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SPACE FABRICATION DEMONSTRATION SYSTEM COMPOSITE BEAM CAP FABRICATOR

FINAL REPORT
MARCH 1982

NASA CONTRACT NO. NAS 8-32472

NATIONAL AERONAUTIC AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35872

GRUMMAN AEROSPACE CORPORATION
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16. Abstract

A detailed design for a prototype, composite beam cap fabricator was established. Inputs to this design included functional tests and system operating requirements. A preliminary design review between MFSC and Grumman was held prior to commitment of long-lead-time procurement. Completed detail designs were presented to MFSC at a critical design review (CDR). Machine fabrication was initiated after obtaining MFSC concurrence at the CDR. All additionally required materials were procured, detail parts were fabricated, and one composite beam cap forming machine was assembled. The machine was demonstrated as a stand-alone system. Two 12-foot-long beam cap members were fabricated from laminates graphite/polysulfane or an equivalent material. One of these members, which was structurally tested in axial compression, failed at 490 pounds. The machine was shipped to MFSC.

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FOREWORD

This report was prepared by Grumman Aerospace Corporation in fulfillment of NASA Contract NAS8-32472, (SFDS) Composite Beam Cap Fabricator. Under this program, a composite beam cap fabricator capable of stand-alone automatic fabrication of composite beams was successfully developed, designed, fabricated, and functionally tested. This report documents the efforts undertaken to achieve this goal.

Major contributors to the successful NASA/Grumman development effort and to this final report included:

Eric E. Engler	- NASA Contracting Officer Representative
Gordon Parker	- Grumman Program Manager
Warren Marx	- Grumman Project Engineer
Ronald Braun	- Control System Design
Chee Huie	- Control System Design
Charles Johnson	- Mechanical System Design
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William Boucher	- Test and Evaluation
Leonard Poveromo	- Material Selection Consultant

CONTENTS

ILLUSTRATIONS

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Section 1
INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

There is a general agreement in the aerospace community that the assembly of large space structures will require automatic production of basic building-block beams in a space-based construction facility. The capability of being able to automatically produce beams has been successfully demonstrated for aluminum structures using the NASA-MSFC/Grumman aluminum beam builder (Fig. 1).

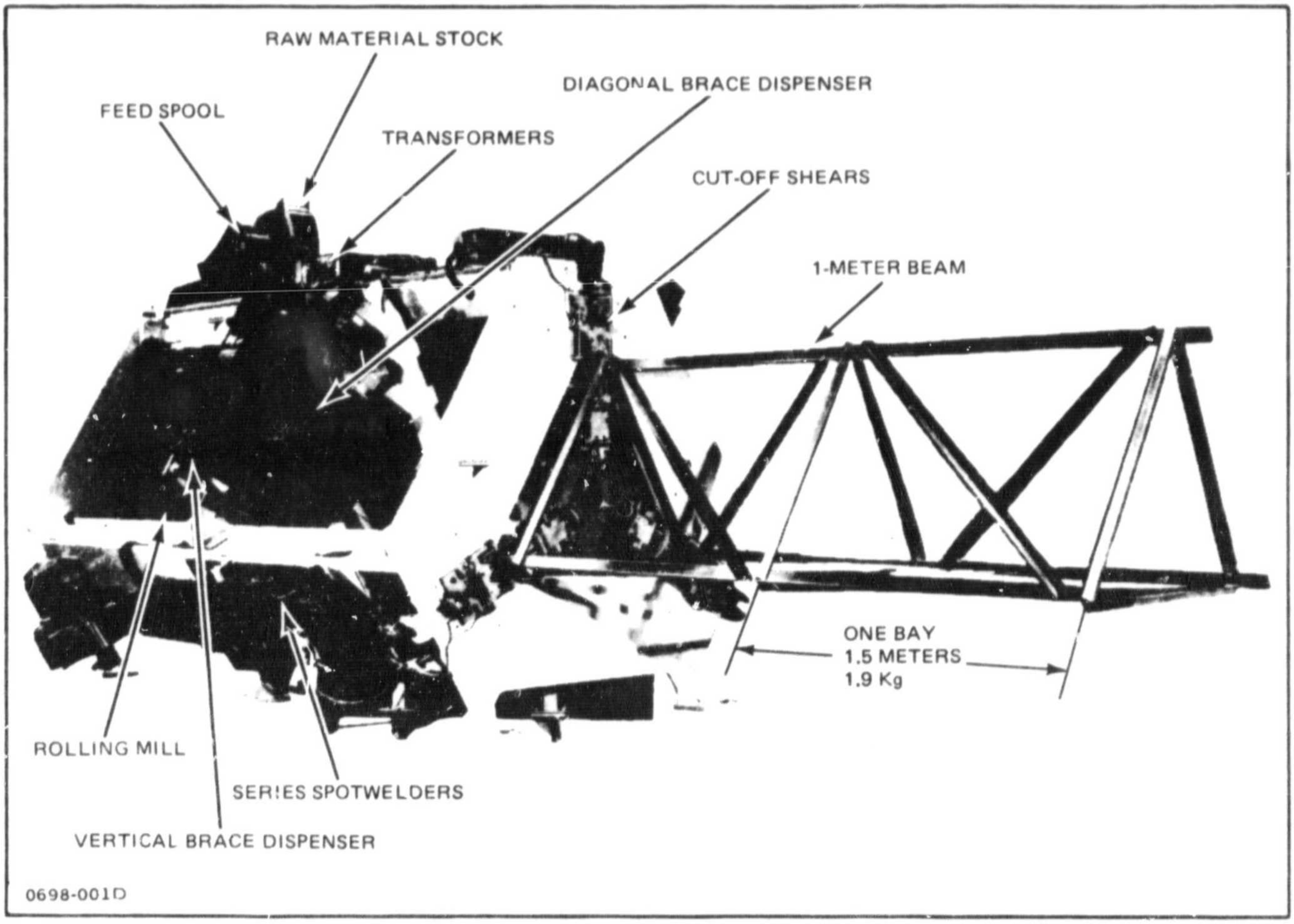

Fig. 1 Aluminum Beam Builder

There has been further agreement in the aerospace community that graphite-reinforced composites will be required to satisfy some specific large space structure applications where structural thermal distortions must be minimized. Grumman, recognizing this need at the time that the aluminum beam builder was being built under contract to NASA-MSFC, began to develop composite forming and fastening techniques utilizing our own independent research and development funding. It has been our contention that a composite beam builder (a counterpart of the aluminum beam builder) which draws on the latter's technology, could be built (Fig. 2). Further, the

