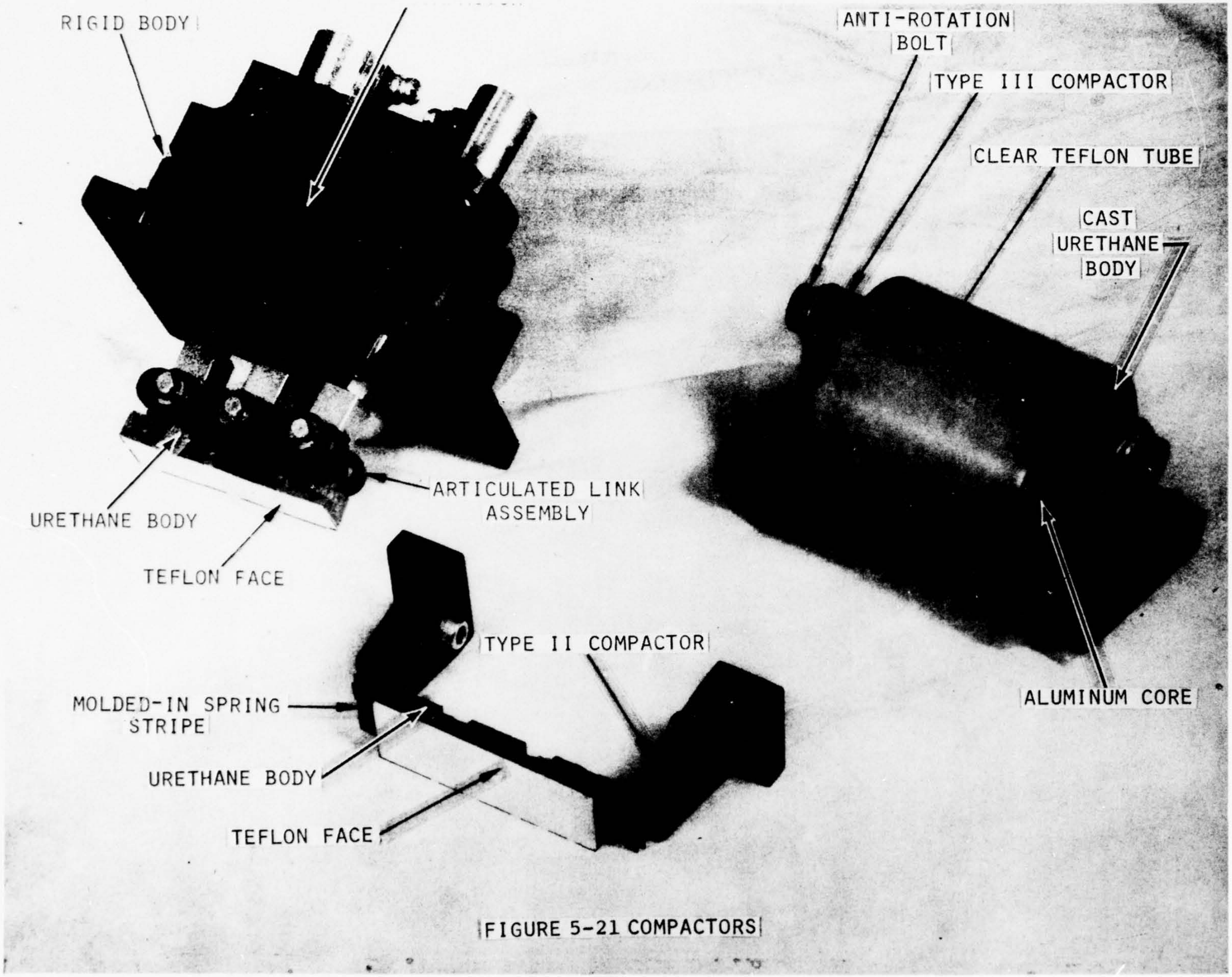


FIGURE 5-21 COMPACTORS

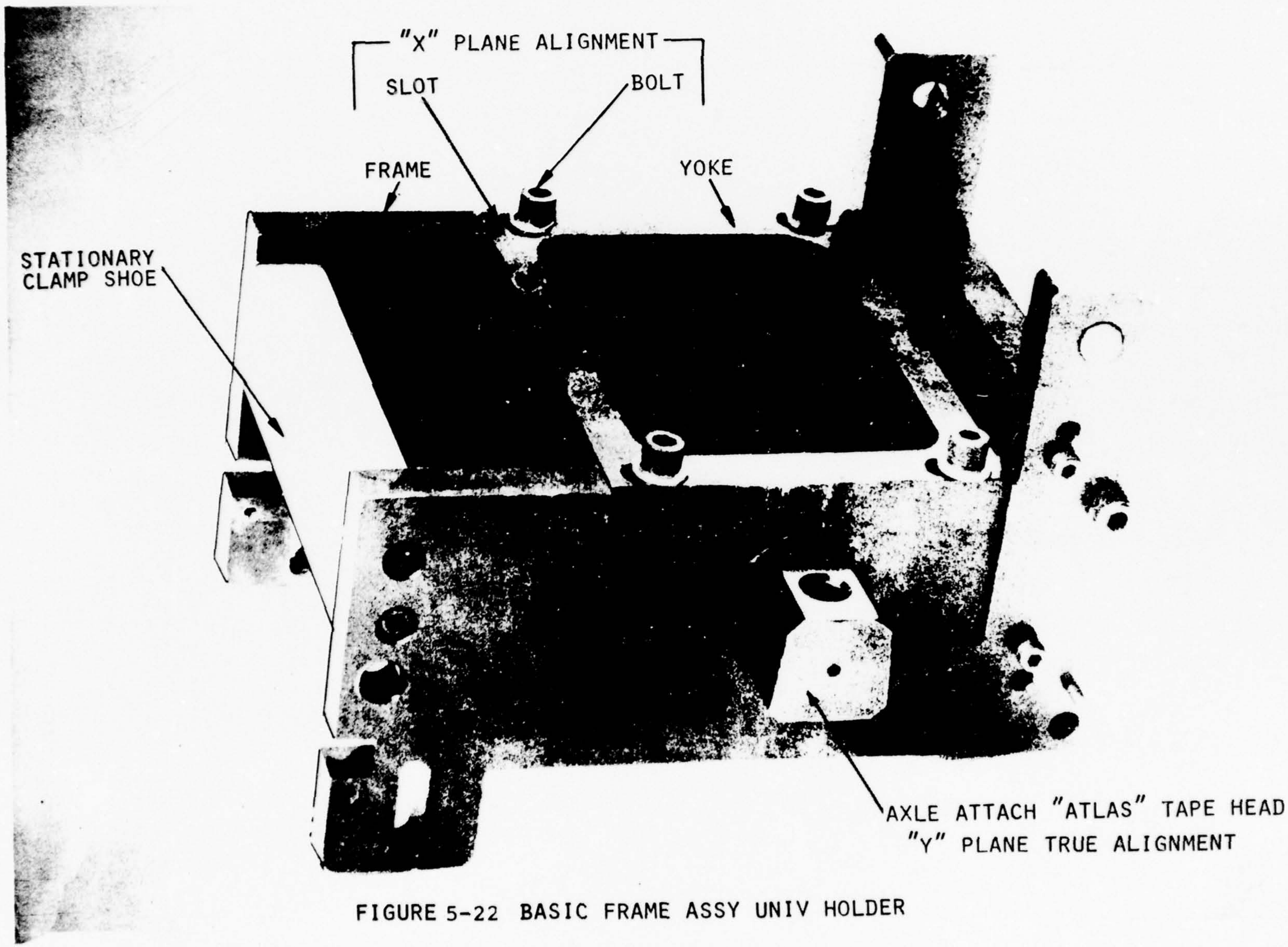


FIGURE 5-22 BASIC FRAME ASSY UNIV HOLDER

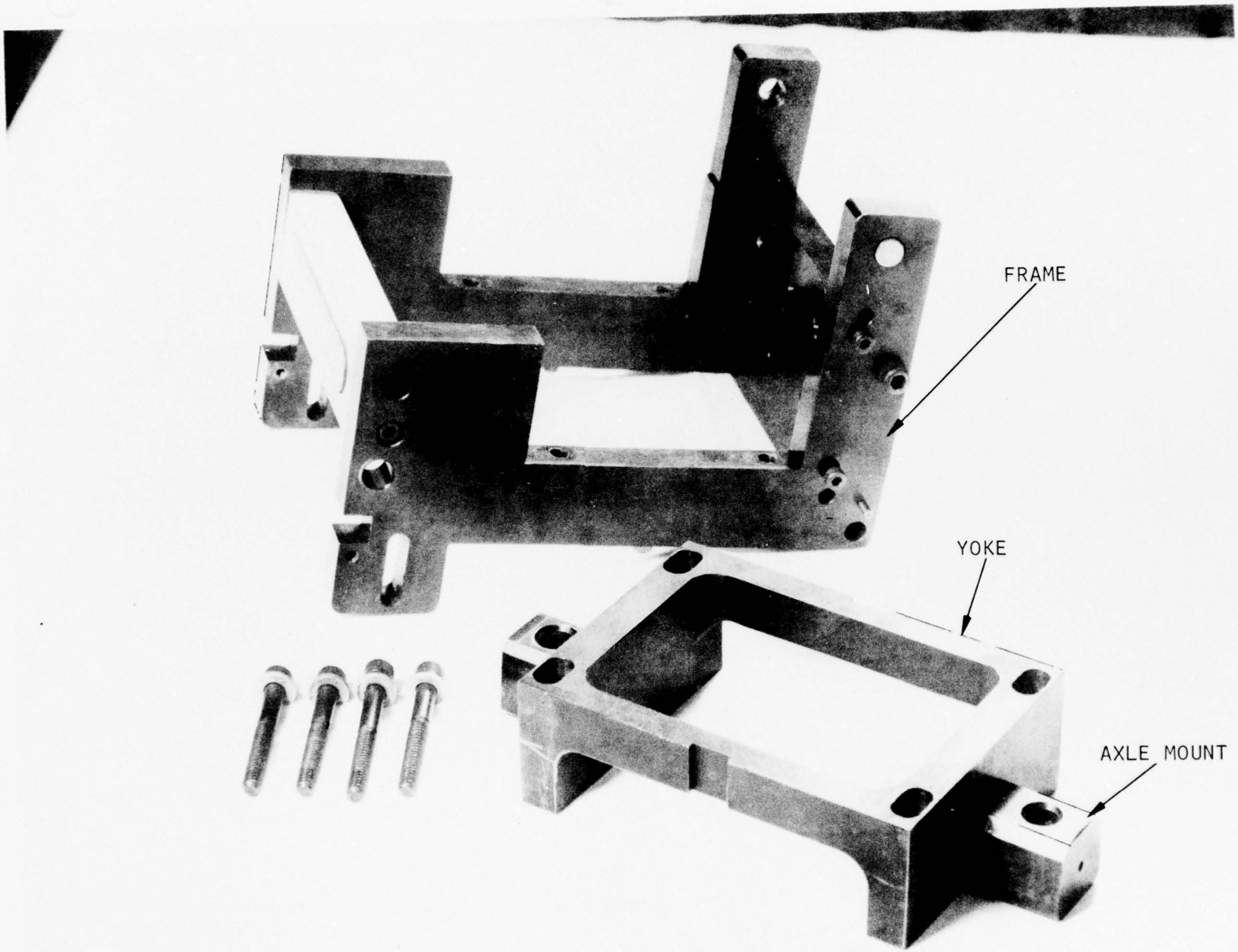


FIGURE 5-23 BASIC FRAME PARTS UNIVERSAL HOLDER

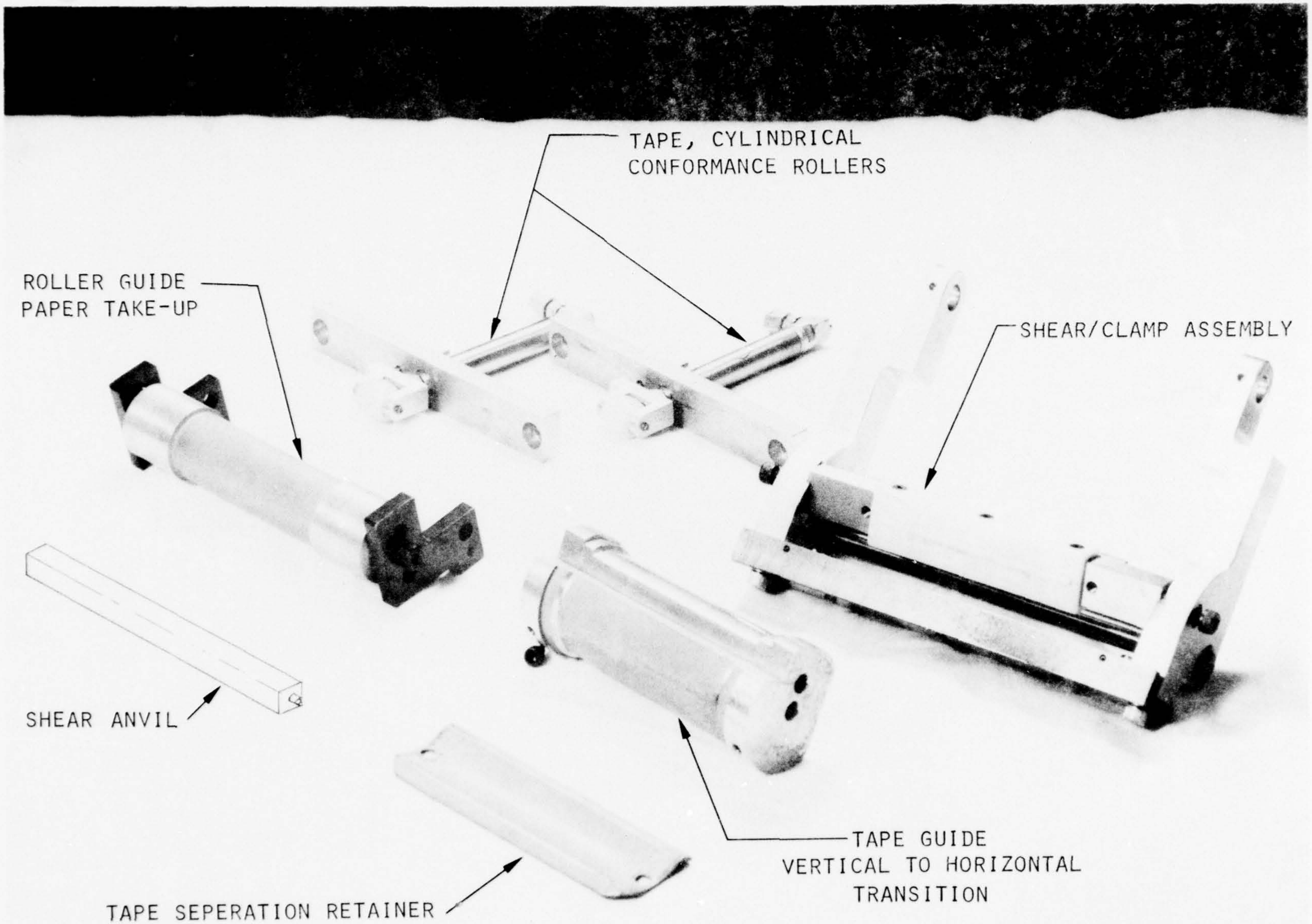


FIGURE 5-24 COMPONENTS, UNIV HOLDER

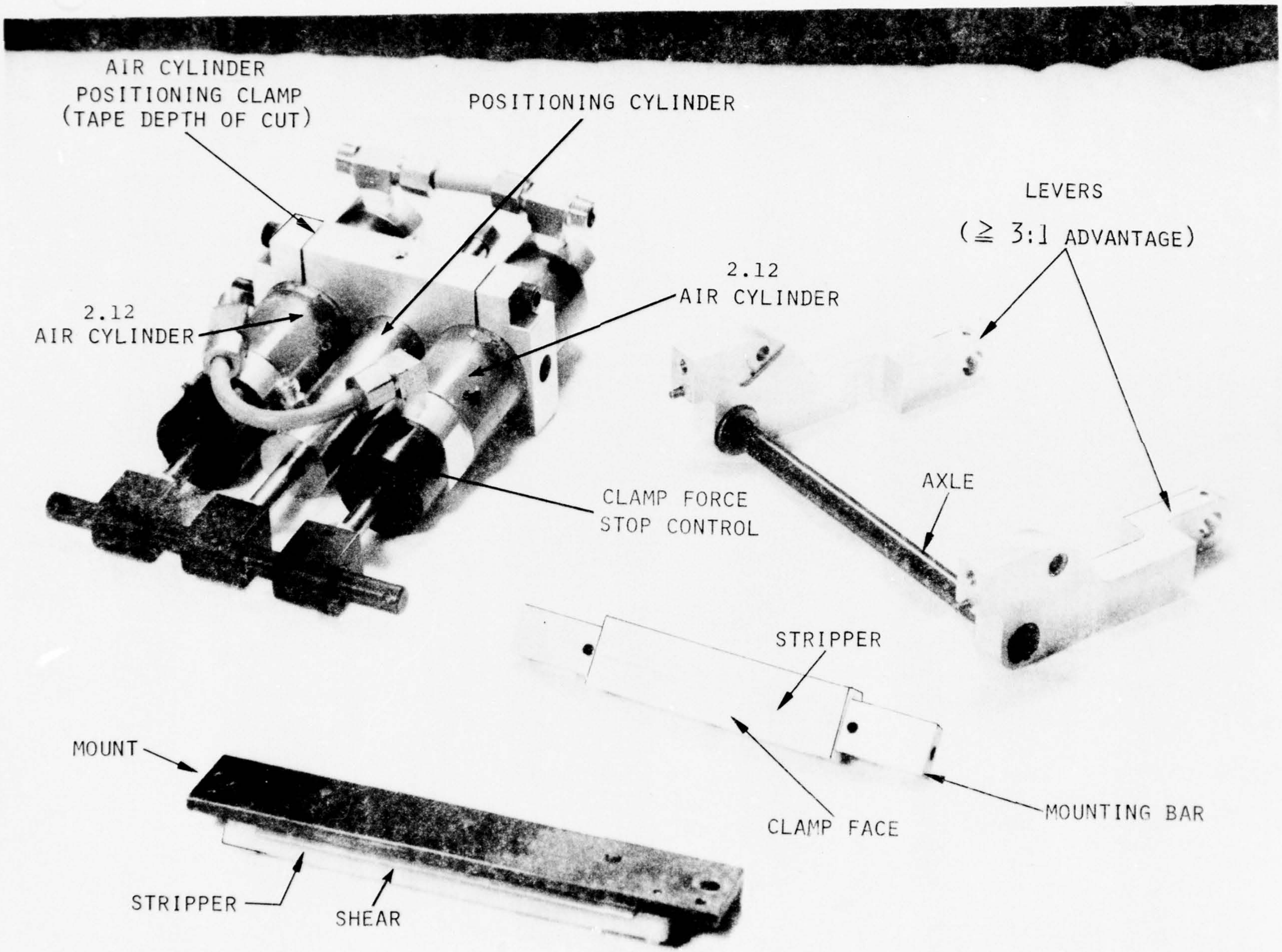
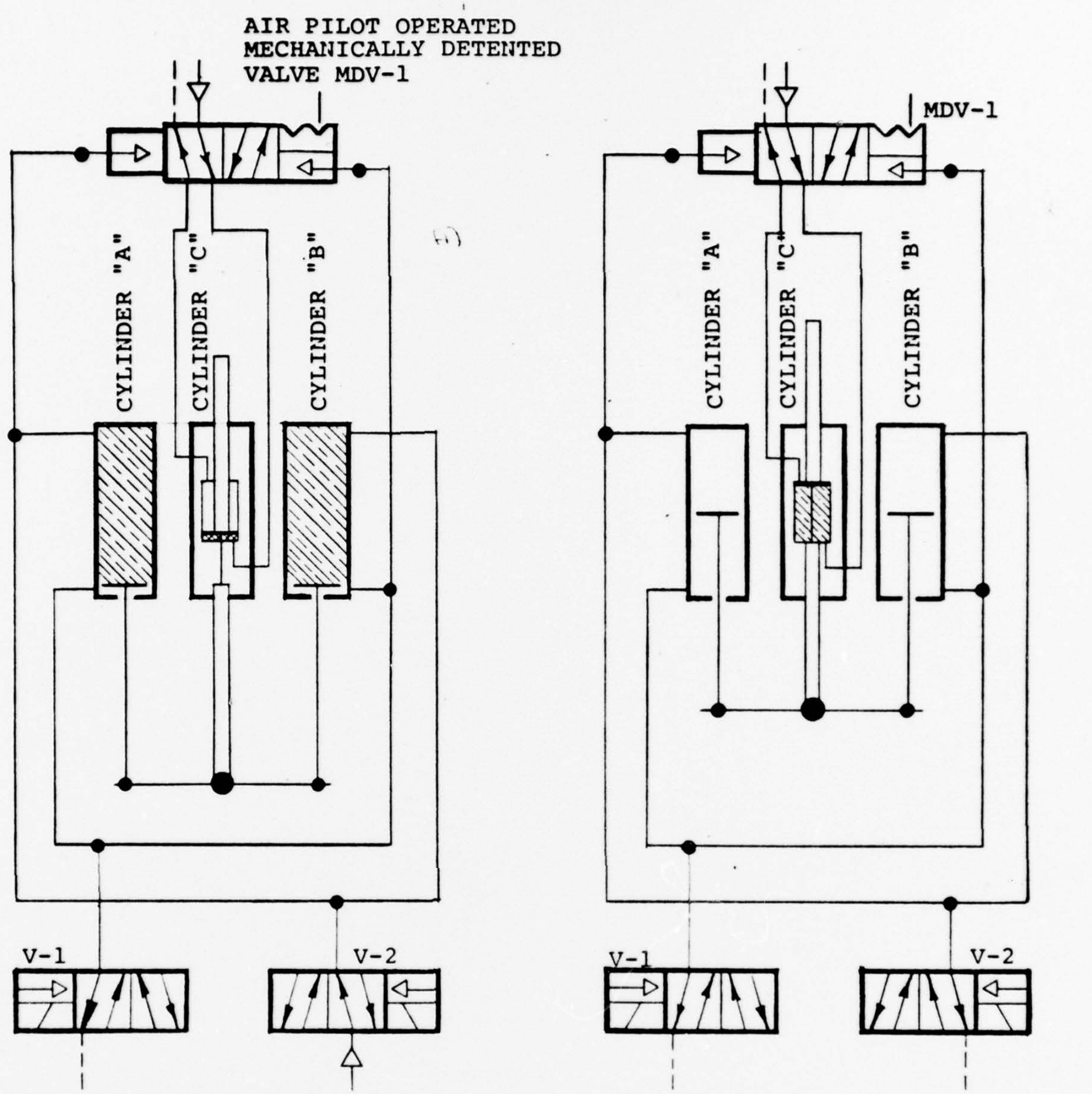


FIGURE 5-25 SHEAR/CLAMP, SUBASSY UNIV HOLDER



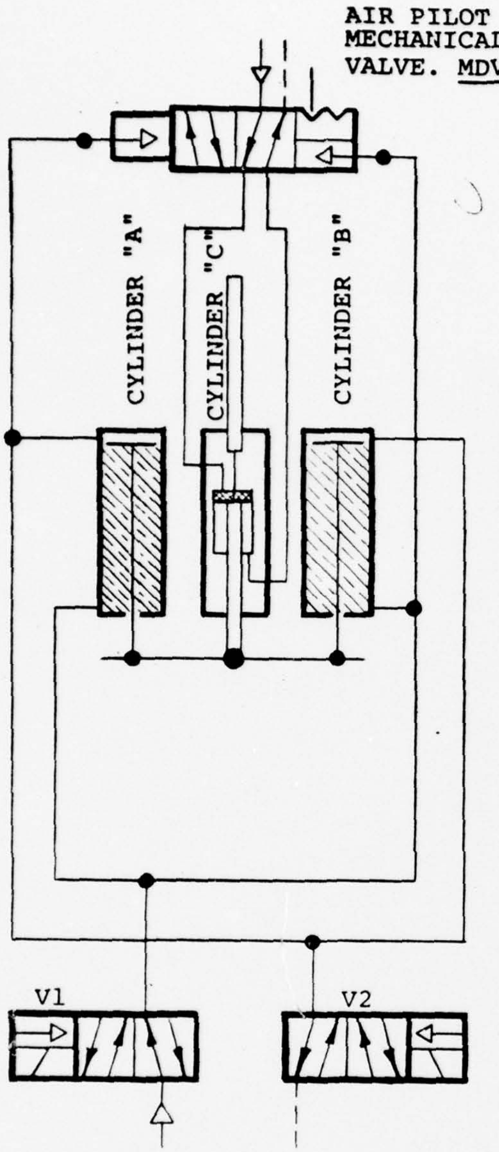
POSITION "A" (SHEARING)

A. CYLINDERS "A", "B", and "C" ACTIVATED TOGETHER.
B. MDV-1 AIR VALVE SHIFTED and MECHANICALLY HELD.
C. CYLINDERS A and B EXTENDED.
D. MECHANICAL LINKAGE REQUIRES CYLINDER "C" TO EXTEND.
E. COMBINED FORCES OF CYLINDERS A & B OVERRIDES FORCE OF CYLINDER "C".
F. POSITION "A" CAN BE HELD INDEFINITELY.

POSITION "C" (NEUTRAL) AFTER SHEARING.

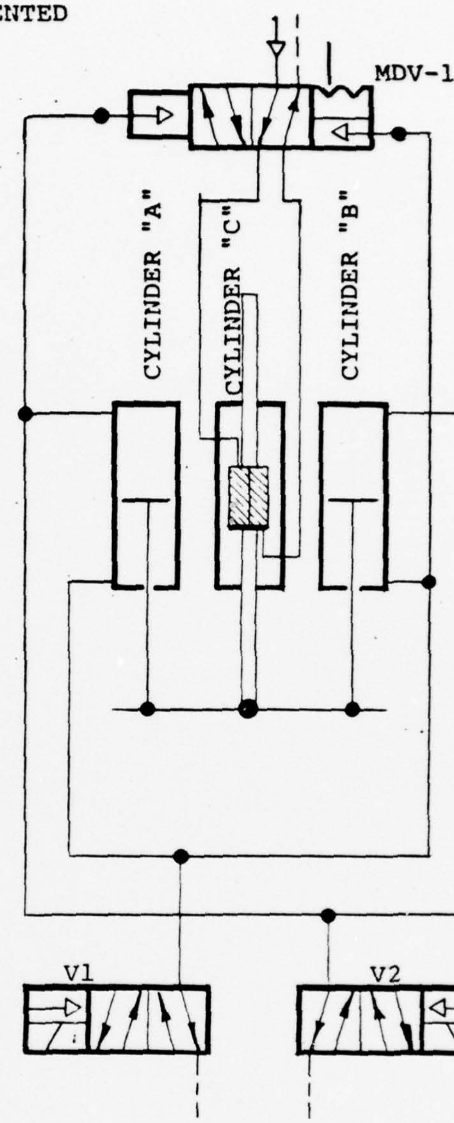
A. CYLINDERS "A" and "B" VENTED BOTH SIDES OF PISTON.
B. CYLINDER "C" FORCE MAINTAINE[D] BY MDV-1.
C. CYLINDER C RETRACTS FORCING A and B TO NEUTRAL THRU MECHANICAL LINKAGE.
D. CYLINDER "C" FORCE CAN BE HELD INDEFINITELY.

FIGURE 5-26 SHEAR-TO-NEUTRAL MECH/PNEU SCHEMATIC



POSITION "B" (CLAMPING)

A. CYLINDERS A, B, and C, ACTIVATED TOGETHER.
B. MDV-1 AIR VALVE SHIFTED and MECHANICALLY HELD.
C. CYLINDERS A and B RETRACTED.
D. MECHANICAL LINKAGE REQUIRES CYLINDER C TO RETRACT.
E. COMBINED FORCES OF CYLINDER A and B OVERRIDE FORCE OF CYLINDER C.
F. POSITION "B" CAN BE HELD INDEFINITELY.



POSITION "C" (NEUTRAL)
AFTER CLAMPING

A. CYLINDERS A and B ARE VENTED BOTH SIDES OF PISTON.
B. CYLINDER "C" FORCE MAINTAINED BY MDV-1.
C. CYLINDER "C" EXTENDS FORCING CYLINDERS A and B TO NEUTRAL.
D. POSITION "C" (NEUTRAL) CAN BE HELD INDEFINITELY.

