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MSFC EVALUATION OF THE SPACE FABRICATION DEMONSTRATION SYSTEM (BEAM BUILDER)

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16. ABSTRACT

The Grumman/MSFC beam builder, designed and manufactured as a ground demonstration model, is a precursor to a machine for use in the space environment, transportable by the Space Shuttle. The ultimate purpose is to provide the capability to automatically fabricate triangular truss beams in low Earth orbit with a highly reliable machine that requires a minimum of in-space maintenance and repair. This report provides a performance assessment of the beam builder, which was fabricated under contract NAS8-32472 from commercial hardware.

17. KEY WORDS

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SUMMARY

The Space Fabrication Demonstration System, generally termed the beam builder, was designed and built by the Grumman Aerospace Corporation under NASA Contract No. NAS8-32472. This machine is a prototype and is for ground demonstration purposes. The beam builder automatically fabricates triangular truss beams of 2024-T3 aluminum alloy up to 300 m (984 ft) long with a weight of 1.265 kg/m (0.85 lb/ft). For demonstration and testing purposes, beams of 1, 2, 4, 6, 7, 10, 11 and 12 bays have been built. To date 508 bays (2500 ft) of aluminum triangular truss beam have been fabricated. Each bay is 1.5 m (59.055 in.) long. The ground demonstration model has proven the concept and feasibility of this method of automatic beam fabrication. Additional development will be required for a flight model of this machine.

INTRODUCTION

The Space Shuttle will be the key element in American Space activities during the remainder of this century. The Shuttle presents numerous opportunities, as well as an exciting challenge to advance the frontiers of technology and improve the quality of life for all mankind. In the thinking and discussion stage are giant solar collectors, communication platforms and space manufacturing facilities. All these ideas require extensive structural elements. There is an economic crossover based on size and the current state of technology, where it is more economical to manufacture structural elements, components and subassemblies in space than on Earth and transport to space. In this case, the requirements are to have a fabrication facility in orbit and transport preprocessed raw materials from Earth.

With this concept in mind the Space Fabrication Demonstration System (Beam Builder) was designed and manufactured (Figs. 1, 2, and 3). This machine is a ground demonstration model to prove the feasibility of automatically fabricating 2024-T3 aluminum 1 m deep triangular truss beams of lengths up to 300 m (984 ft). Longer beams could be fabricated in space by resupplying the machine with additional material.

The beam builder is 4.26 by 3.35 by 2.74 m (14 by 11 by 9 ft) and weighs 9979 kg (22,000 lb). The flight version will be considerably lighter and will utilize flight rated components of higher reliability than the "off-the-shelf" systems currently used in the ground demonstration model.

The ground demonstration model has successfully fabricated beams of up to 12 bays. Each bay is 1.5 m (59.055 in.) long. The machine automatically rolls the flat coil stock to a triangular cap section and spot welds the cross members to form the truss beam (Figs. 4, 5, and 6).

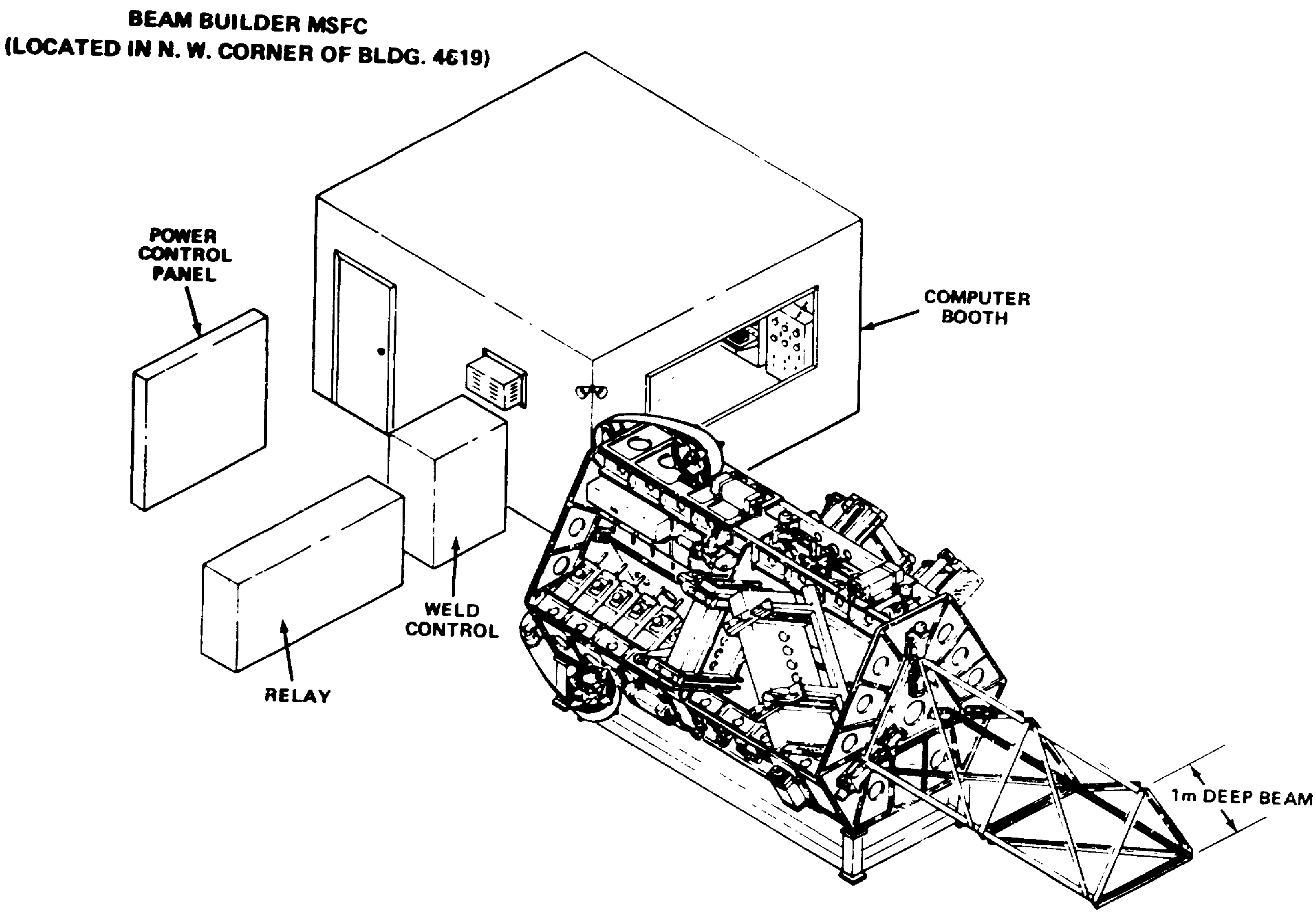

Figure 1. Space Fabrication Demonstration System.

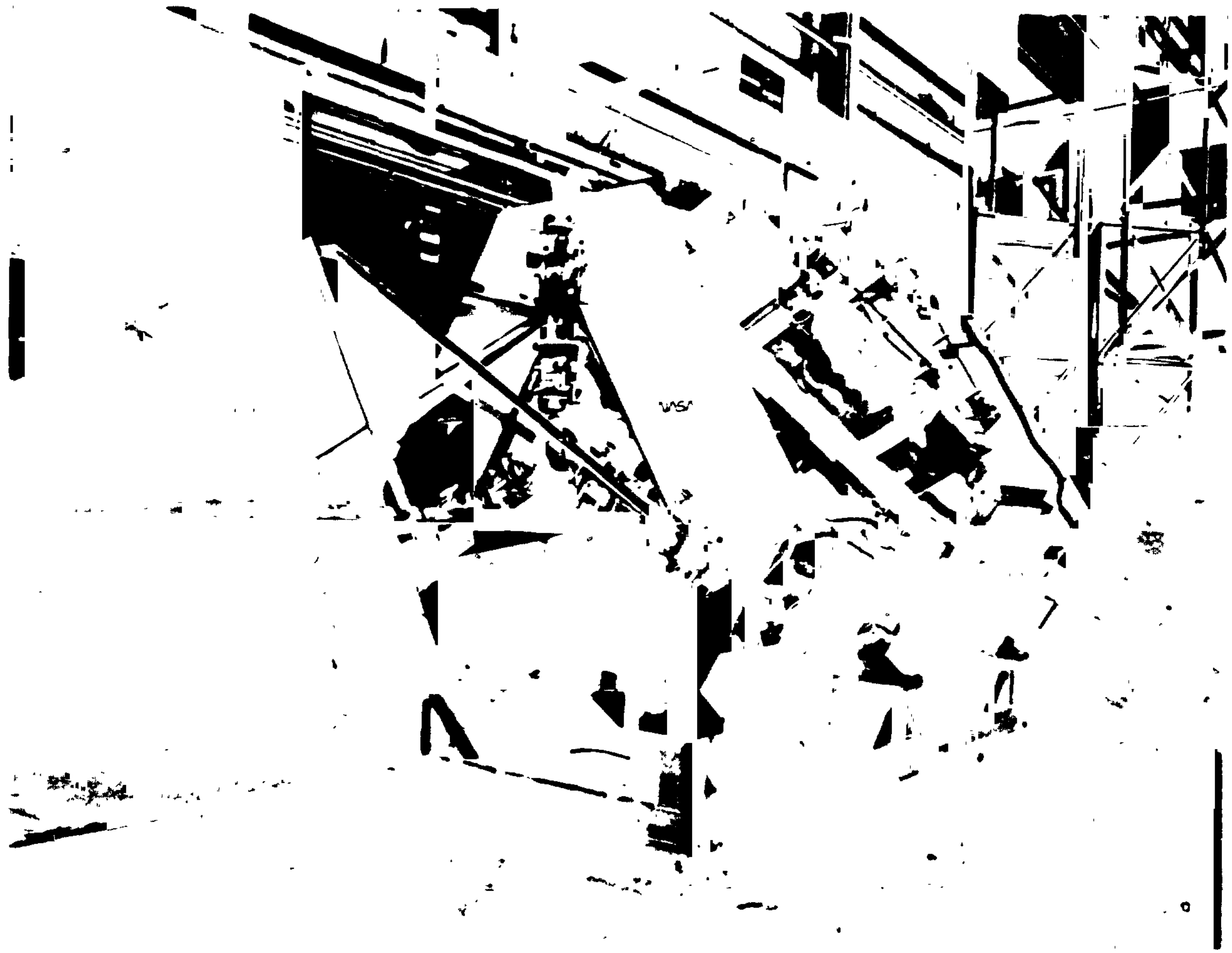

Figure 2. Space Fabrication Demonstration System (front view).

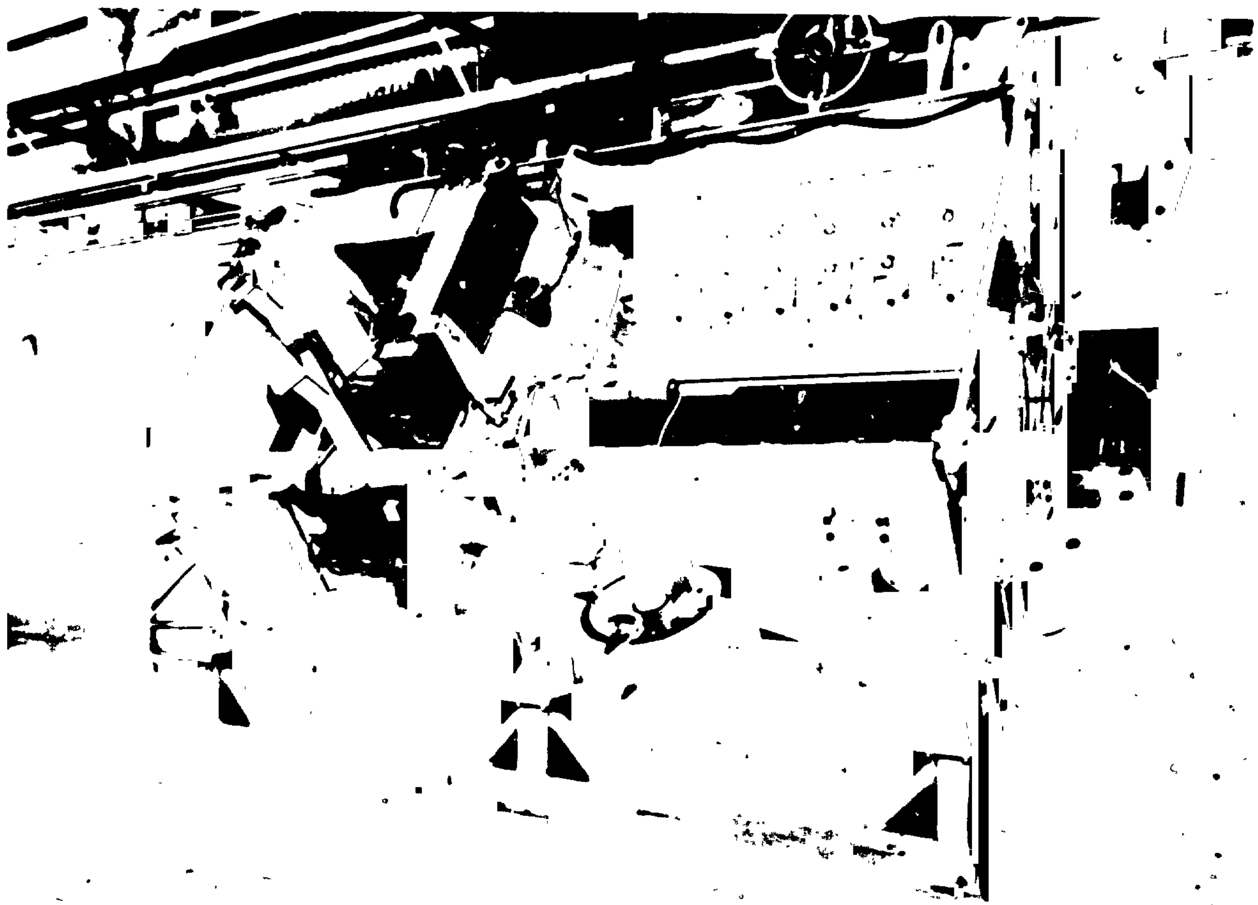

Figure 3. Space Fabrication Demonstration System (left view).