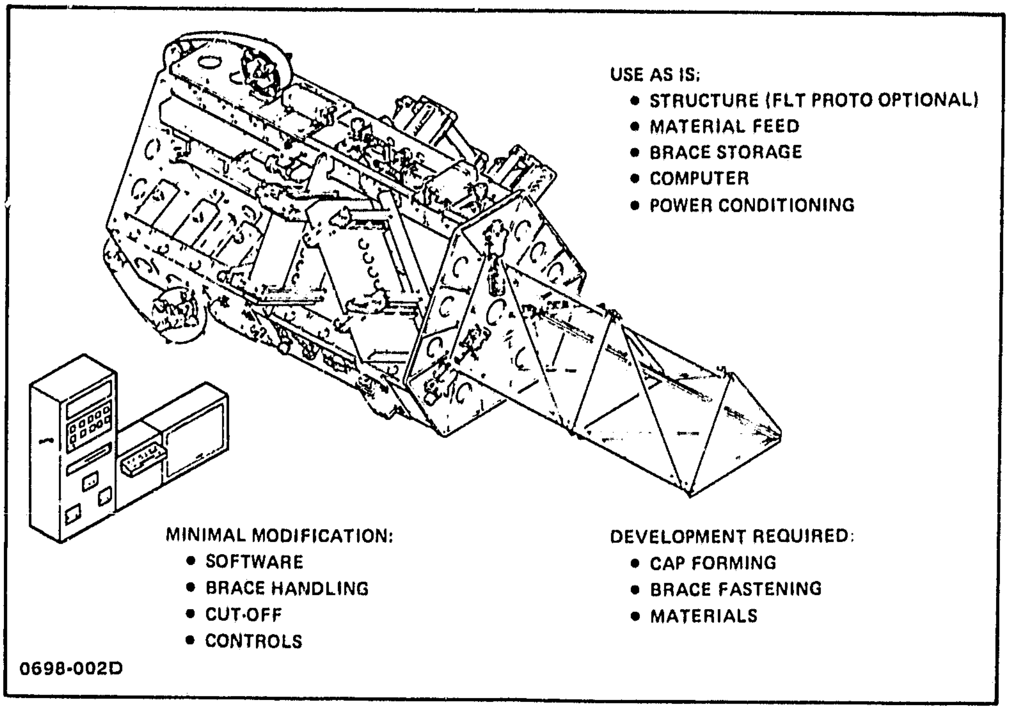

Fig. 2 Composite Beam Builder Development Technology Assessment

composite machine could be built so that many of its components would be interchangeable with the aluminum beam builder. The concept of shared or modified components results in the following advantages:

- Reduced design effort
- Reduced fabrication and assembly time
- Minimized development testing
- Greater probability of success
- Flexibility of choice of beam material
- Lower cost
- Shorter schedule.

Taking this concept a step further, that of aluminum versus composite beam builder technology assessment, it was concluded that the prime areas requiring development were:

- Beam cap forming
- Brace-to-cap fastening
- Composite materials.

The highest risk technological area is cap forming, since no production experience and only limited laboratory data exists in this area. This project addressed the design, fabrication and testing of a ground demonstration prototype of a composite beam cap fabricator for NASA-MSFC. A composite beam cap fabricator was designed with specific capability to form a high-temperature-forming graphite-reinforced thermoplastic (polyethersulfone or equivalent) from flat laminated strip stock into a beam cap similar in cross-section to the aluminum beam cap (Fig. 3.).

The composite beam cap fabricator will provide NASA-MSFC with a versatile technology development tool which can be used for processed beam cap material evaluation and fiber orientation structural properties verification. The composite beam builder will also facilitate completion of such technological evaluations as:

- Fastening technique verification
- Beam dimensional control capabilities
- Beam test specimens (static and dynamic)
- Beams for space construction demonstrations
- Structures for dynamic simulation.

1.2 SUMMARY

The technical effort consisted of three tasks which were conducted over an 11-month period with one additional month for final documentation. Where practical, tasks were conducted concurrently to minimize both the project period of performance and lead-time delays on procured items.

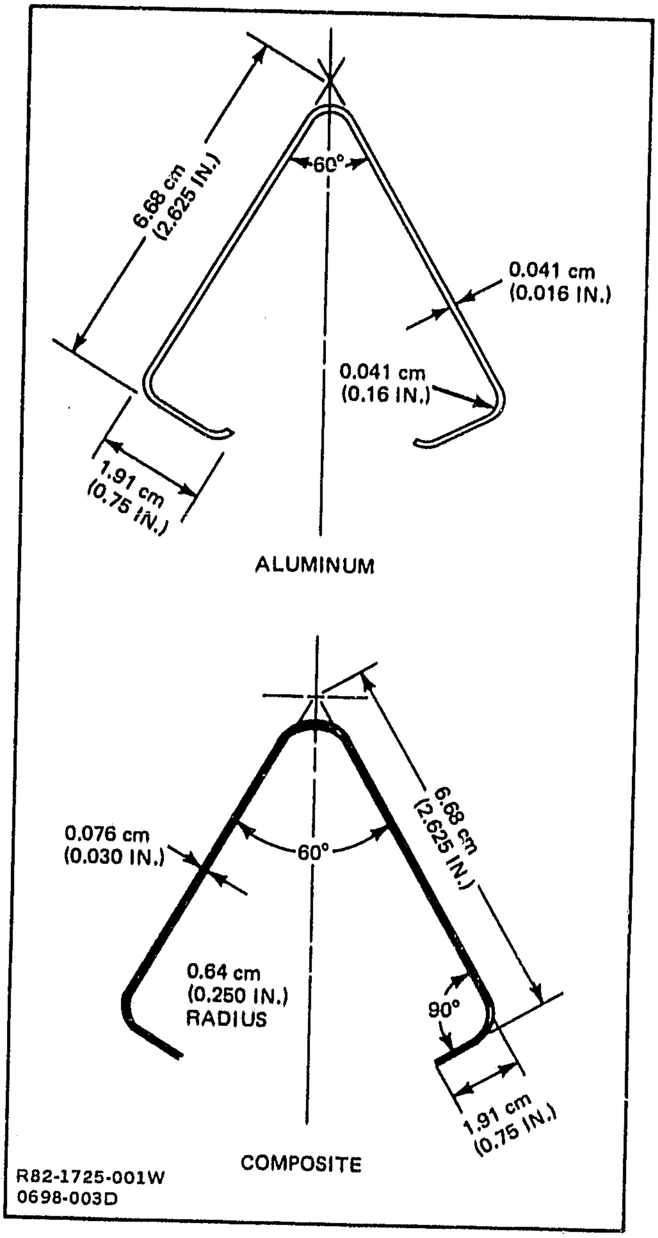

Fig. 3 Beam Cap Cross-Section

A detailed prototype cap fabricator design was established. Inputs to this design included functional tests and system operational requirements. A preliminary design review between MSFC and Grumman was held prior to commitment of long-lead-time procurement. Complete detailed designs were presented at the end of this task at a Critical Design Review (CDR).

Machine fabrication was initiated after MSFC concurrence at the CDR. All additionally required materials were procured, detailed parts fabricated and final assembly performed for one composite beam cap forming machine.

The machine was then demonstrated as a stand-alone system. Two 12-ft-long beam cap members were produced from laminated graphite/polysulfone or its equivalent. One of these members was structurally tested in axial compression to ultimate failure which occurred at 490 pounds. The machine was then shipped to the George C. Marshall Space Flight Center.

Section 2
BACKGROUND

2.1 GENERAL APPROACH

The technology assessment of material and processing requirements for automated production of composite beams highlighted two high-risk development areas: composite materials and cap-forming processes. Due to the inter-relationship between composite materials and cap-forming processes, this program focused first on establishing the forming process which, in turn, became the yardstick by which new materials were evaluated.

The first step in this effort was to establish composite beam fabrication machine requirements. These included:

- Fully automated operation
- Compatibility with the aluminum beam builder
- Compatibility with the Shuttle structure
- Compatibility with the Shuttle mission.

The second step focused upon material and process development in order to expedite development of the composite beam builder. The only structural performance criterion adopted was that the composite cap have the same strength as the aluminum cap.

2.2 MATERIAL AND CONFIGURATION RATIONALE

The open-cap-section configuration (Fig. 3) offers the same producibility advantages (that is, ease of beam assembly and simplicity of cap cut-off) for composites as it does for aluminum. Also, commonality with the composite and aluminum caps is maintained. With the exception of corner radii, cap geometry is identical.