FIGURE 5-27 CLAMPING TO NEUTRAL MECH/PNEU SCHEMATIC

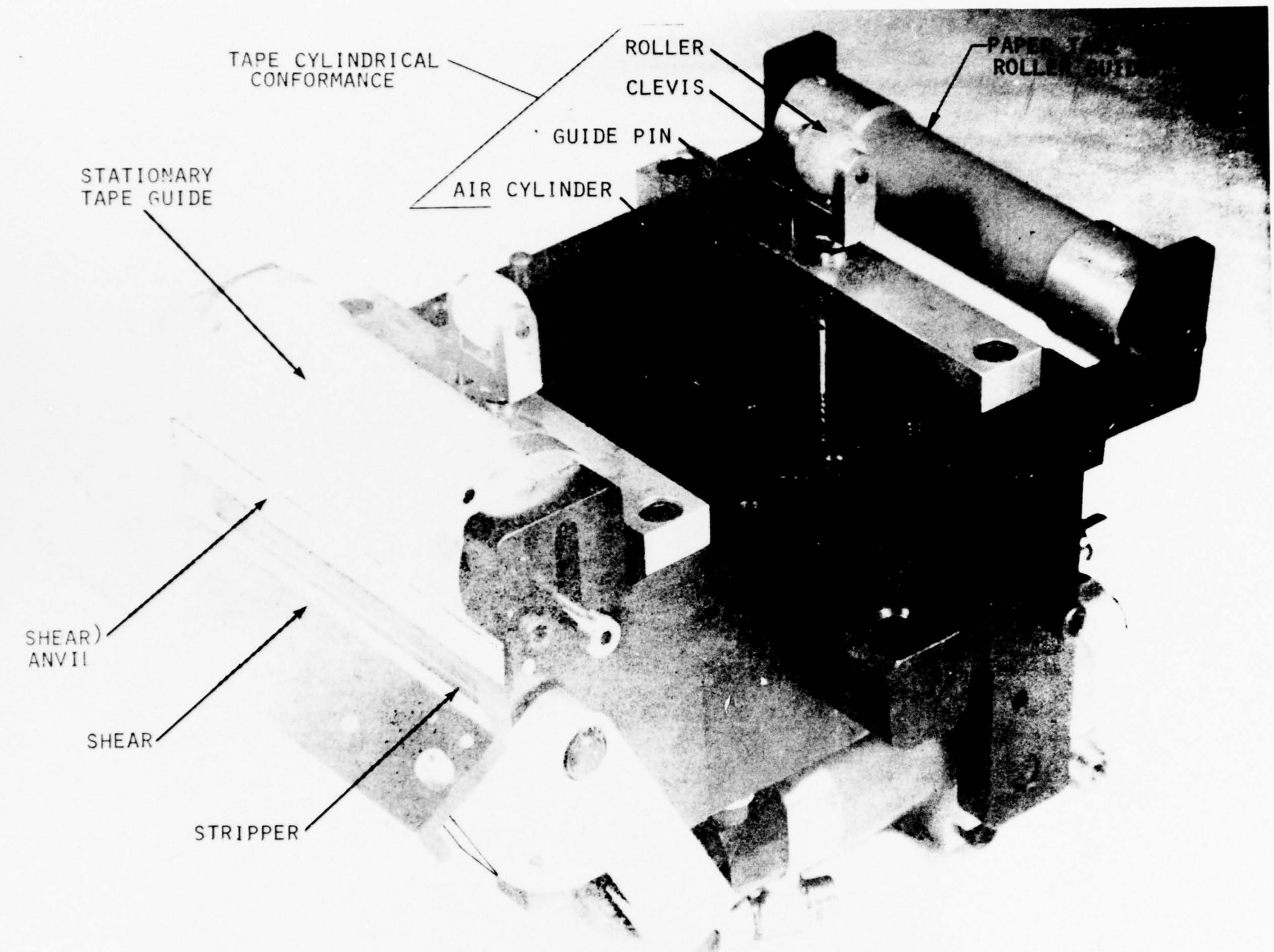


FIGURE 5-28 TAPE GUIDE HARDWARE, UNIV HOLDER

TRUE POSITION, COMPACTOR ALIGNMENT/ATTACHMENT

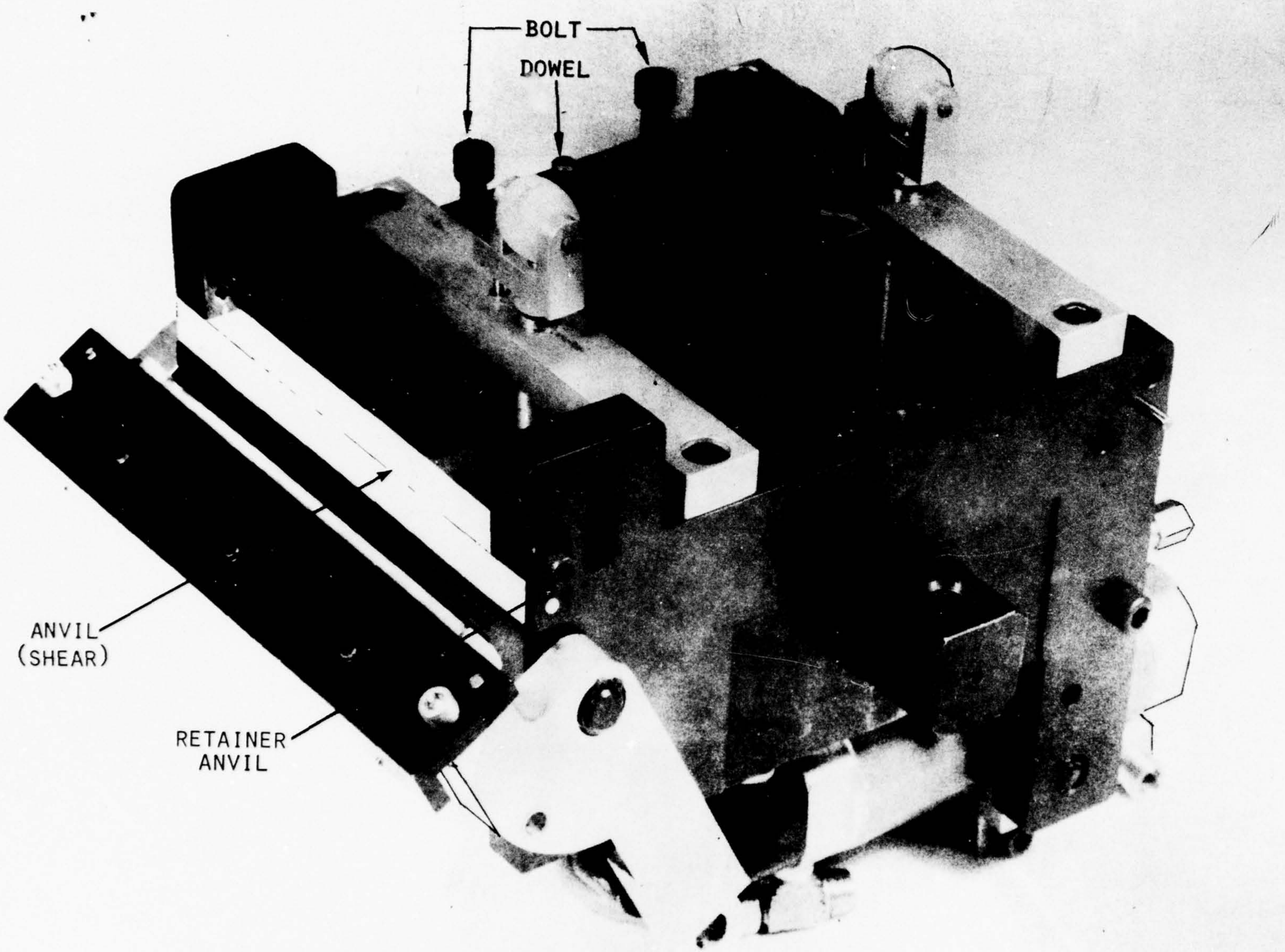


FIGURE 5-29 TRUE POSITION ALIGNMENT, UNIV HOLDER

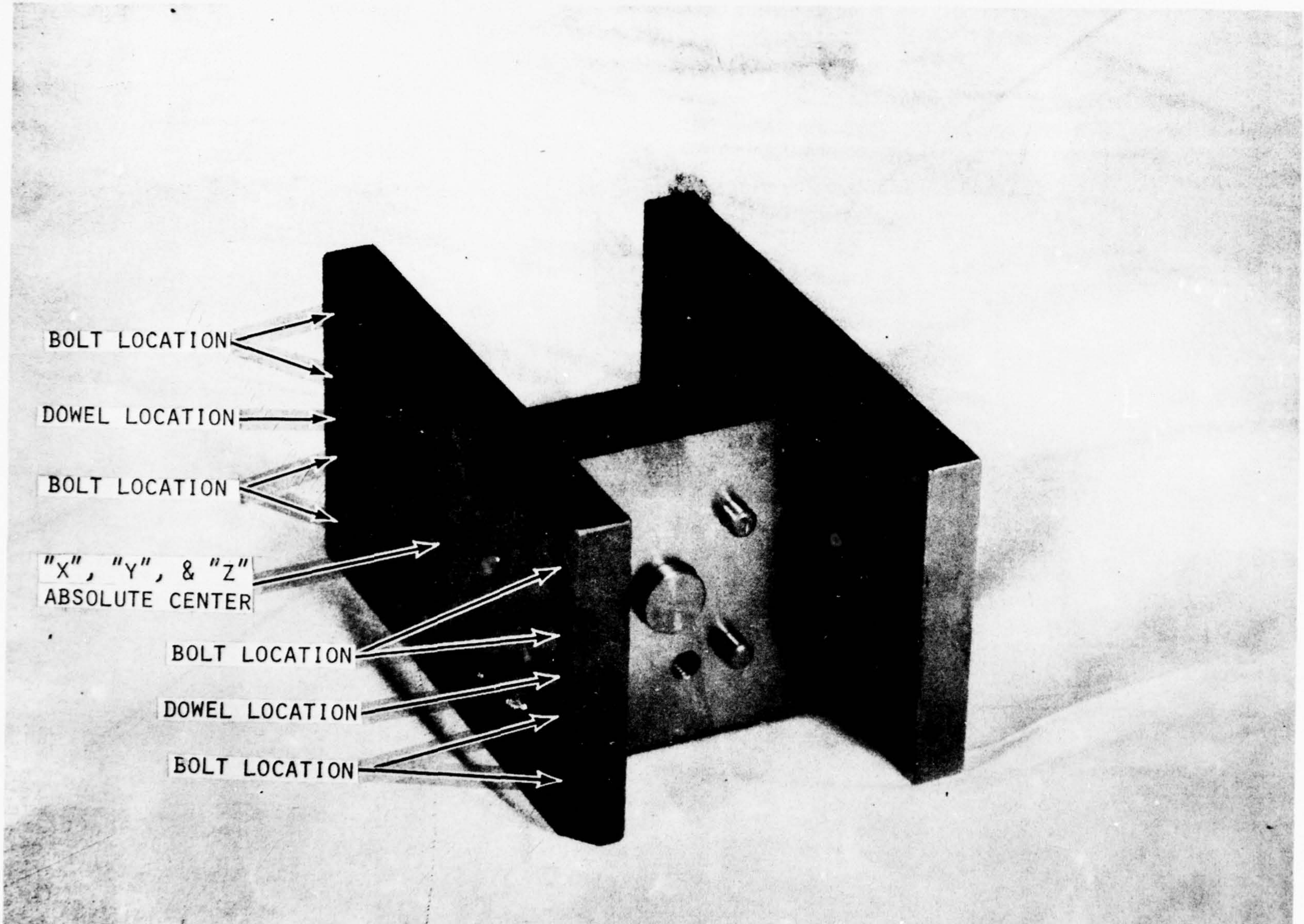


FIGURE 5-30 HARDENED DRILL FIXTURE

SECTION 6

6.0 TYPE I COMPACTOR (Figure 6-31)

6.1 PURPOSE

The Type I Compactor tests examined the ability of a flexible compactor foot to compact a composite tape on the transitional area between a flat surface and a concave, convex, or cylindrical shape.

6.2 TYPE I COMPACTOR REQUIREMENTS

6.2.1 Compactor Foot

6.2.1.1 The compactor foot is rigid in the 'Y' plane but extremely flexible in the 'Z' plane.

6.2.1.2 The compaction surface of the foot has a low coefficient of friction to resist the tackiness of different tape composites, thereby affecting a minimal buildup of residue.

6.2.2 Compactor Assembly

The Type I Compactor assembly is self-contained and easily removed from the ATLAS tapehead.

6.3 TYPE I COMPACTOR DESIGN DESCRIPTION (Figure 6-32)

6.3.1 Compactor Foot

The compactor foot is urethane backed with a chemically bonded teflon face. Six ball shaped cavities are cast within the urethane body, Figure 6-33 . The foot is capable of either concave or convex flexing.

6.3.2 Flexible Foot, Method of Attachment

Three yokes are each attached by a clevis pin to the fixed member and the air cylinders, Figure 6-33. The two cylinder-mounted yokes are prevented from pivoting by slotted guide bars, Figure 6-32. Mounted on each side of the three yokes and pivoting about the centrally fixed member clevis pin, the guide bars allow the cylinder-mounted yokes movement in the 'Z' plane. Attached to each yoke by a dowel pin are two spherical retainers, Figure 6-32. The flexible compactor foot is pressed onto the spherical retainers so that each spherical retainer is grasped by a cavity cast into the urethane body, Figure 6-33. In this way, flexibility in the 'Z' plane and rigidity in the 'Y' plane were accomplished, as shown in Figures 6-34 and 6-35.

6.3.3 Type I Compactor, Assembled Unit (Figure 6-33)

Compactor sub-assemblies are contained within a rigid, box-like structure, Figure 6-32 . The complete compactor assembly is located on the universal holder by dowel pins and securely fastened with four bolts, Figure 6-31 . The air supply has a quick disconnect.

6.3.4 Compaction Pressure

Compaction pressure is applied through a centrally fixed member and two swivel mounted air cylinders, Figure 6-32 . With these cylinders, a preshaping of the compaction foot to convex, concave or slope to the right or left may be programmed prior to actual operation.

6.3.5 Type I Compactor Operational Controls (Figure 6-32)

A two-way, solenoid operated air control valve energizes each of the air cylinders. Flow control valves are used on the air supply side of the valves to regulate compaction pressures. The control valve assembly is not attached to the main compactor assembly. Air and electrical quick disconnects are used to facilitate removal of the unit from the ATLAS tapehead.

6.4 TYPE I COMPACTOR TESTS AND RESULTS

6.4.1 Flat Surface Layup, Test No. 1

6.4.1.1 The first layup pass was run under the following conditions:

(a) Program No. 1 was used, Figure 6-36,
(b) compaction force was set at 46 lbs.,
(c) feed rate was set at 10% of 720 ipm,
(d) the softest urethane foot was used, and
(e) air flow pressure was not regulated down from 120 psi line pressure for the dual pistons.

6.4.1.1.1 Test Results
Excessive pressure was noted in the form of dark lines across the width of the tape, Figure 6-37. This excessive pressure was attributed to full line air pressure to the dual operating air cylinders.

6.4.1.2 A second laydown pass was made with a decrease in the air pressure to the dual air cylinders.

6.4.1.2.1 Test Results
Visually, it appeared the pressure was dispersed evenly across the width of the compactor foot.

6.4.1.3 Force measurements were then taken to establish a known level throughout the compactor foot's width.

6.4.1.3.1 Results (Figure 6-39)
Figure 6-38 shows the method used to obtain those dimensions; two dimensions are given for each line of deformation. The method: an initial measurement was made, there was a delay of thirty seconds, then a stabilized measurement analysis of those dimensions given showed a maximum of five thousandths of an inch (.0028) variation. The force reading of the compactor foot at the three attach points of 16.6 lbs. each, totaling 49.8 lbs., established that there was consistent compaction throughout the width of the

6.4.1.3.1 continued

tape. This was further borne out by the fact that tracking was consistent throughout the laydown pass and within five thousanths of an inch (.005). Further analysis of those dimensions indicated that there was a maximum of .1085 thousandths on an inch to a minimum of .1060 thousandths of an inch. Considering this is a ten-ply layup of ten thousandths inches (.010) thick composite tape, the total of 49.6 lbs. compaction force, when distributed over the compactor foot area of 2.25 square inches, becomes a pressure of only 22.04 psi. Industry's current position is that 100 psi minimum compaction pressure is required, showing the significance of this test's results. The test compaction had excellent repeatability and consistency within three thousandths of an inch (.003). Tracking upon a flat surface showed layers' edge alignment within five thousandths of an inch (.005) per side.

6.4.2 <u>Cylindrical Layup, Test No. 2</u>

Although the Type II Compactor deals with cylindrical layups, Type I was also tested for its cylindrical capabilities. Compaction pressure remained as established during flat surface layup testing. Feed rate was set at 20% of 720 ipm. Two programs were initiated to accomplish these cylindrical tests. They were Machine Program No. 2 with conformance rollers as shown in 6-41, and Machine Program No. 3 without conformance rollers as shown in Figure 6-42.

6.4.2.1 Machine Program No. 3 was used for the initial layup pass. During this first pass it was obvious that conformance rollers were required. Excessive pressure was brought to bear upon the backing paper at the outer end of the leading edge of the compactor foot. However, the pass was allowed to reach its conclusion. It was observed during this pass that crinkling of the composite tape was being caused by this excessive pressure on the leading edge of the backing paper.

6.4.2.2 Machine Program No. 2 was installed. A second laydown pass was initiated with the conformance rollers in use. The result was smooth compaction over the longitudinal width of the compactor foot throughout the length of the layup. During passes 2, 3, and 4, conformance, smooth compaction, and edge repeatability of the different layers was excellent. Starting with pass No. 5, deformation lines the length of the tape started to appear. These deformations continued to get deeper and were attributed to the concentration of downward energy through the spherical balls retaining the compactor foot. Figure 6-43 illustrates the profile of this 15 ply layup. Severe deformation is visible across the width of the tape. It was determined that this deformation exceeded twenty thousandths inches (.020)and further tests were discontinued.

6.4.3 Simulated Spar Tool Layups, Test No. 3

This test examined the Type I Compactor's capabilities for multi-ply layup of a simulated spar tool, starting from a flat surface and proceeding to a crowned shape. Testing conditions:

(a) Program No.4 was used, Figure 6-44,

(b) compaction force was set at 46 lbs.,

(c) feed rate was set at 10% of maximum 720 ipm, and

(d) travel from flat to convex.

6.4.3.1 Test Results

During progressive layup passes it was found that compaction pressures had to be increased so that adequate control of the tape could be maintained. As the foot wrapped around the spar form the pressure from each cylinder had to be equalized. If one side of the foot compacted a wider rise than the other side, that side had to have less compaction pressure than the short side. To insure that complete and even compaction was maintained throughout the width of the compactor foot, tapehead compaction pressures were made equal to the total of the dual operating cylinders. Upon completion of the first ten-ply layup, force measurements were taken of the compactor foot. Three specific measurements were taken:

6.4.3.1 continued

(a) the left air cylinder, or short side of the spar tool layup, had a force reading of 35 lbs.,

(b) the right air cylinder, or long side of the spar tool , had a force measurement of 50 lbs.,

(c) the center load, or the tapehead cylinder, had a force reading of 80 lbs.

With a bar mounted upon the force gauge and the compactor foot down upon it, all forces were activated for a total reading of 84 lbs. This pressure was considerably less than those now used by Boeing-Vertol. During the fourth ten-ply layup photos were taken as shown. Figure 6-45 shows the beginning of the spar tool layup. Figure 6-46 is a side view,midway, spar tool layup. Figure 6-47 is sideview, end of spar tool layup. Figure 6-48 is an end view of the spar tool layup. Figure 6-49, shows a composite tape separation from the paper. This was attributed to the tight radius of the stationary tape guide as described in the universal holder section. By the 5th layup, excellent tracking and compaction were obtained.

6.4.4 Simulated Spar Tool Layup, Test No. 4

This test examined the Type I Compactor's capabilities for multi-ply layup of a simulated spar tool, starting from a crowned surface and proceeding to the flat. Testing conditions:

(a) Program No. 5 was used, Figure 6-50,

(b) compaction force was set at 46 lbs.,

(c) feed rate was set at 10% of maximum 720 ipm, and

(d) travel was from crown to flat.

6.4.4.1 Test Results

Repeated attempts were unsuccessful. The tape would not stay centered as the compactor foot formed the crown of the tool which lead to uneven tracing and warp of the tape as it progressed toward the flat end of the spar tool Decreasing the compaction pressure caused drag and non-payoff of tape.

6.4.5 Concave Layup at 45° Angle, Test No. 5

For this test, a three inch (3") black line digitizing tape, Figure 3-2 was laid at 45° by hand in a compound curve of the concave tool, Figure 4-13.

6.4.5.1 The optical finder with line follower attached, Figure 4-16, was used to digitize a path and thereby generate Progran No. 6, Figure 6-52. The program was edited and a tape was written, Figure 6-51.

6.4.5.2 Test Results

The 45° curved skin layup, Figure 6-52, shows the excellent tracking of the two-ply layup adjacent to the digitized tape. There was only a total of ten thousandths inches (.010) variation in tape tracking. It should be noted that layup accuracy depends on how the tape starts. If the tape is not in contact with the backing paper, a wrinkle will cause bad tracking. Figure 6-56 shows the uniformity at start of the 45° layup. It was within seven thousandths (.007) of being exactly the same. The problem of composite tape separation from the backing paper prior to lay-down did occur, so prior to each laydown a check was made to insure that the composite tape was tacked to the backing paper. Figure 6-53 shows multiple passes of the 45° curved skin layup. Consistency of tracking and leading was excellent, Figure 6-54, is a dimensional comparison of 45° layup two plys. Figure 6-55 shows the direction of the layups. Figure 6-57 shows the uniformity at the end of these 45° layups. Compaction was smooth. However, pressure lines similar to those experienced during the flat surface layup were in evidence. Figure 6-58 shows compactor foot conformance at start of 45° layup. Figure 6-59 shows the maximum tape head tilt during a 45° layup pass with the conclusion of this particular test. It was observed that excellent compaction and excellent repeatability of guidance and tracking of the composite tape was accomplished.

6.4.6 Concave Tool Layup. Linear, Test No. 6

6.4.6.1 Machine Progran No. 7 was used, Figure 6-60. Ten plies were laid.

6.4.6.2 Test Results

Figure 6-61 shows the linear compaction of the skin on the concave layup. Again pressure lines were observed throughout the length of these laydown passes similar to those on the flat surface layup. Figure 6-62 shows the compactor foot conformance to a convex surface part of the concave tool. Excellent compaction with repeatability of tape tracking and guiding was accomplished.

6.4.7 Concave Tool Layup, Radial, Test No. 7 (Figure 6-63)

6.4.7.1 Test Conditions:

(a) Machine Program No. 7 was used,
(b) the counterbalance force was set at 16 lbs.,
(c) the compaction force was set at 20 lbs., and
(d) softest urethane foot available was used.

6.4.7.2 Test Results

Figure 6-63 shows the excellent radial surface conformance of this test. Figure 6-64 gives a rear view of the excellent radial conformance of the compactor. Figure 6-65 shows the clearance of the tapehead within the confines of this tool. Figure 6-66 shows a two-ply layup pass on this radial surface with excellent compaction. Figure 6-67 shows two three-ply layups in the radial area of concave tool. Figure 6-68 shows five passes each for a three-ply layup. Tracking consistency can be noted by the thin line separating each layup pass, Figure 6-68.

6.5 SUMMARY OF TYPE I COMPACTOR TESTS

In general, the results of the Type I Compactor tests were excellent. The quality of compaction and tracking repeatability were highly acceptable in all cases except for cylindrical laying up (which is handled by the Type II Compactor), and when making the transition from a crown to a flat on the spar simulation tool (the reverse transition was accomplished). Thus, the Type I Compactor showed highly positive results across the wide series of tests to which it was subjected.

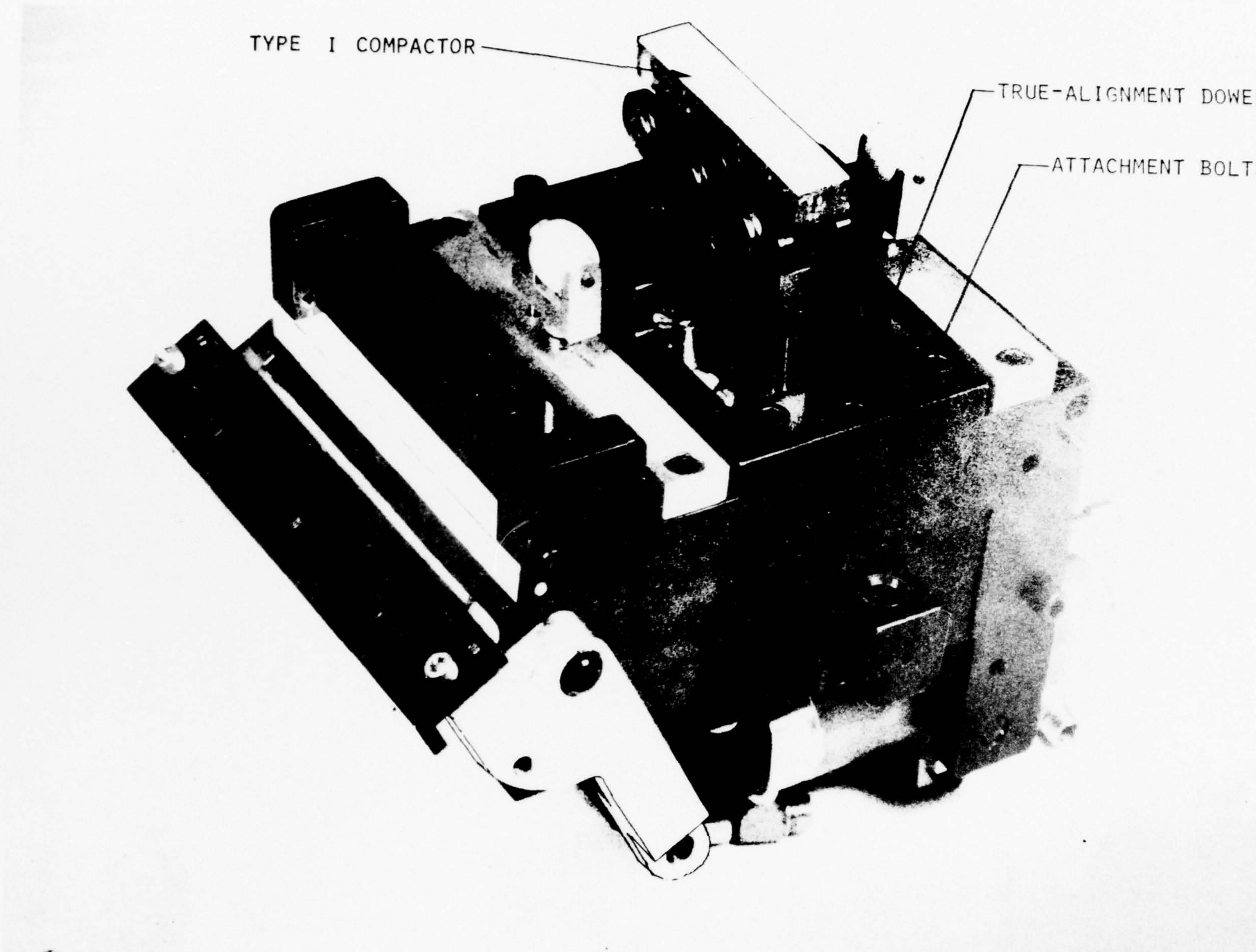


FIGURE 6-31 TYPE I COMPACTOR MOUNTED

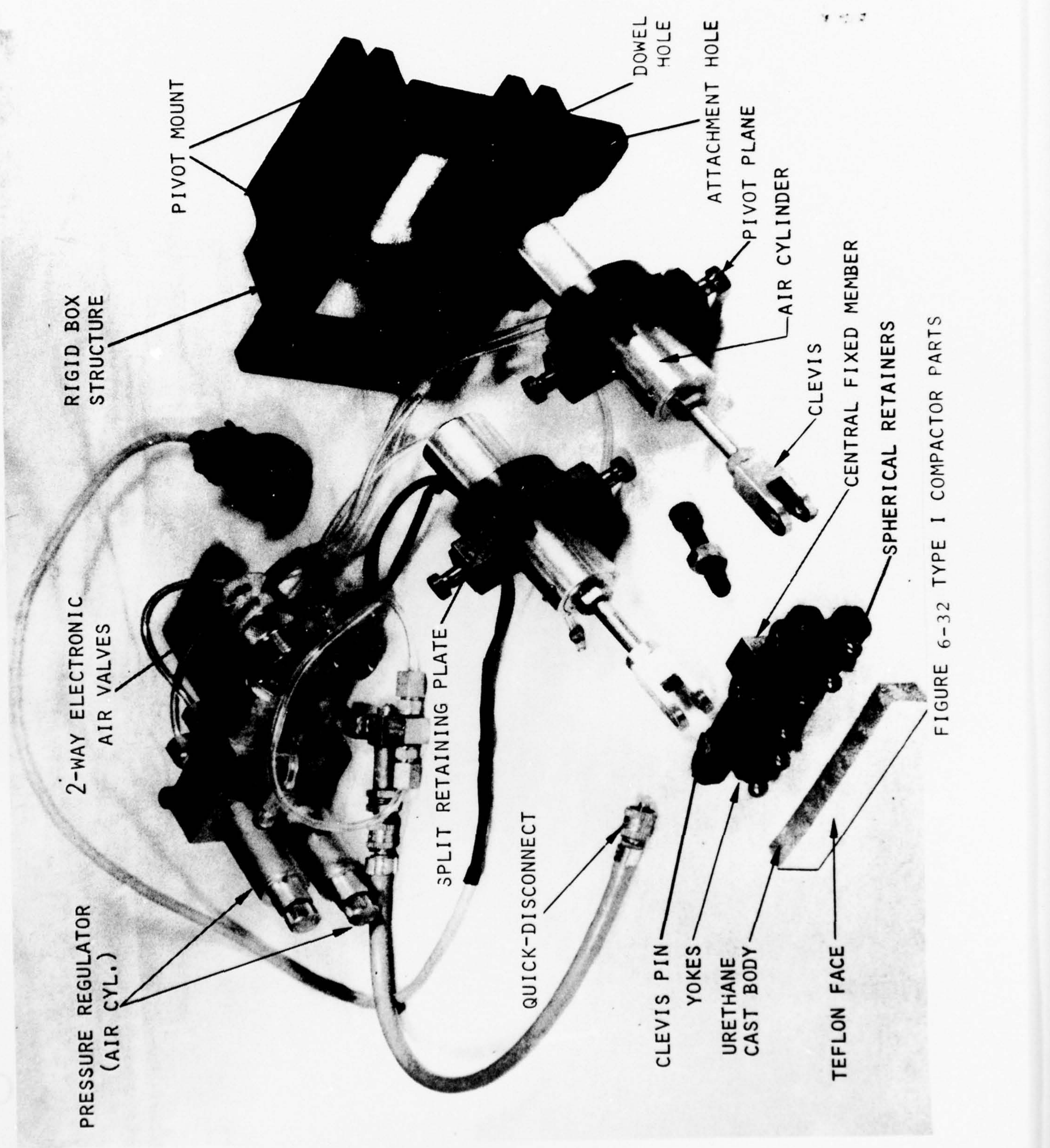


FIGURE 6-32 TYPE I COMPACTOR PARTS

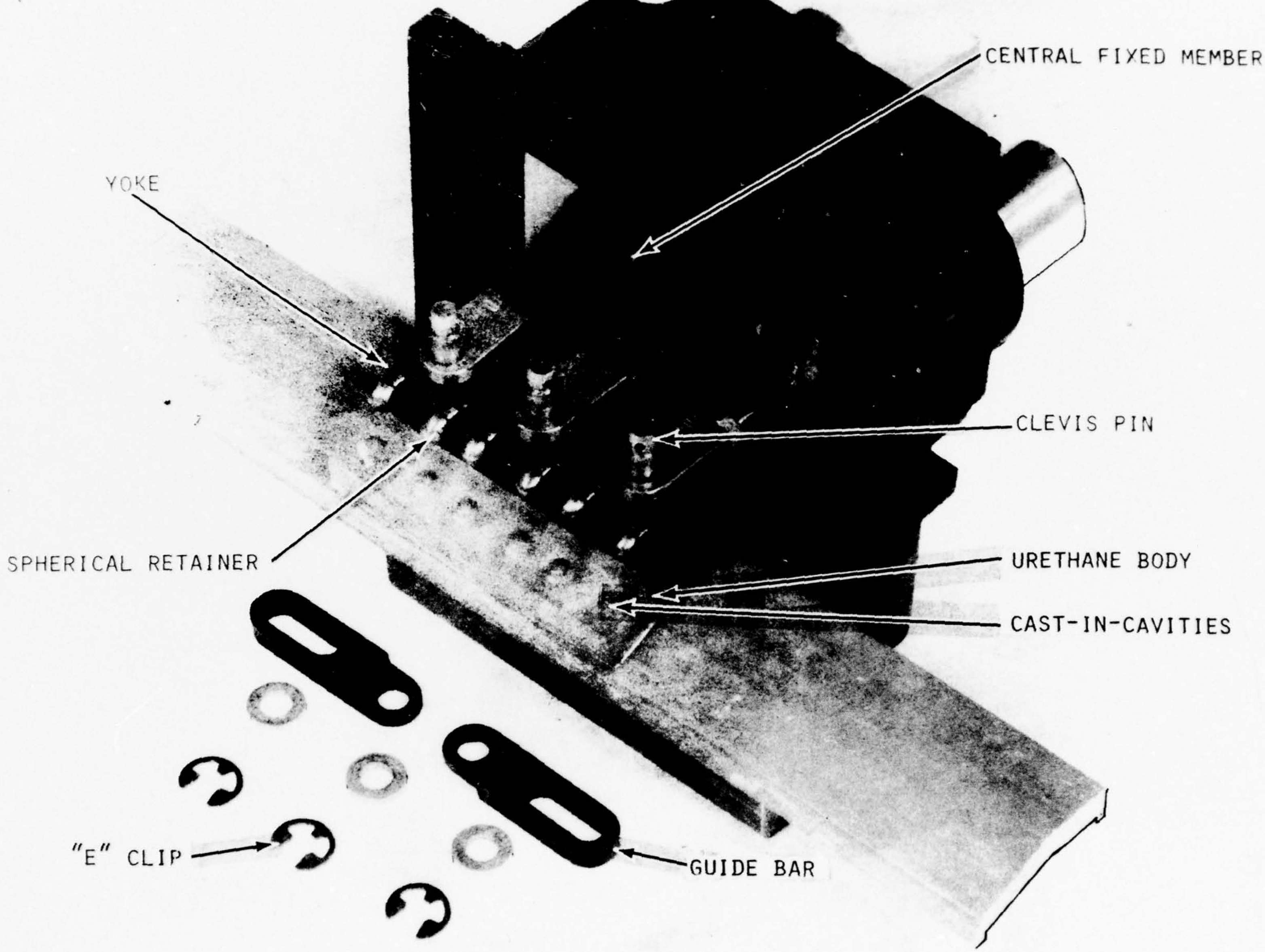


FIGURE 6-33 BASIC PARTS, FLEX COMP ASSY

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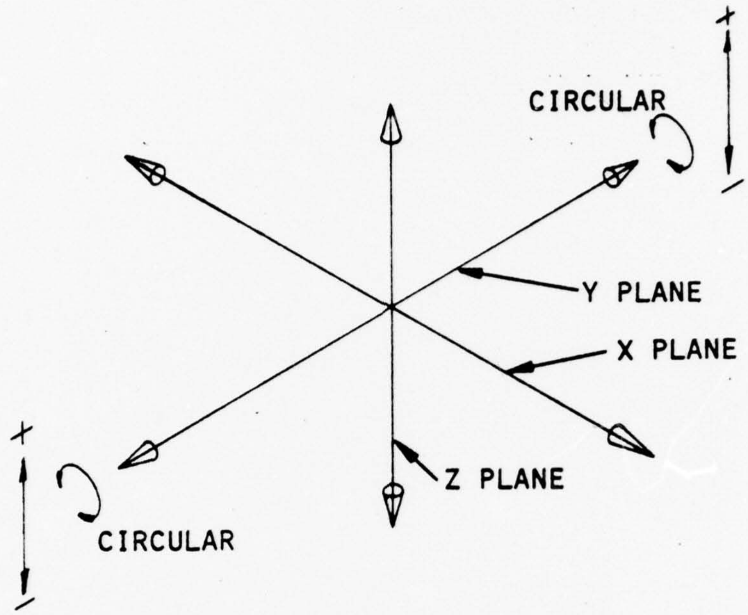