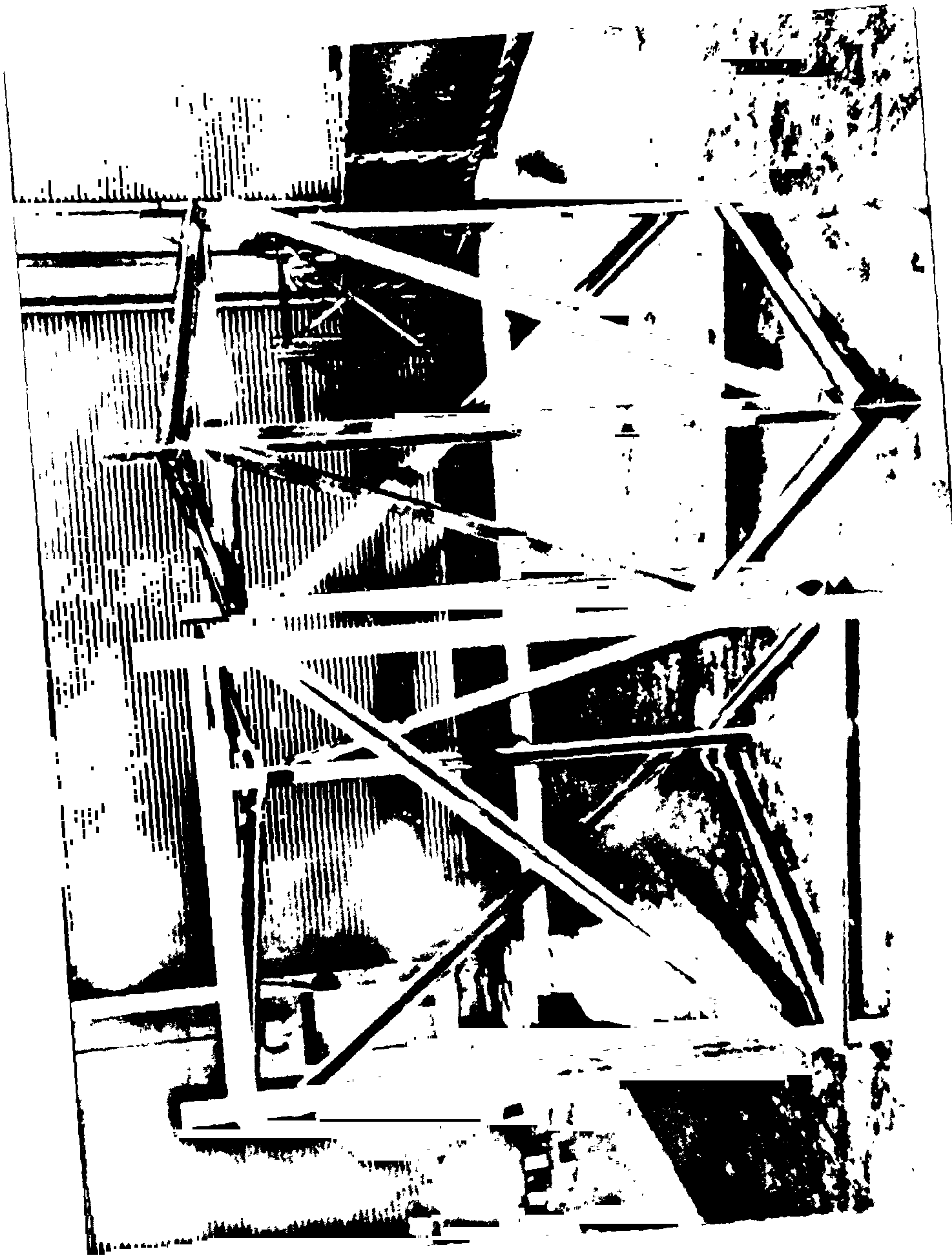

Figure 4. Beams of 1 bay length.

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Figure 5. Beams of different lengths automatically fabricated by the beam builder.

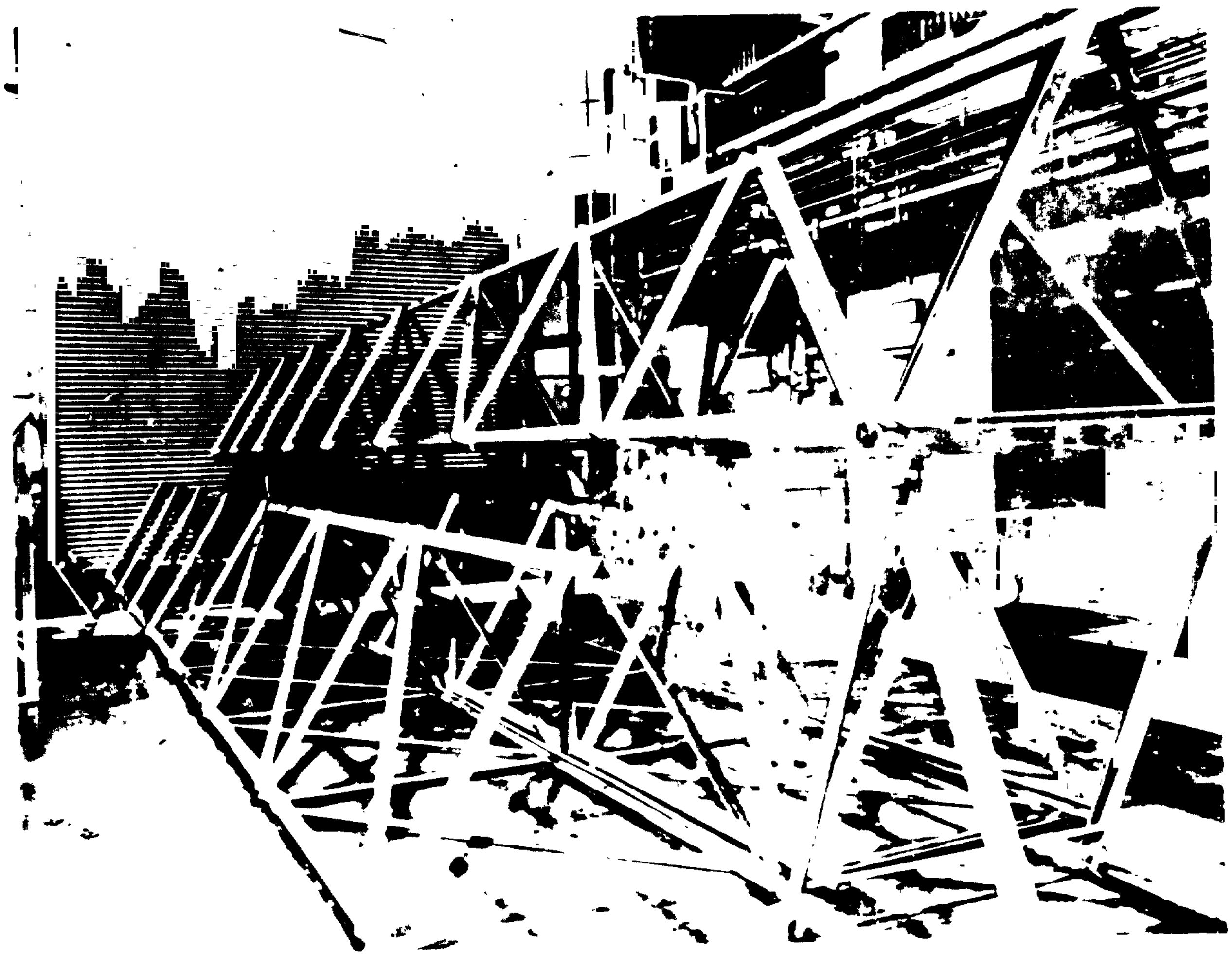

Figure 6. Beams of different lengths automatically fabricated by the beam builder.

DEVELOPMENT

The 1 m deep aluminum truss structure design evolved from structural work that had been done in earlier programs. This particular design had previously been developed for a photovoltaic solar power system thermo/structural study made by Grumman. It was recommended for the solar array and the microwave antenna. The design was visualized as a primary building block from which the required structure could be fabricated by using appropriate end fittings to join the truss beams.

Beams of this design have been structurally tested with good results. Grumman hand-assembled a 4-bay beam and potted the end members with Hysol compound (to stabilize the ends and prevent local cap failure during loading). A compressive load was applied, and the beam failed at 6703 N (1507 lb) or 116 percent of design ultimate. A machine fabricated beam was also tested under the same conditions and failed at 6111 N (1374 lb) or 106 percent of design ultimate load.

The beam builder was designed to automatically fabricate this 1 m deep aluminum truss beam. For the ground demonstration model, no new technology was required. Off-the-shelf components and systems were utilized to demonstrate the feasibility of this concept. This approach represented a considerable saving in cost and schedule time. A flight model will require system upgrading to use flight rated motors, switches, computer, etc,. Additionally, effort was not expended to arrive at the minimum weight design, although it was realized that considerable weight could be removed from a "for flight model" of the beam builder.

Final acceptance of the ground demonstration beam builder was at the Grumman Corporation by representatives of the Marshall Space Flight Center (MSFC) and NASA Headquarters. During this acceptance/machine demonstration, a 4-bay beam and a 10-bay beam were automatically fabricated. The beams were visually inspected and were of acceptable quality. The beams were visually straight and the spot welds were of good appearance. One cap section did contain slight wrinkles, attributed to improper adjustment of one rolling mill. Although these wrinkles were determined not to be structurally degrading, they did represent an undesirable appearance factor.

Because of this cap member wrinkle, it was decided to remove the offending rolling mill for rework. The beam builder was delivered to MSFC without this rolling mill, which had been returned to the vendor. All tooling for forming the braces and slitting and indexing the coils remained at Grumman.

CAP FORMING MILL (YODER ROLLS) LUBRICATION

The Yoder Corporation determined that a lack of lubrication and misalignment had caused one of the cap forming mill gears to be badly worn. Consequently, the other Yoder rolls (top and left) on the beam builder were inspected, and brass chips were also found. MSFC had intended to run these mills using Everlube 620, a space-rated lubricant, to replace the lubricant normally specified by the Yoder Corporation. It was believed that, because of the relatively low speed of the beam builder, the lubricant recommended by MSFC would be sufficient. However, after the discovery of the brass chips, the two Yoder rolls on the beam builder were lubricated with Molykote "G", as well as the moving gear parts for the "pancake" motors. The right Yoder mill at

Cleveland was lubricated with a graphite lubricant, but this was later changed to Molykote "G." To date, MSFC has experienced no further lubrication problems using Molykote "G" on the beam builder. However, it should be pointed out that Molykote "G" is not currently approved for space use in this application.

BEAM BUILDER SYSTEM DESCRIPTION

The beam builder is designed into a series of systems which can function indepen dently from each other.

Power Supply System

This system is composed of five main circuit breaker switches to supply and control the power for:

1) The control system (208 V, three phase, 20 A)

2) Motor control (208 V, three phase, 20 A)

3) Servomotor drives (208 V, three phase, 20 A)

4) Sciaky weld control (220 V, single phase, 30 A)

5) Spotwelding (220 V, single phase, 100 A).

Control System

This system (Fig. 7) controls and monitors all the other systems of the beam builder in the automatic or manual mode through its PDP-8A computer. The automatic mode provides complete system control for the automatic truss beam fabrication. This automatic truss beam fabrication can be altered momentarily if a minor problem occurs, such as braces not being dispensed properly. If the problem is of greater magnitude, such as weld block expulsion, the beam builder can be shut off completely by pressing the Emergency Stop Switch. The manual mode is utilized to provide auxiliary functions, such as loading spools, cut off excess cap material, maintain and set up he beam builder, etc. The teletype for this system provides useful information on malfunctions in other systems.