Composite material selection was guided by functional, economic and processing requirements. The composite laminate was to exhibit low thermal distortion, high stiffness and low density, while lending itself to both in-space fabrication and low-cost continuous processing. Both physical and mechanical properties were satisfied by graphite fiber reinforcement. The low-cost continuous processing capability was partially satisfied by using woven fabric in lieu of unidirectional tape.

Space processing (forming) dictates that a thermoplastic resin system be utilized. Thermosetting plastics outgas volatiles during curing, necessitating special handling in the uncured or "B"-stage condition and presenting significant in-orbit inspection problems after curing. By contrast, thermoplastic resin systems can be handled and formed in much the same way as sheet metal, if the stock is completely processed as strip and coiled onto a spool or drum in an earth-oriented atmosphere.

Thermoplastic matrix materials that have been evaluated using woven graphite cloth include:

- Polysulfone (Gr/PS)
- Polyethersulfone (Gr/PES)
- Acrylic
- Polycarbonate
- Phenoxy
- Polyester

Evaluation criteria were applicable to future production processing, forming temperatures and basic structural properties. The principal material characteristics and processing parameters that led to an interim matrix material selection are summarized in Fig. 4. Current candidate resin systems with more advanced capabilities are presented in Fig. 5.

2.2.1 Interim Material Selection

Early in the Grumman Beam Builder development effort, Gr/PS and Gr/PES strip materials were evaluated using the equipment and technology developed for aluminum forming. The state-of-the-art, high-temperature, thermoplastic composites used at this stage were not sufficiently mature to permit development of acceptable forming machinery. Prepregging techniques for Gr/PS and Gr/PES were still being refined by the manufacturers. In addition, the continuous-lamination processing procedures needed to finalize the beam builder design had not yet been developed. The inherently limited, forming temperature range for the available Gr/PS material (260°C ± 10°C) would severely retard development of the operating parameters for the basic cap fabricator machine. The selection of graphite/acrylic with wide forming temperature range (140°C ± 30°C) was the ideal composite material system for initial machine development work.

LAMINATE IDENT	MFG	RESIN	CLOTH REINFORCEMENT	PROCESS PARAMETERS TEMP (°F)	PRESS (psi)	TIME (min)	LONG. TENS. STRESS (ksi)	LONG. TENS. MODULUS (msi)	RESIN CONT (%)	THICKNESS (in.)*
201P	3M	Polycarbonate	Gr. 2423	500	100	30	48.4	6.26	–	0.038
101PH	Hexcel	Phenoxy	Gr. 1313	350	100	30	48.7	4.88	–	0.029
102PH	Hexcel	Phenoxy	Gr. 1313	350	100	30	49.5	5.71	–	0.023
101A	GAC	Acrylic	Gr. 1212**	300	100	30	68.1	9.09	48.3	0.031**
201A	GAC	Acrylic	Gr. 2423	300	100	30	64.5	8.46	35.4	0.031
301A	GAC	Acrylic	Gr. 2423/ Glass Scrim	300	100	30	62.0	6.21	–	0.045
302A	GAC	Acrylic	Gr. 2423	300	100	30	62.8	7.20	–	0.036
101PL	Hexcel	Polyester	Gr. 2424	–	–	–	36.3	4.4	–	0.055
102PL	Hexcel	Polyester	Gr. 2424	–	–	–	40.8	4.36	–	0.059
303A	GAC	Acrylic	Gr. 2423	300	100	30	41.2 @ 170°F	5.24 @ 170°F	–	0.026
501A	Hexcel	Acrylic	Gr. 2423	400	200	2	65.5	6.88	–	0.036
501A	Hexcel	Acrylic	Gr. 2423	400	200	2	39.2 @ 170°F	5.79 @ 170°F	–	0.036

* LAMINATES – 2 PLIES THICK EXCEPT AS NOTED
** LAMINATES – 4 PLIES THICK

0698-004D

Fig. 4 Interim Material Evaluation Summary

REINFORCEMENT	GRAPHITE LAMINATE STACKING SEQUENCE	THICKNESS (IN.)	ULTIMATE TENSILE STRENGTH, (KSI) -150°	RT	125°	170°	TENSILE MODULUS, (MSI) -150°	RT	125°	170°	ULTIMATE FLEXURE STRENGTH (KSI) RT	170°	250°	FLEXURE MODULUS (MSI) RT	170°	250°
24x23 $0°/90°_T$ CLOTH (T-300)	$0°/90°_T$-$90°/0°_T$ 1/	0.040	—	64.5	—	—	—	8.5	—	—	82.9	75.2	71.0	7.0	6.6	6.5
24x23 $0°/90°_P$ VCP-45 CLOTH	$0°/90°_P$-$90°0°_P$ 2/	0.040	29.8	40.2	38.3	—	10.9	10.6	10.2	—						
24x23 $0°/90°_T$ CLOTH (T-300)	$0°/90°_T$-$90°/0°_T$ 3/										153.1		130.4	9.9		9.6

1/ POLYSULFONE/GRAPHITE 2/ ACRYLIC/GRAPHITE 3/ POLYETHERSULFONE/GRAPHITE

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Fig. 5 Composite Beam Cap Material Candidates

The advantages of the graphite/acrylic system, which led to its interim selection, were as follows:

- Low sensitivity to forming parameters enhancing process development
- Low forming temperature (about 350°F) minimizing required energy inputs
- Strength and stiffness
- Resin is liquid at room temperature providing excellent fiber-wetting properties
- Monomer and polymer are relatively inexpensive and commercially available in large quantities.

The acrylic monomer/polymer blend used consisted of 77.5 percent methylmethacrylate monomer, 22.0 percent acrylic polymer and 0.5 percent benzoperoxide (by weight). The woven graphite fabric selected for initial evaluation was Woven Structures' Style ES 1252, 24 x 23, 8 HSW made with Union Carbide's T-300 graphite fiber. Because this material molded (compacted) to about 0.015 in. per ply and is readily formable, it lent itself well to the continuous processes required for composite cap fabrication.

2.2.2 Current Advanced Material Candidates

The graphite/acrylic system met structural requirements for a passive structure. However, the need still existed for composite beams that would operate in the higher temperature regime of active antenna equipment. With the degree of material/machine development achieved by the graphite/acrylic forming effort, the work was extended on a limited basis to again include Gr/PS and Gr/PES strip material (Fig. 6). The initial Gr/PES panels were press molded by Spec Max, Ltd., which subsequently expanded this capability to include a strip laminating process. The Hexcel Corporation was also actively working to develop continuous laminating equipment in conjunction with Grumman requirements. This process, which was originally developed for graphite/acrylic, was modified to enable it to supply strips of Gr/PS or Gr/PES up to 50 meters long for Grumman's cap beam fabricator.