FIGURE 6-34 FLEXABLE AXIS PLANES

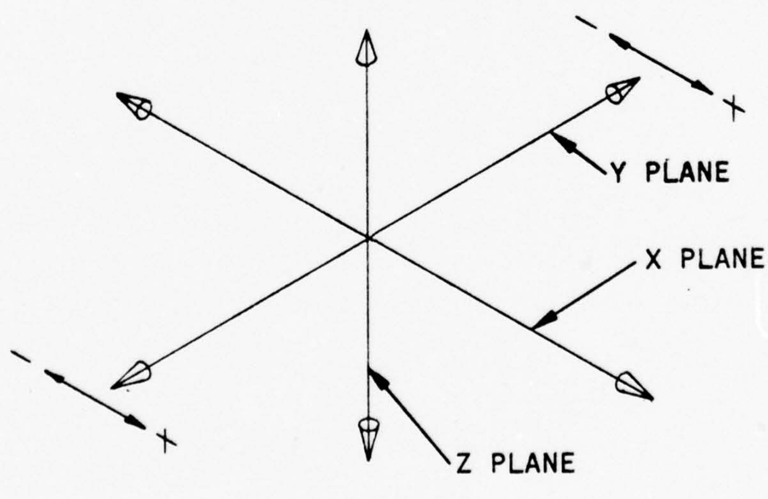
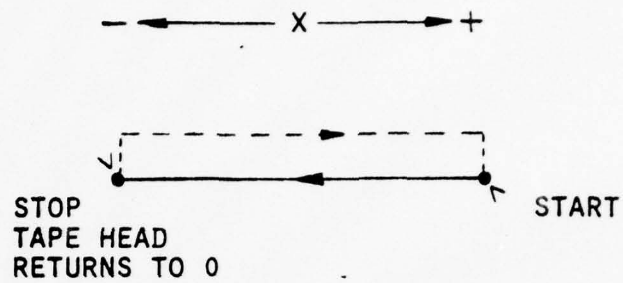


FIGURE 6-35 NONFLEXABLE PLANE

```
GØØG91
X-2ØØØZ-2ØØØFØ
Z-2ØØ
M62
M74
X-1Ø58ØØ
M8Ø
X-142ØØ
M75
M63
Z2ØØ
X-2ØØØZ2ØØØ
X124ØØØ
MØ2
```



MACHINE PROGRAM NO.1

FIGURE 6-36

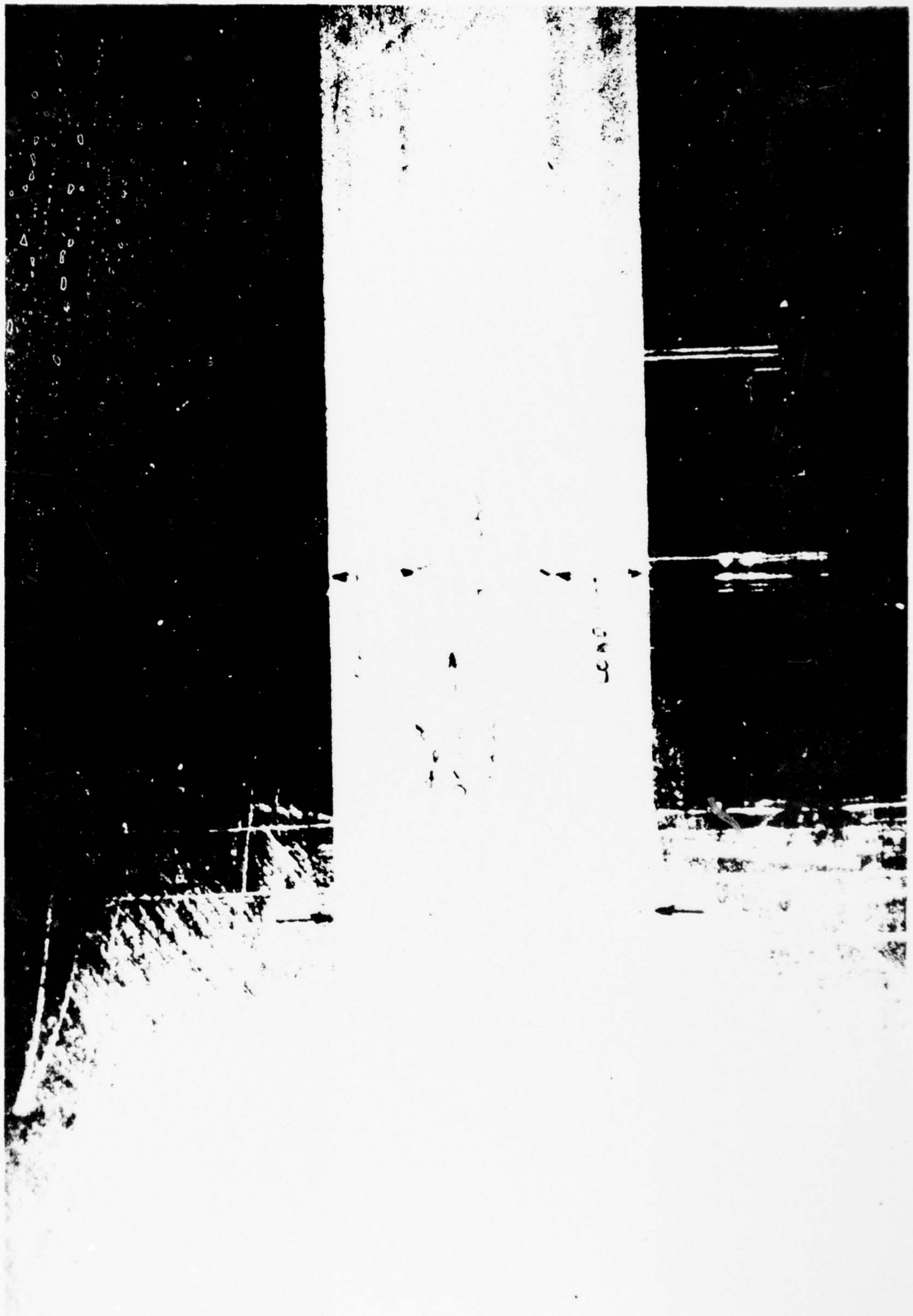


FIGURE 6-37 FIRST LAY-UP 1 PLY

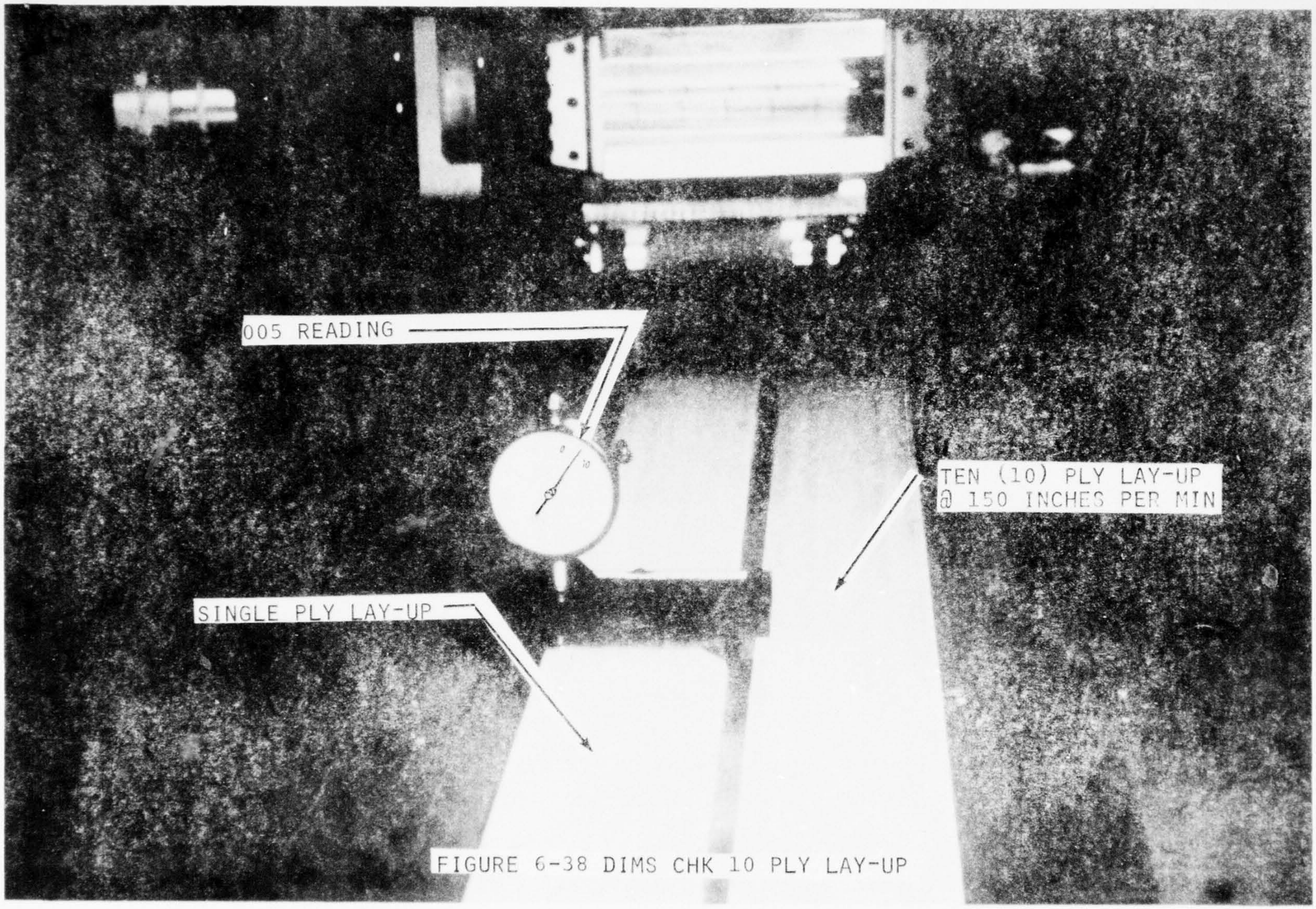


FIGURE 6-38 DIMS CHK 10 PLY LAY-UP

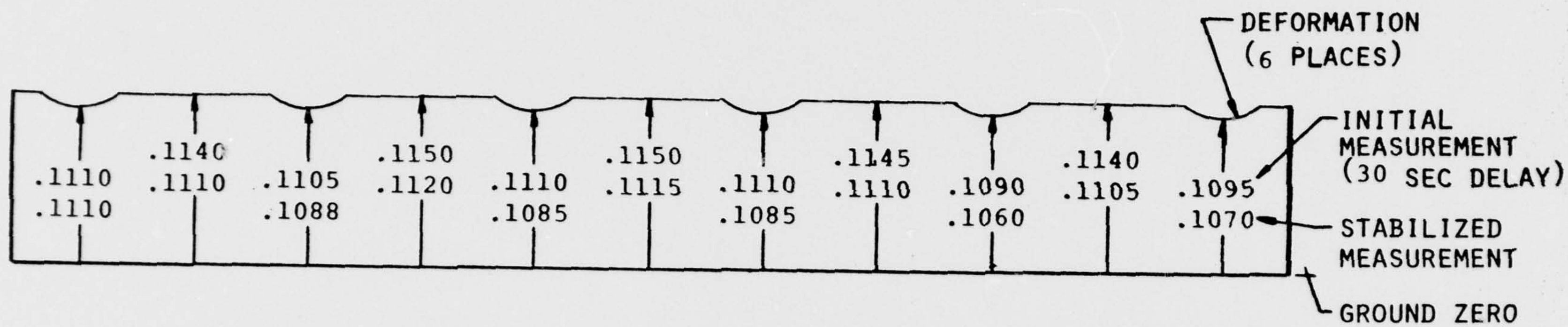


FIGURE 6-39 COMPARISON, 10 PLY DIMS CHK

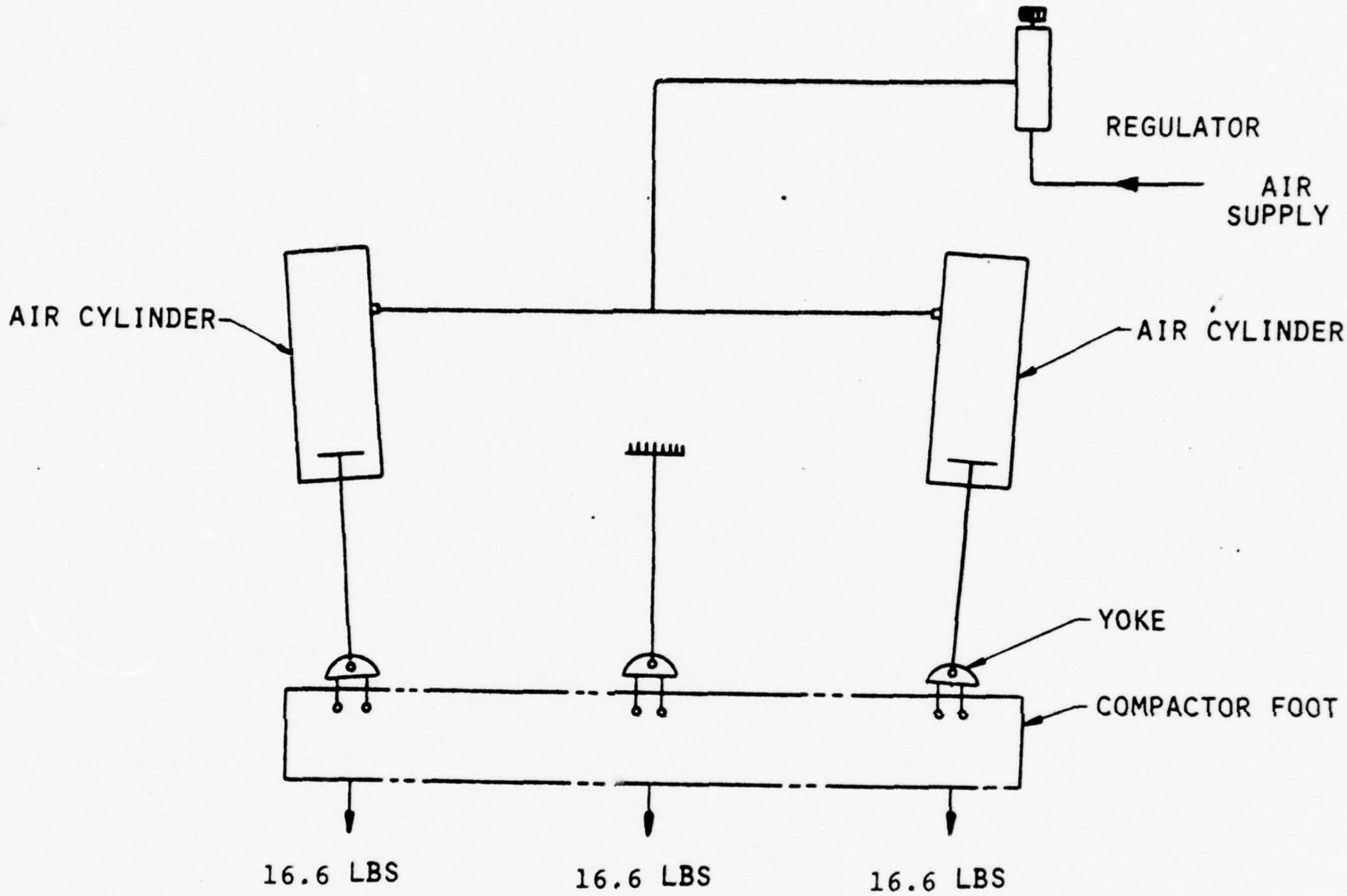
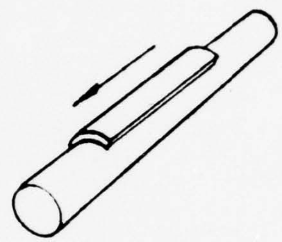


FIGURE 6-40 REGULATED DISTRIBUTION OF COMPACTOR FORCES

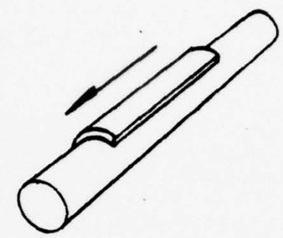
```
G00G91
X-2000Z-2000
Z-200
M62
M83
M74
X-30000
M80
X-14300
M75
M69
M81
M63
Z200
Z-2000Z2000
X48300
M02
```



TYPE I COMPACTOR
6 INCH CYLINDER EVALUATION
PROGRAM NO. 2 WITHOUT/FORE/AFT ROLLERS

FIGURE 6-41

```
G00G91
X-2000Z-2000
Z-200
M62
M68
M83
M74
X-30000
M80
X-14300
M75
M69
M81
M63
Z200
X-2000Z2000
X48300
M02
```



TYPE I COMPACTOR
6 INCH CYLINDER EVALUATION
PROGRAM NO. 3 WITH/FORE/AFT ROLLERS

FIGURE 6-42

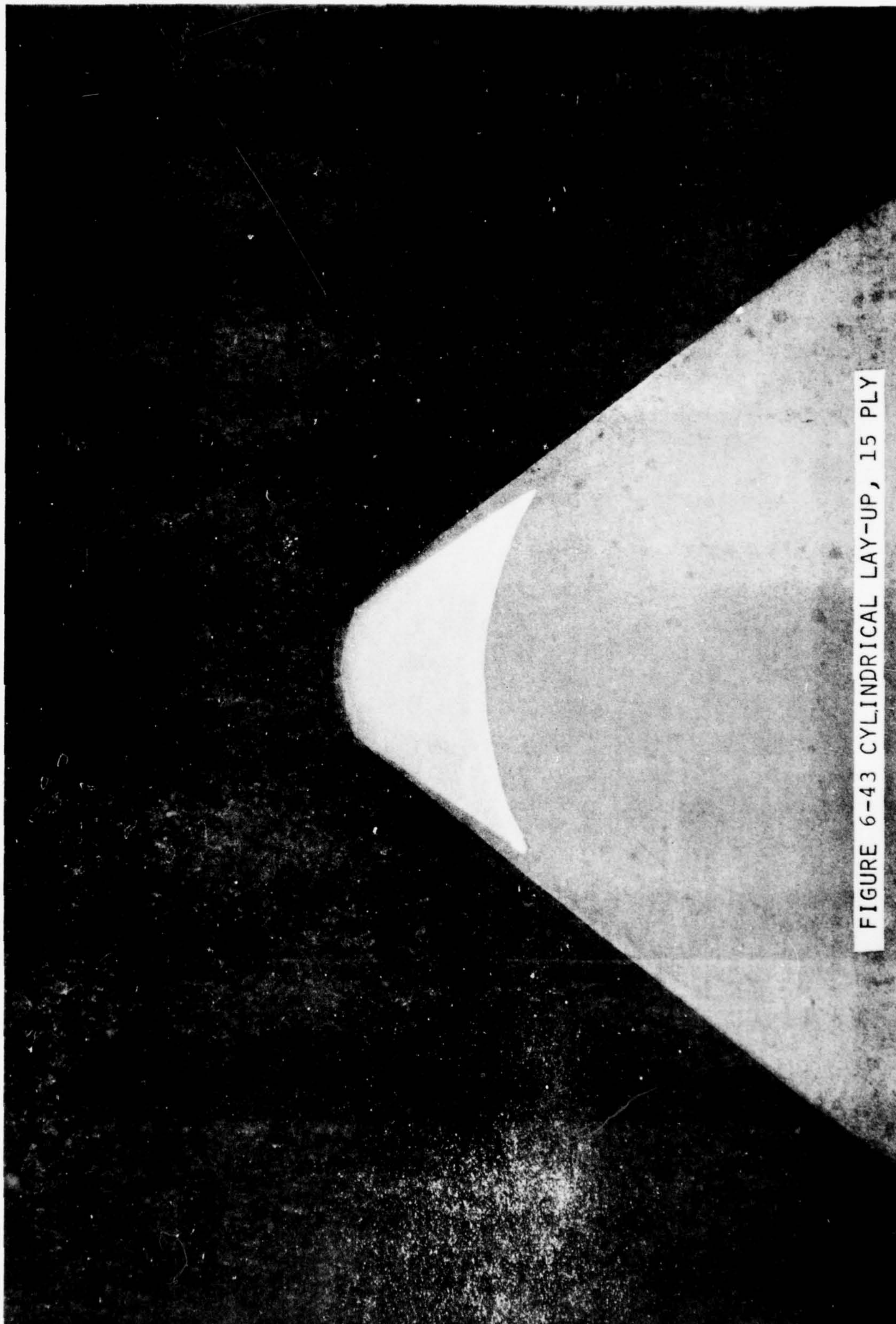
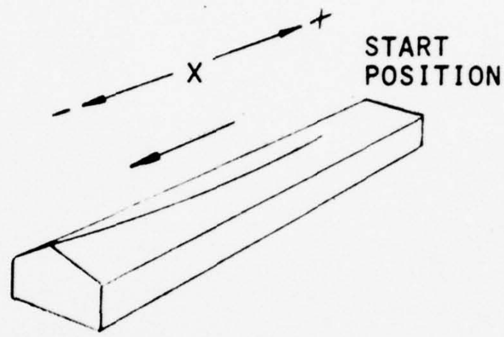


FIGURE 6-43 CYLINDRICAL LAY-UP, 15 PLY

```
GØ1G91
X-2ØØØZ-2ØØØF2ØØØØØ
Z-2ØØ
GØ4F2ØØ
M74
M62
M68
M83
GØ4F2ØØ
X-9ØØØ
X-2Ø2ØØZ5ØØ
GØ4F2ØØ
M8Ø
X-33ØØZ1ØØ
X-11ØØØ
GØ4F2ØØ
M75
M69
M81
M63
GØ4F2ØØ
Z2ØØ
X-2ØØØZ2ØØØ
X475ØØZ-6ØØ
/Z1Ø
MØ2
```