The Control System contains three separate sections: upper, middle, and lower. They have the switches and controls for:

1) AC power control

2) Weld control actuator and feed back signals

3) Material measurements

4) Rolling mills drive system

5) Welding system

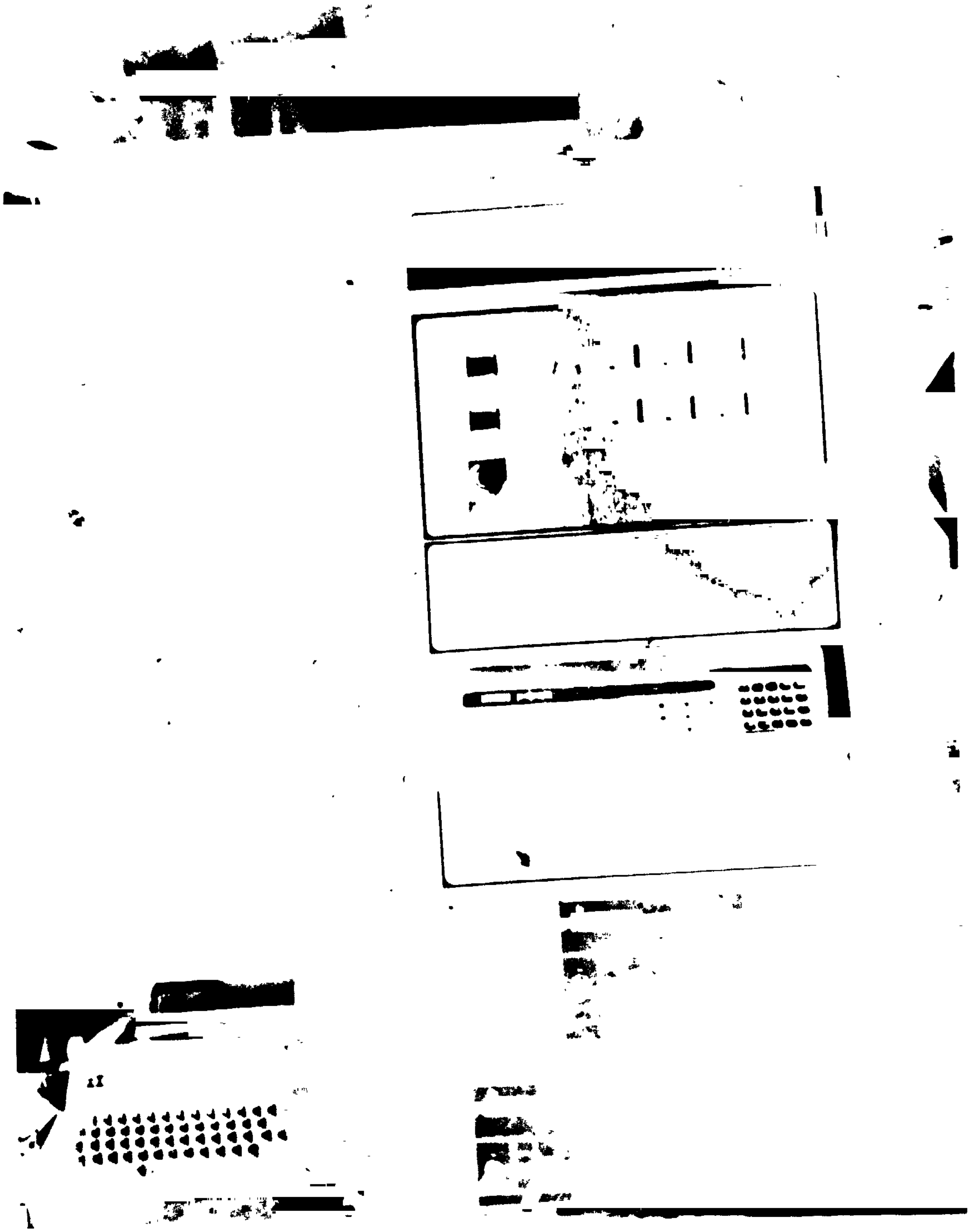

Figure 7. Control system.

6) System executive software

7) Rolling mills mainline software

8) Fastening cycle executive software

9) Parts programming

10) Interrupt service software

11) Shear actuator

12) Assembly mode software

13) Roll-all software

14) Single cycle software

15) Binary loader program

16) System operating program tapes.

Spool Storage System

The beam builder has three spools (two on each side and one on top). In these spools (Fig. 8), the aluminum alloy 2024-T3 for the fabrication of the cap members is stored. This flat material is prepared in coils of 16.2 cm. (6.375 in.) wide, 0.04 cm (0.016 in.) thick, and up to 300 m (984 ft.) long. It is precleaned to remove any oil or foreign matter which could cause a failure in the spot welding. Slots of 0.317 cm. (0.125 in.) wide are stamped in the material every 1.5 m (59.055 in.) for synchronization of the Rolling Mills System.

Feed Guide System

Three sets of five rollers (Fig. 9) constitute the feed guide system. This system dispenses and guides the aluminum flat material into the Rolling Mills System. The alignment of the guiding rolls is important for the fabrication of the cap members.

Rolling Mills System

This system is composed of three rolling mill assemblies. Each assembly consists of a set of seven forming rolls or stations and its respective servodrive motor (Fig. 10). Each assembly can be operated independently from each other through the manual mode of the Control System. The three assemblies are synchronized through their respective electro-optical slot detector sensor. The alignment and synchronization of the forming mills have to be correct for the automatic fabrication of the triangular truss beams.

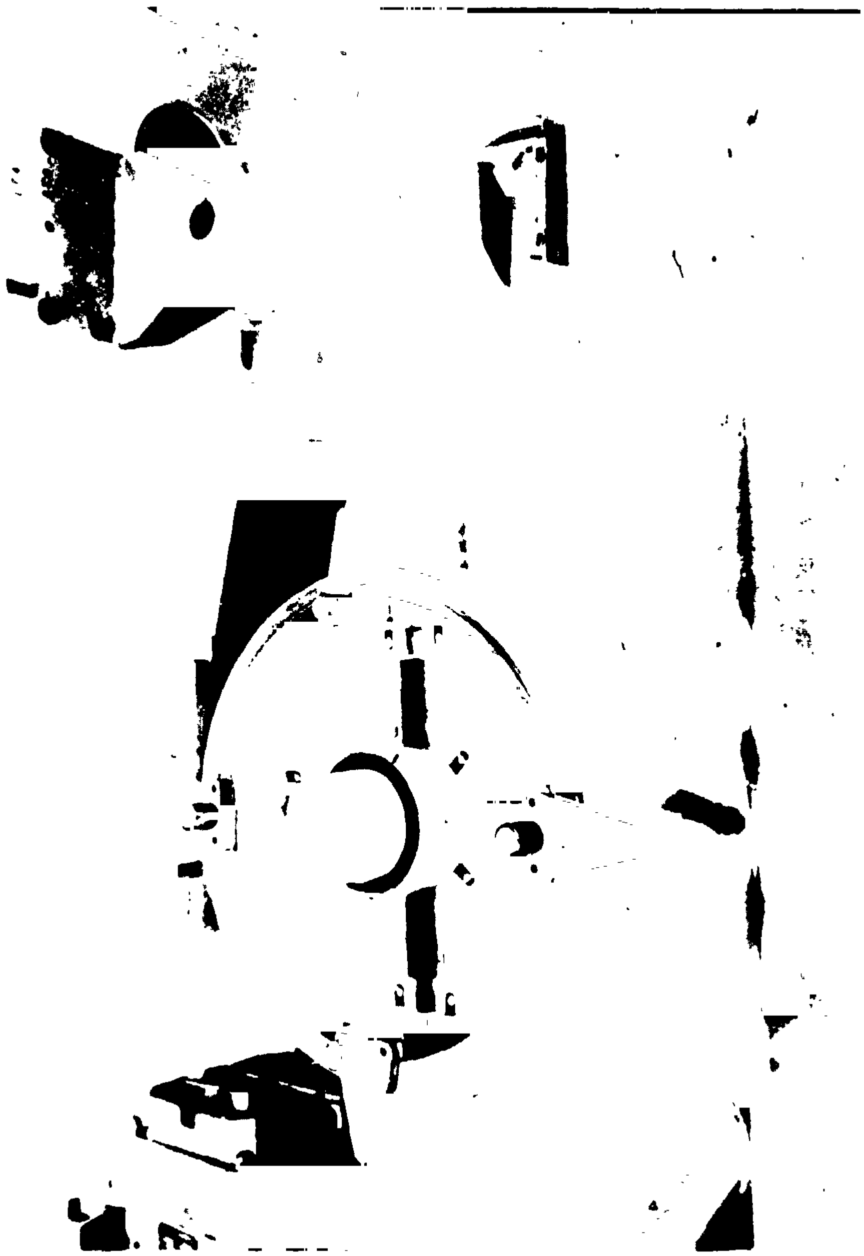

Figure 8. Storage spool.

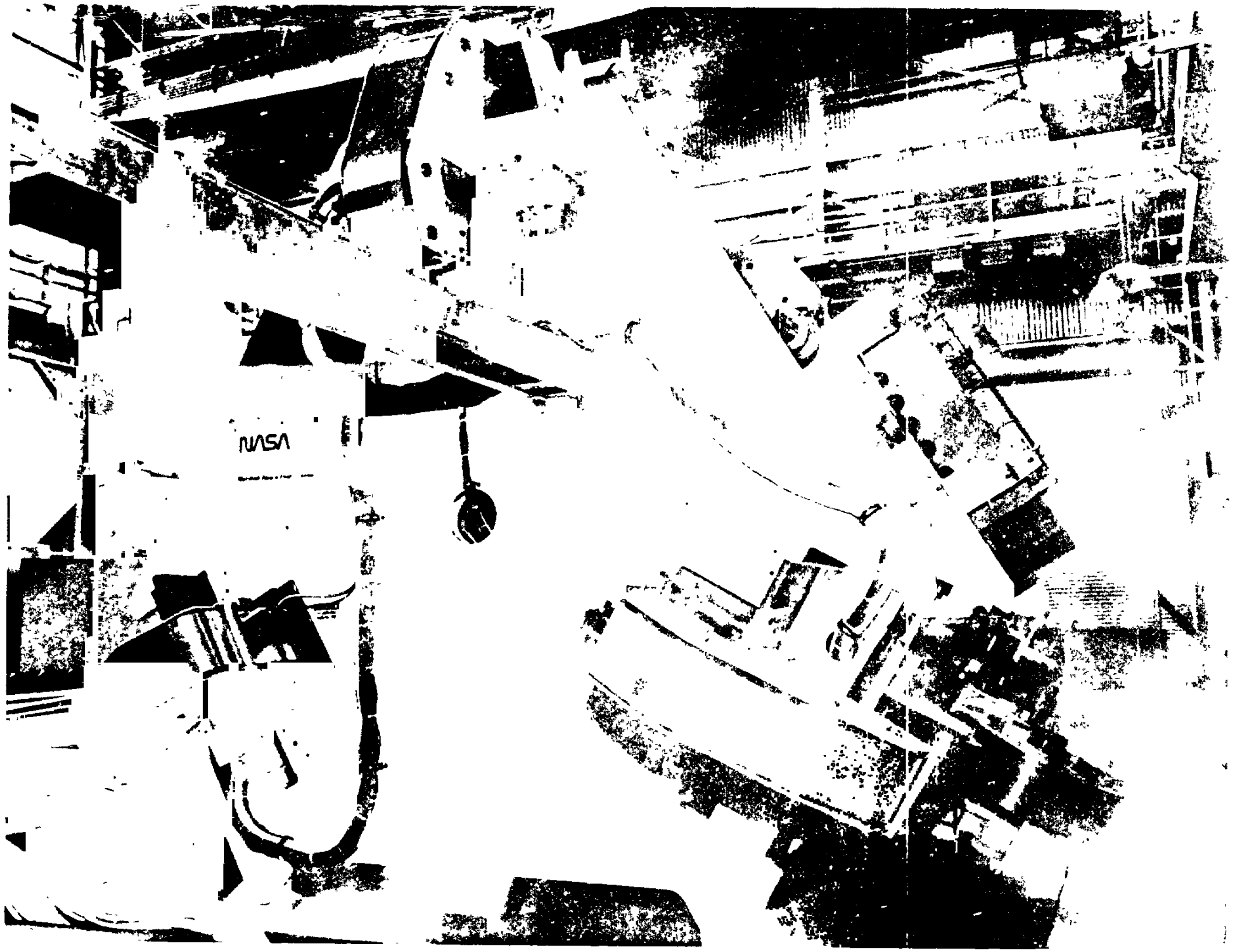

Figure 9. Feed guide system.