COMPOSITE CAP FORMING

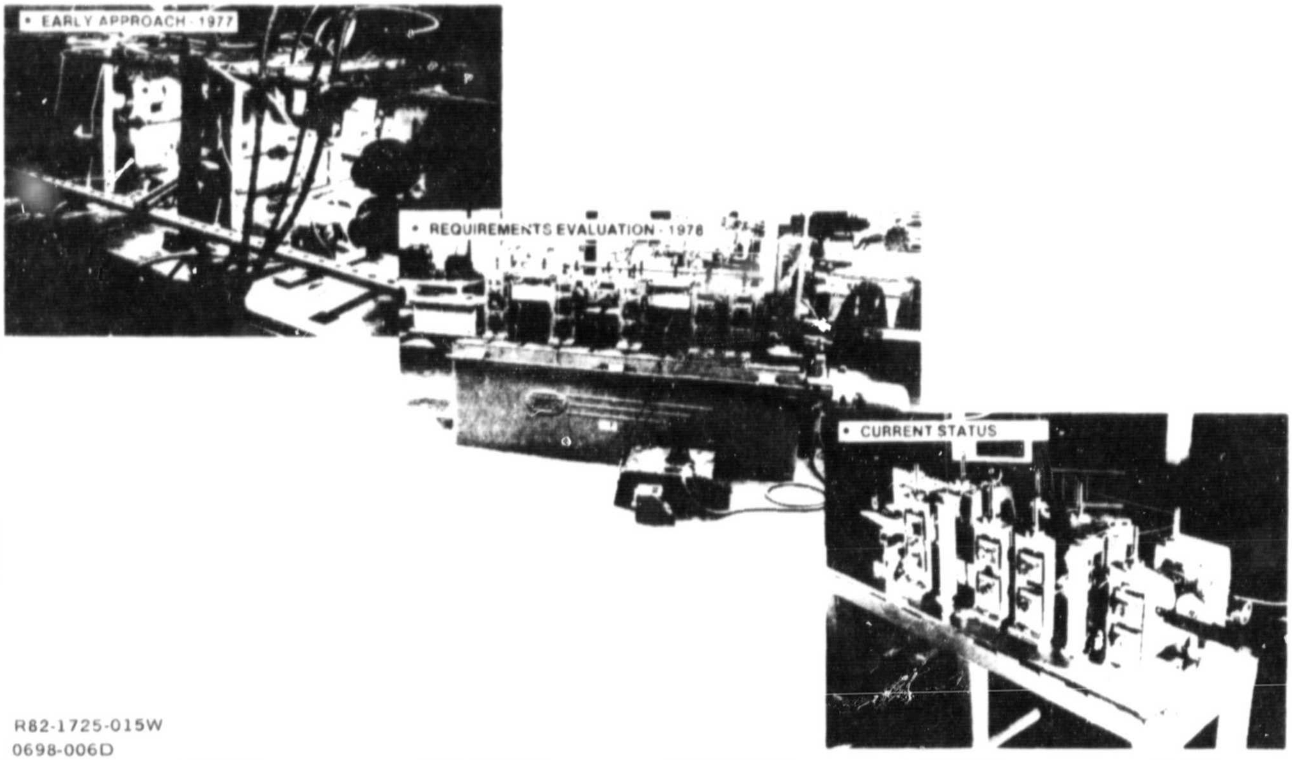

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Fig. 6 Evolution of Roll Forming Composite Materials

This work should be backed up by additional resin-matrix studies in order to develop a space-grade material for beam forming having the following general characteristics:

- Structurable Sound Material in Space Environment
  - Vacuum ultraviolet exposure
  - Vacuum electron (proton radiation)
- No Out-Gassing
  - During cap beam formation in space
  - During its operational life span (over 30 years)
- Safe Material to Handle and Fabricate
- Simple to Preprocess and Fabricate
- Long-Term Ground Storage Life without Degradation
- Long Space Life (over 30 years).

Possible improvements to composite reinforcement used in the beam cap material were also explored. Several reinforcing materials which have the potential of lightening and stiffening the beam were evaluated. Data is given in Fig. 5.

A material, consisting of unidirectional pitch graphite on the outside layers and the baseline, 24 x 23-graphite-weave center layer, was successfully roll-formed on our beam cap fabricator. As stated previously, development of the material (machine relationships and operating parameters) was severely curtailed because of budgetary restrictions. Grumman feels strongly that extensive development work in this area, as well as evaluations of single-ply, hybrid reinforcement of graphite, fiberglass and metal-matrix composites (specifically, graphite/aluminum), must be conducted in order to optimize the strength (weight/cost parameters) for the cap fabricating machine.

2.3 PROCESS SELECTION RATIONALE

Fabrication of large space structures (Fig. 7) presents an environment with restricted power and working envelopes. The environment encompasses a negligible atmosphere (vacuum), weightlessness, and radar radiation exposure. Power supplies and working envelopes are constraints imposed by the Space Shuttle. These conditions necessitate that the process selected have the following minimum characteristics:

- Debris-free (produces no gases, vapors or dust)
- Does not require gravity for processing
- Utilizes minimal processing energy
- Involves minimal space and weight equipment, and material storage
- High degree of reliability.

Matching these requirements with those of interchangeability for the existing Beam Builder, makes composite cap roll-forming a logical choice. This process is ideally suited for high-volume production, environmental constraints and Shuttle compatibility.

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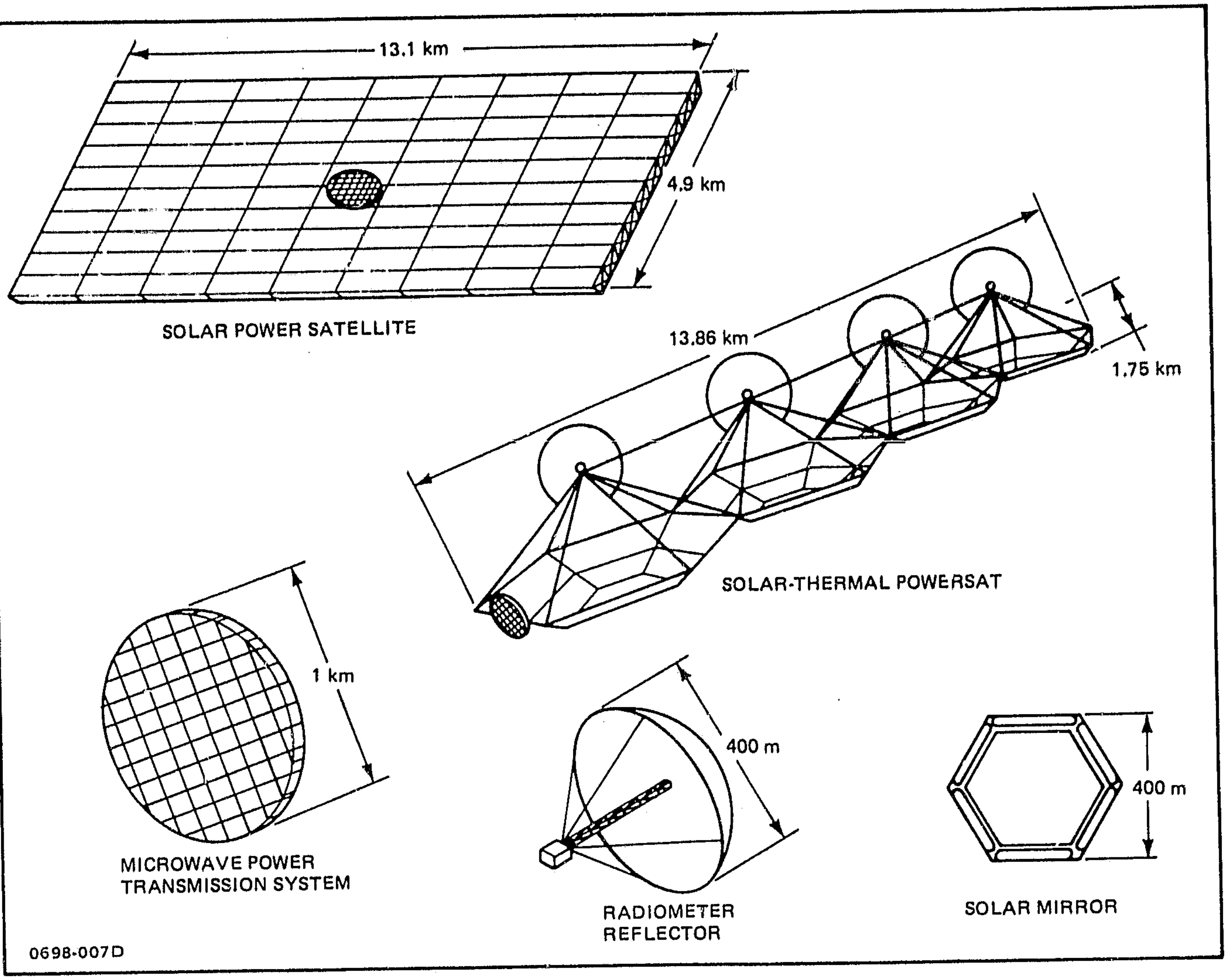