TYPE I COMPACTOR

SPAR LAY-UP PROGRAM NO. 4

START ON FLAT

FIGURE 6-44

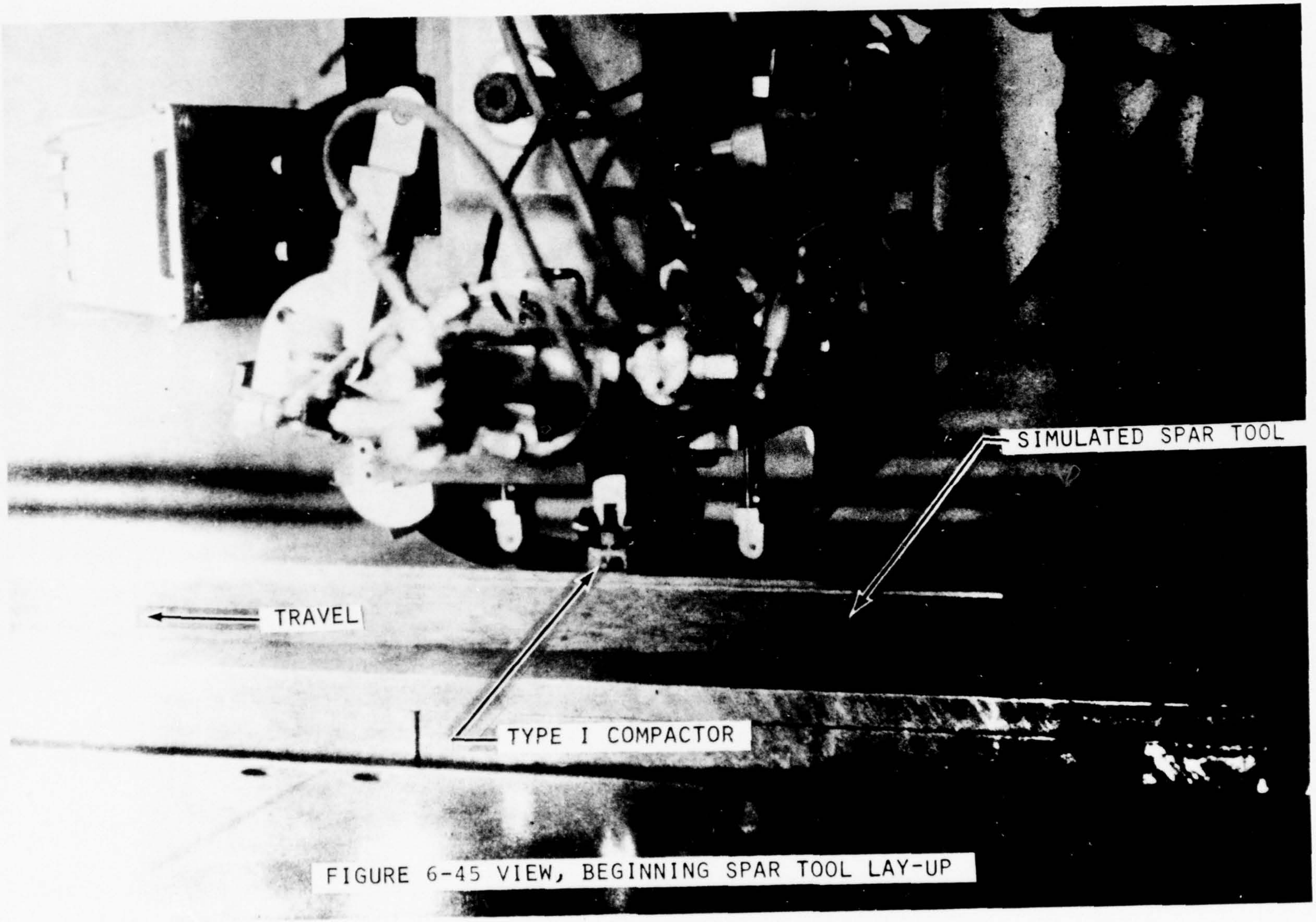


FIGURE 6-45 VIEW, BEGINNING SPAR TOOL LAY-UP

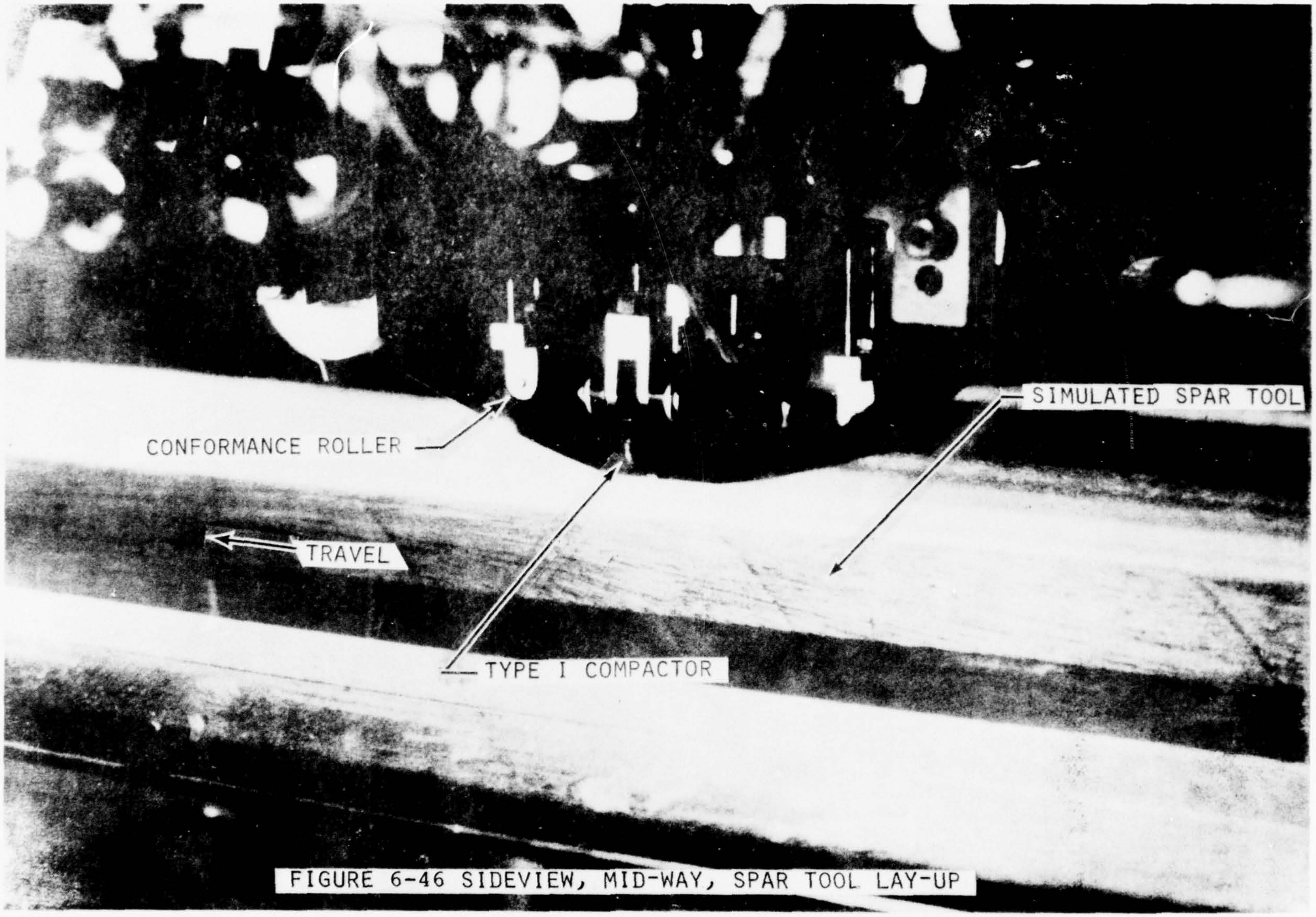


FIGURE 6-46 SIDEVIEW, MID-WAY, SPAR TOOL LAY-UP

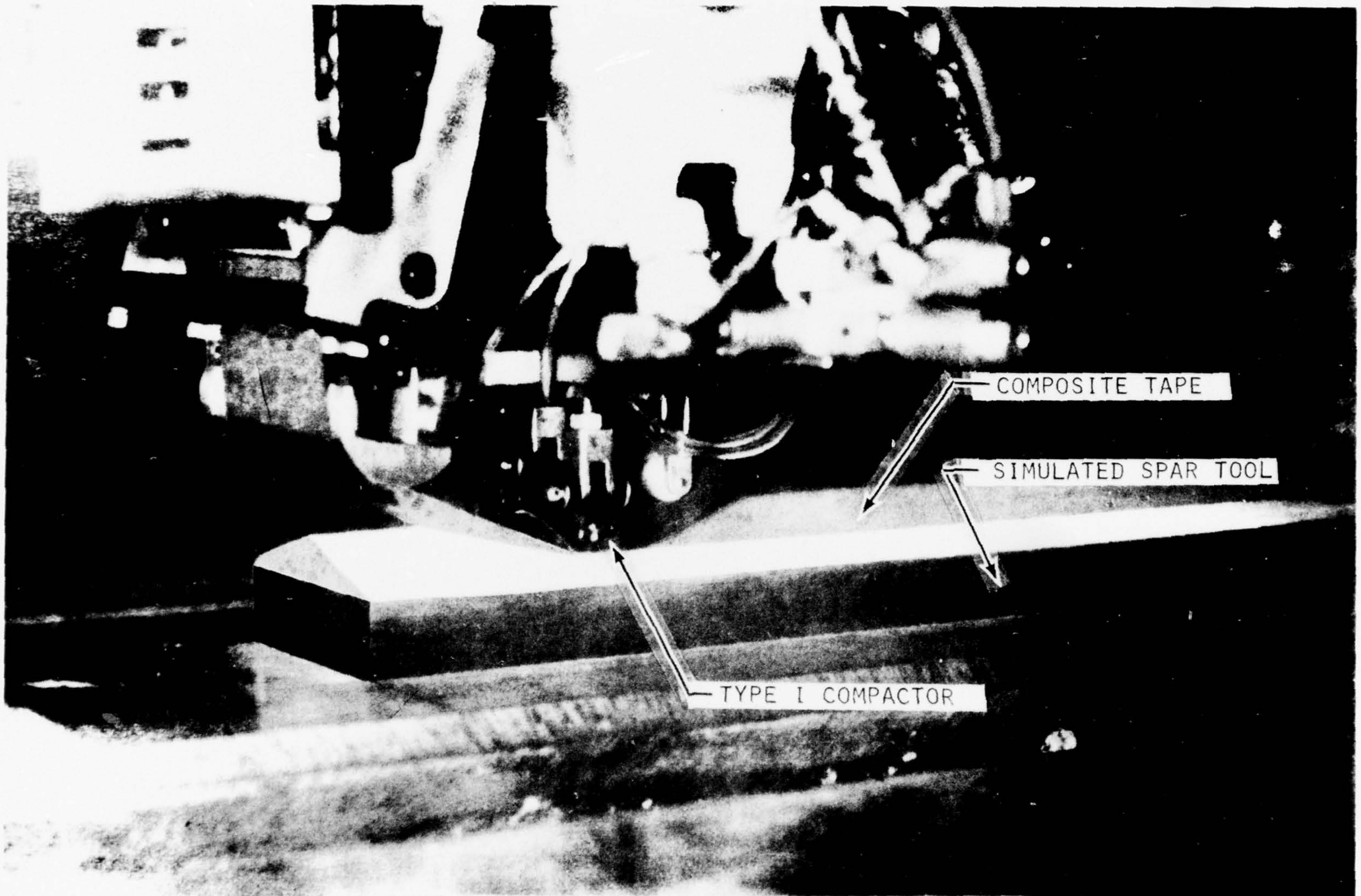


FIGURE 6-47 SIDEVIEW, END OF SPAR TOOL LAY-UP

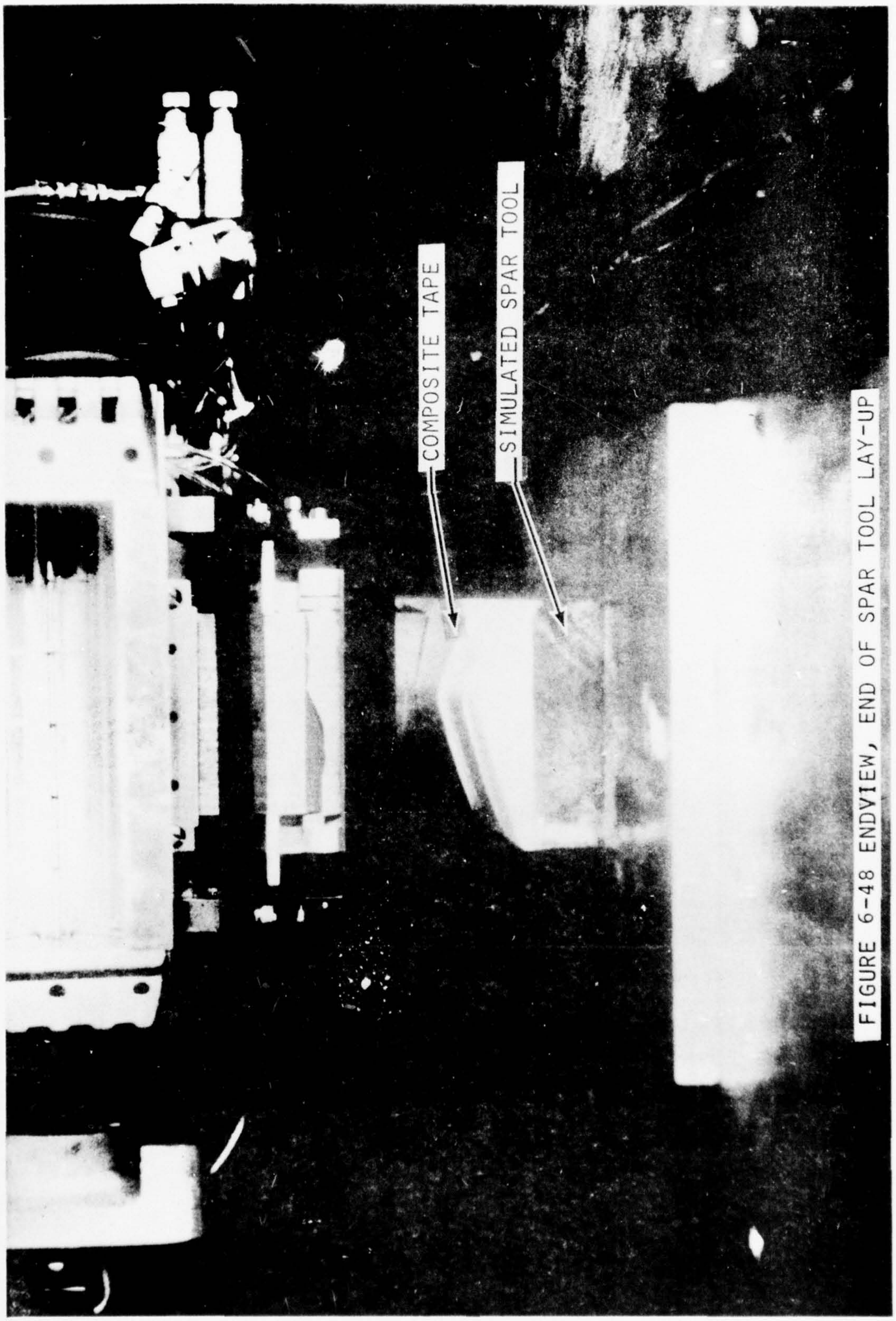


FIGURE 6-48 ENDVIEW, END OF SPAR TOOL LAY-UP

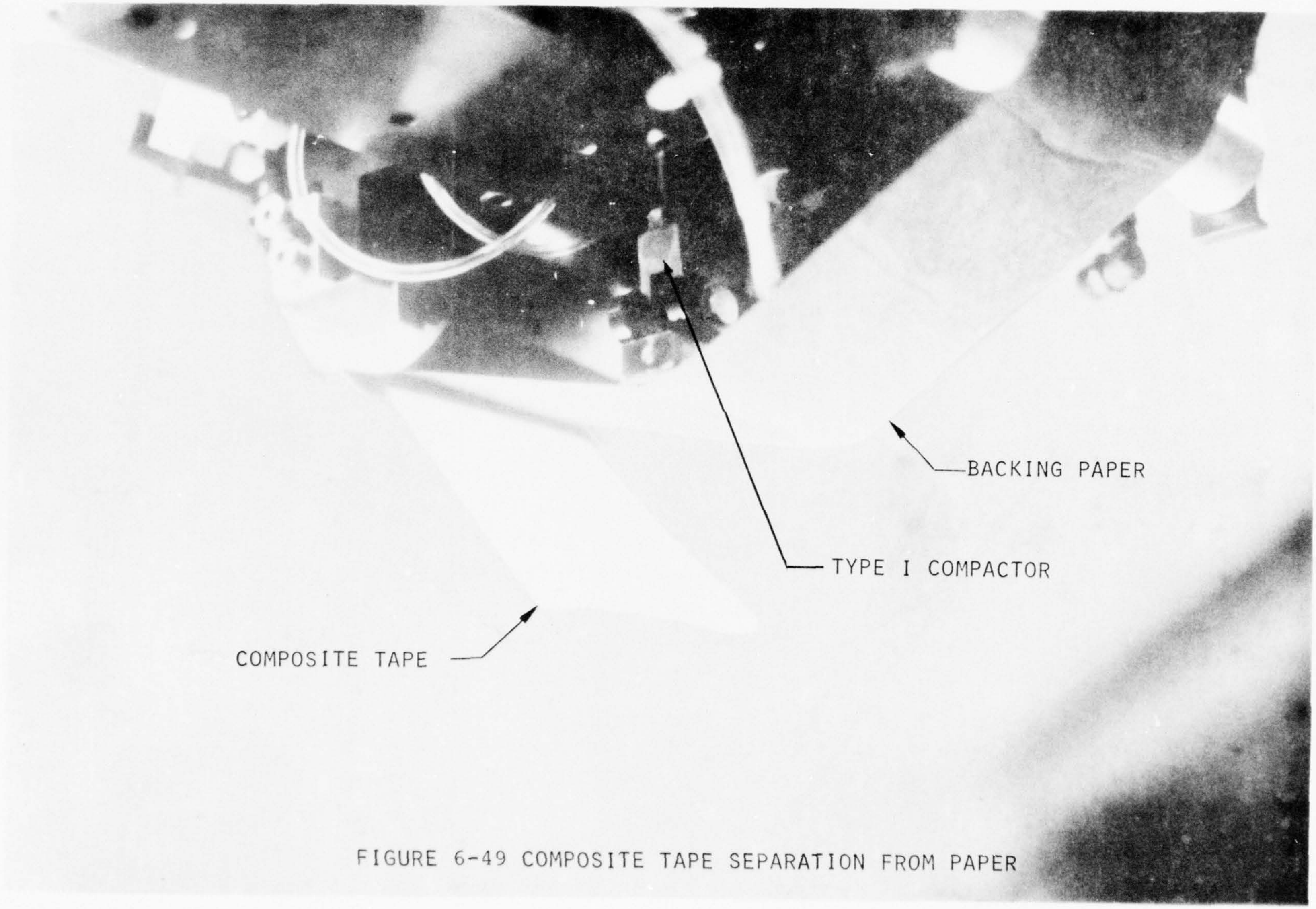
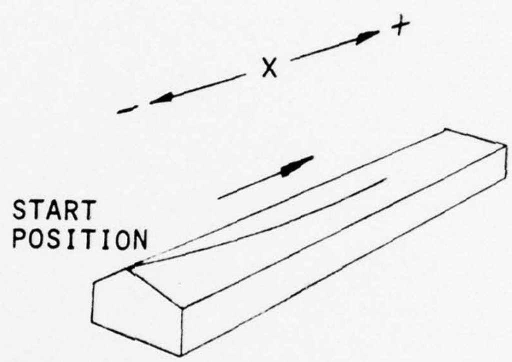


FIGURE 6-49 COMPOSITE TAPE SEPARATION FROM PAPER

```
G01G91
X2000Z-2000F200000
Z-200
G04F200
M74
M62
M68
M83
G04F200
X9000
X20200Z-500
G04F200
M80
X5300Z-100
X9000
G04F200
M75
M69
M81
M63
G04F200
Z200
X2000Z2000
X-47500Z2600
/Z10
M02
```



TYPE I COMPACTOR
SPAR LAY-UP PROGRAM NO. 5
START ON CROWN

FIGURE 6-50

CONCAVE TOOL. PROGRAMS FOR TYPE 1 COMPACTOR.

.070 WIDE BLACK LINE TAPE SET ON FLAT PORTION OF TOOL. OPTICAL ALIGNMENT DEVICE USED TO POSITION X,Y,Z COORDINATES.

REF. POINT IS FROM HOME POSITIONS OF ALL AXES.

X-93641Y4280Z4836A2001.

45 DEGREE PASS GOING IN X-,Y+ DIRECTION WAS DIGITIZED.

```
N1G90X-106066Y2281Z6829C31500A2002D0
G91X-2000Y2000Z-2000F200000
Z-100
G04F300
M74
M62
M83
G04F200
X-1000Y1000Z19C0A0D-1
X-1000Y996Z40C0A-1036D-1
X-600Y599Z0C0A-1213D0
X-700Y700Z-130C0A-10878D0
X-800Y777Z-170C0A-202D0
X-2000Y1962Z-360C0A1830D-1
X-3825Y3755Z-620C0A1960D0
M80
X-3341Y3282Z-461C0A1485D-1
X-2000Y1970Z-160C0A2825D0
X-2000Y1977Z-40C0A3821D0
X-2000Y1969Z100C0A4789D-1
```

FIGURE 6-51 MACH.PROG.NO.6, 45°CURVED SKIN LAY-UP

```
X-7Ø1Y7ØØZ79CØA1727DØ
M75
M81
M81
M63
GØ4F2ØØ
XØY-1Z3ØØCØAØDØ
X-6ØØY4ØØZ999CØAØDØ
X-3ØØY3ØØZ1ØØØCØA-1DØ
MØ2
TO MAKE SIDE BY SIDE PASSES USE A G98 OFFSET AFTER EACH PASS
TO MOVE X AXIS OVER BY REQUIRED AMOUNT.
5 PASSES WERE PROGRAMMED TO LAY IN Ø DEG. DIRECTION IN TOOL.
DIRECTION OF LAY-UP IN X+ FOR EACH PASS.
PROGRAM IS IN ABSOLUTE, FROM AXES HOME POSITIONS, TO GIVE START
POINT FOR EACH PASS.
THEN GOES INTO INCREMENTAL FOR THE PASS.
PASS 1
G9ØX-139892Y26173Z5955C18ØØØA2Ø246
GØØG91
X2ØØØY75ØZ-2ØØØ
Z-1ØØY38
GØ4F2ØØ
M74
M62
/M68
M83
X277ØØ
```

FIGURE 6-51 MACH.PROG.NO. 6, 45°CURVED SKIN LAY-UP (Cont)

```
M80
X14300
M75
/M69
M81
M63
Z100Y-38
X2000Y-750Z2000
X-46000
M02
NOTE.  TURN BLOCK DELETE SWITCH TO ON.  M68/69 NOT NEEDED.
PASS 2.
G90
X-139892Y23670Z5193A8476C18000
G00G91
X2000Y400Z-2000
Z-100
G04F200
M74
M62
M83
G04F100
X27700
M80
X14300
M75
M81
M63
```

FIGURE 6-51 MACH.PROG.NO.6, 45°CURVED SKIN LAY-UP (Cont)

```
GØ4F1ØØ
Z1ØØ
X2ØØØY-4ØØZ2ØØØ
X-46ØØØ
MØ2
PASS 3.
N3G9ØX-139892Y21Ø38Z5Ø16AØC18ØØØ
GØØG91
X2ØØØZ-2ØØØ
Z-1ØØ
GØ4F1ØØ
M74
M62
/M68
M83
X277ØØ
M8Ø
X143ØØ
M75
/M69
M81
M63
GØ4F1ØØ
Z1ØØ
X2ØØØZ2ØØØ
X-46ØØØ
MØ2
```

FIGURE 6-51 MACH.PROG.NO.6, 45° CURVED SKIN LAY-UP (Cont)

```
N4G9ØX-139892Y1819ØZ5Ø64C18ØØØA-576Ø
GØØG91
X2ØØØY-2ØØZ-2ØØØ
Z-1ØØ
GØ4F1ØØ
M74
M62
/M68
M83
X277ØØ
M8Ø
X143ØØ
M75
/M69
M81
M63
GØ4F1ØØ
Z1ØØ
X2ØØØY2ØØZ2ØØØ
X-46ØØØ
MØ2
N5G9ØX-139892Y153ØØZ5547A-9395C18ØØØ
GØØG91
X2ØØØY-33ØZ-2ØØØ
Z-1ØØ
GØ4F1ØØ
```

FIGURE 6-51 MACH.PROG.NO.6, 45° CURVED SKIN LAY-UP (Cont)

```
M74
M62
/M68
M83
X27700
M80
X14300
M75
/M69
M81
M63
G04F100
Z100
X2000Y330Z2000
X-46000
M02
```

FIGURE 6-51 MACH.PROG.NO.6, 45° CURVED SKIN LAY-UP (Cont)