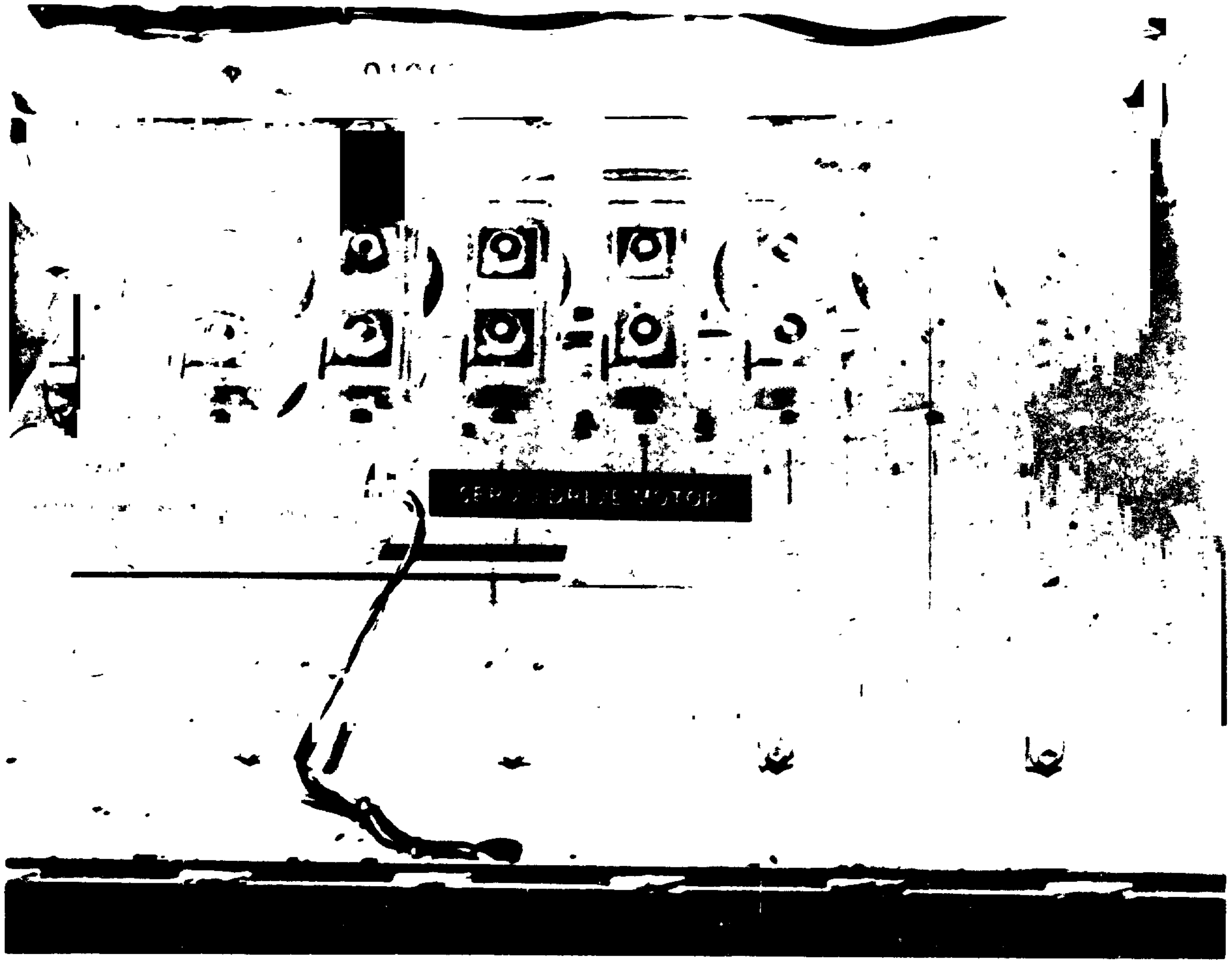

Figure 10. Roll forming mills.

Brace Storage System

This system consists of six brace magazines (three vertical and diagonal, Fig. 11) which store and dispense the braces. Each magazine has two brackets on which the braces are placed (Fig. 12). The four helices on each magazine select and dispense the braces. The helices are driven by a single pancake motor. After the magazines are loaded with braces, the brace brackets press the stack of braces against the upper portion of the single-turn helices of the magazines. The helices are rotated 360 degrees with the leading edge of each helix acting as a selector to dispense the first upper brace.

Carriage System

This system consists of six carriage mechanisms (one for each magazine of the storage system). Each carriage mechanism has two selector fingers (Fig. 13). The selector fingers are rotated 90 degrees to be in position over their respective brace magazine. The function of the selector fingers is to seize the brace that the helices of its respective brace magazine will dispense. The braces, which will be translated and placed over their respective cap member, are maintained in position by a scissor-type mechanism for the spot welding.

Spot Welding System

This system consists of 72 electrode copper weld tips (Fig. 14), six electrode copper weld blocks, six transformers, and one Sciaky weld controller. Of the 72 weld tips, 36 are used to spot weld the vertical braces, and 36 to spot weld the diagonal braces. Of the six weld blocks, three are used to spot weld the vertical braces and one end of the diagonal braces. The other three are used to spot weld the other ends of the diagonal braces. It is important to maintain constantly their proper alignment in relation to the center line of the beam builder. If misaligned, they can create a weld block expulsion during the spot welding of the braces to the cap member. The Sciaky Weld Controller (Fig. 15) controls the amount of heat needed for the spot welding of the braces. The beam builder usually is operated at 84 percent for the vertical braces and 87 percent for the diagonal braces.

Shear Cut-Off System

The Shear Cut-Off System is designed to automatically cut off the triangular truss beam after the fabrication cycle has been completed. This system consists of three separate shear cutoff mechanisms (Fig. 16). Each mechanism (Fig. 17) consists of an inner die assembly, an outer die assembly and their respective pancake-type drive motor. The three cutoff mechanisms are designed to operate independently and synchronously through manual and automatic modes. When the triangular truss beam is cut, the aluminum chip will fall into the chip collector compartment.

BEAM BUILDER PREPARATION AND OPERATION

Before the fabrication of the triangular truss beams, special emphasis is given to the preparation of the beam builder for its operation. For example, the storage spools must contain enough flat aluminum material. The remaining length of this material in the spools can be determined by measuring the thickness of the coils, Table 1. If

Figure 11. Vertical and diagonal brace magazines.

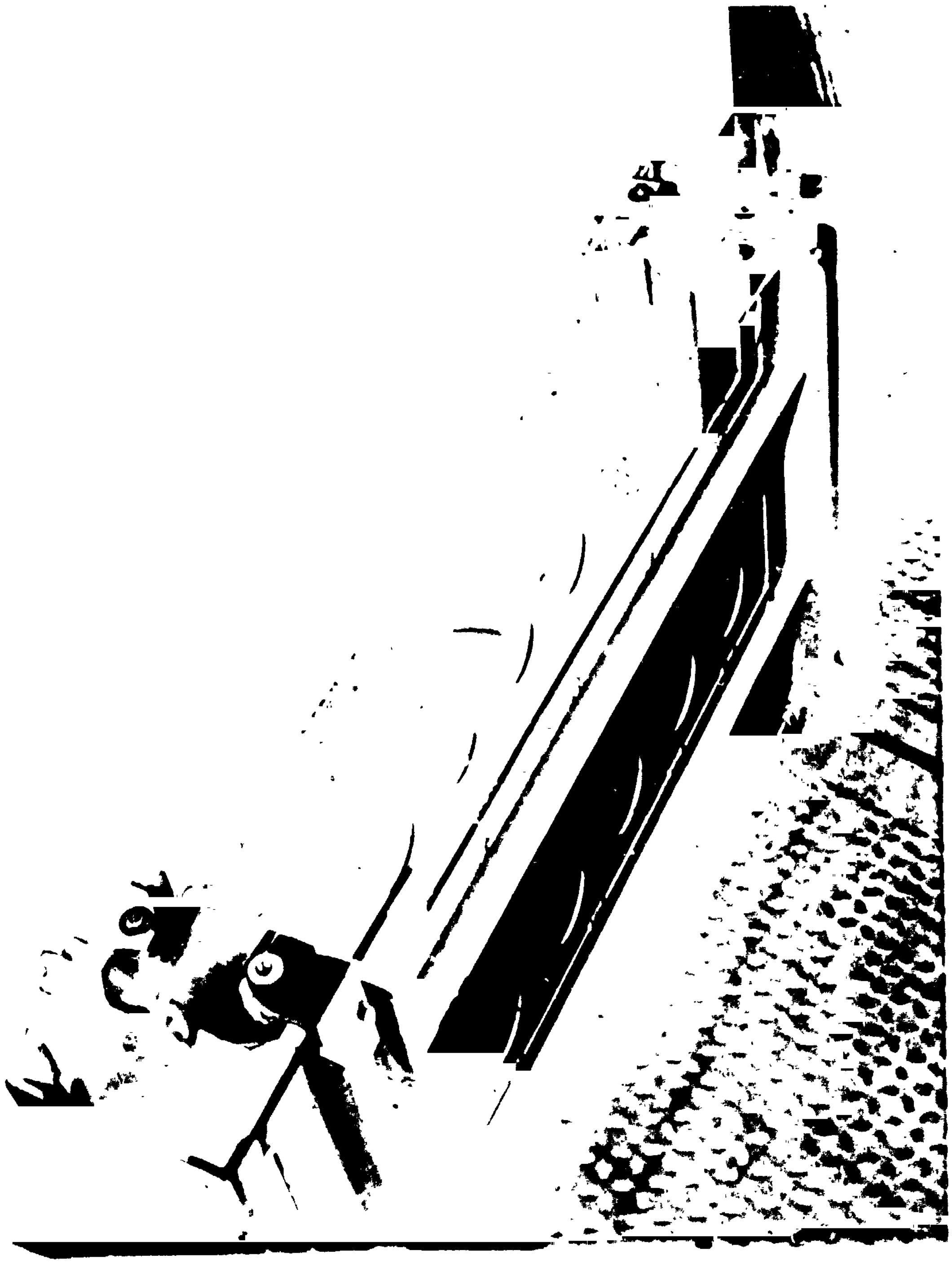

Figure 12. Brace magazine.

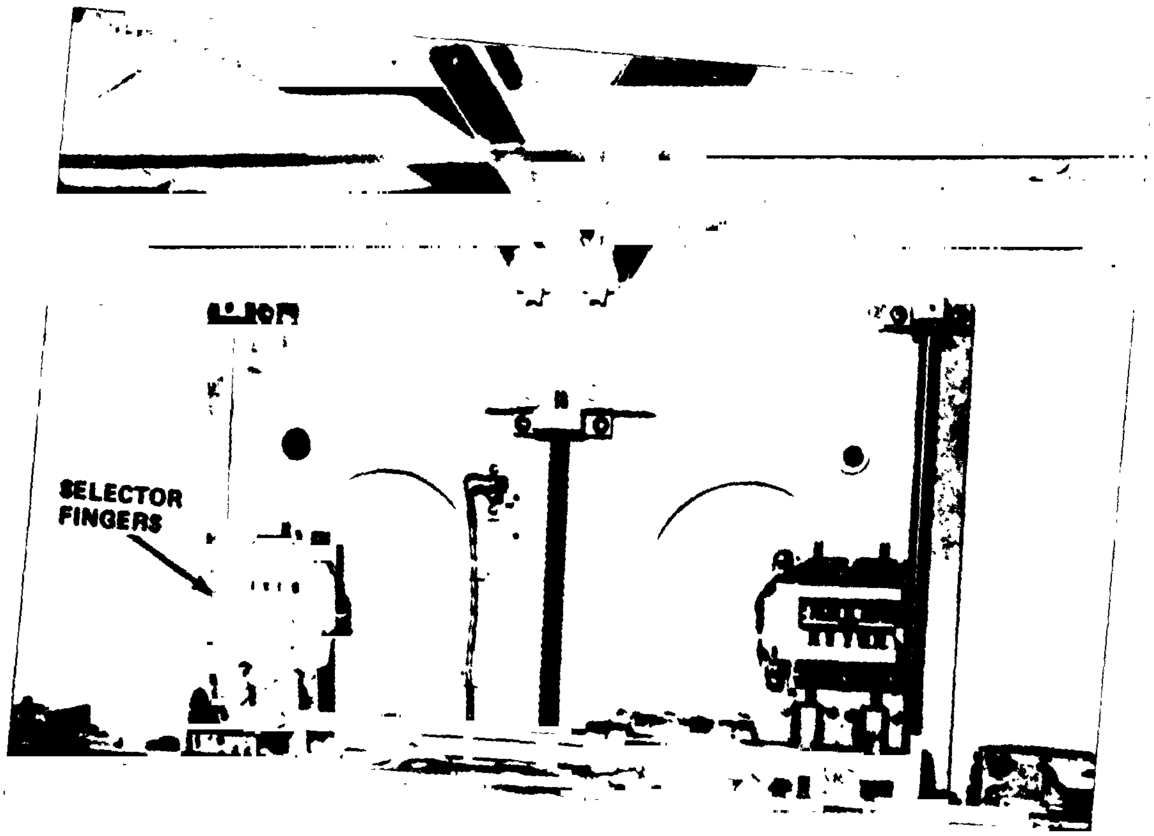

Figure 13. Brace carriage mechanism.