Fig. 7 Typical Large Space Structures

Section 3

TECHNICAL APPROACH

The approach taken in this program was to design, fabricate and demonstrate a composite cap, roll-forming machine that would be compatible with the Marshall Space Flight Center (MSFC) aluminum beam builder. Development of primary material fabrication technology (strip fabrication) was beyond the scope of this program; only the effort discussed in Sections 2.2 and 2.3 was addressed. Although primary material fabrication technology has progressed substantially, continuous thermoplastic composite strip forming is not at the level of true production capability. This program has underscored the need to develop materials and strip laminating technologies to a point where consistent engineering and functional properties can be achieved. This program consisted of the following three tasks:

- Task I - Prototype Cap Fabricator Design
- Task II - Fabrication of Composite Beam Cap Forming Machine
- Task III - Test and Evaluation.

3.1 TASK I - PROTOTYPE CAP FABRICATOR DESIGN

Preliminary system development and functional tests were performed on existing, Grumman cap roll-forming equipment in order to finalize the machine configuration for this program. The significant finding is that it is desirable to heat the material from both sides instead of one. This is especially true when working with higher-forming-temperature materials such as graphite/polyethersulfone. The reasons for this are as follows:

- Entire formed area must be heated to a temperature of 500°F to 600°F
- To overcome the thermal inertia of heat traveling from one surface through the material to the other surface
- A maximum allowable heating period of 25 seconds
- A maximum surface energy density which the resin can tolerate without deterioration.

After completion of the preliminary functional tests, detailed design of a Space Fabrication Demonstration System (SFDS) was initiated. This involved a capability for completely automated operation and beam builder functional requirements for stop-and-go operation. The detail and assembly drawings (Appendix A) contain sufficient information for direct part fabrication, assembly and final installation.

3.1.1 System Requirements

The overall, driving system requirements were maintaining interchangeability with the existing, aluminum cap-forming equipment and compatibility with the same Shuttle envelope constraints used in the SFDS design (Fig. 8). The composite cap fabricator was designed as a subsystem module that could be directly interchanged with the aluminum roll-forming equipment shown in Fig. 9.

The electrical controls and hardware for the cap fabricator have the inherent capability to be integrated into a beam builder system. However, the focus of this program was to provide a stand-alone capability and a functional simulation of the stop-and-go operation required for actual true beam fabrication.

3.1.2 Subsystem Design

The composite cap, roll-forming module (Fig. 10) consists of the following basic elements:

- Base plate
- Drive housings
- Roll-form tooling
- Heating system
- Servo-drive system
- Feed reel
- Support structure
- Control system.

Each of these elements is discussed in detail in the following subsections.

Base Plate - The base plate was designed to permit interchangeability with its counterpart on the aluminum beam builder. All of the detail parts that comprise the composite cap fabricator are mounted on the base plate. To minimize weight, the base plate should be made from aluminum.

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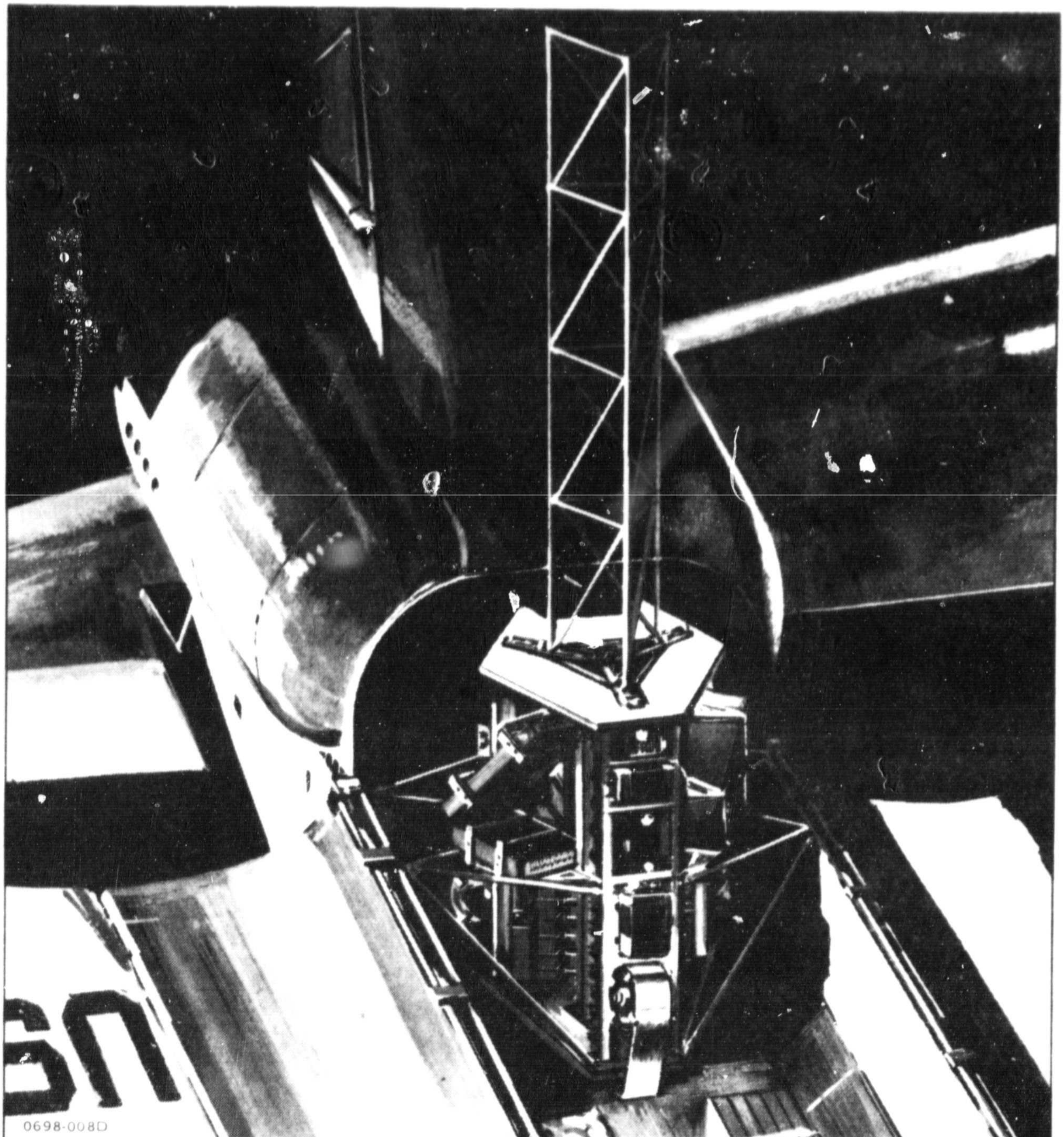