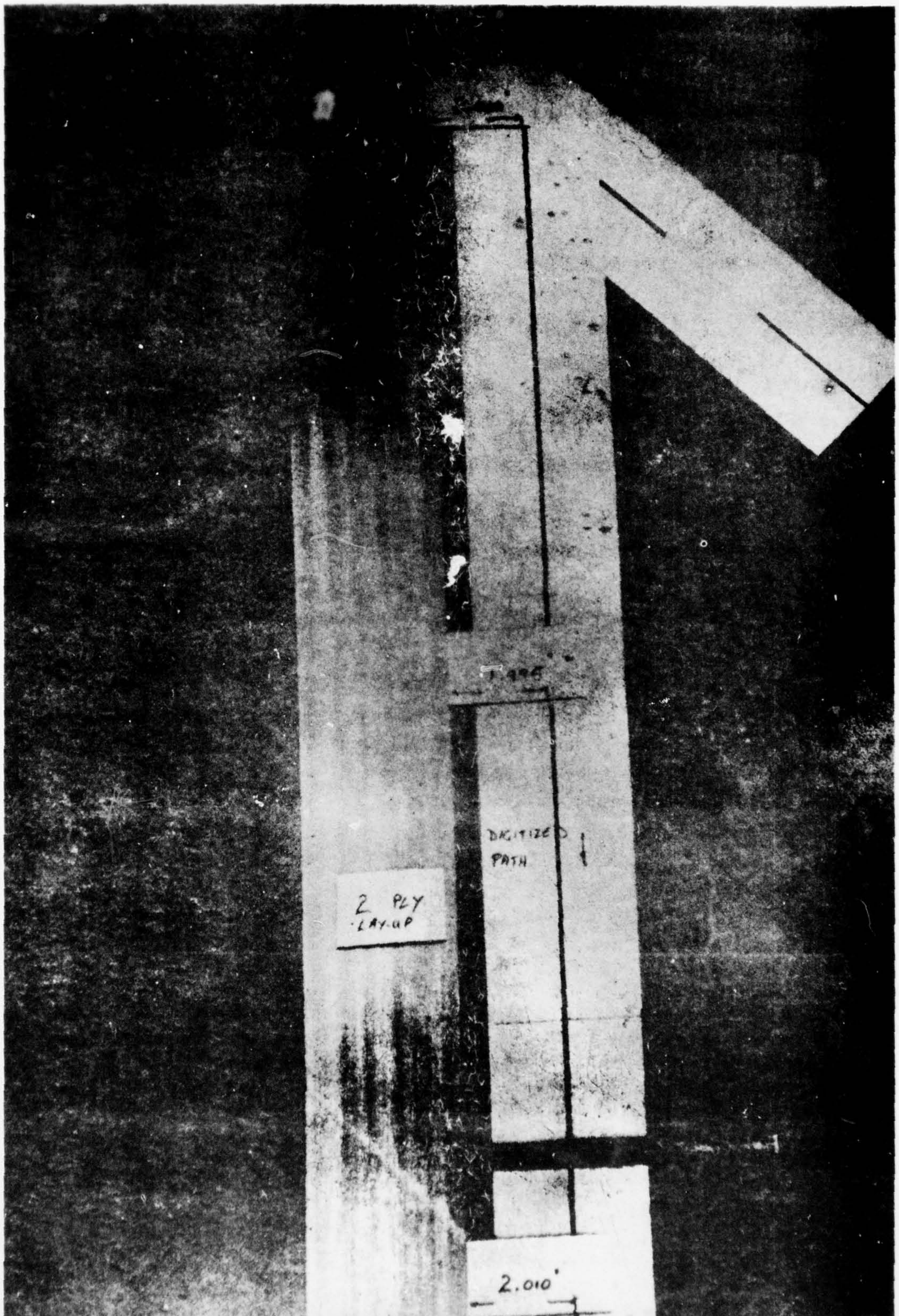


FIGURE 6-52 45° CURVED SKIN LAY-UP 2 PLY

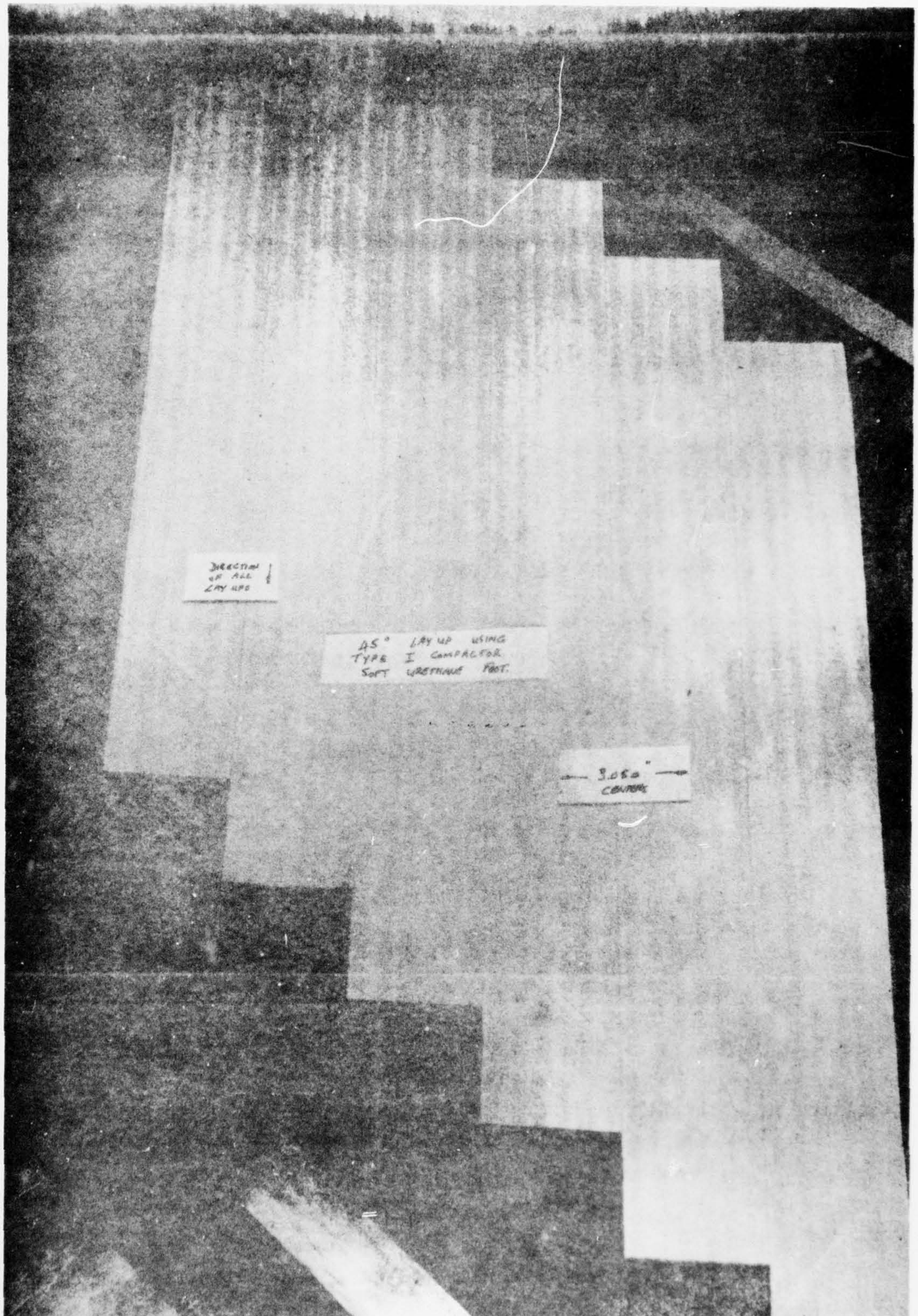


FIGURE 6-53 MULTIPLE 45° CURVED SKIN LAY-UP 2 PLY

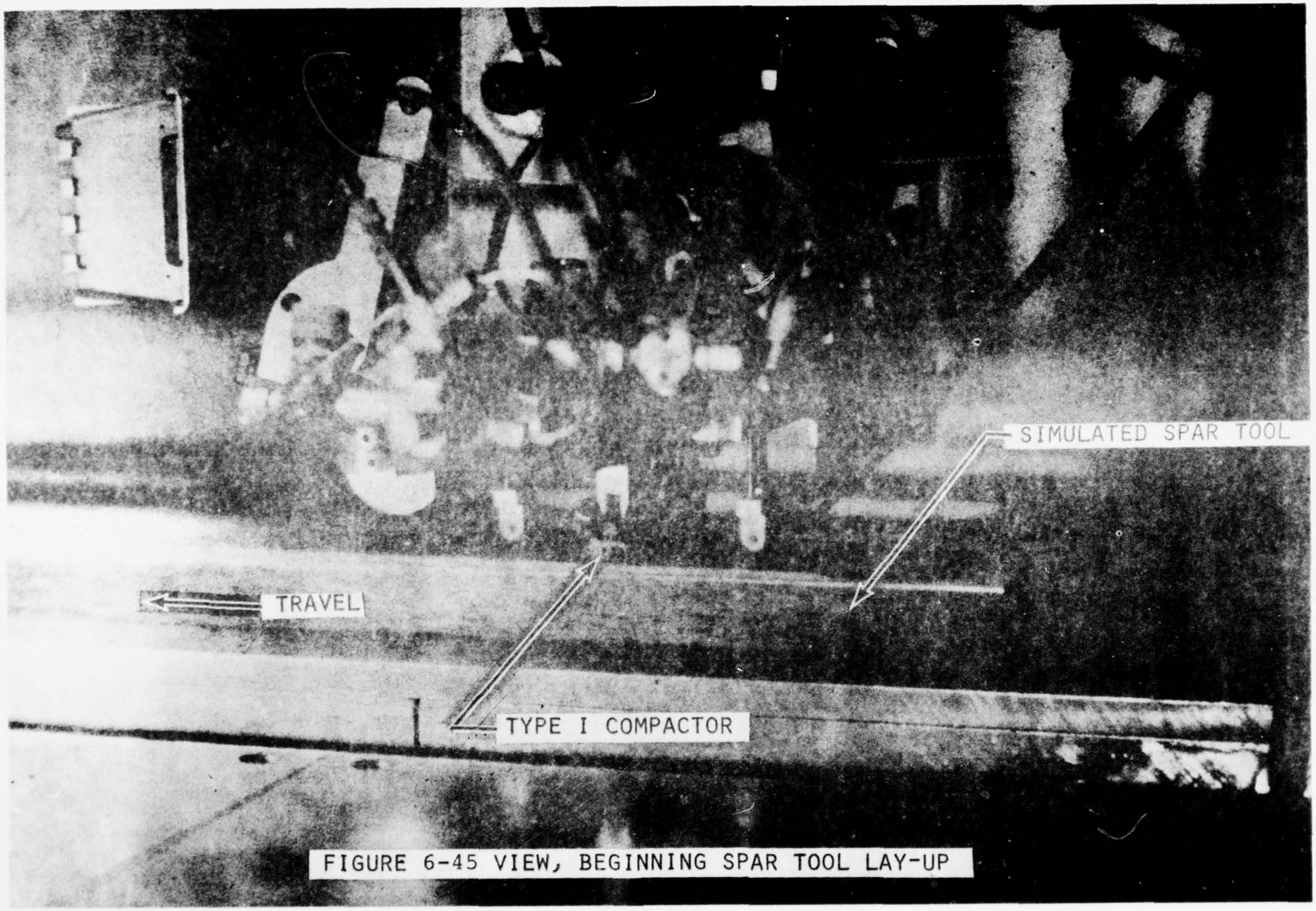


FIGURE 6-45 VIEW, BEGINNING SPAR TOOL LAY-UP

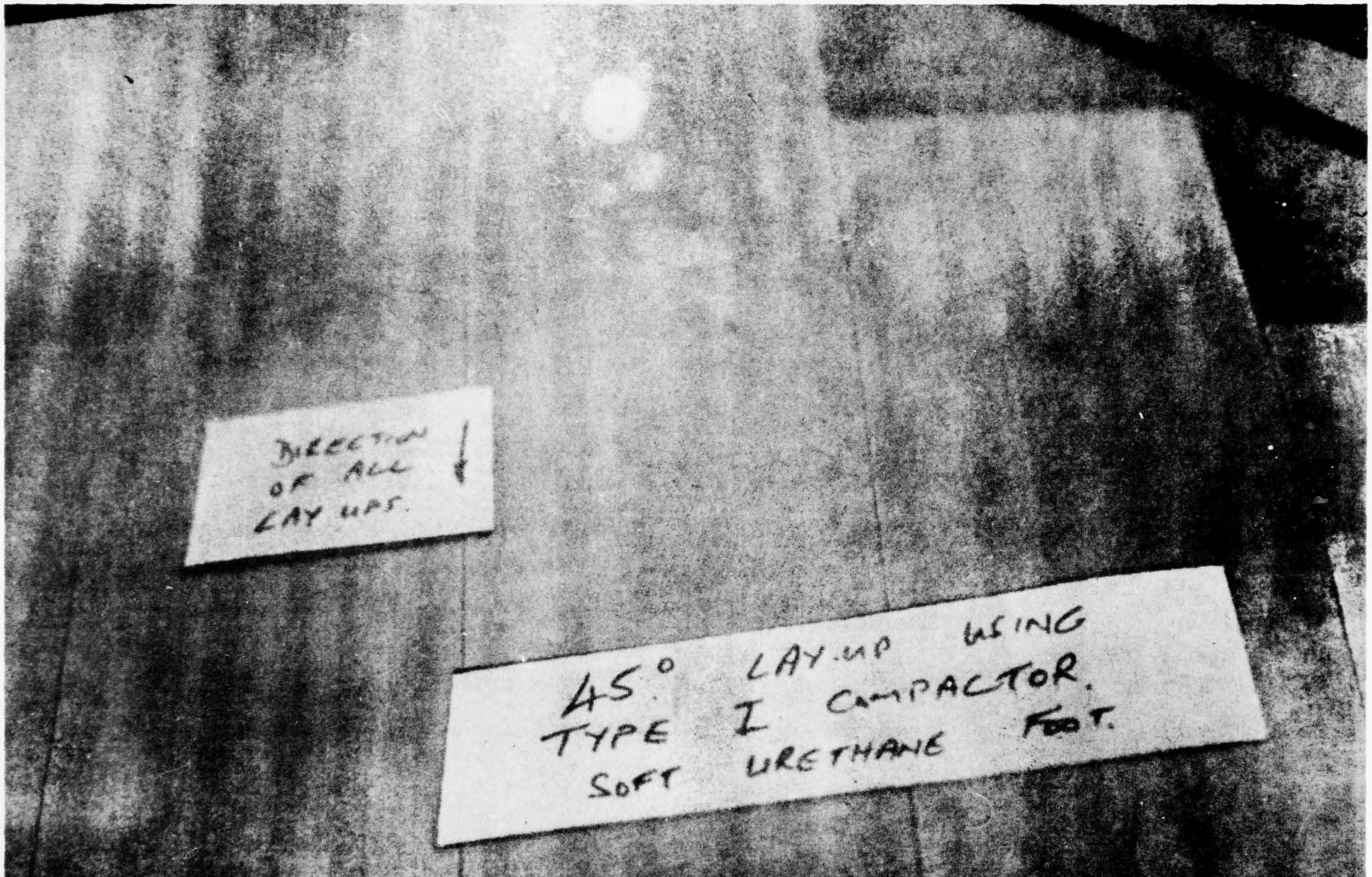


FIGURE 6-55 VIEW, DIRECTION OF LAY-UP

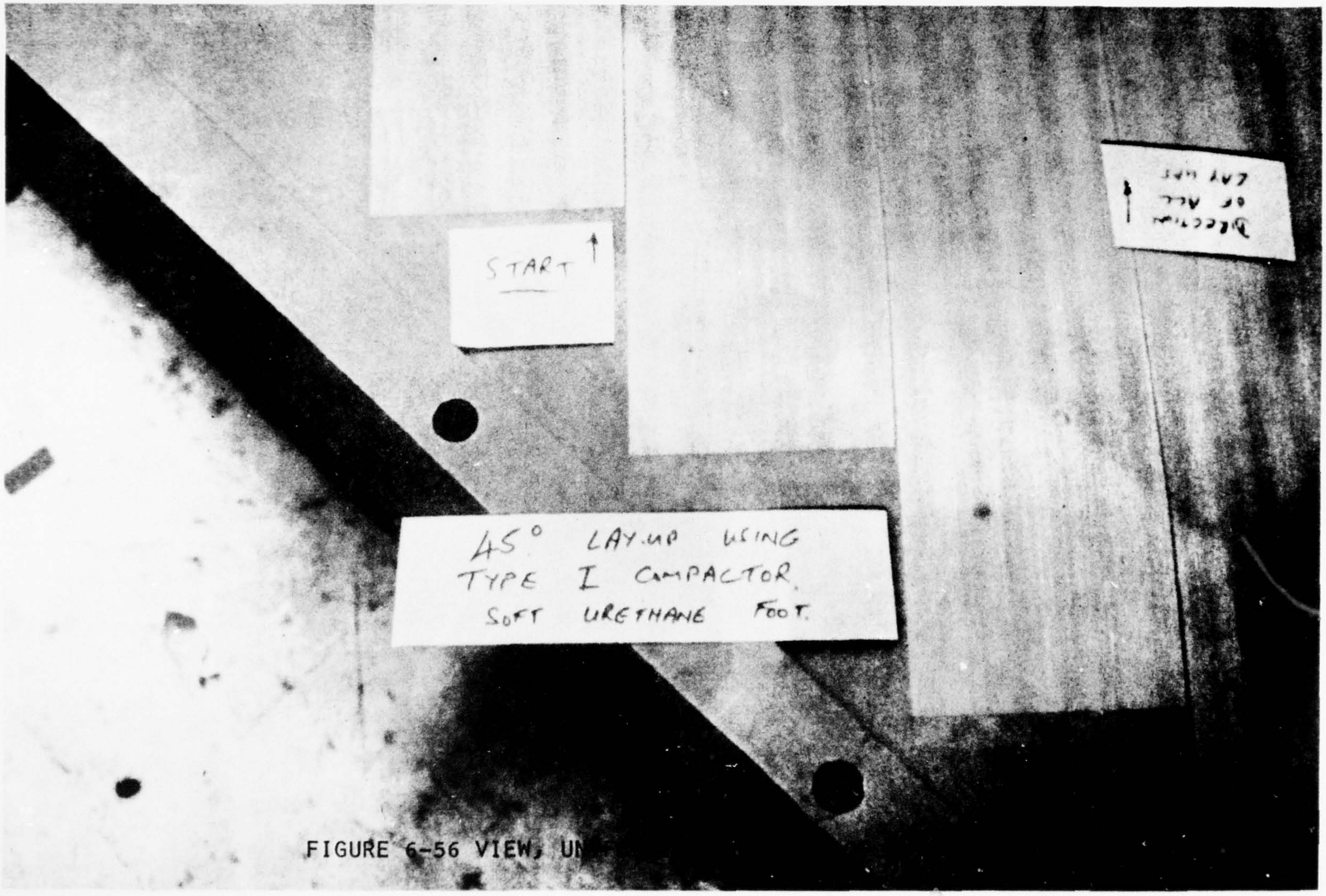


FIGURE 6-56 VIEW, UN

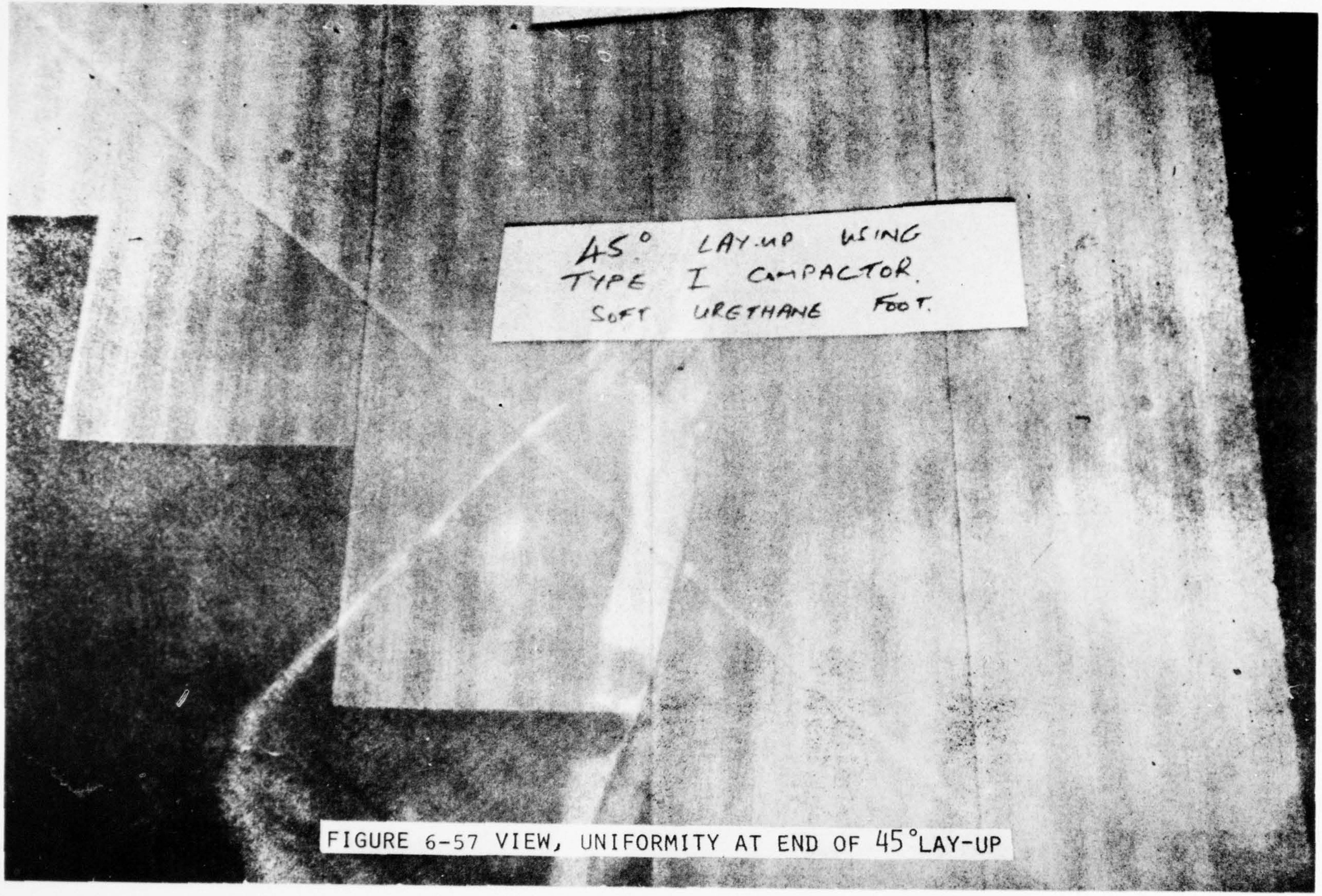


FIGURE 6-57 VIEW, UNIFORMITY AT END OF 45° LAY-UP

FIGURE 6-58 VIEW, SURFACE CONFORMANCE AT START OF 45° LAY-UP

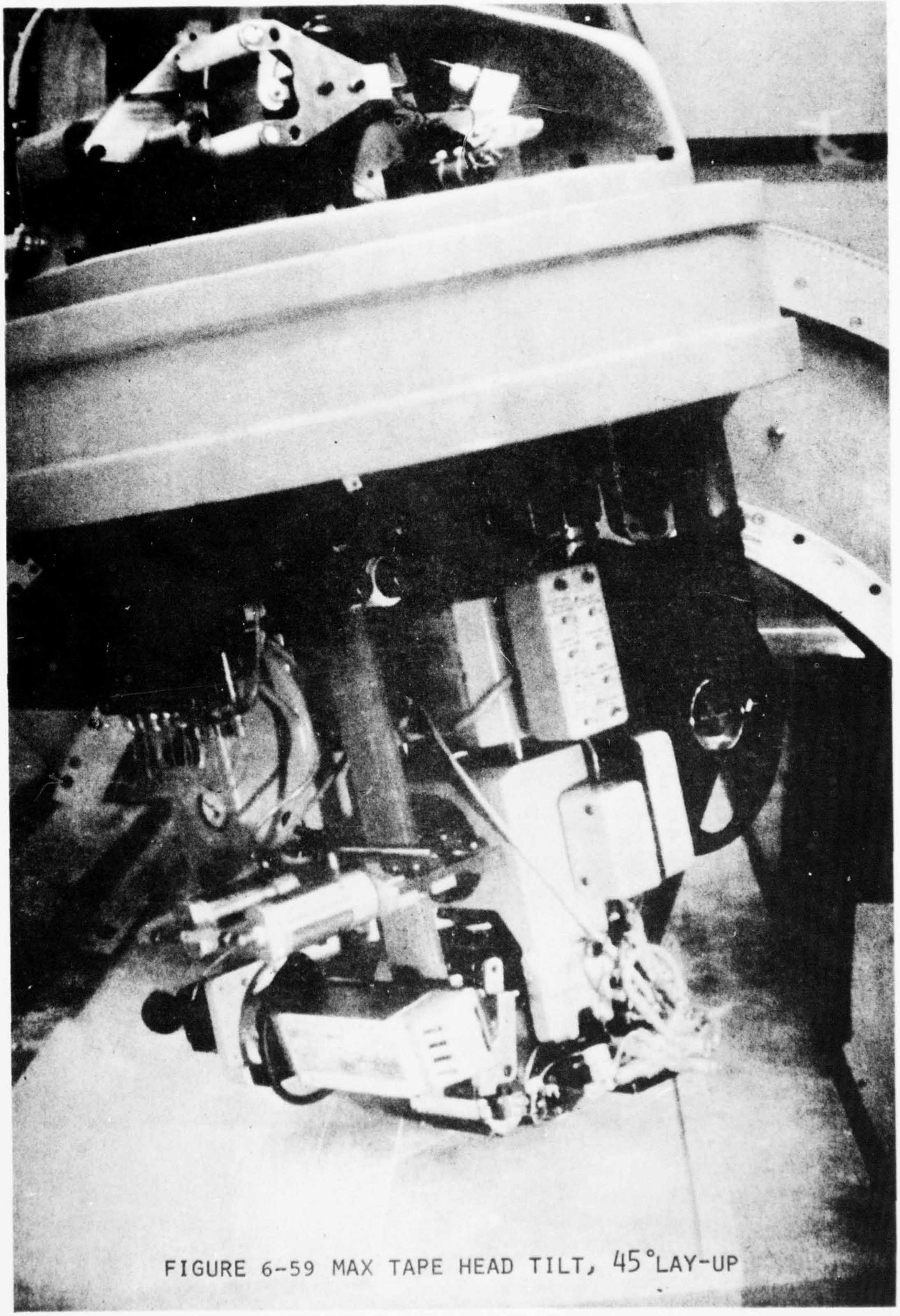
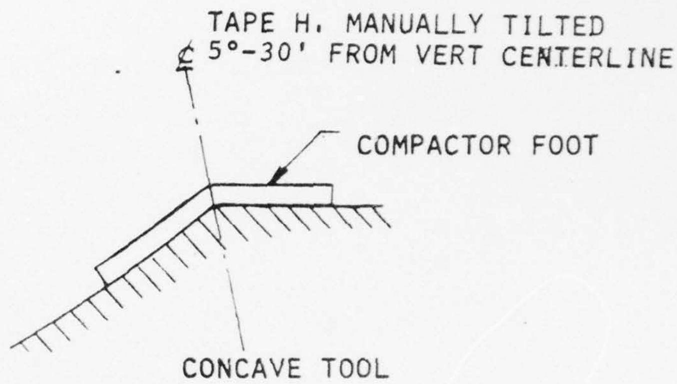


FIGURE 6-59 MAX TAPE HEAD TILT, 45°LAY-UP

```
G00G91
X-2000Z-2000F200000
Z-200
M74
M62
/M68
M83
X-27700
M80
Z-14300
M75
/M69
M81
M63
Z200
Z-2000Z2000
Z46000
M02
```



TYPE I COMPACTOR

MACHINE PROGRAM NO. 7

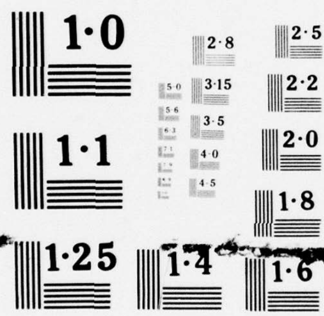
CONCAVE SKIN LAY-UP

FIGURE 6-60

AD-A039 217 GOLDSWORTHY ENGINEERING INC TORRANCE CALIF F/G 13/9
INVESTIGATION OF COMPOSITE TAPE LAY-UP DEVICES FOR AN AUTOMATED--ETC(U)
AUG 75 L B ROSS, J SUETA DAAJ01-75-C-0284
UNCLASSIFIED DRSAV-77-6 NL

2 OF 2
ADA
039217

END
DATE
FILMED
5-77


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·5
2·8
3·15
3·5
4·0
4·5
5·0
5·6
6·3

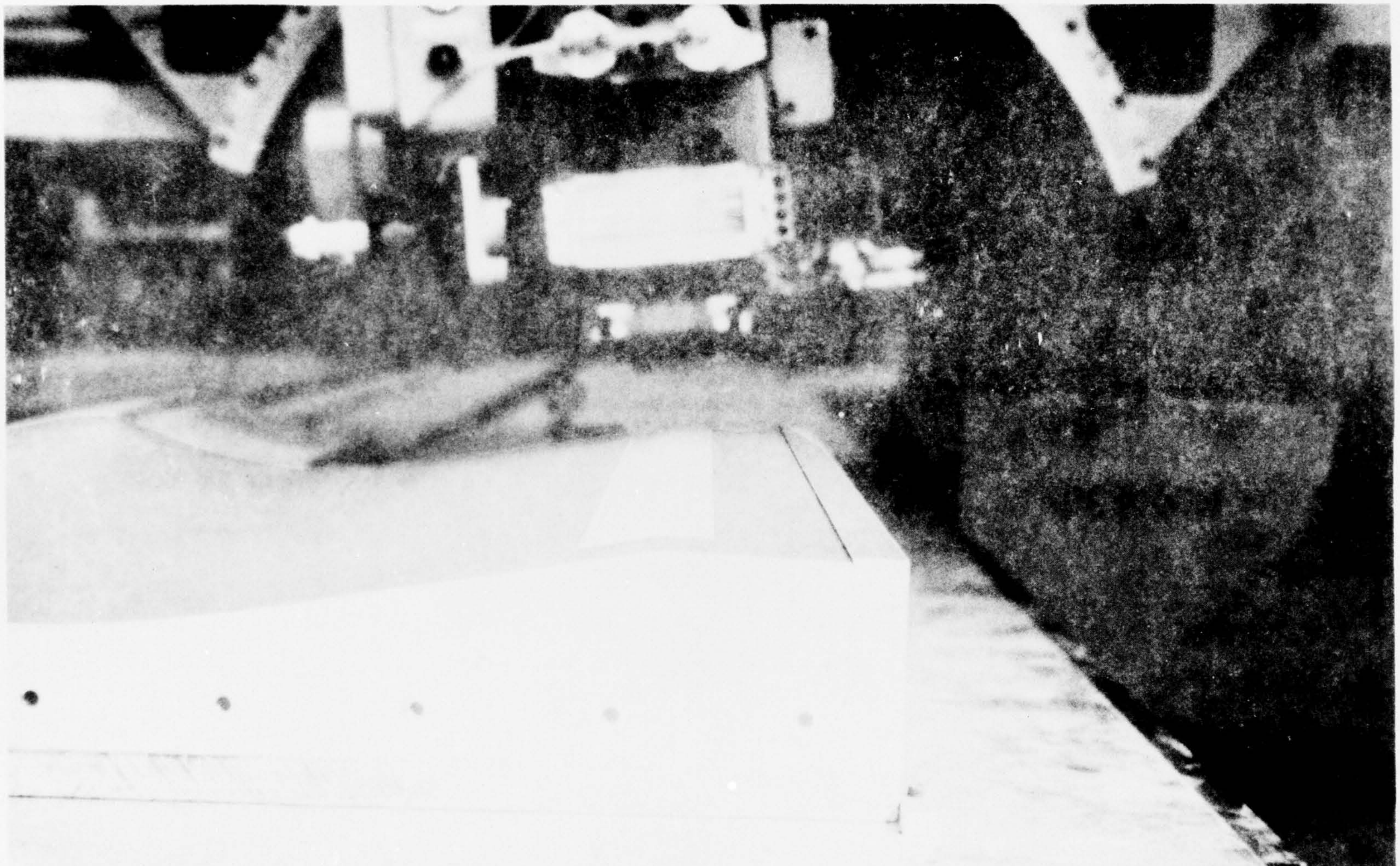


FIGURE 6-61 LINEAR COMPACTION, CONCAVE SKIN LAY-UP

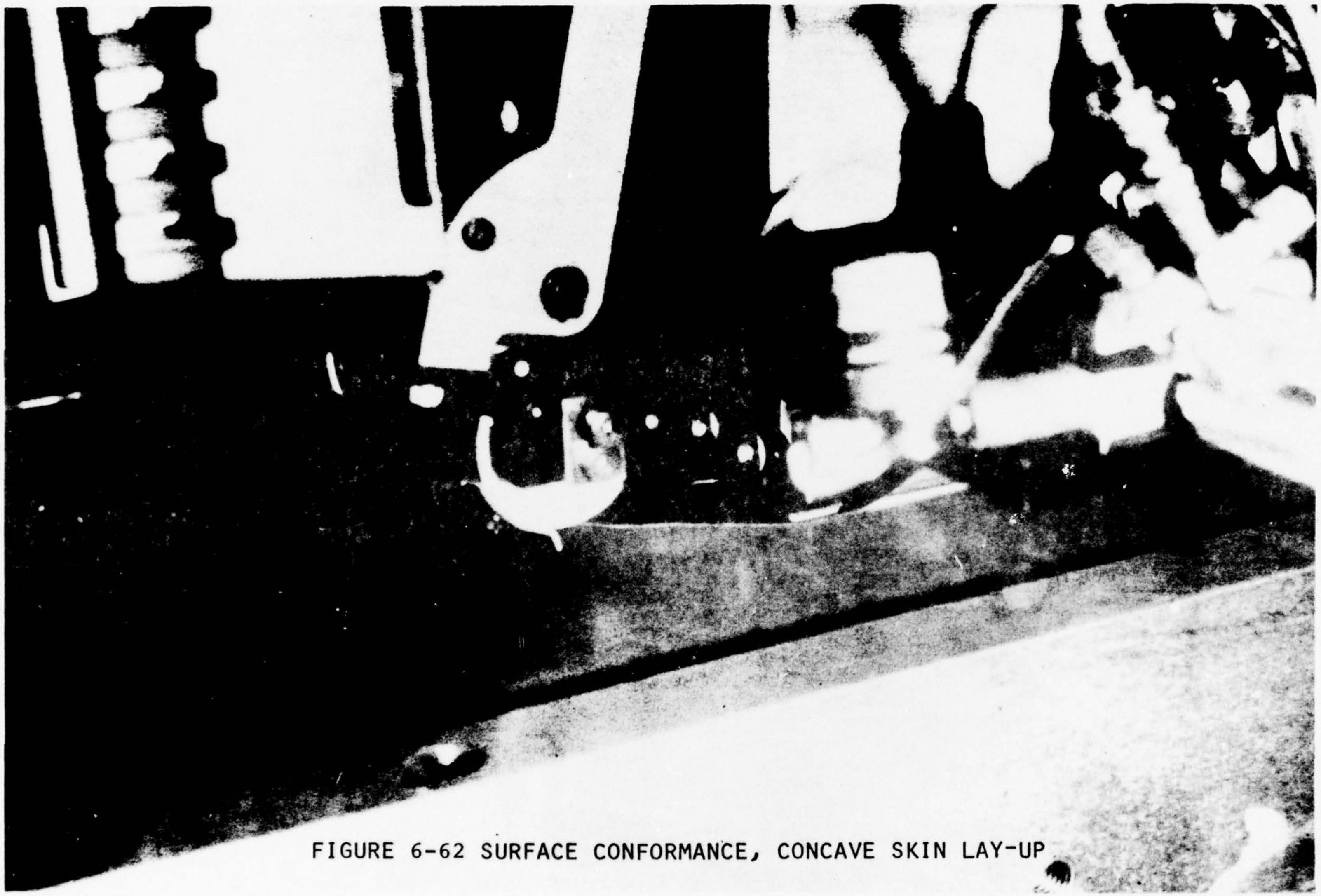


FIGURE 6-62 SURFACE CONFORMANCE, CONCAVE SKIN LAY-UP

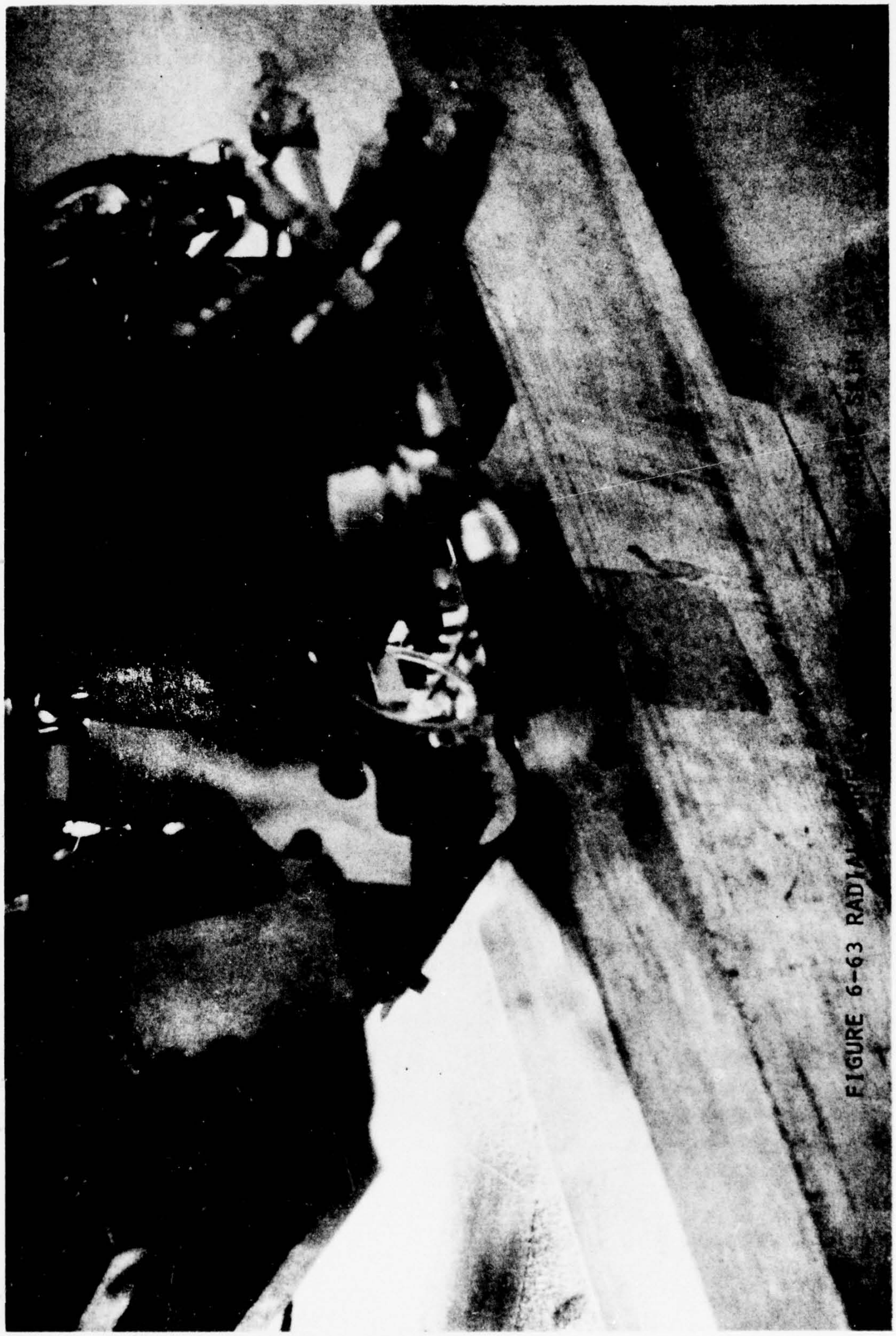
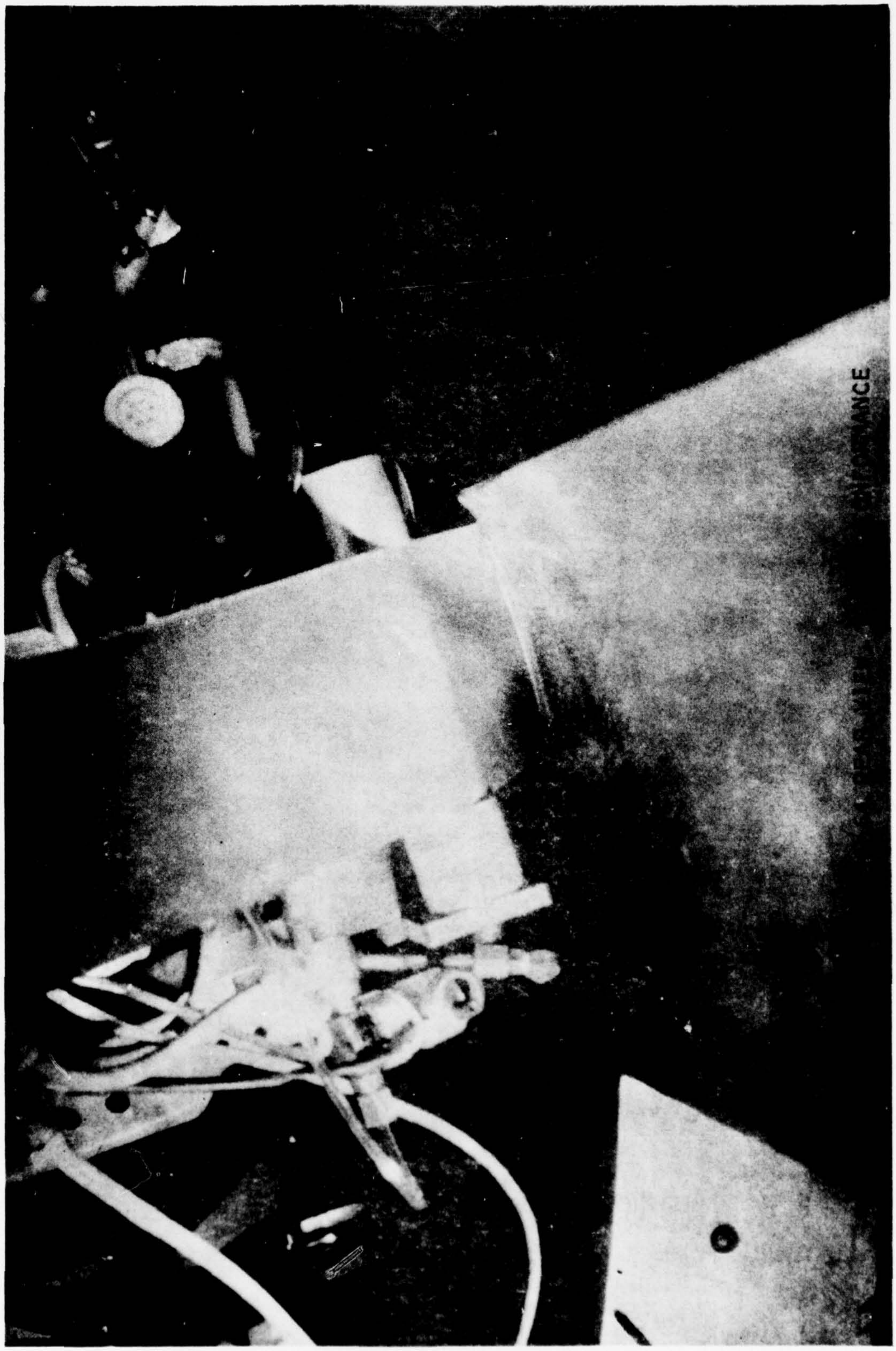