Figure 14. Electrode weld tips.

Figure 15. Sciaky weld controller.

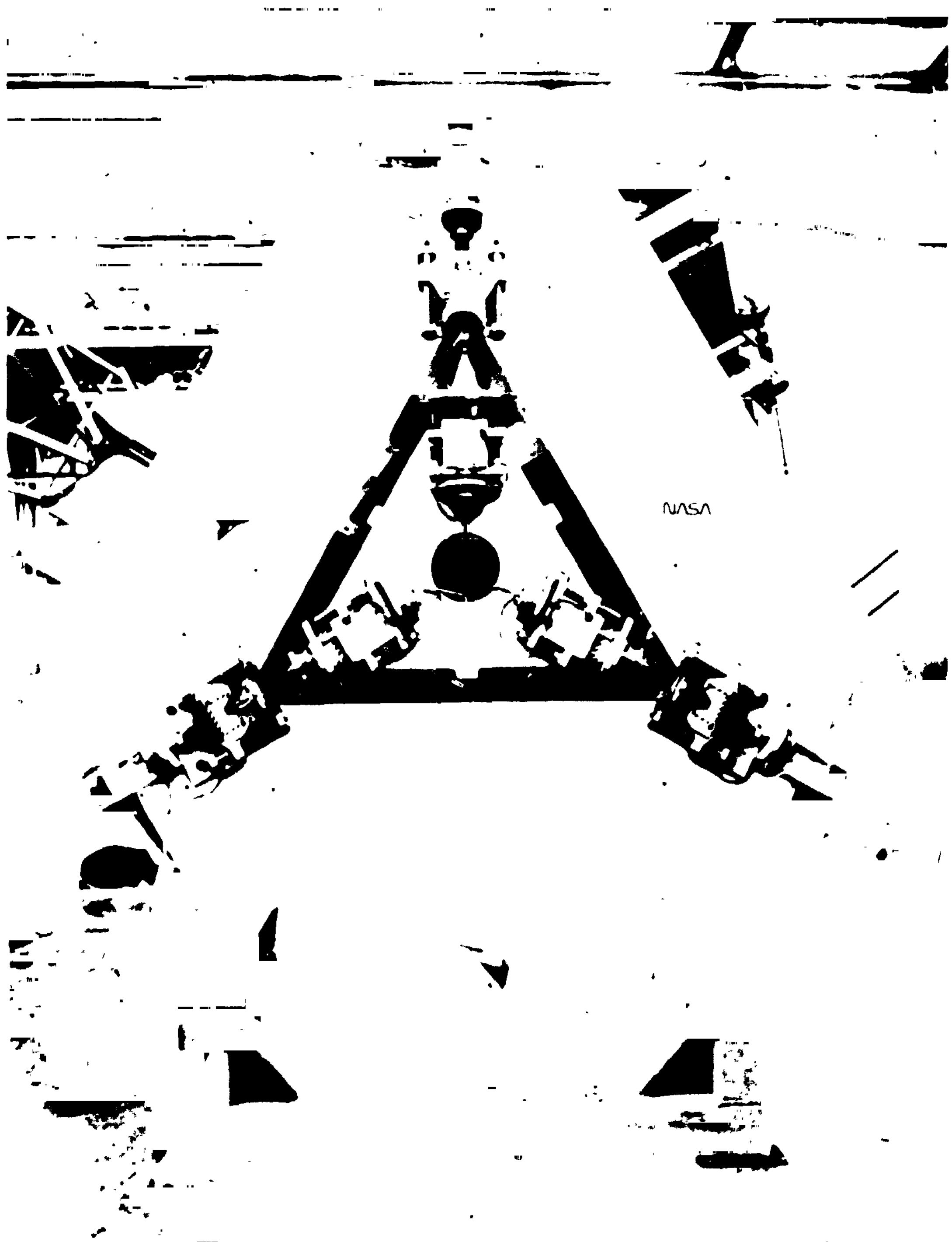

Figure 16. Shear cut-off mechanisms.

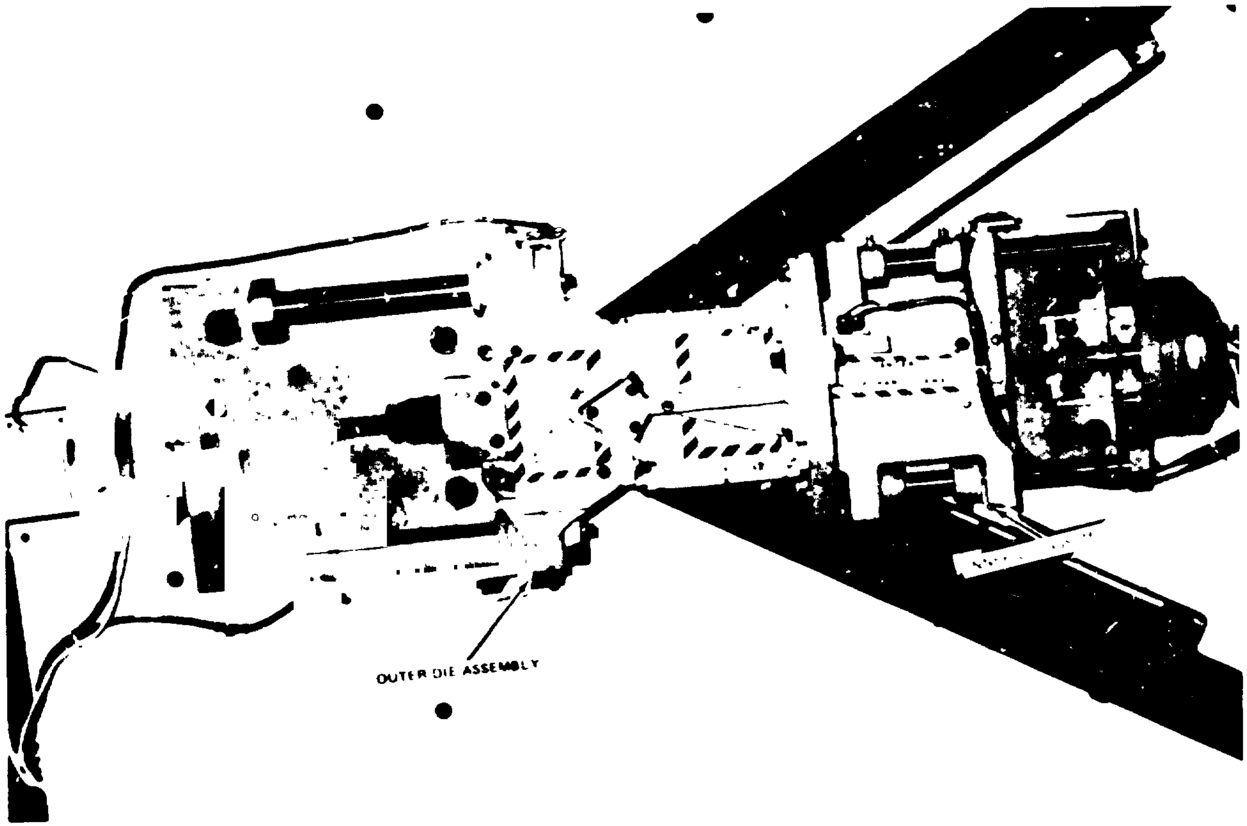

Figure 17. Inner die and outer die assemblies.

more flat material is needed, the spool must be reloaded with another coil of material. After depositing the coil of material in the spool, the end of the material must be cut in an arrowhead shape, and carefully guided into its respective forming mills. The servodrive motor of these forming mills is activated through the manual mode of the Control System. Its speed can be increased or decreased for faster synchronization of the forming mills.

TABLE 1. MATERIAL IN SPOOL

Coil Thickness (In.)	Feet Remaining (In Spool)
3.00	500
2.75	445
2.50	415
2.25	375
2.00	330
1.75	290
1.50	250
1.25	205
1.00	165
0.75	125
0.50	80
0.25	40
0	0

Before depositing the vertical and diagonal braces into their respective brace magazines, their ends must be cleaned. Wire brushes and isopropyl alcohol are used to remove the aluminum oxide (Al_2O_3) and other particles to avoid failure in the spot welding. Braces must not be loaded without the stacking spacers (Fig. 13). Without them, the braces cannot be dispensed by the helices because the selector fingers of the Carriage System cannot seize and translate the braces to the cap member for spot welding. The number of braces in each magazine determines the number of bays that can be fabricated, Table 2. During loading, the selector fingers must be in their respective home position. To acquire this position, the manual mode of the Control System is used.

The 72 copper weld tips must be also cleaned. Melted aluminum can deposit on these electrodes during the spot welding. To remove the melted aluminum from them, sandpaper and an electrical eraser are used carefully to clean and maintain the tolerance of the weld tips. If their tolerance is altered, weld block expulsion may occur.

*From Space Fabrication Demonstration System (SFDS), Volume 1, p. 2-14.

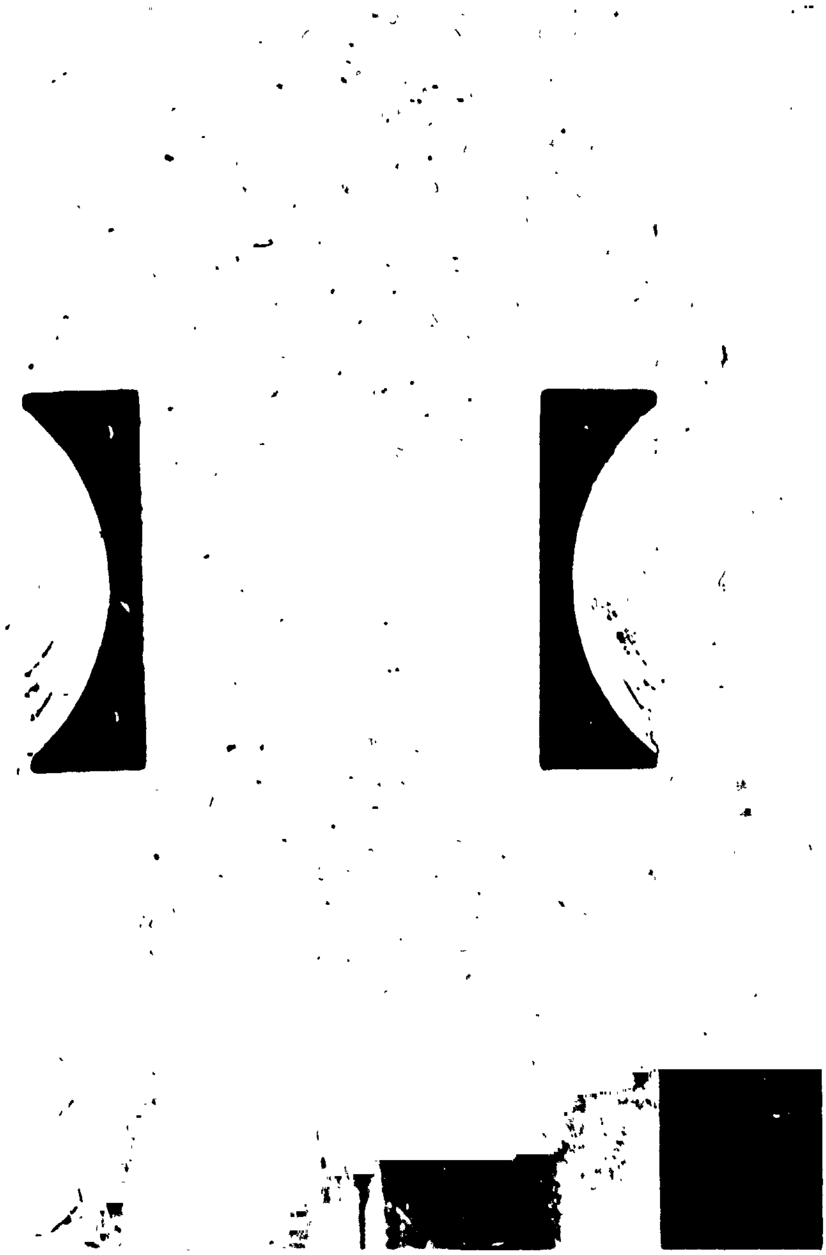

Figure 18. Brace stacking spacers.

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TABLE 2. NUMBER OF BRACES IN MAGAZINES TO DETERMINE NUMBER OF BAYS*

BRACES IN MAGAZINE		NUMBER OF BAYS
VERTICAL	DIAGONAL	
0 or 1	0 or 1	0
2	1	1
3	2	2
4	3	3
5	4	4
10	9	9
15	14	14
20	19	19
25	24	24
30	29	29
35	34	34
40	39	39
45	44	44
50	49	49
55	54	54
60	59	59

To verify that the spot welding system is operational, a special test procedure is conducted to assure that a good contact exists between the copper weld tips and the braces which are placed on the cap members. Carbon paper is placed between the weld tips and braces. By instructing the beam builder to simulate spot welding (no weld heat is applied), the pressure exerted on the carbon paper will show the points of contact. If markings in the carbon paper are not shown by any weld tip, the particular weld tip must be shimmed or changed. Without shimming, the air gap between the weld tip and the brace could create a severe weld block expulsion during spot welding. The weld tips are cleaned every 10 bays.