Fig. 8 SFDS Beam Builder Shuttle Payload Bay Constraint

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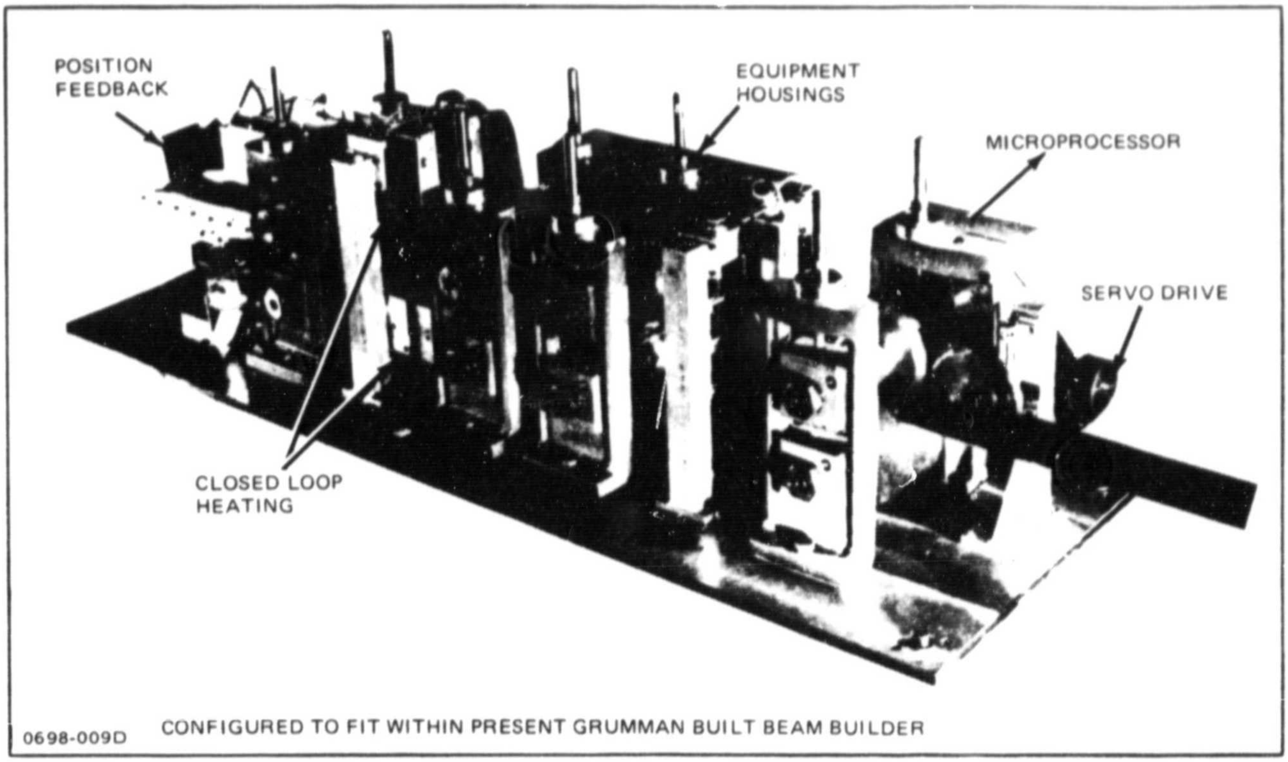

Fig. 9 Composite Cap Fabricator Interchangeability

Drive Housings - The composite cap, roll-forming machine consists of four roll-forming stations spaced sufficiently apart to permit the mounting of heating and temperature measurement devices. These stations support the roll-forming tooling as well as the gearing needed to simultaneously operate the cap roll-forming stations at the same relative speed. A lightweight version of these housings (aluminum casting) was estimated by the Yoder Company to cost about $12,000 more than standard steel castings (Fig. 11).

Roll-Form Tooling - The roll-form tooling consists of four sets of progressive roll forms fabricated from 4130 steel. These tools can be coated with a fluorocarbon material to minimize adhesion and friction during roll-forming of the hot thermoplastic composite material. A tooling flower diagram is shown in Fig. 12.

Heating System - The selection of a thermoplastic composite cap material necessitates a non-contact type of heating to raise the temperature of the material to a range slightly above its forming temperature. The system selected uses infrared energy provided by quartz heaters. Elliptical reflectors focus the energy to locally heat the composite material before it is formed at the two primary forming stations. At the entry station, heating is accomplished with parabolic reflectors in order to heat a wider band of material before it enters the first rolling station (Fig. 13). The material is evenly heated from both sides to compensate for lower incident energy density on the surface of the material and higher operating speeds.