FIGURE 6-63 RADIA



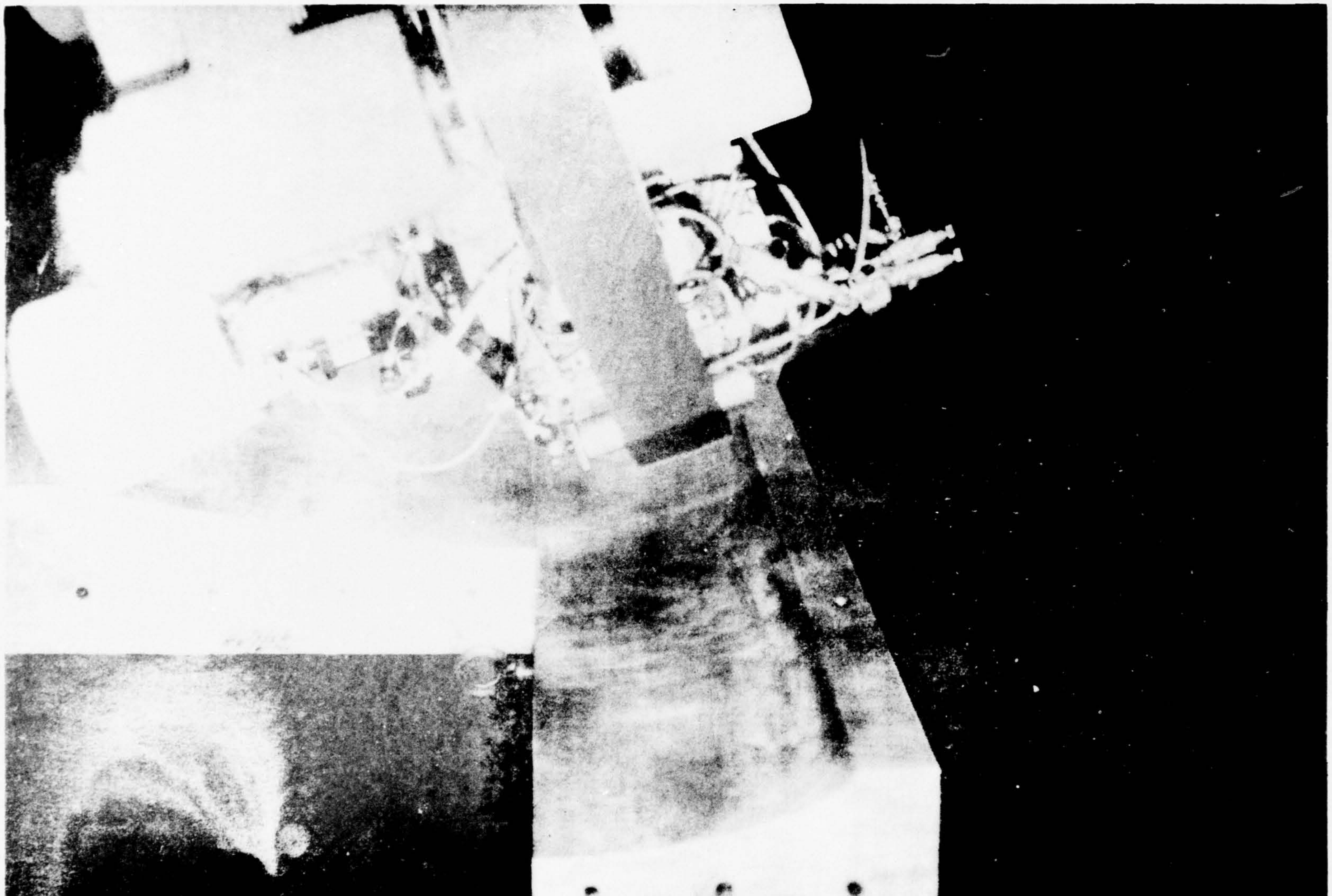


FIGURE 6-65 TAPE HD CLEARANCE, CONCAVE LAY-UP

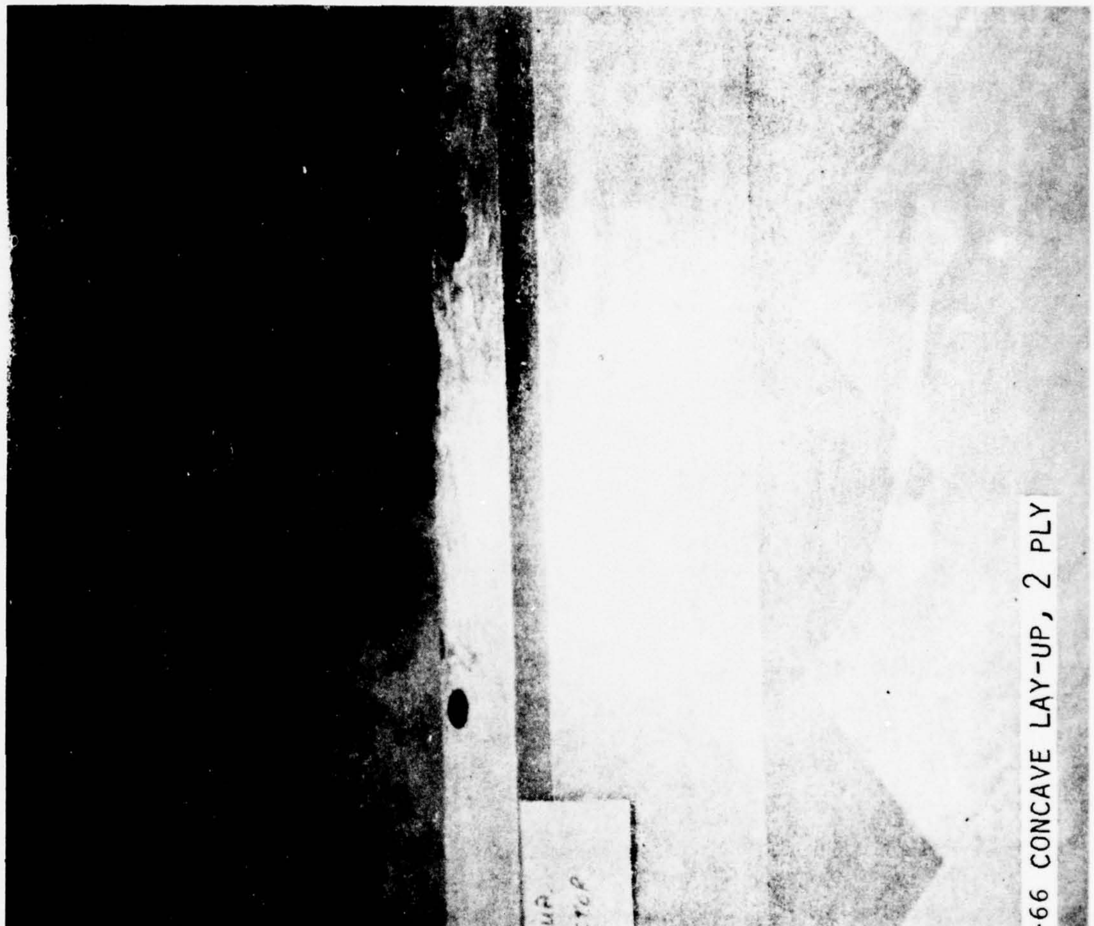


FIGURE 6-66 CONCAVE LAY-UP, 2 PLY

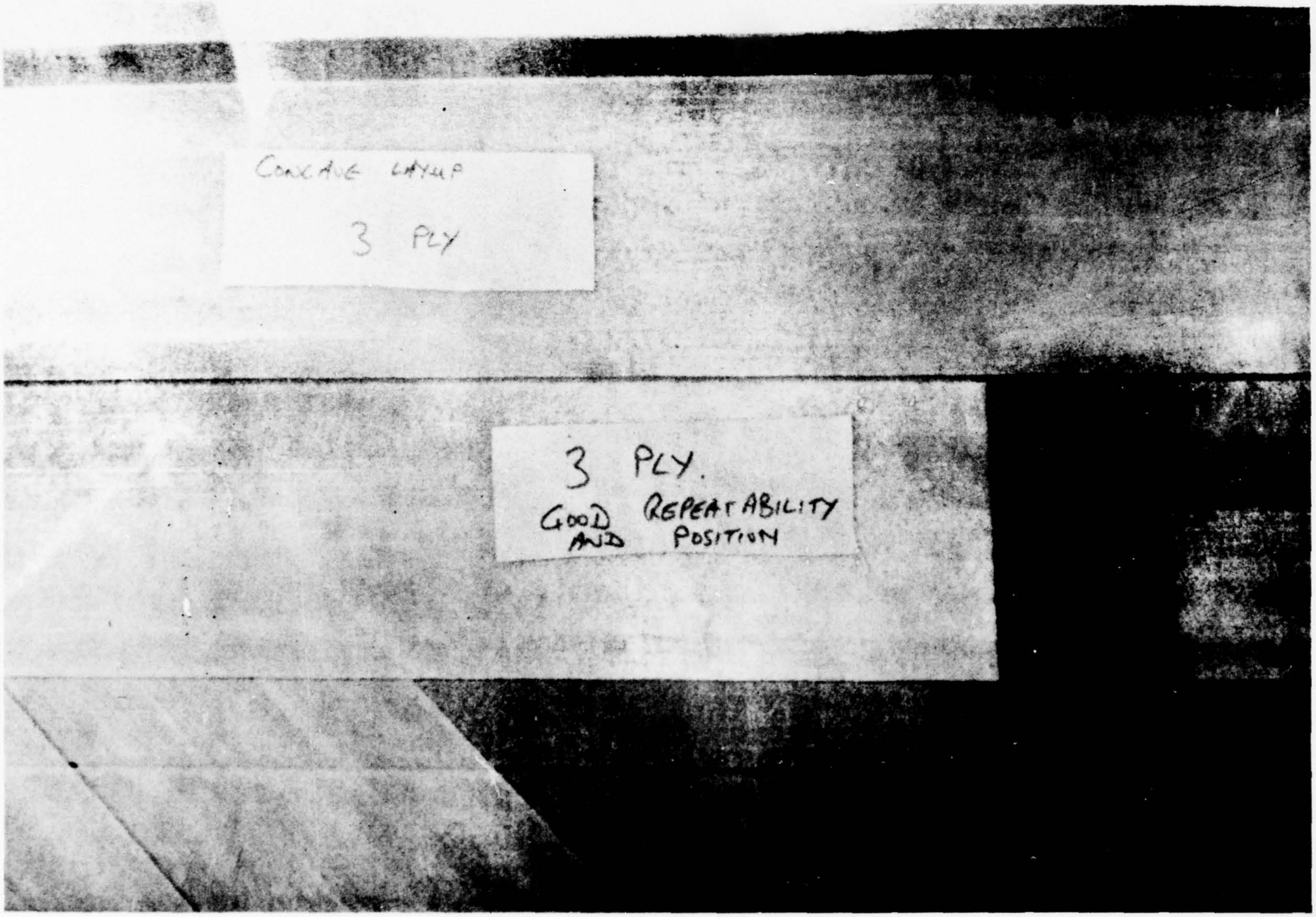


FIGURE 6-67 COMPARISON LAY-UP, 3 PLY

FIGURE 6-68 COMPARISON LAY-UP, 3 PLY

SECTION 7

7.0 TYPE II COMPACTOR (Figure 7-69)

7.1 PURPOSE

The Type II Compactor examined layup conformance to a convex surface using minimal pressure. A convex radius of three inches (3") was the minimum tested.

7.2 TYPE II COMPACTOR REQUIREMENTS

Preliminary tests were made to determine the most effective material for the compactor foot. The most desirable compaction properties were gained with a rectangular shaped, urethane foot which was teflon coated. Because the combination of a soft cast urethane body with a thin layer of teflon is quite unstable, it was necessary to cast a flexible metal strip within the urethane body.

7.3 TYPE II COMPACTOR DESIGN DESCRIPTION

7.3.1 The compactor foot is a spring steel strip encapsulated in a urethane body with a chemically bonded teflon face. This compaction foot is stretched between two flexible spring steel side supports, Figure 7-69.

7.3.2 The compactor is quickly attached or removed from the universal holder by four threaded bolts. Exact location of this unit is assured by two dowel pins, Figure 5-29.

7.3.3 Downtravel of the ATLAS tapehead forces the compactor to conform to the layup shape, Figures 7-72, 7-73 and 7-74. Conformance rollers were used during all linear layups, Section 5, paragraph 5.2.8.

7.4 TYPE II COMPACTOR TESTS AND RESULTS

The degree of repeatability for linear and wrapping compaction was established by a series of tests. Prior to testing, the cylindrical layup tool, Figures 4-12, was installed and properly aligned to the ATLAS Machine. Next, the Type II Compactor was mounted with the compacting surface in intimate contact with the tool layup surface. The compactor was then traversed the length of the tool, insuring alignment of the layup tool. Compaction pressure was preset at 46 psi, Figure 3-8 and 3-9.

7.4.1 Longitudinal Compaction, Test No. 1

Compaction was not uniform for the longitudinal layup of the six inch (6") diameter cylinder. *Higher compaction loading* in the middle of the foot was evident, with the outer edges having minimal or no load, Figure 7-72 . A three thousandths (.003) thick feelergage was inserted between the foot and the tool surface to a depth of .187 of an inch at both outer edges, demonstrating the uneven compaction.

7.4.2 Longitudinal Compaction, Test No. 2

In an effort to eliminate this condition, compaction pressure was increased to 87 psi. The intention was to force the compactor into total longitudinal conformance. This action resulted in an unacceptable deformation through the center portion of the compactor body and eventual destruction of the compactor's metal bridge at its mounting points.

7.4.3 Longitudinal Compaction, Test No. 3

A third attempt at achieving uniform compaction was through the use of the most flexible compactor body available. Compaction force was reset at 46 psi. Without installing composite tape, the compactor was forced onto the layup tool and measurements were taken. Visually, longitudinal conformance was appreciably increased. However, the insertion of a .003 thick feelergage to a maximum depth of .090 was still possible at the outer edges.

7.4.4 Cylindrical Wrap, Test No. 4

The objective of this test was to attain continual compaction of composite tape onto a revolving surface with even distribution of forces and exact repeatability. This was not possible due to the imcompatable acceleration/deceleration of the 'D' and 'X' axes of the ATLAS Machine. The cylindrical wrap attempted, as shown in Figures 7-75 , 7-76 , and 7-77 , was not uniform.

7.5 SUMMARY OF TYPE II COMPACTOR TESTS

7.5.1 Linear Compaction of Cylindrical Shape

Uniform compaction was neither achieved by varying the compaction pressure nor by using a more flexible compactor material.

7.5.1.1 Light compactor pressure did not exert sufficient pressure on the outer edges of the compaction zone, while heavier pressures caused excessive tape stress in the center of the compaction zone.

7.5.1.2 A compactor made of very soft urethane yielded improved compaction byt the outer edges were still not down.

7.5.1.3 Increased compaction uniformity can be gained by widening the compactor pivot points, Figures 7-73 and 7-74 , but totally acceptable results are not predicted.

7.5.2 Wrapping Cylindrical Shape

Due to the non-synchronization of the ATLAS Machine's acceleration/deceleration on the 'X' and 'D' axes, a thorough evaluation of the non-uniform compaction results was not possible, Figures 7-78 thru 7-83.

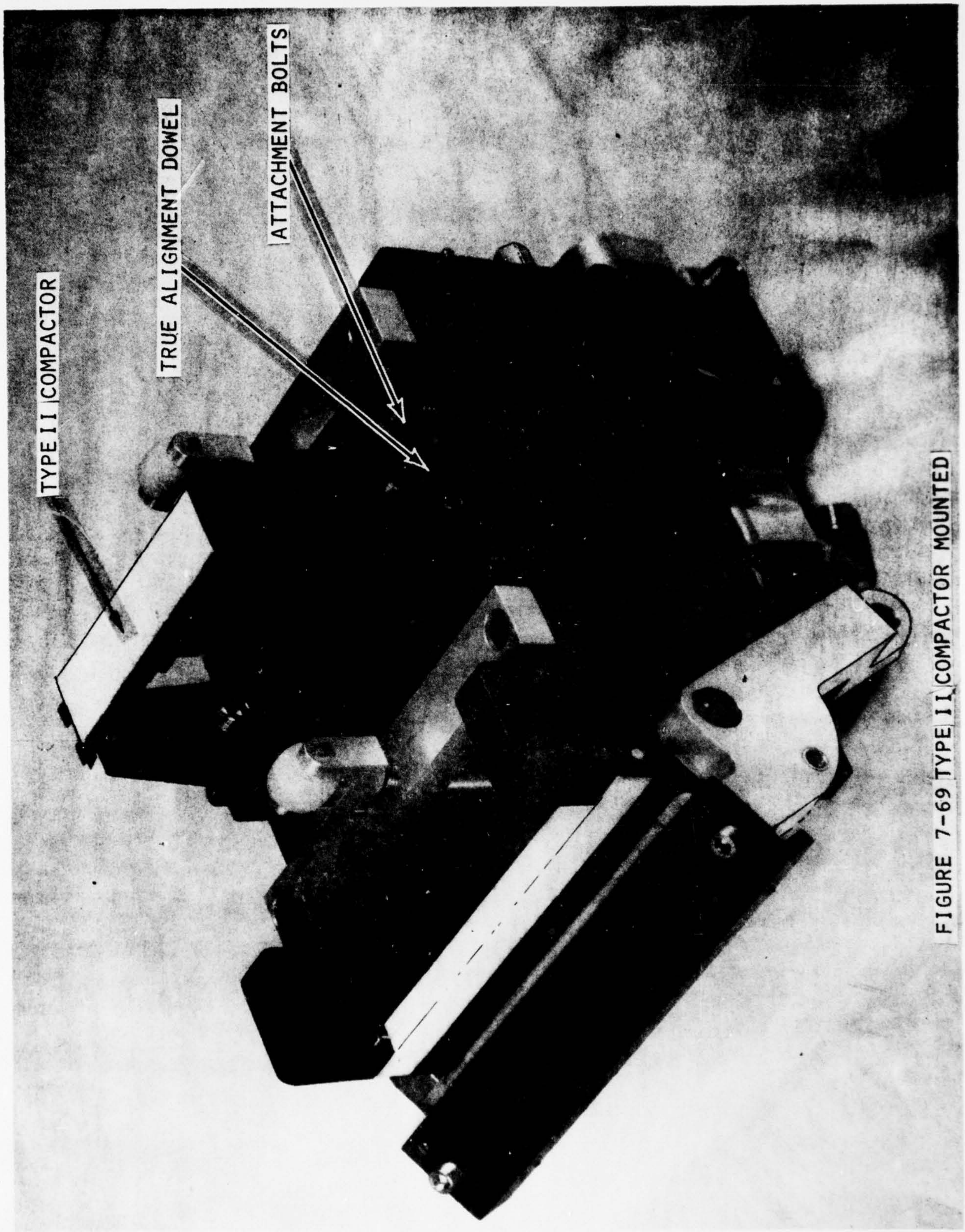
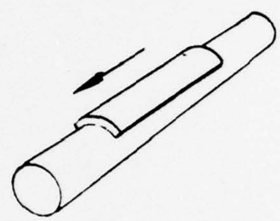


FIGURE 7-69 TYPE II COMPACTOR MOUNTED

```
G00G91
Z-2000X-2000
Z-100
M62
M74
Z-375
X-20000
M80
X-5250
/X-8750
M75
Z375
M69
M63
Z2100X-2000
X29250
/X8750
M02
```



TYPE II COMPACTOR

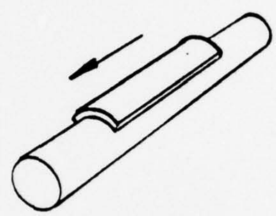
6 INCH CYLINDER EVALUATION

LINEAR TRAVEL WITHOUT FOR/AFT ROLLERS

PROGRAM NO. 8

FIGURE 7-70

```
G00G91
Z-2000X-2000
Z-100
M62
M68
M74
Z-375
Z-20000
M80
Z-5250
/X-8750
M75
Z375
M69
M63
Z2100X-2000
Z29250
/X8750
M02
```