*From Space Fabrication Demonstration System (SFDS), Vol. 1, p. 2-14.

The inner die assemblies and the outer die assemblies of the shear cut off system must be in the in home position. If not, they will block the passage of the cap members. To restore their position, if necessary, the manual mode of the Control System is used. The chip collector compartments must be cleaned every 10 bays to avoid jamming the die assemblies.

Before turning the Sciaky weld control circuit breaker switch on, the water, for cooling the system, must be on. After this switch has been actuated, the Sciaky weld controller must have the following setting.

1) Weld controller "On" (lower toggle switch)

2) Squeeze 10 cycles

3) Hold 02 - cycles

4) Non-repeat (toggle switch)

5) Weld - 01 cycle

6) Off - 10 cycles

7) Weld "On" (toggle switch)

8) Heat % - 84 for vertical braces & 87 for diagonal braces

9) Transformer 1, TAP 3

10) Transformer 2, TAP 3

11) Transformer 3. TAP 4

12) Transformer 4, TAP 3

13) Transformer 5, TAP 4

14) Transformer 6, TAP 4.

The spot welding of the braces to the cap members is controlled by the PDP 8A computer through the Sciaky weld controller. When the command is received by the controller, it energizes the primary circuits of all six of the weld transformers at the same time. The length of time (ms) that the transformers are powered-up is controlled by the heat percentage dial of the controller. Even though all of the transformer primary circuits are powered-up simultaneously, the secondary circuit of only one of the transformers supplies current at a given time. This is accomplished by allowing only one set of electrodes to make contact with the cap section at a time.

To activate the Control System, the following steps must be followed.

1) Turn Control System main power supply switch on.

2) Set teletype in on-line position.

3) Turn computer on (middle section).

4) Reset Encoder Digital Display (bac of computer).

5) Press power on switch (upper section).

6) Type on teletype length of beam for fabrication.

7) Press auto or manual switch (upper section) as needed.

8) Through the communication system, which has been adapted to the beam builder, verification that all personnel are "CLEAR" of dangerous positions are made by the computer operator.

9) If all systems of the beam builder are as required, the automatic fabrication of a triangular truss beam is ready to start by pressing the start switch (upper section).

BEAM BUILDER OPERATING EXPERIENCE

As expected with a "first-of its kind" ground demonstration unit, operational problems have developed with the beam builder. Since its installation and test at MSFC, the PDP-8A computer has been an area of continuing concern. It was initially believed that it became damaged during the transportation of the beam builder from the Grumman Corporation at Bethpage, N.Y. to MSFC. A defective computer board was replaced and the beam builder became operational. Also the rolling mills system did not function as expected. The right forming mill, which had produced wrinkled caps in Bethpage, was reworked by the Yoder Corporation before reinstallation in the beam builder. After rework, realignment, and lubrication with Molykote "G," the forming mills produced cap members with minimized appearance wrinkles. However, despite the best adjustment efforts of Yoder's representative to form wrinkle-free caps, the wrinkle cap condition still existed. Consequently, the tooling from the lower right mill and the tooling from the upper and left mills were returned to the Yoder Company, Cleveland, Ohio, for comparative measurements of the three sets of tooling (rolls and spacers), station by station. The discrepancies found were: the sixth station or pass in the lower right mill was found 0.020 in. undersize and the first station or pass caused crimping of the flanges, whereas the other first passes (left and top mills) did not. As a result of these discrepancies, the Yoder Company modified all of the top rolls on the right Yoder mill, as well as the bottom rolls of the first and second stages (passes) to resolve the waviness problem. The rolls were reworked and "Armalloyed," a process which uses a proprietary surface finish to minimize surface defects.

The right mill now gives an acceptable cap with 6.370 to 6.375 in. wide material, i.e., relatively free of surface defects and wrinkles. However, when using 6.352 in. wide material, the results are somewhat marginal with respect to appearance.

On May 3, 1979, the computer again malfunctioned. Electrical spikes from the servo-translators appeared to be the cause of the erratic behavior of the computer. A low voltage power supply was experienced. Two chips were changed on the peripheral board, and a battery pack was utilized to supply the required power. Later, the power supply was corrected with information submitted by Grumman. Further investigation showed that the control system failure was directly related to heliarc welding taking place elsewhere in the same building (4612) causing severe supply voltage fluctuation. The solar power simulation facility, located in the same building, experienced malfunctions also. Another computer failure was experienced later. It was believed that it was caused by the excessive heat in the computer booth. An air conditioner unit was installed to prevent failures of this kind. (See Table 3 for a complete chronological list of problems experienced with the beam builder.)

Weld block expulsions have been experienced (a total of 11, Table 3). These occur whenever there is an air gap that creates a very high resistance between the weld tips and the triangular copper weld blocks during the spot welding. Air gaps exists when:

1) Weld tips are not clean

2) Weld tips are not in tolerance

3) Weld blocks are misaligned

4) Cap members are misaligned

5) Braces are not placed on cap members during spot welding

6) Improper function of the cam gears mechanisms or failure of the cam gear elastomer.

If the weld block expulsion is critical, replacement and alignment of the weld block may be necessary. Otherwise, plugging and polishing the weld block are sufficient.

Additionally, the original Furane elastomer of the cam gear failed. It was replaced with Proseal 899-C-2. No additional elastomer failures have been experienced.

In the shear cutoff system, the inner die assembly of the right shear cutoff mechanism did not retract. This failure was caused by its defective pancake motor, which was replaced. Another failure occurred in the left cutoff mechanism. Its outer die assembly was jammed by an aluminum chip (which resulted from cuts of the beams fabricated) in the chip collector compartment. The jamming caused the respective pancake motor to burn out. The operation of the beam builder continued after replacing the damaged motor and its respective fuse in the motor control relay junction box, and cleaning all the aluminum chip collector compartments. The chip collector compartments are cleaned periodically to avoid similar problems.

The beam builder has approximately 160 electro-mechanical switches (Fig. 19). To date, all limit switch failures have been the result of either broken (switch) arms or improper adjustments.

Adjustment of all the switches is by trial and error. Bending of the arms in a skewed position was required for some of the switches to make proper contacts. The function of all the limit switches is critical. Therefore, to avoid their vulnerability to external damage, protective covers have been installed on some switches. The reliability of this type of switch is not completely satisfactory. For a higher reliability and dependency, electro-optical limit switches (Fig. 20) have been installed in the Carriage System mechanisms. The reliability of these switches is greater than that of the electro-mechanical limit switches. They provide a better feedback to the Control System and can prevent malfunctions in the beam builder systems. Other malfunctions in the beam builder are related to relay failures, Table 3. High humidity, with resulting corrosion, is considered the main cause for the relay failures.

Figure 19. Electro-mechanical limit switch.

Figure 20. Optical limit switch.

TABLE 3. BEAM BUILDER OPERATIONAL SUMMARY

Event	Date	Cumulative Operational Time (min)	Reported Malfunction	Cause	Disposition	Recommended Additional Action
1	11/13/78	0	Computer Inoperative	Possibible Shipping Damage	DEC Repair Back Plane and One Board	
1	12/8/78	40	Rolling Mills (Chips in Gear Boxes)	Improper Lubricant	Remove Chips, Lubricated Mills With Molykote "G"	Identify Appropriate Space Rated Lubricant
3	12/11/78	100	Limit Switches (Arms Broken)	Improper Adjustment	Replaced Switches Installed Protective Covers	Upgrade to More Rugged Switches and Install Covers
4	12/14/78	120	Weld Block Expulsion	Suspected Misalign-ment	Replugged Weld Block	Realigned All Weld Blocks
5	12/15/78	180	Right Shear Cut Off Mechanism	Limit Switch (Arm Broken)	Replaced Limit Switch and Motor	Upgrade to More Rugged Switches – Install Protective Covers
6	12/18/78	230	Beam Cap Wrinkles	Rolling Mill Not to Tolerance	Returned Tooling to Yoder Co. for Rework	
7	2/15/79	240	Weld Block Expulsion	Brace Did Not Release	Replaced Back-up Weld Block	
8	3/16/79	250	Right Rolling Mill Inoperative	Encoder Mounting Bracket Loose	Replaced Encoder Bracket	Add Encoders to Periodic Maintenance List
9	4/9/79	252	Shear Cut Off Inoperative	Limit Switch Maladjusted	Proper (Switch) Adjustment	Upgrade to More Rugged Switches
10	4/9/79	369	Weld Tips Worn Beyond Specification	Hand Polishing Electrodes	Replaced All 72 Electrodes	Inspect Tips Periodically
11	4/11/79	400	Weld Block Expulsion	Weld Head Yoke Pin Loose	Replugged Weld Block	Periodic Set Screw Inspection
12	4/11/79	410	Cam Gear Failure	Elastomer Degenerated	Replaced Elastomer With Proseal 899-C-2	Use Proseal 899-C 2

TABLE 3. (Continued)

Event	Date	Cumulative Operational Time (min)	Reported Malfunction	Cause	Disposition	Recommended Additional Action
13	4/17/79	435	Servo Drive Motor Failure	Relay Failure	Replaced Relay	
14	5/3/79	502	Computer Failure on Start Up	Suspected Noise From Servo Translators	Corrective Software Changes by Grumman and Changed Relay To Turn on Three Servo Motors To Rolling Mills Synchronously	
15	5/3/79	510	Computer Failure	Heliarc Welding Elsewhere in Same Building Suspected To Cause Power Supply Fluctuation	Replaced Chips	Install Separate 440 Vac Power Supply Independent of Building Usage
16	5/4/79	550	Spot Weld Blow Out (Upper Left Forward Diagonal)	Debris Between Cap and Diagonal	Clean Weld Blocks and Weld Tips	Clean Weld Tips After Every 10 Bays – Clean Weld Blocks After Every 50 Bays
17	5/14/79	594	Computer Failure	Burned Out Fuse and Chip (Possibly Result at 95°F Summer Temp.)	Replaced Fuse and Chip Installed Air Condition in Computer Booth	Use Air Condition During Summer When Operating Computer
18	6/12/79	610	Bottom Diagonal Selectors Did Not Actuate	Limit Switch Arm	Replaced Limit Switch	Upgrade to More Rugged Switch
19	7/31/79	620	Computer Failure	Power Fluctuation	Replaced Faulty Chips	Install Separate 440 Vac Power Supply Independent of Building Usage. Add Metal Oxide Varistors to Protect Against Transient Voltages

TABLE 3. (Continued)

Event	Date	Cumulative Operational Time (min)	Reported Malfunction	Cause	Disposition	Recommended Additional Action
20	10/19/79	660	Left Diagonal Selectors Did Not Actuate	Gear Motor Malfunction	Repaired Motor	
21	1/10/80	710	Left Shear Cut Off Mechanism (Inner Die Assembly) Did Not Actuate	Defective Pancake Motor	Replaced Motor	
22	2/6/80	770	Top Rolling Mill Stopped	15 A Fuse Failure Suspected Deterioration With Age	Replaced Fuse	Replace All Fuses on Beam Builder
23	2/11/80	880	Left Diagonal Brace Selectors Did Not Actuate	Relay Failure	Replaced Relay	
24	2/11/80	890	Slippage of Left Vertical Braces	Cause Not Clearly Identified		
25	2/27/80	914	Slippage of Left Vertical Braces	Cause Not Clearly Identified – Brace Finger Mechanism	Realigned Brace Magazine – Shimmed Brace Finger Mechanism and Replaced Selector Blades	
26	4/22/80	1030	Minor Weld Block Expulsion	Weld Heat Too High	Polished Weld Block Weld Heat Reduced to 78 Percent or Less on Heat Setting	
27	4/22/80	1030	Limit Switches Failures	Broken Switch Arms	Replaced Switches	Upgrade to More Rugged Switches – Install Protective Covers
28	4/23/80	1054	Right Slot Detector Failed	Exposed Wires Shorted Out by Aluminum Cap	Repotted Wires With Epoxy	Instruct Operator to be More Careful Threading Cap Material Into Rolling Mills

TABLE 3. (Continued)

Event	Date	Cumulative Operational Time (min)	Reported Malfunction	Cause	Disposition	Recommended Additional Action
29	7/21-23/80	1118	Major Beam Builder Modification Brace Magazines, Carriage System, and Control System, etc.	Repeated Problem With Switches and Brace Dispensing	Brace Magazines Modified Replaced Mechanical Switches With Optical Switches in the Carriage System for Better Feedback to the Control System	
30	8/30/80	1194	Weld Block Expulsion (Right Rear Block)	Weldment on Scissor Arm Failed	Rewelded Scissor Arm and Repaired the Weld Block. Replaced 4 Weld Electrodes	Inspect Weldments After Every 50 Bays
31	9/1/80	1242	Major Weld Block Expulsion (Top Rear Weld Block)	Scissor Shear Pin Failed	Replaced Shear Pin and Weld Electrodes. Repaired Weld Block	
32	9/16/80	1242	Computer Failure	Cause Not Identified	DEC Repair	DEC Recommended High Speed Reader and LA 36 Console
33	10/2/80	1244	Weld Block Expulsion (Top Forward Block)	Pin Failure On Scissor Caused Weld Block Not to Properly Clamp	Repaired Weld Block and Replaced Pin	
34	2/18/81	1335	Major Weld Block Expulsion (Left Rear Weld Block)	Exact Cause Not Determined	Repaired Weld Block	
35	2/18/81	1341	Computer Lost Program	Not Identified	Reloaded Systems Tapes	
36	2/18/81	1341	Limit Switch Failure	Broken Arm	Replaced Mechanical Switches	
37	2/18/81	1341	Four Relay Failures	Not Identified	Replaced Relays	