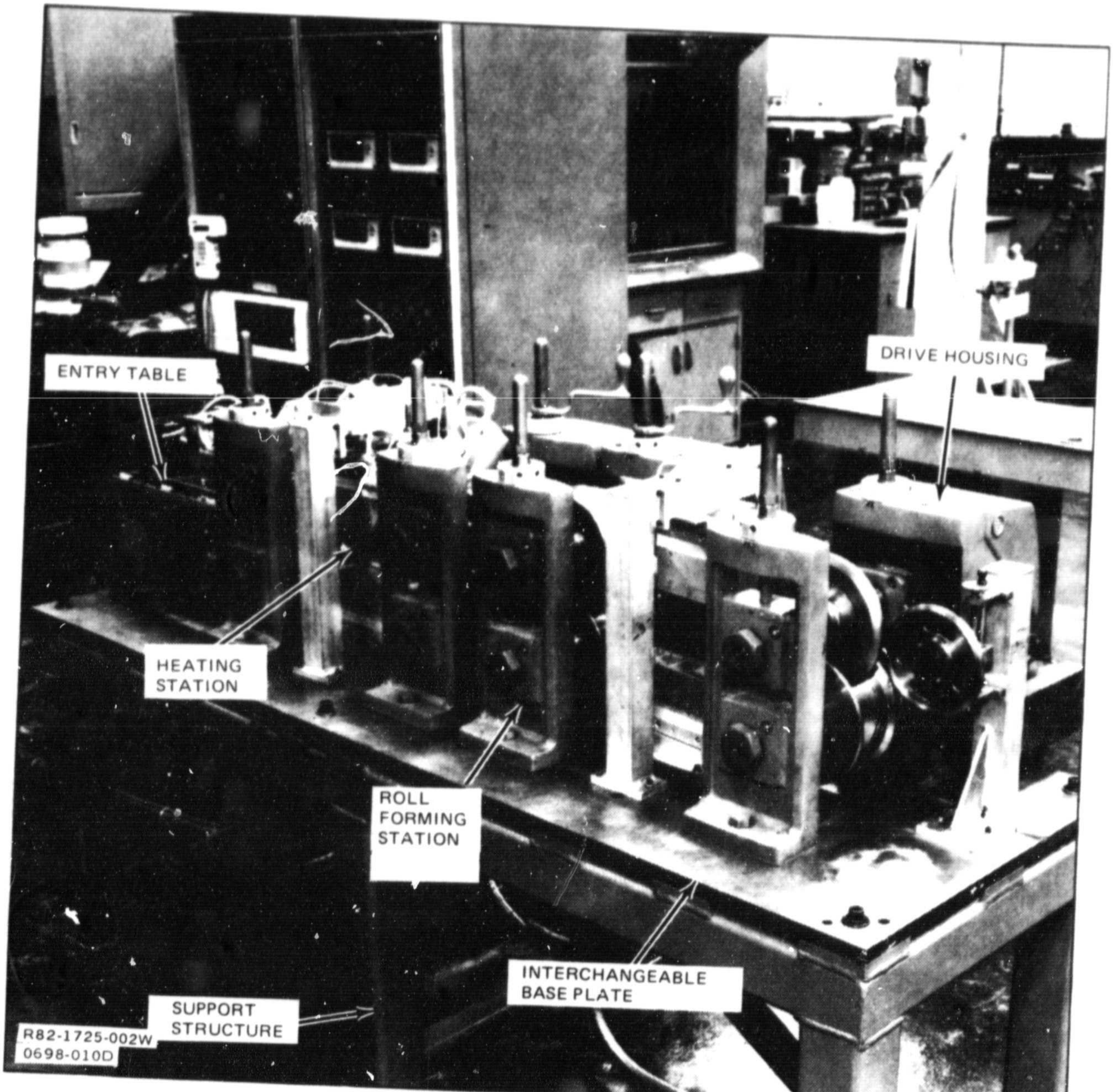

Fig. 10 Subsystem Assembly

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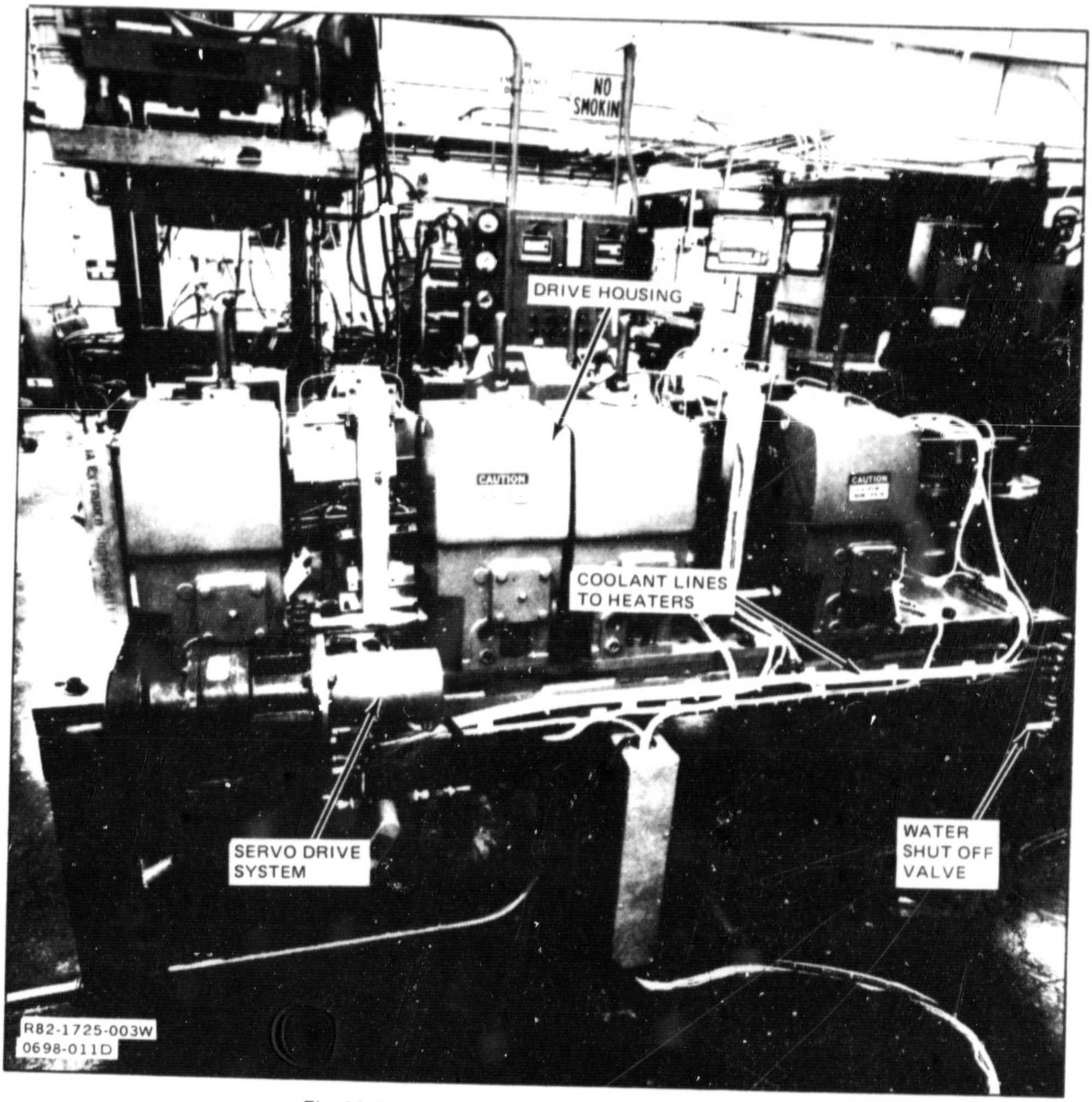


Fig. 11 Drive Housing and Servo-Drive System

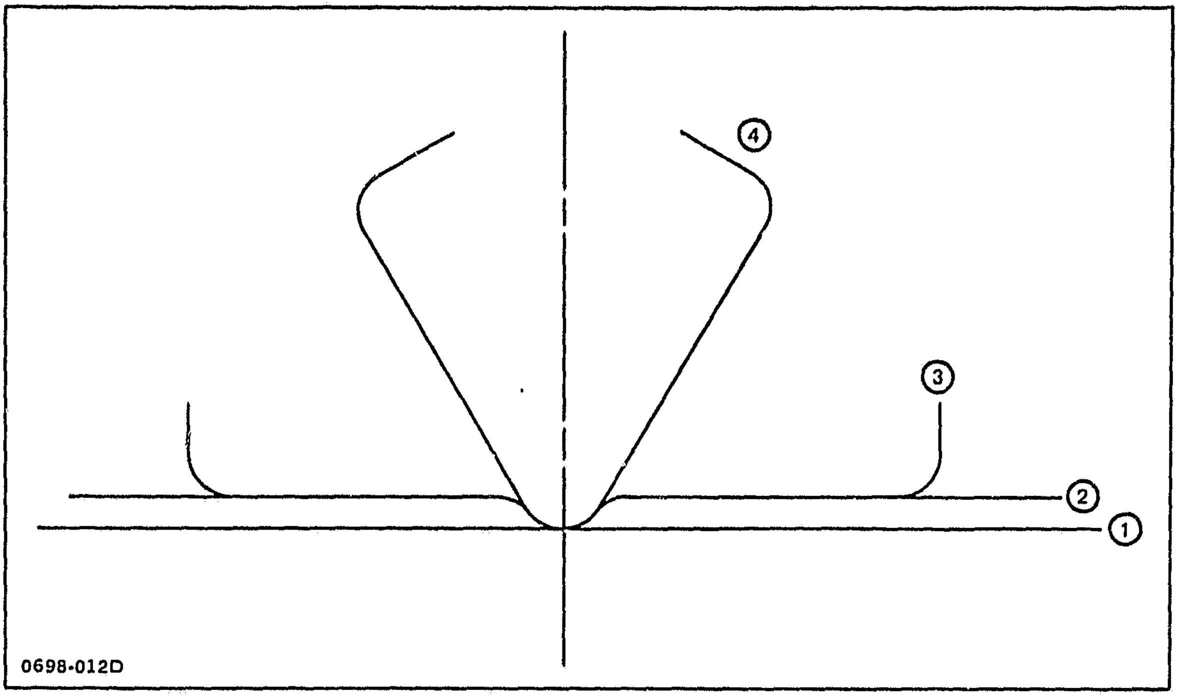


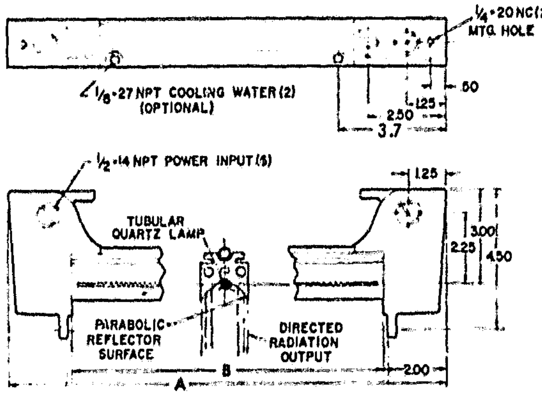
Fig. 12 Flower Diagram For Roll-Form Tooling Configuration

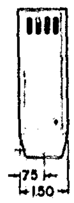
The temperature-sensing system is electro-optical in nature and has a feed-back control capability to the central controller or CPU (Fig. 14). Temperature control is governed by the energy source rather than speed control. This is because speed control requires a logic associated with the speed of the overall truss fabrication in order to assure a straight truss while adjusting speed for a specific cap member temperature.