TYPE II COMPACTOR

6 INCH CYLINDER EVALUATION

LINEAR TRAVEL WITH/FORE/AFT ROLLERS

PROGRAM NO. 9

FIGURE 7-71

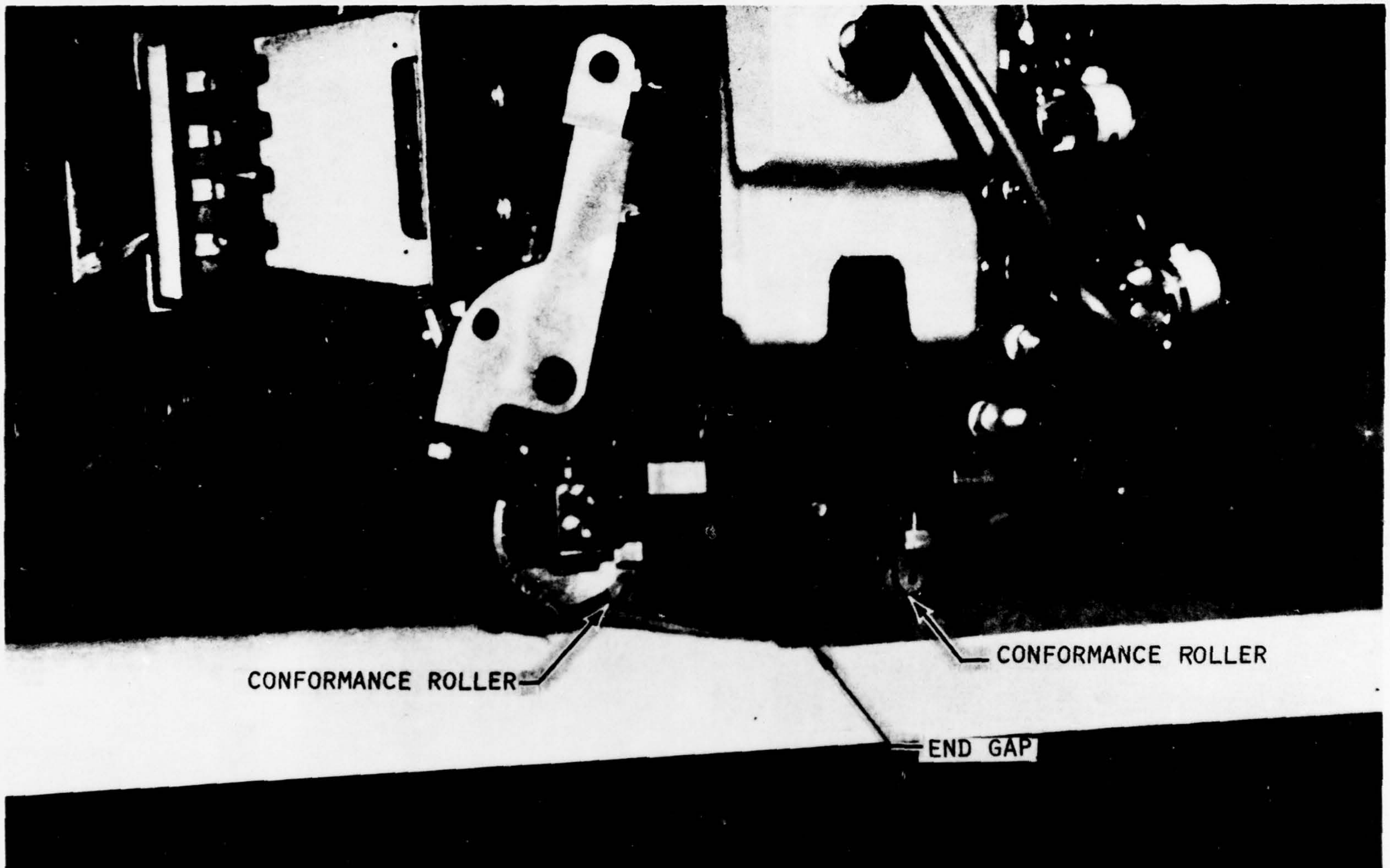


FIGURE 7-72 SURFACE CONFORMANCE, CYLINDRICAL LAY-UP

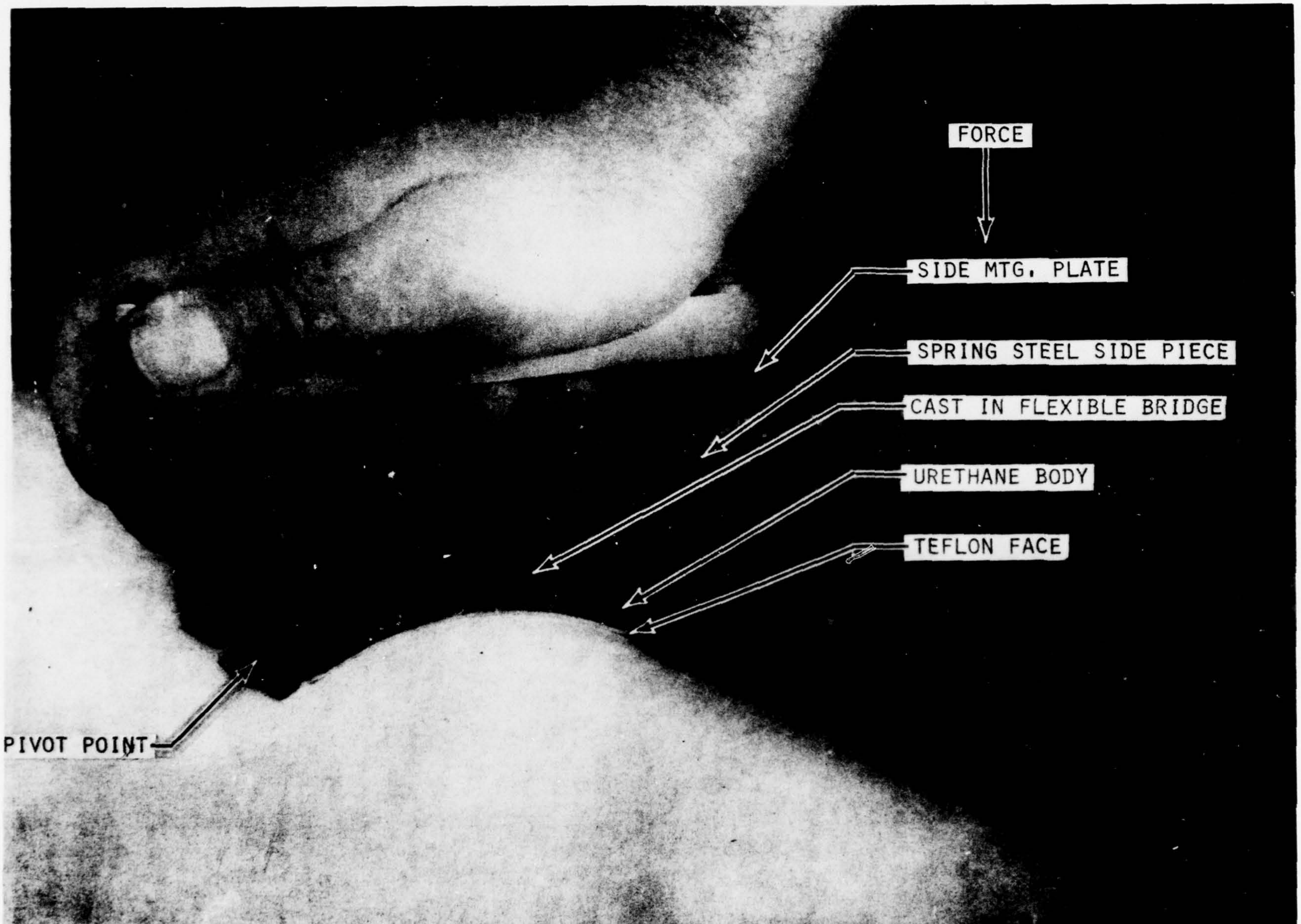


FIGURE 7-73 LINEAR SURFACE CONFORMANCE BY FORCE

FIGURE 7-74 ANGULAR SURFACE CONFORMANCE BY FORCE

FIGURE 7-75 CYLINDRICAL WRAP,START AREA

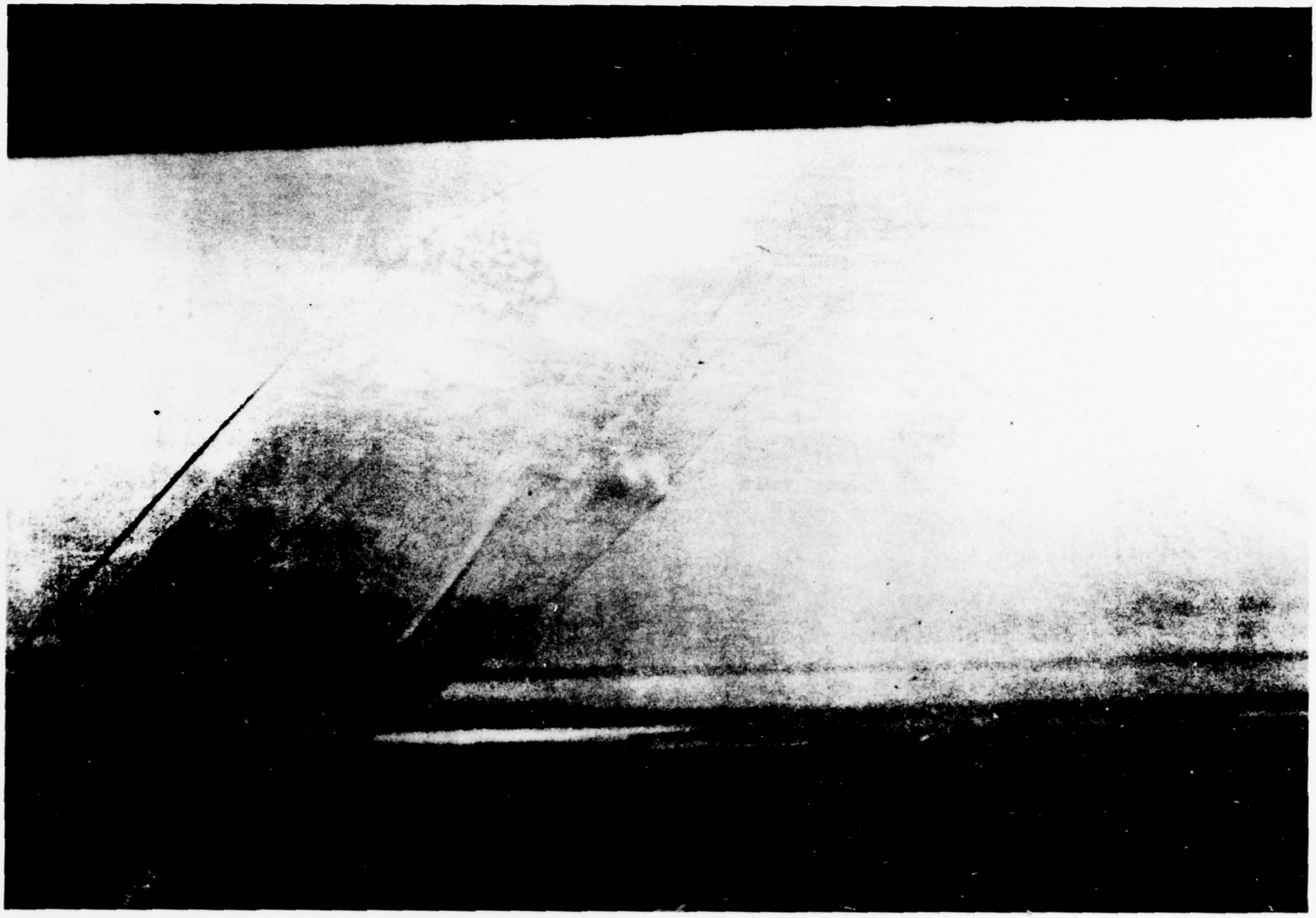


FIGURE 7-76 CYLINDER WRAP, MIDWAY OF LAY-UP PASS

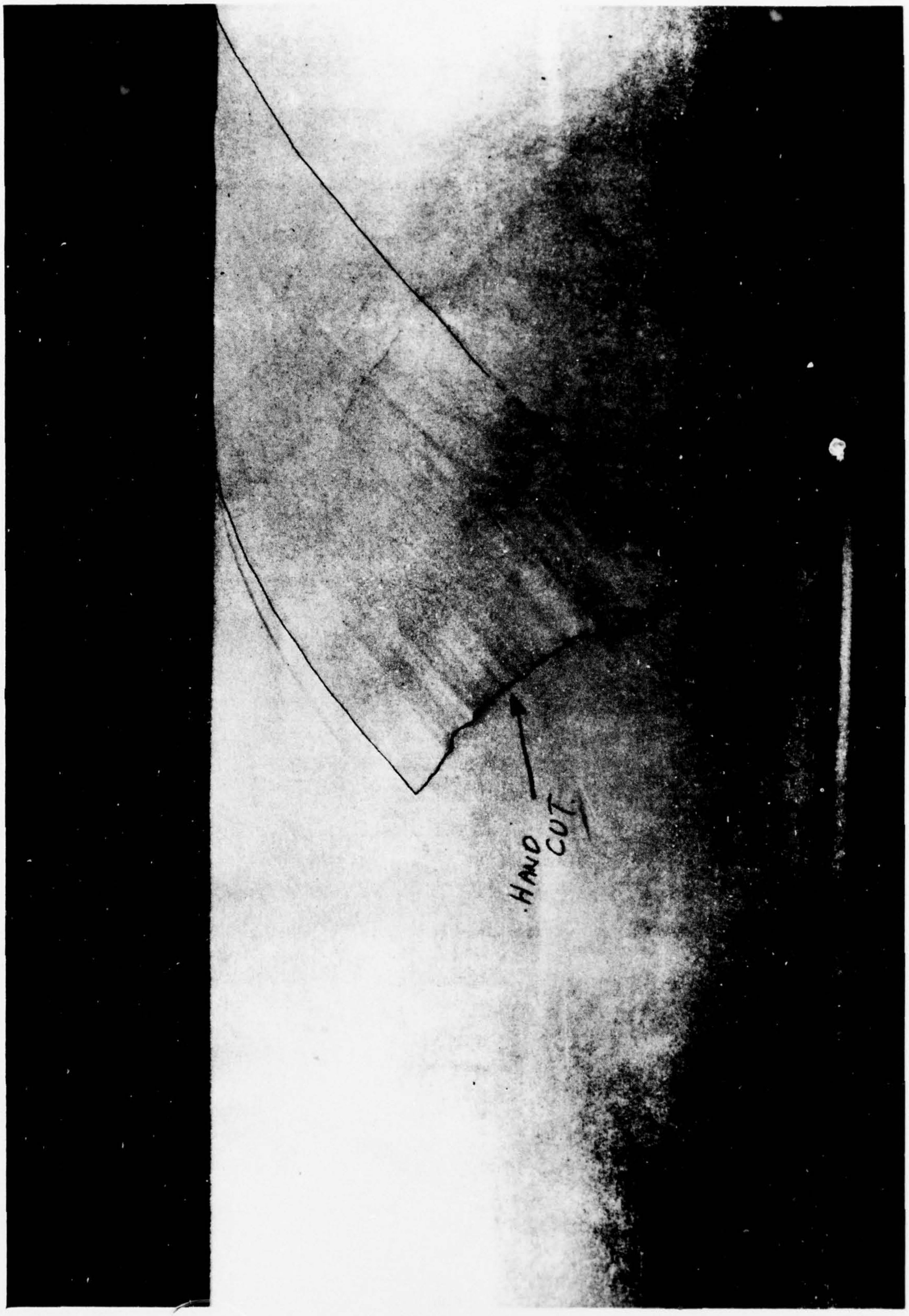


FIGURE 7-77 CYLINDRICAL WRAP, END OF LAY-UP PASS

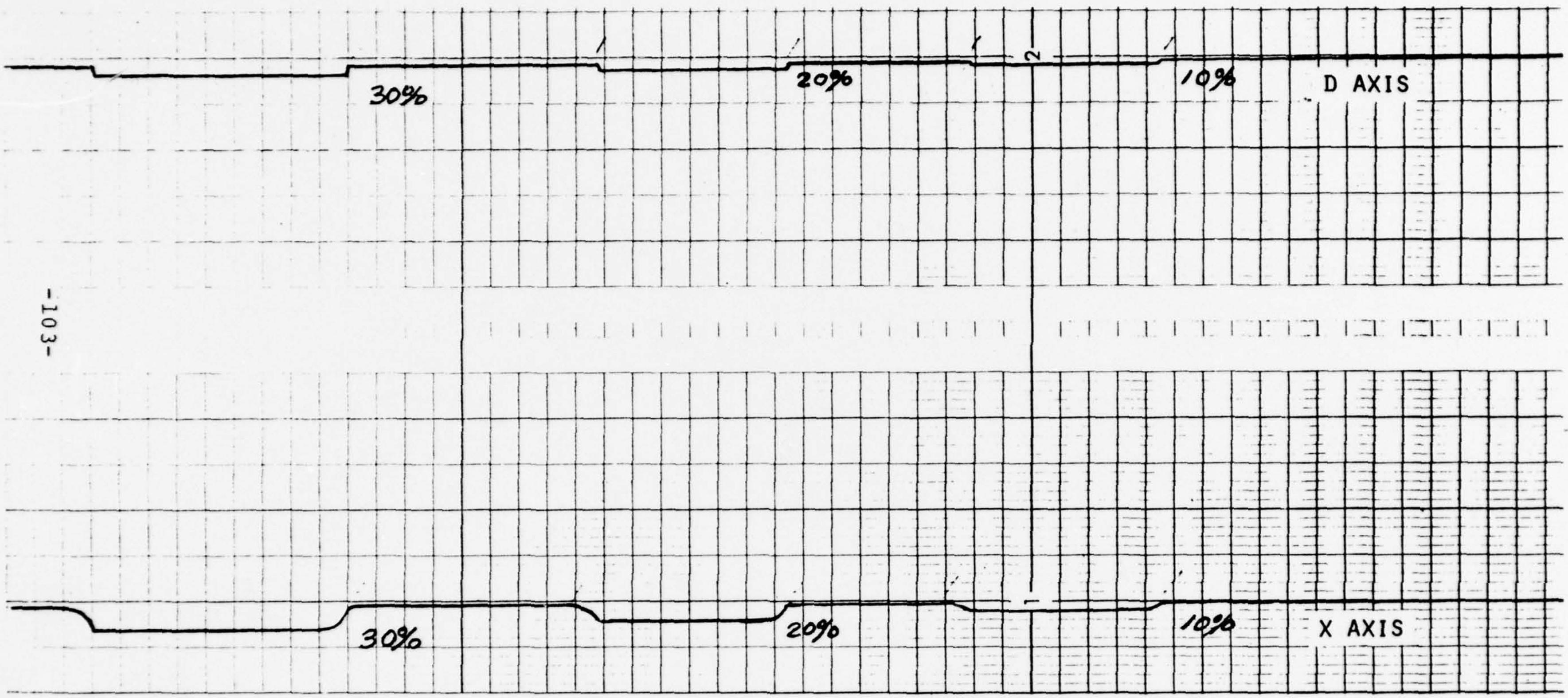


FIGURE 7-78 ACCEL/ DECEL WAVE COMPARISON

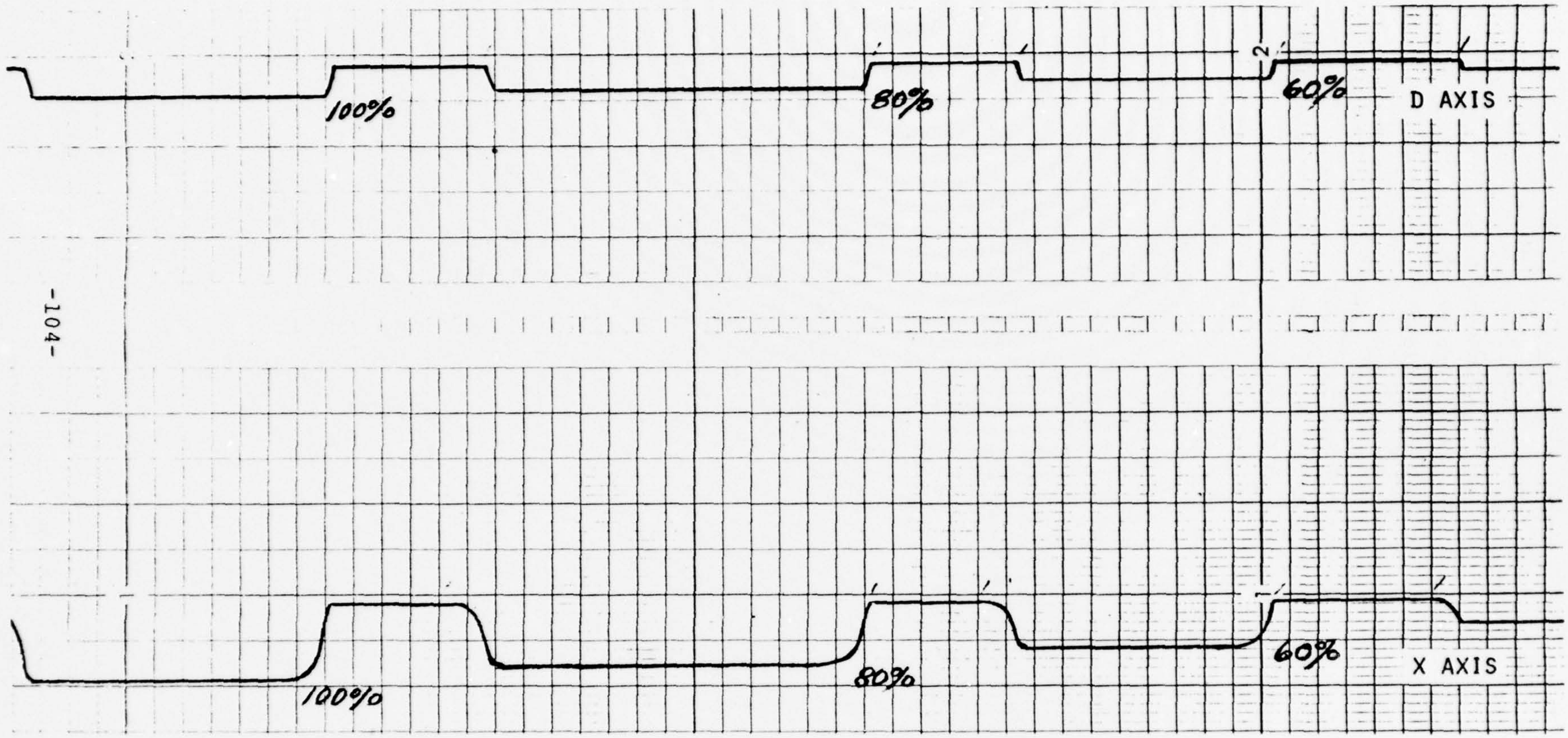


FIGURE 7-79 ACCEL / DECEL WAVE COMPARISON

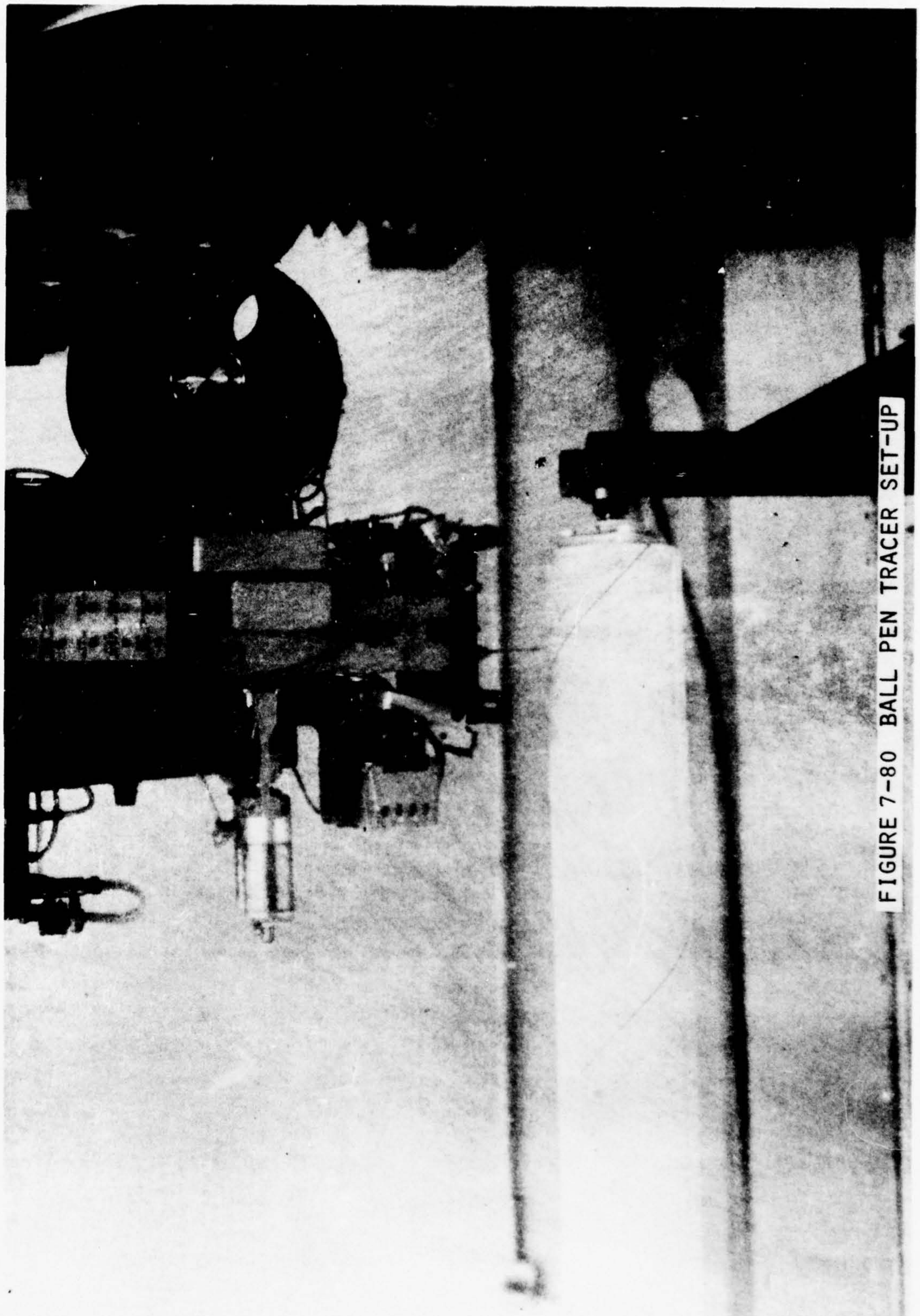


FIGURE 7-80 BALL PEN TRACER SET-UP

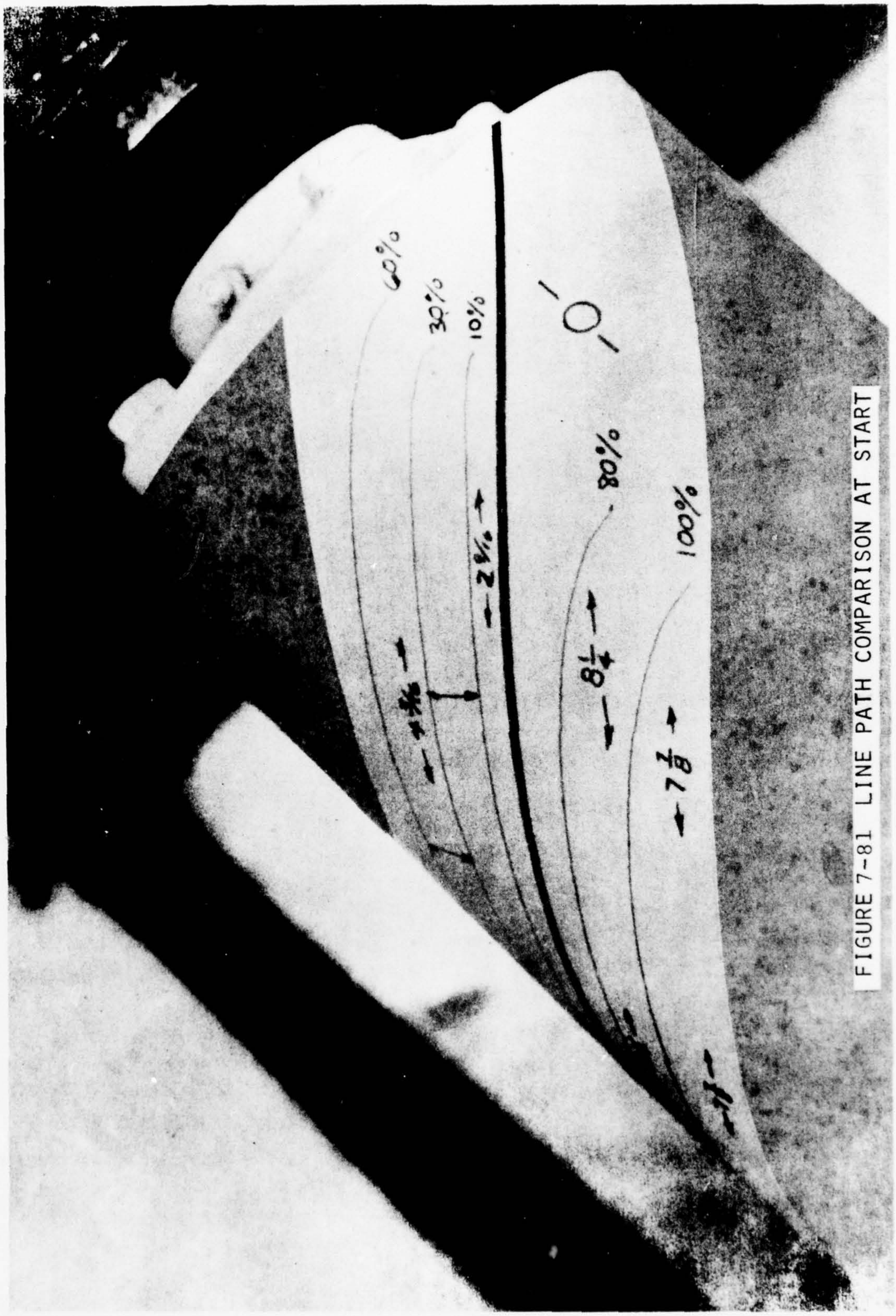


FIGURE 7-81 LINE PATH COMPARISON AT START

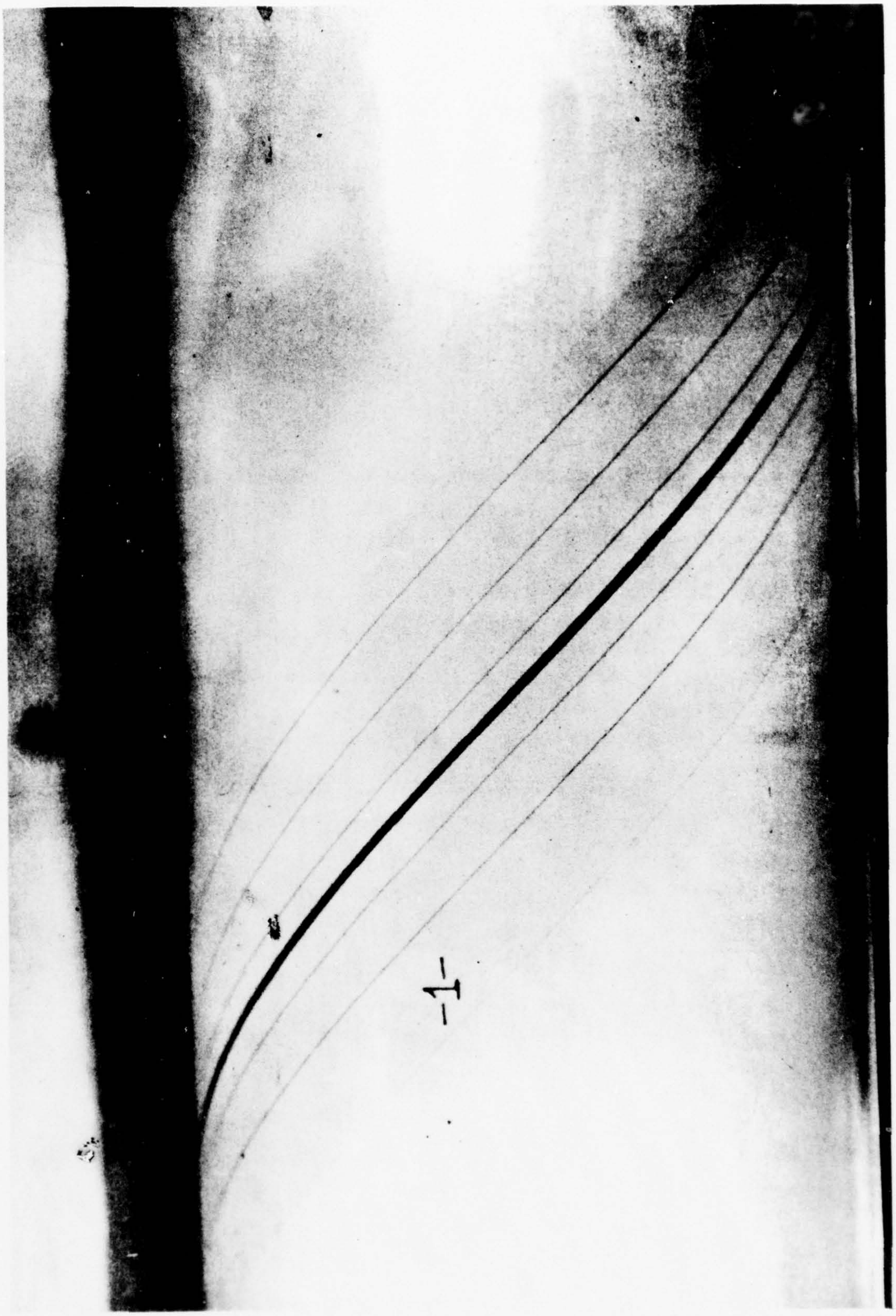


FIGURE 7-82 LINE PATH COMPARISON, MIDWAY

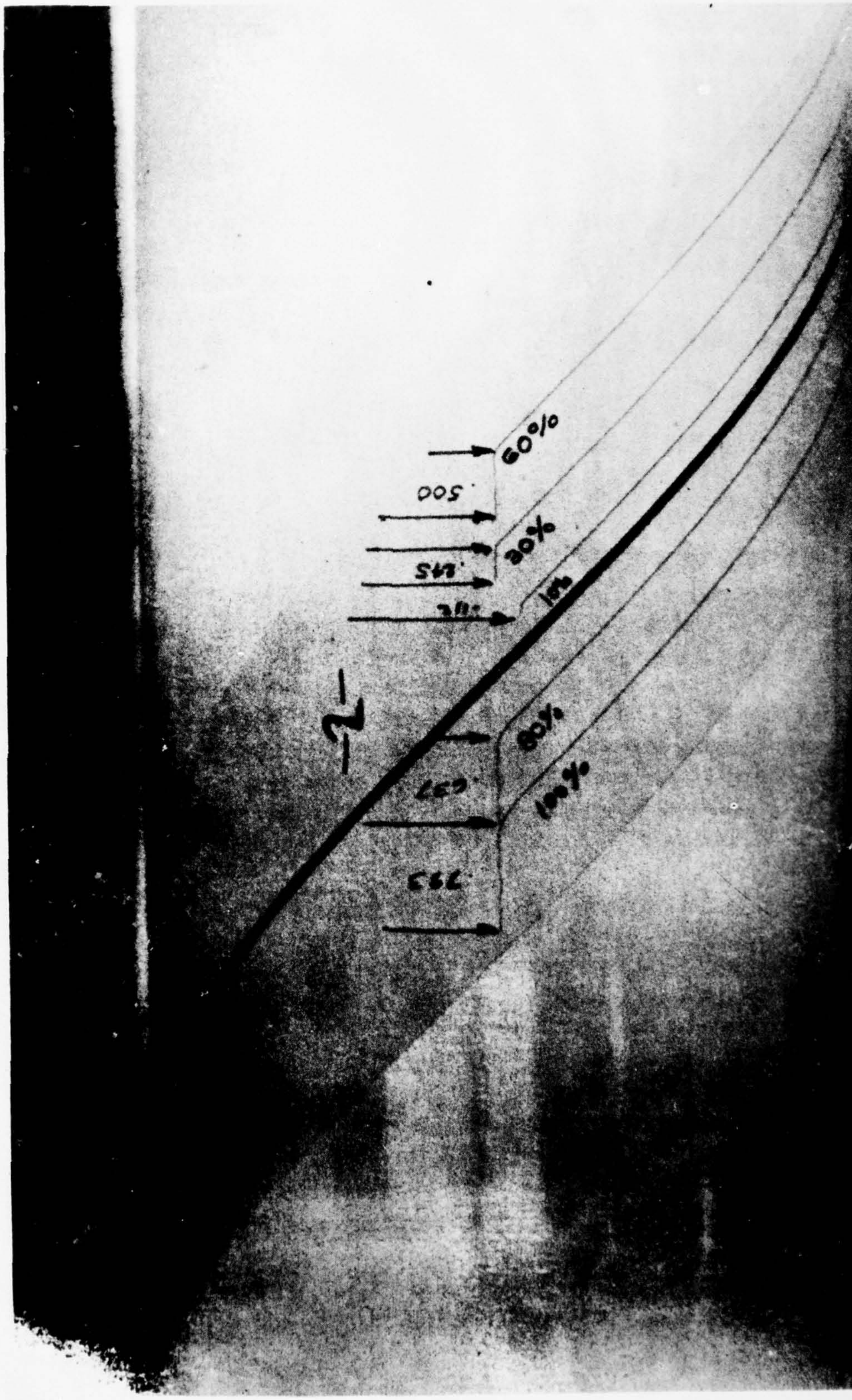


FIGURE 7-83 LINE PATH COMPARISON, AT END OF PASS

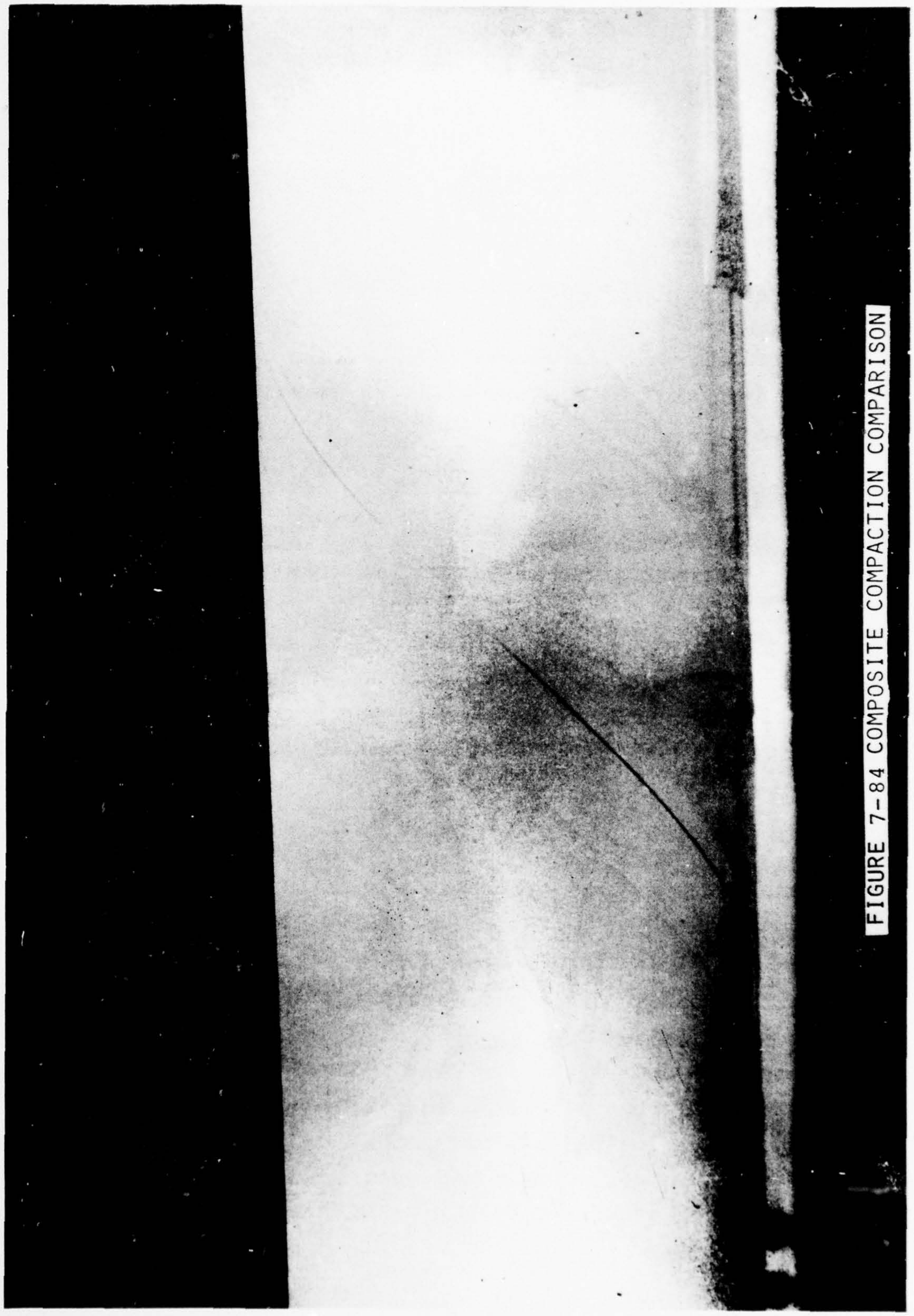


FIGURE 7-84 COMPOSITE COMPACTION COMPARISON

SECTION 8

8.0 TYPE III ROLLING COMPACTOR (Figure 8-85)

8.1 PURPOSE

An industry survey (Appendix I) indicated the use of roller compacting devices for automated tape layup machines was the most widely accepted method. To further investigate this type of device, three different rolling compactors were developed.

8.2 TYPE III COMPACTOR DESIGN REQUIREMENTS

8.2.1 Roller Assembly

The roller must have minimal rotational friction.