TABLE 3. (Continued)

Event	Date	Cumulative Operational Time (min)	Reported Malfunction	Cause	Disposition	Recommended Additional Action
38	2/20/81	1365	Right Rolling Mill Ran While Top and Left Mills Stopped Rupturing the Beam	Right Mill Tachometer Servo Motor Drive Screw Loose	Tighten Screw	Check All Set Screws After Every 100 Bays
39	2/21/81	1461	Right Forward Diagonal Cam Motor Did Not Actuate Weld Cycle Properly	Relay Failure	Replaced Relay	
40	2/23/81	1[illegible]93	Left Outer Shear Cutoff Mechanism Failure	Aluminum Chips in Chip Collector Compartment Cause Outer Die Assembly to Jam. Pancake Motor Burned Out.	Replaced Burned Out Motor. Clean Chip Compartment	Clean All Chip Compartment After Every 10 Bays
41	2/23/81	1559	Weld Block Expulsion (Left Rear Weld Block)	Broken Nylon Insulator Pin on Right Vertical Lower Weld Head	Repaired Weld Block and Replaced Pin. Repolished Silver Plated and Lubricated All Weld Head Sliding Joints	
42	2/23/81	1566	Roll Pin Broken on Right Forward Diagonal Translate Welding Heads	Suspected Binding of Sliding Weld Head	Replaced Pin	
43	2/26/81	1643	Weld Block Expulsion	Broken Nylon Insulator Pin	Replaced Nylon Insulator and Repaired Weld Block. Repolished Silver Plate and Lubricate Sliding Joints of Weld Head	

TABLE 3. (Concluded)

Event	Date	Cumulative Operational Time (min)	Reported Malfunction	Cause	Disposition	Recommended Additional Action
44	2/28/81	1723	Left Vertical Top Weld Head Not Cycling	Broken Insulator Nylon Pin	Replaced Nylon Insulator and Repaired Weld Block. Repolished. Silver-plated and Lubricated Sliding Joints on Weld Head	
45	3/4/81	1806	Weldment Failure (Left Vertical Clamping)	Weldment on Scissors Arm Broken	Repaired Scissors Arm	Inspects Weldments After Every 50 Bays
46	3/17/80 to 5/4/81	1816	Computer/Grumman Software Failure	Computer Can Not Retain Memory	DEC Repair. Replaced Memory Board	Install a High Speed Reader. Transient (Spike) Voltage Recorded is Needed for Troubleshooting

TYPES OF FASTENING SYSTEM ADAPTABLE TO THE BEAM BUILDER

The beam builder spot welding system requires an excessive amount of energy for the fabrication of the triangular truss beams. Therefore, some research has been done looking for alternative fastening systems which require less energy and are adaptable to the beam builder. Table 4 presents a comparison of these fastening systems.

TABLE 4. FASTENING SYSTEMS ADAPTABLE TO THE BEAM BUILDER

Fastener Systems	Activating System	Joules Per Truss Bay	Debris Generation
Spotwelding	Electrical Resistance	37,000	None
Ultrasonic Welding	Transducer	24,000	None
Pierce and Fold	Solenoid	3,600	None
Stamp-Lock	Solenoid	3,600	None
Self Piercing Rivet	Solenoid	3,600	Yes
Staple	Solenoid	3,600	Yes
Grommet	Solenoid	2,500	None

The pierce and fold system (Fig. 21) was selected for further development because it requires:

1) Minimum energy for operation

2) Minimum or no maintenance

3) No additional material, such as rivets, bolts, staples, etc., to join the braces to the cap members

4) No continuous adjustment.

This system (Pierce and Fold) consists of:

1) A movable punch head (Fig. 22) with a pressure block and 4 square shaped punches - the pressure block maintains the brace alignment on the cap member (Fig. 23) for piercing. The square-shaped punches perforate the brace and cap together (Fig. 24).

2) A punch block (Fig. 25) with 2 cutting plates and 4 movable dies. The cutting plates stay partially open for lancing of the brace and cap member which are placed on the punch block (Fig. 26). The 4 movable dies fold the triangular edges or cuts (resulting from the piercing or perforation) of the brace and cap member, after they

Figure 21. Pierce and fold system.

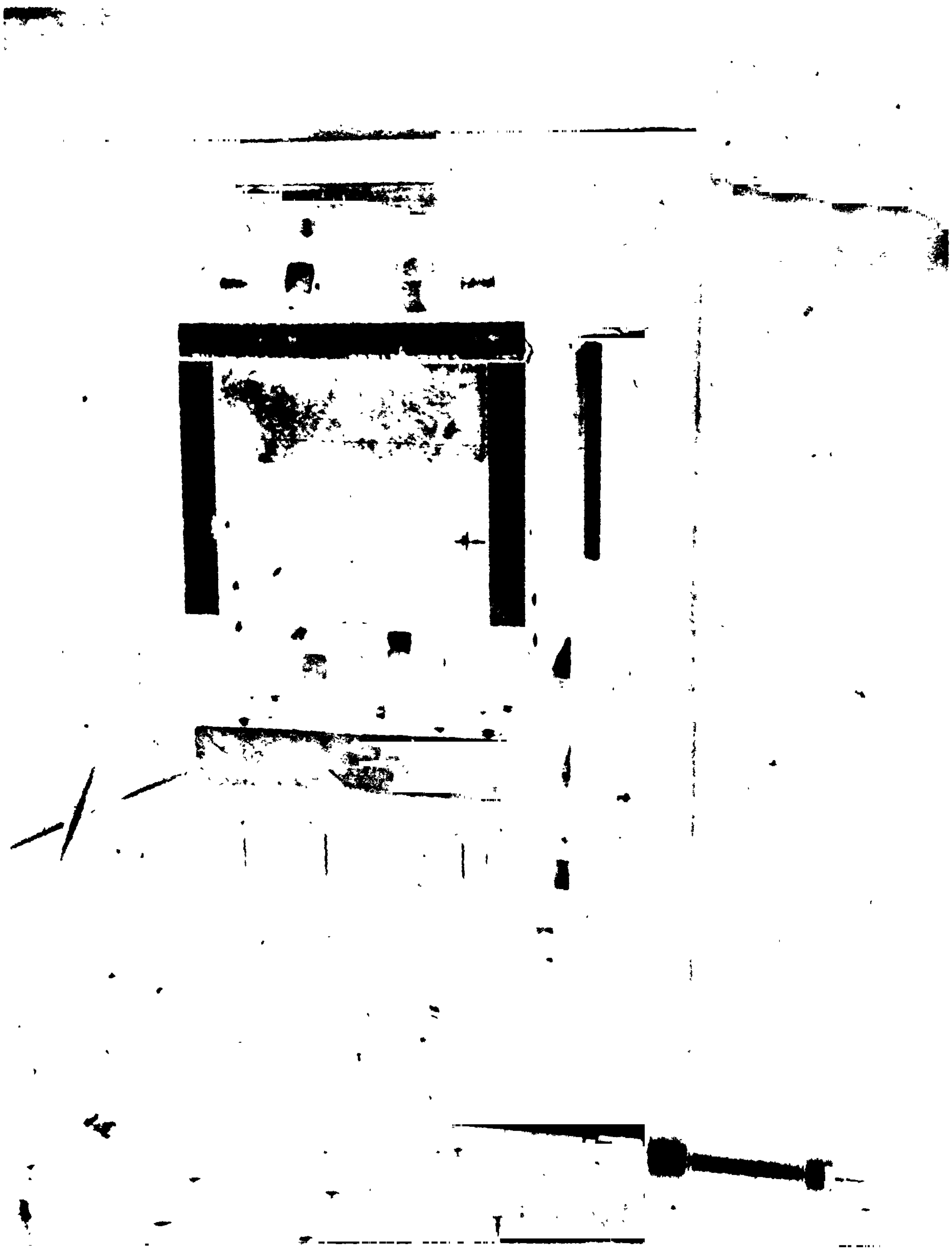

Figure 22. Movable punch head.

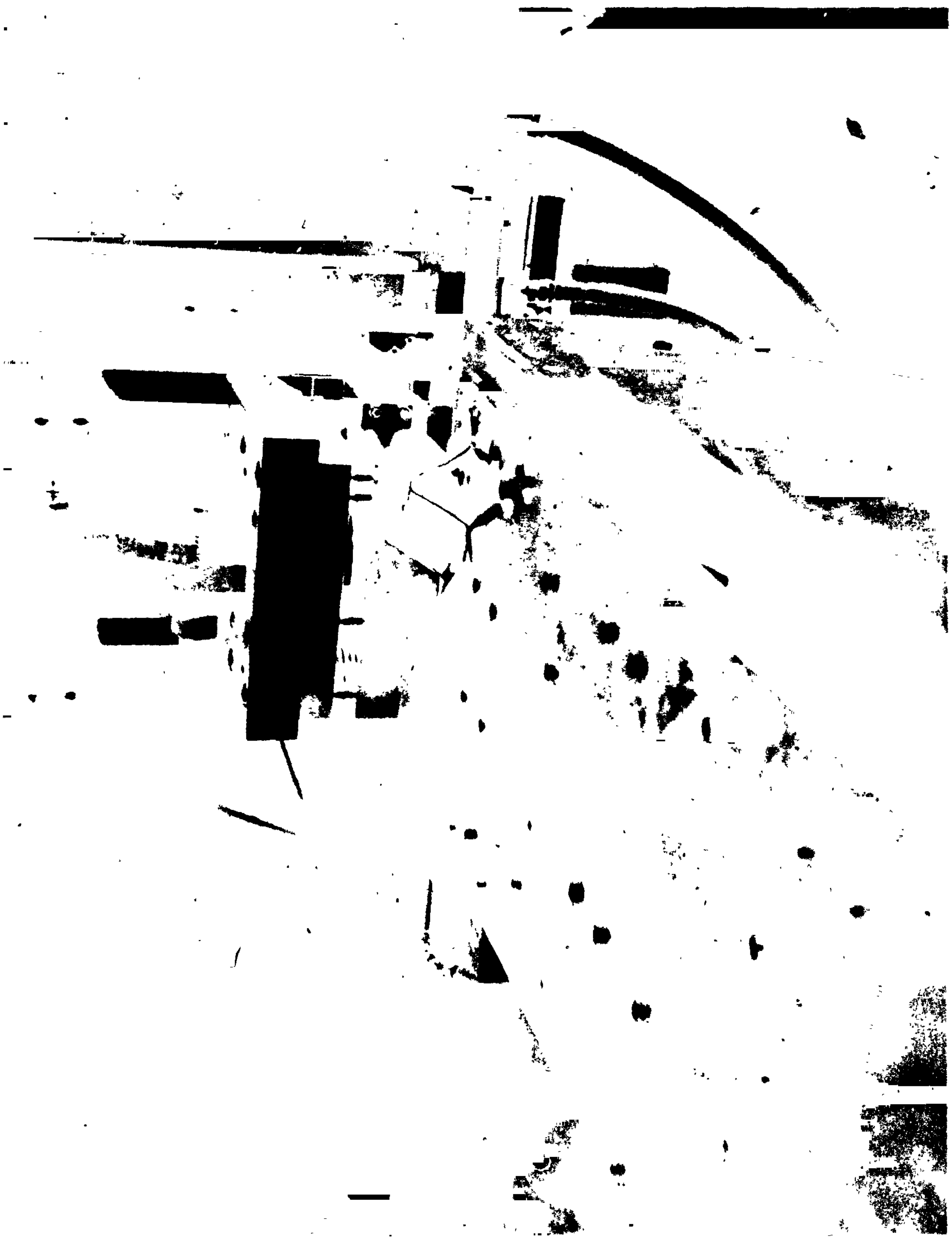

Figure 23. Pressure block.

Figure 24. Brace and cap pierced together.

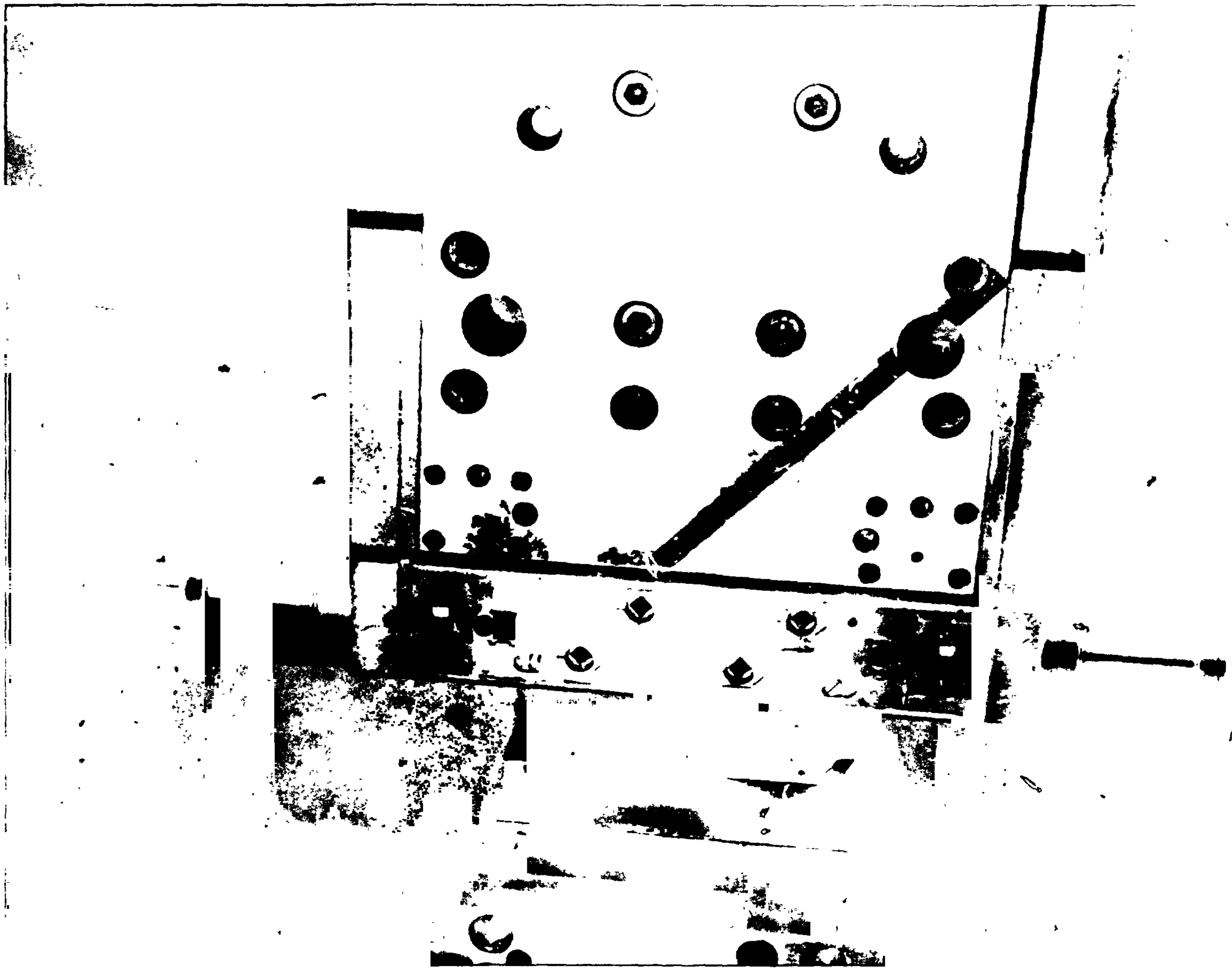

Figure 25. Punch block.

Figure 26. Brace and cap on punch block.

have been pierced together (Fig. 27) to make the joint. After the cycle is completed (piercing and folding), the movable punch head retrieves to its home position (Fig. 28). To determine the maximum (flatwise) shear load of the pierce-and-fold mechanical fastener, one hundred samples were tested. Fifty samples had a single hole and fifty samples had two holes aligned with each other. The load vectors pointed in the direction of the square hole diagonal. The shear loads in the single hole samples ranged from 75 to 137 lb, and the arithmetic mean obtained was 98 lb. The shear loads in the two hole samples ranged from 208 to 275 lb, and the arithmetic mean obtained was 236 lb.

ASSESSMENT

The beam builder, as a ground demonstration system and precursor of a space beam builder machine, has proven the capability of automatically fabricating triangular truss beams. These beams, made of aluminum alloy 2024-T3 have an axial design ultimate load of 5540 N (1245 lb) based on the Grumman photovoltaic solar power system design reference structure. When fabricated in space, these beams could constitute the building block of superstructures such as large reflector antennas, microwave radiometer antennas, radar astronomy telescopes, solar thermal power systems, photovoltaic solar power systems, microwave power transmission antennas, communication systems, and manned space stations, etc.

Inhouse system experience has been acquired with the operation of the ground demonstration beam builder by the automatic fabrication of 508 bays (2500 ft) of triangular truss beams. The present model can be upgraded for better reliability by substituting critical mechanical switches with more rugged switches, more reliable motors, a fast reader, improved software, etc. By making these improvements and additional reductions to structural weight, the required reliability of a flight rated beam builder can be obtained. Additional work needs to be done to determine the life of spot welding tips in a vacuum environment. Additionally, system improvement will be required for the rolling mills to guarantee reliability and proper lubrication for space operation.

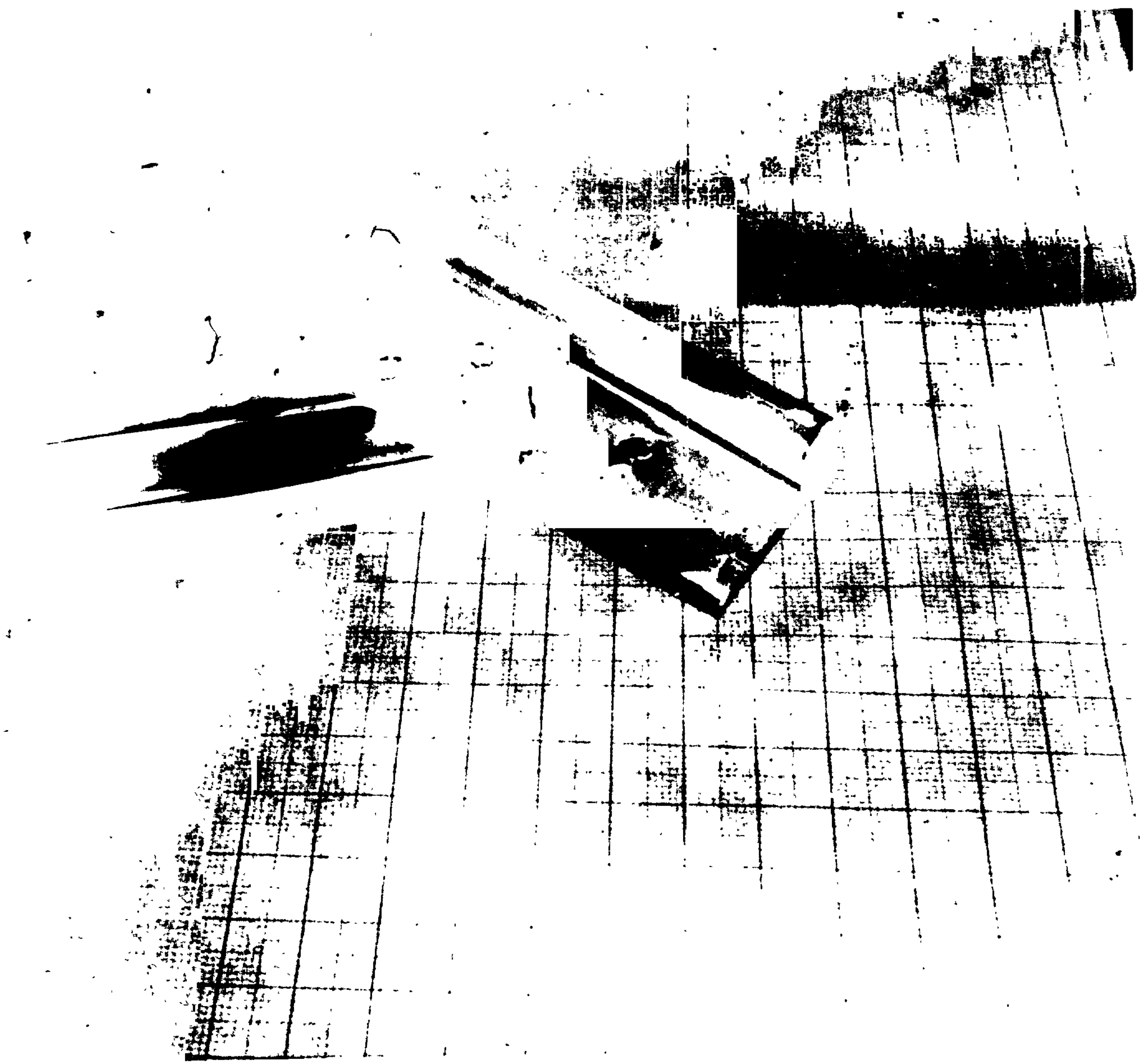

Figure 27. Cuts folded.

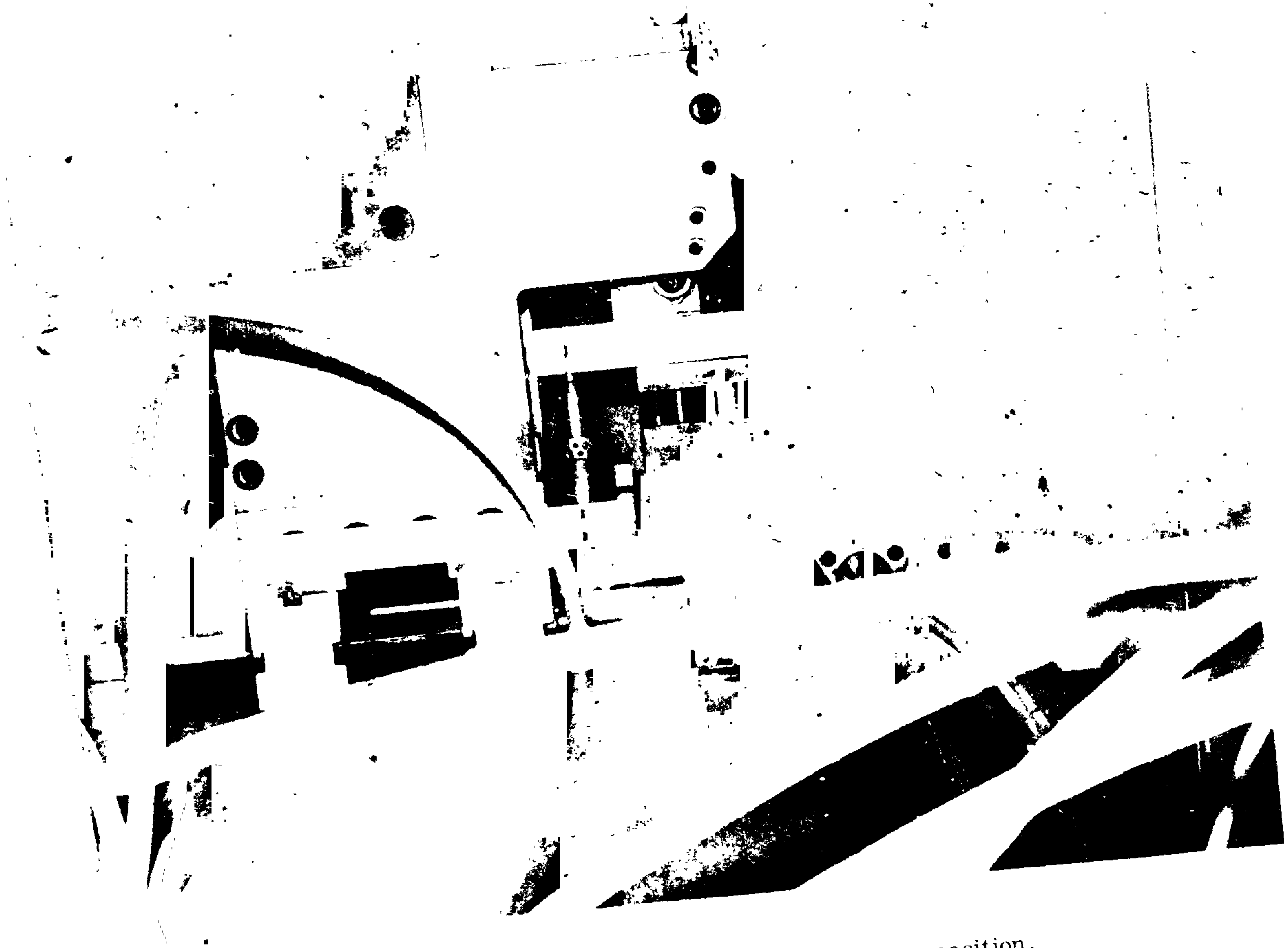

Figure 28. Movable punch head in home position.

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APPROVAL

MSFC EVALUATION OF THE SPACE FABRICATION DEMONSTRATION SYSTEM (BEAM BUILDER)

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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