8.2.2 The roller must be capable of locking in order to evaluate static versus dynamic characteristics.

8.2.3 Rollers of varying surface hardnesses must be tested and compared.

8.3 TYPE III COMPACTOR DESIGN DESCRIPTION

8.3.1 Roller Body

The roller body is a hollow aluminum core covered with molded urethane. A thin layer of teflon covers the urethane, Figure 8-85 .

8.3.1.1 Three roller bodies, each with different hardnesses, were made by varying the urethane chemical composition. The urethane roller bodies had durometer readings of 28, 36, and 65. The outer teflon layer increased the durometer hardness reading of the three rollers to 35, 48 , and 79 respectively.

8.3.2 Roller Compactor Assembly

Roller bearings were mounted on an axle and then pressed into each end of the roller body. The bearings provide low axial friction for the compactor's rolling action.
The axle is held between two side mounting plates and prevented from rotating by pins, Figure 8-85.

8.3.3 Roller Compactor Assembly Mounting

The two side mounting plates of the roller assembly, Figure 8-85, are bolted to the universal holder. Alignment is established by the two dowel pins.

8.4 TYPE III COMPACTOR TESTS AND RESULTS

In all tests the tool layup surface was flat with a length of seventy two inches (72"). Compaction forces and feed rates were varied. The ATLAS Machine was run both automatically and in the incremental mode.

8.4.1 Free Rolling, Test No. 1

Test Conditions:

(a) Program No. 1 was used, Figure 6-36
(b) compaction pressure was set at 46 psi,
(c) feed rate was 50 ipm, and
(d) a three ply layup was completed.

8.4.1.1 Test Results

Compaction and tracking repeatability were minimal.

8.4.2 Free Rolling, Test No. 2

Test Conditions:

(a) Program No. 1 was used, Figure 6-36,
(b) compaction pressure was set at 46 psi,
(c) the feed rate was increased to 200 ipm,
(d) the softest roller (35 durometer) was used, and
(e) a three ply layup was completed.

8.4.2.1 Test Results

During the first pass the backing paper and composite tape separated between the universal holder's stationary guide and the compaction zone. Separation was in the form of a wave, Figure 8- 86. When the backing paper became taut again a crease formed on the tape surface. Three additional attempts at compacting with a free rotating roller had the same results. The feed rate was progressively decreased to find the maximum feed rate within which paper and composite tape would not separate. Fifty inches per minute, 6.94% of the maximum of 720 inches per minute, was the best feed rate obtainable before separation occurred. It was observed that as separation occurred, control of tracking was lost and the composite tape would veer to the right or left of center, to a maximum of .030 thousandths of an inch.

8.4.3 Locked Roller, Test No. 3

Testing Conditions:

(a) Program No. 9 was used, Figure 8- 88 ,

(b) compaction pressure was 46 psi,

(c) the feed rate was 200 ipm,

(d) the roller was locked,

(e) four layups were completed in the incremental mode; each block of information was progressively stepped, thereby allowing prolonged observation,

(f) the tapehead was moved six inches (6") and four additional layups were completed in the full automatic mode, and

(g) repeatability levels for stop and start alignment were established.

8.4.3.1 Test Results

The tape and backing separation did not occur, and creasing was therefore eliminated. Linear alignment during start and stop of any laydown pass was within .005 of the true linear centerline of compaction. Tracking repeatability of layers two, three and four on both test layups was excellent and the linear edge relationship

8.4.3.1 continued

between any two layups was within .010. The compacted surface was smooth and level.

8.5 SUMMARY OF TYPE III COMPACTOR TESTS

The free rolling compactor produced moderate compaction and tracking at a feed rate of 50 ipm. Above that feedrate, separation between tape and paper backing occurred which lead to compacted tape creasing. Tracking was also non-acceptable. With the roller locked in a non-rotating position, separation did not occur even at 200 ipm, tracking was excellent, and the compacted surface was smooth.

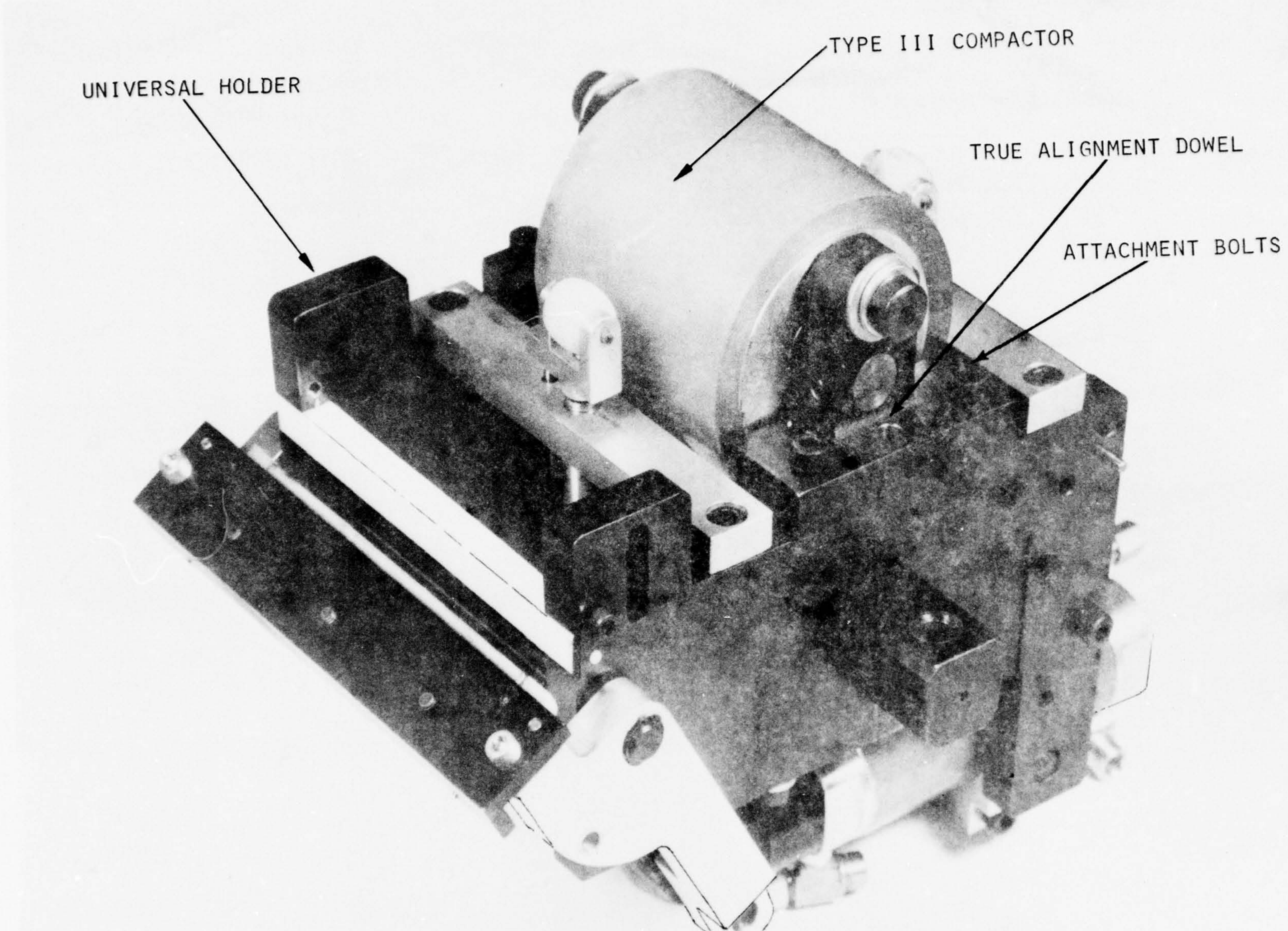


FIGURE 8-85 TYPE III COMPACTOR MOUNTED

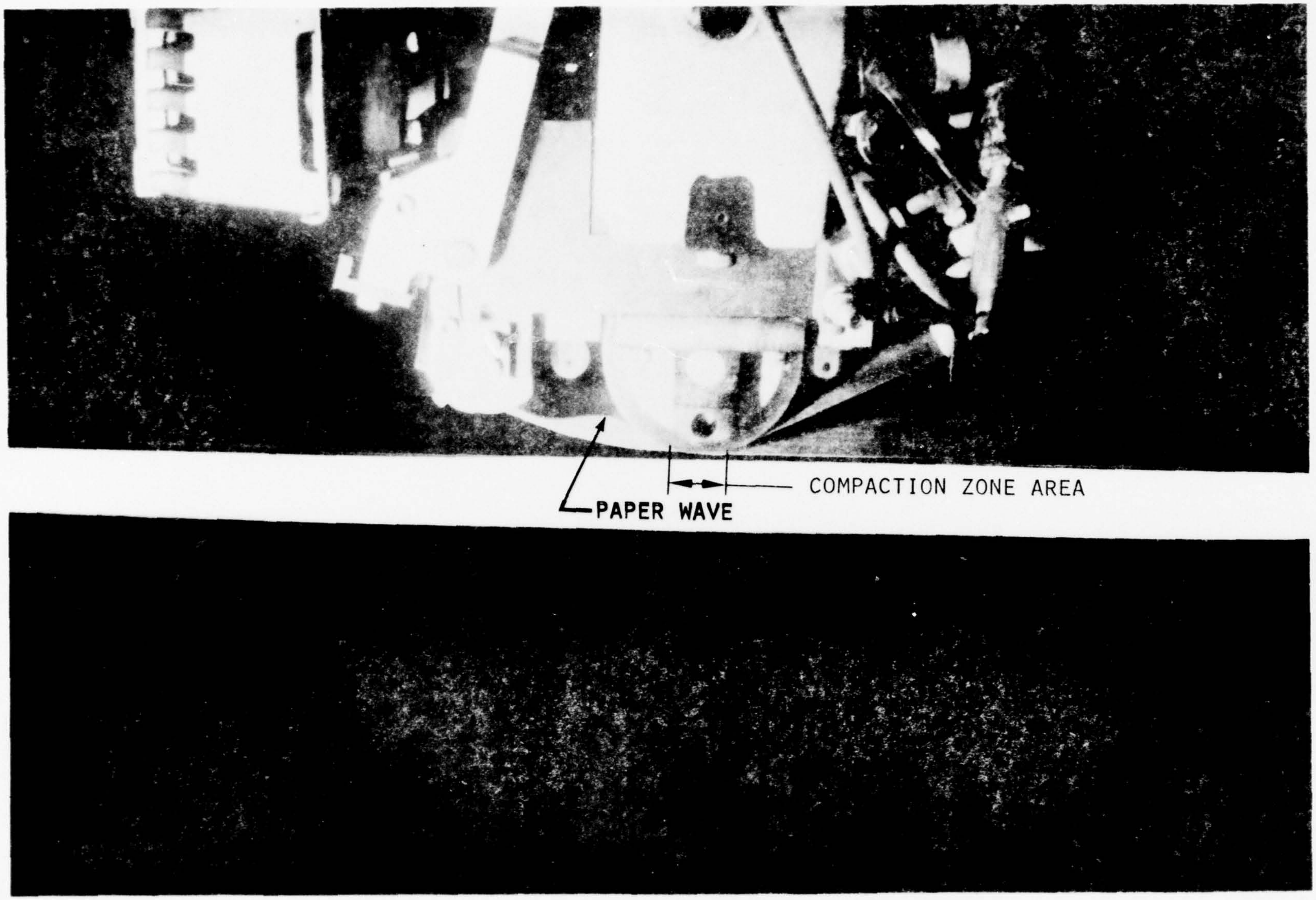


FIGURE 8-86 COMPOSITE TAPE AND PAPER SEPARATION

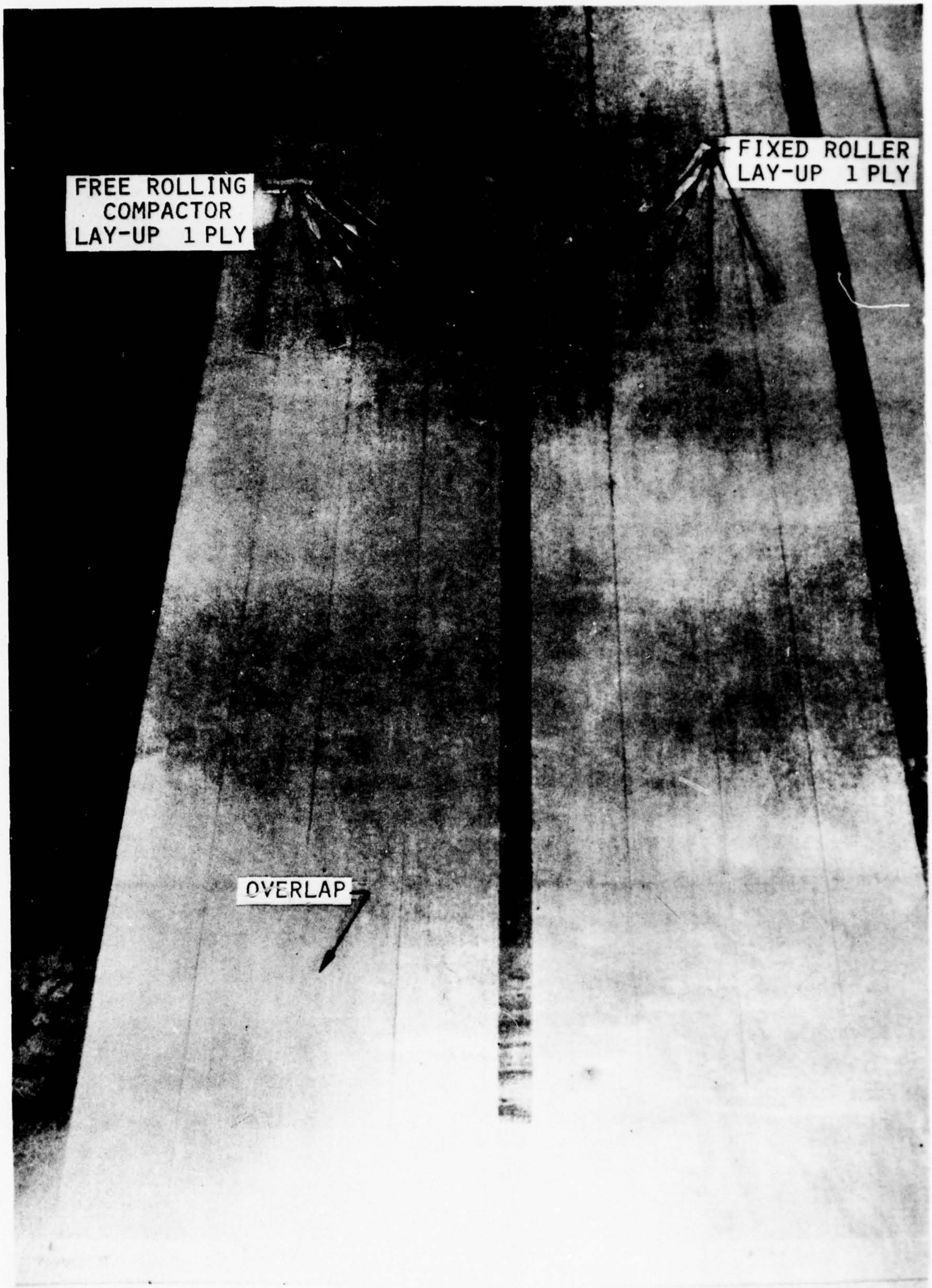


FIGURE 8-87 LAY-UP TRACKING COMPARISON

```
GØØG91
X-2ØØØZ-2ØØØFØ
Z-2ØØ
M62
M74
Z-1Ø58ØØ
M8Ø
Z-142ØØ
M75
M63
Z2ØØ
Z-2ØØØZ2ØØØ
C18ØØØY3Ø5Ø
X2ØØZ-2ØØØ
Z-2ØØ
M62
M74
X1Ø58ØØ
M8Ø
Z142ØØ
M75
M63
Z2ØØ
X2ØØØZ2ØØØ
Z-18ØØØY3Ø5Ø
MØ2
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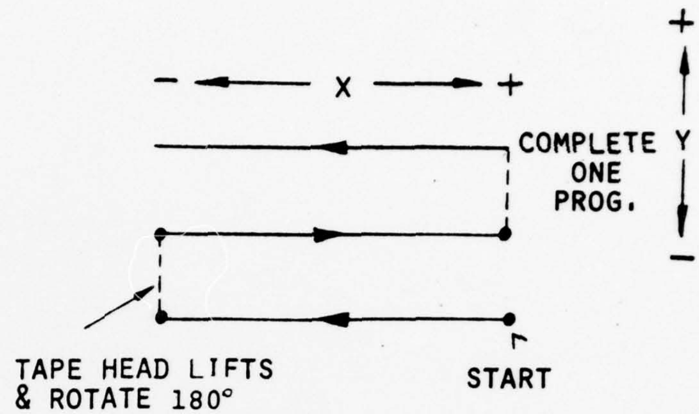

TYPE III ROLLER COMPACTOR

PROGRAM NO. 10

FIGURE 8-88

SECTION 9

CONCLUSIONS

The overall results of the foregoing series of tests conclusively demonstrated the viability of the compactor concepts utilized. In referring to the original tasks defined in Section 2, this project has been successful. The configurations chosen to demonstrate the ATLAS Machine's capabilities were compacted smoothly, with excellent tracking alignment replication.

During the tests, the variables of tape feedrate, compaction pressure, roller hardness, tapehead position, counterbalancing pressures, et al were accounted for and manipulated.

The Type II Compactor (Section 7) did not achieve good linear nor wrapping compaction of cylindrical shapes. However, there are sufficient indications that the use of a softer compactor foot and wider pivot point spacing will improve performance. Furthermore, the inherent ATLAS Machine's non-synchronization of acceleration/deceleration for the 'X' and 'D' axes prevented conclusive testing.

The Type III Compactor (Section 8) produced moderate compaction when free rolling at slow tape feedrates. At higher feedrates, tape and backing separation occurred with ensuing tape creasing. The rolling action also produced a stress footprint in the highly ductile tape material. However, when the roller was locked in a non-rotational position, separation did not occur even at 200 ipm, tracking was excellent, and compaction was smooth. Thus, a sliding roller proved effective.

The Type I Compactor (Section 6) proved to be a consistently excellent compactor for flat surface, spar type transitions from flat to convex, concave at a 45° angle, concave linear, and concave radial layups. Compaction quality and tracking replication were totally acceptable. For cylindrical laying up, minor design changes would bring about smooth compaction, e.g. small steel plates inserted at the tips of the spherical balls in the foot would distribute the compaction load.

Though the Type I Compactor can not properly be labeled a "universal" compactor, it does have an incomparable breadth of applications. The ability of this compactor to meet the complexities of a pass at 40% of the 720 ipm feet rate is outstanding. In general, the Type I Compactor showed a degree of excellence surpassing all known methods of compacting.

The compactor data established by these tests justify continued research. This project has demonstrated the capabilities of particular compactor concept; it remains to apply those concepts to specific manufacturing requirements.

APPENDIX I

INDUSTRY SURVEY

OF

COMPOSITE TAPE LAYING EQUIPMENT

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F. J. Weir

U. S. ARMY AVIATION SYSTEMS COMMAND

CONTRACT - DAAJ01-75-C-0284(P1G)

GOLDSWORTHY ENGINEERING, INC.
2917 W. Lomita Boulevard
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February 1975

TABLE OF CONTENTS

122

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

1. PURPOSE OF THE SURVEY

Early in the history of the use of filamentary composite materials for structural applications it was recognized that the need existed for machine layup of the parts being fabricated. This need was met, primarily, through the "in-house" development of such machinery by the individual companies engaged in the use of composite members. The design of these machines varied across a fairly broad spectrum in accordance with the particular philosophy existant within each organization's composite technology department.

As the usage of composite structures matured, more sophisticated machinery was developed to meet the needs of the intricate shapes being considered for production. This added sophistication, both in the parts being produced and the means of producing them, spotlighting the need for in-depth knowledge of the tape placement characteristics and capabilities of the various machines presently in use. This knowledge, properly disseminated, should provide a basis for future designs wherein the machine capabilities envisioned exceed that currently available. Further, the ability to accurately place and compact the tape beyond current limits should enhance the part internal structural composition with an attendant increase in strength or reduction in material requirements.

Recognizing this need, the United States Army Aviation Systems Command (AVSCOM) issued a Contract [DAAJ01-75-C-0284(P1G)] calling for the development of several compactors adapted to the ATLAS Tape Laying Machine with which to study the effects of laying tape on a variety of representative airframe shapes.

123

2. SURVEY METHODS

Since it is recognized that two viewpoints are better, and more objective than one, a team of two men conversant in the art of tape laying machinery was established. They were given the task of visiting a representative group of aerospace manufacturers and discussing their operating experiences within the realm of composite part fabrication by the use of tape laying machinery.

The results of this effort are presented in this document.

3. SURVEY RESULTS

The initial objective of the survey was to look at the different forms of compacting or placement devices being used in industry. It became increasingly apparent that a more overall view of each company's machine would be necessary in order to fully determine the relative effectiveness of the techniques employed. This is due, in a large part, to the need to set the tape in proper position prior to being applied to the mold surface so that it is correctly placed by the compacting device.

The means of implementing tape placement varies from machines with fixed guidance to those utilizing servo controlled axially shifting mechanisms which cause the tape load to be moved in a direction tending to minimize any generated error in the tape path. The two systems are capable of producing parts of equal quality but the fixed guidance type of machine requires a longer run in which to correct an error since it depends upon the differential tension generated in the tape by the disturbing force to cause the tape to re-align itself and thereby equalize the tensile force across the tape face. As an adjunct to this, the fixed guidance type of machine will usually require greater back tension on the tape payoff reel so as to minimize the effect of the disturbing force initially and to assist in rapid re-alignment of the tape once it has been displaced. It is generally agreed that tape edge guidance is not too successful; therefore, at least one machine utilizes overwidth liner paper having accurately spaced punched holes running on guide sprockets for its tape position control. The system has the capability of producing very accurately spaced layups but is dependant upon the ability of the manufacturer to apply the tape to its liner within the required limits and for the tape to remain in the position initially placed during handling and usage.

The servo controlled method of tape placement has the ability to produce parts to exacting tolerances at the cost of added machine complexity. The actual placement accuracy becomes a function of system responsiveness which, in turn, is dependant upon the amount of tape placement error required to cause the system to respond. An additional factor is the area in which the error is detected. Obviously, the further away from the point of placement that the error is detected the more readily it is shifted to its proper position since the tape is in a relatively free state. Unfortunately, there is no guarantee that the tape has remained where it is thought to be when it reaches the point of placement. In other words any overshift in the tape will not be seen by the sensors.

Systems in which the placement device itself is shifted will probably not be as responsive as the system discussed earlier but, in practice, have shown the capability to maintain the tape position within acceptable limits.

3. SURVEY RESULTS (continued)

Three methods of applying the tape to the mold surface are presently being used:

A. Direct compaction as it is applied to the mold surface by use of a roller having limited compliance to surface curvatures.

B. Indirect compaction by virtue of trailing rollers having limited compliance to surface curvature.

C. Direct compaction by the use of a pad having limited compliance to surface curvatures.

In all but one case, the rollers or pads were capable of variable compaction pressure. The one machine that did not have this feature used the weight of the tape head, which was estimated to be in the neighborhood of 400 pounds, bearing on the tape through a polyurethane coated roller. It was further estimated that the compaction pressure was approximately 50 pounds per square inch.

The degree of compaction being used varies from a low of 5 psi to a high of 50 psi although at least one machine has the capability of exerting a compaction pressure as high as 200 psi. It appears, from tests performed on the effect of compaction pressure, that compaction pressure in the range of 50 psi in conjunction with a low pressure oven cure (13 - 15 psi) can produce parts having physical values equivalent to parts that have been cured in an autoclave under 50 psi pressure.

Low compaction pressure tests were run by one company using hand laid specimens as the control articles. The tests were run at 3, 6, 10 and 15 ply laminations using 5 and 10 psi compaction.

3. SURVEY RESULTS (continued)

Specimens were divided into three groups, one-third being press cured, one-third being autoclave cured and the last group were vacuum bag/oven cured. The results indicated that the autoclave cure provided slightly higher physical characteristics as a group but there was no appreciable difference among the specimens within that group.

The results of this survey are best presented in tabular form so that a concise picture can be shown of the activity taking place within the aerospace industry. It must be emphasized that there is no attempt to delineate the capability of each machine. Rather, the tables indicate the type of parts being fabricated along with details of the methods used at this time.

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

COMPANY: Boeing Vertol   Date: 2/75

Types of parts being fabricated using tape placement lay-ups.	Helicopter Blade Parts
Materials used	Glass
Backing paper	Green Patapar type
Layup techniques used	Multi-ply lay-ups on flat and contoured parts.
Gaps/overlaps Tolerances allowable	.05" Gap - No cumulative overlaps
Machine Type	6 Axis motion plus shear angle - full N/C control in contouring mode.
Placement/ Compaction System	Teflon coated fixed and flexing shoe.
Compaction Pressure	Variable air cylinder pressure
Other	

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

COMPANY: General Dynamics Date: 2/75

Types of parts being fabricated using tape placement lay-ups.	Wing Panels Stabilizer Parts.
Materials used	Graphite mostly Boron and Glass
Backing paper	4" wide with sprocket holes.
Layup techniques used	Lay-up on FLAT MYLAR. 2, 4, 6, 8, 10 or more ply lay-ups according to amount of drape required.
Gaps/overlaps Tolerances allowable	Graphite .100" gaps allowable
Machine Type	4 Axis motion and shear angle Numerically Controlled
Placement/ Compaction System	4" diameter hard rubber coated (70 - 80 Durometer)
Compaction Pressure	Not controllable. Weight of head applies pressure. Varies with weight of spool.
Other	

129

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

COMPANY: Grumman Aircraft Date: 2/75

Types of parts being fabricated using tape placement lay-ups.	Stabilizer Skins Fuselage Sections - Closure Doors
Materials used	Large percentage 3" wide Boron also Graphite
Backing paper	Green Patapar type
Layup techniques used	Lay-up on flat mylar held on lighted table. Photocell edge sensing system guides tape head for true path alignment.
Gaps/overlaps Tolerances allowable	Boron .06" gap. No overlap. Graphite .06" gap some overlap.
Machine Type	Two Axis motion. HEAD turn around for opposite direction layup. Mylar work sheet indexing.
Placement/ Compaction System	Two 3" diameter rollers. Urethane coated 60 Dur. Rollers on free float mounts ensuring even contact.
Compaction Pressure	Air cylinder pressure regulated.
Other	

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

COMPANY: LTV **Date:** 2/75

Types of parts being fabricated using tape placement lay-ups.	Wing Panels
Materials used	Graphite - Boron 3" wide tapes
Backing paper	Special with reinforcing. 3" wide net width. Also capable of using 3-1/2" wide paper.
Layup techniques used	5 Axis motion capable of multi-ply lay-up with fiber orientation in all directions.
Gaps/overlaps Tolerances allowable	Graphite .05 gaps overlaps allowed.
Machine Type	N/C controlled with a number of additional NDT and gauging systems.
Placement/ Compaction System	5" diameter placement roller. Urethane coating .35" thick. 60 - 70 durometer
Compaction Pressure	Air cylinder control of "Z" axis counterbalance.
Other	

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

COMPANY: Lockheed Date: 2/75

Types of parts being fabricated using tape placement lay-ups.	Small Panels
Materials used	Graphite
Backing paper	Green Patapar type
Layup techniques used	Multi-ply. Fibers can be oriented in 15° increments.
Gaps/overlaps Tolerances allowable	None specified
Machine Type	4 Axis motion. 2 Axis N/C contour control.
Placement/ Compaction System	8" diameter inflatable hard tread tire.
Compaction Pressure	Variable. Using air cylinder control. Also roller pressure variable.
Other	

132

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

COMPANY: Northrup Date: 2/75

Types of parts being fabricated using tape placement lay-ups.	None at present.
Materials used	Graphite.
Backing paper	Manufacturers standard.
Layup techniques used	Tape dispensing head used as assist for manual lay-up. On flat surface. Drape forming.
Gaps/overlaps Tolerances allowable	.05" Gaps
Machine Type	Tape Dispensing Head. Hand operated.
Placement/ Compaction System	Hand compacted. Vacuum Bag compaction where needed.
Compaction Pressure	Not applicable.
Other	

INDUSTRY SURVEY OF TAPE LAYING EQUIPMENT

COMPANY: Rockwell International Date: 2/75

Types of parts being fabricated using tape placement lay-ups.	Experimental Parts.
Materials used	Graphite.
Backing paper	Green Patapar
Layup techniques used	Multi-ply layups on flat parts: Fibers can be oriented in 45° increments.
Gaps/overlaps Tolerances allowable	.06" Gaps - Minimum overlaps.
Machine Type	Two Axis motion - Head turnaround for opposite direction layup - rotating work table (45° indexing)
Placement/ Compaction System	Teflon coated fixed shoe.
Compaction Pressure	Not controllable Weight of head applies pressure.
Other	

4. CONCLUSIONS

The majority of parts being fabricated on Tape Placement machinery today fall into the category of aircraft skin type components. In some instances the parts are being laid to the final contours, particularly in the area of wing and tail plane members, but there is a growing acceptance of the viability of laying the parts in the flat and drape forming them to attain the final configuration. It is particularly interesting to note that the manufacturing methods employed by the individual airframe manufacturers varies across a wide spectrum, ranging from single ply layup to numerically large ply buildups, in some instances exceeding one hundred plies of material. To some extent this is governed by the part configuration, the type of service it performs and manufacturing economics but primarily it seems to indicate the degree of acceptance, or confidence level in composite structures. Several companies want formal inspection of each ply prior to final lamination, while others will require the machine operator to provide primary inspection with quality assurance by non-destructive inspection methods of the cured part.

It was noted that gaps between adjacent tape strips on the order of .060 inches seems to be generally quite acceptable in flightworthy parts. It was reported that one company felt a gap of .100 inches would be acceptable on composite parts being designed for a fighter type aircraft entering production. The concern about overlapping still exists when Boron/epoxy tapes are being used but the concensus of opinion indicates that overlaps not exceeding .060 inches in Graphite or Fiberglass materials is acceptable. This is due to the ease with which the fibers can shift during the curing operation so that it is virtually impossible to locate these faults in the cured parts.

4. CONCLUSIONS (continued)

There is evidence of the value of compaction pressures in the range of 40 to 50 psi. As stated earlier, tests using low pressure compaction showed no significant gain over hand layup techniques. This leads one to believe that a man using a squeegee or roller compactor probably exerts forces equivalent to the 5 - 10 psi compaction pressures noted. The test data summarized in Technical Report AFML-TR-73-307 section 5.4.5 clearly defines the gains to be made through the use of the higher compaction pressures, both in densifying the laminate and the possible use of a simpler curing operation.

There is a limit to the amount of pressure that can be exerted through a rolling element type of compactor, particularly if it is desired to have a compliant covering surrounding a metallic hub. It follows then, that a pad type of compacting device would provide a means of exerting higher pressures and, depending on the type of material used, be able to provide some compliance to changes in surface condition. Experiments with teflon covered pads capable of being forced to follow the surface contour have shown some promise. This area of compactor design will be pursued to the fullest under the AVSCOM Contract. It is expected that techniques will be developed that will enhance the automatic production of parts having compound curvatures as well as parts which are spar-like in construction.