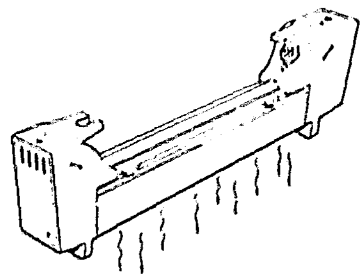
Control System - The control system (Fig. 15) is designed to permit stand-alone operation of the composite cap-forming system without being integrated into the complete beam builder. This provides the needed flexibility to experimentally determine the forming parameters.

The control system (Fig. 16) consists of the following permanent components:

- A single-board microcomputer and associated peripheral equipment to perform the overall temperature control algorithm, servo-motor control for the rolling mill, and sequencing for simulated bay-section fabrication







PERFORMANCE DATA

HEAT FLUX DENSITY — High heat flux density up to 378 watts per lineal inch per unit can be directed on target surface.

POWER RATINGS — See table, units may be operated up to double rated voltage at reduced duty cycles depending upon components overheating. Characteristics resulting from particular setup.

EMITTER CHARACTERISTICS — Emitter is tungsten in argon environment enclosed in a 3/8 inch O.D. clear quartz tube. Operates at approximately 4000°F at rated (5400°F at 2X rated) voltage, with 1.1 and .85 micron spectral energy peak, respectively.

COOLING PROVISIONS — Cooling water at 80°F or less in the quantities called for in the specification table should be provided. In some instances, such as low intensity or short cycle operation, operation without water cooling may be permissible. Operation of units with 100 watts per inch power without water cooling will produce reflector temperatures of about 500°F.

SPECIFICATIONS

	MODEL NO.	5305-2A		5305-5A		5305-7A		5305-10A		5305-16A	5305-25A		5305-38A
	Dimension A	6.56		10.00		11.96		15.00		21.00	30.00		43.00
	Dimension B	2.50		6.00		7.90		11.00		17.00	26.00		39.00
	Weight, Lbs.	1.5		2.3		3.1		2.9		3.6	4.6		6.0
Lamp (One Required But Not Included)	Type	Q500T3/CL■	Q1000T3/4CL■	500T3/CL	1200T3/CL	Q1500T3/CL■	Q1250T3/CL■	1000T3/2CL	2000T3/CL/HT	1600T3/CL	2500T3/CL	5MT4/1CL HT	3800T3/CL
	Lighted Length, Inches	2.37	2.6	5.00	6.00	6.75	6.0	10.00	10.00	16.00	25.00	25.00	38.00
	Rated Voltage	120	120	120	144	240	208	240	240	240	480	600	570
	Current, Amps	4.17	8.34	4.17	8.34	6.25	5.8	4.17	8.34	6.66	5.21	8.34	6.66
	Rated Power, KW	.50	1.0	.5	1.2†	1.5	1.25	1.0	2.0	1.6	2.5	5.0	3.8
	Power at 2 x Rated Voltage	■	■	1.4	3.4	■	■	2.8	5.7	4.5	7.1	14.2	10.0
	Water Coolant Flow, GPM	.06	.10	.04	.10	.13	.12	.08	.16	.13	.20	.40	.30
Heat Flux Output	Output Watts Per Linear Inch at Rated Voltage	140	255	58	140	134	111	63	126	66	67	135	68
	At 2 x Rated Voltage	■	■	156	378	■	■	170	340	178	181	364	184

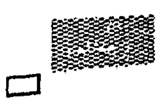
⊕ Alternate reflector body B is slightly less efficient (approx. 5%) than body A, but is more directional since it has a deeper parabolic reflector.
† At 240 volts, 1200T3/CL dissipates 2.6 KW, produces, 302 watts/in. ■ Iodine cycle type. Rated Voltage only.
• Toggle switch is wired for remote on-off control only, and plug is not provided on end of 8 foot leads.

ORDERING EXAMPLE: 5305 — Basic Model; —10 — Lighted Length; —B — Alternate Reflector Body⊕ (Order Lamp Separately From Above Table)

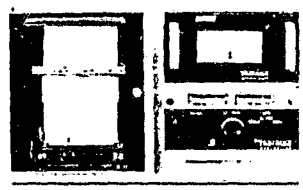
CLOSED-LOOP TEMPERATURE CONTROL

Standard R-I Thermac* Temperature Power Controllers and Data-Trak® Curve-following programmers offer practical high-performance closed-loop temperature control for both static (set point) or dynamic (programmable) heating conditions. Phaser* Proportional SCR Power Controller provides manual open-loop control in a compact package.

*Trade Marks of Research, Incorporated, Minneapolis, Minn.



Phaser SPR Solid-State Proportional Power Controller



DATA TRAK® Model 5300 | THERMAC* Model 625

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Fig. 13 Comparison of Elliptical/Parabolic Heaters (Sheet 1 of 2)

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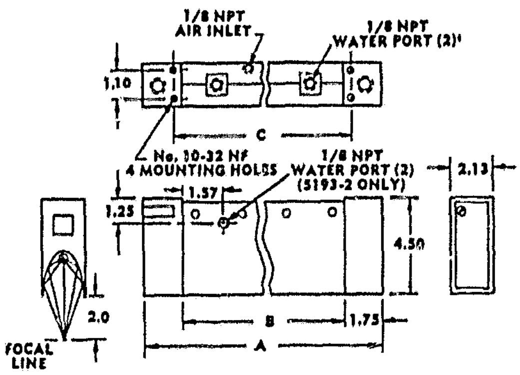
OPTIONS

-W Quartz window of 1/16 inch polished quartz. Used where reflector and lamp contamination may be a problem due to specimen fumes. The window reduces the efficiency by approximately 10%.

-R Reflector of specular Ceragold tm attaches at the ends of the unit to reduce end-radiant losses.

DIMENSIONS



SPECIFICATIONS													
Dimensions	MODEL NUMBER	5193-2		5193-5		5193-6		5193-10		5193-16	5193-25		5193-38
	A Overall Length, in	6.08 (15.4 cm)		9.5" (24.1 cm)		11.0" (27.9 cm)		14.5" (36.8 cm)		20.5" (52.1 cm)	29.5" (75.0 cm)		42.5" (108.0 cm)
	B Chamber Length, in.	2.58 (6.6 cm)		6.0" (15.2 cm)		7.5" (19.1 cm)		11.0" (27.9 cm)		17.0" (22.2 cm)	26.0" (66.0 cm)		39.0" (98.8 cm)
	C Mounting hole spacing	3.33 (8.5 cm)		6.75" (17.2 cm)		8.25" (21.0 cm)		11.75" (29.9 cm)		17.75" (24.1 cm)	26.75" (67.9 cm)		39.75" (100.7 cm)
Weight, pounds		3.0 lbs (1.4 kg)		5.2 lbs (2.3 kg)		6.0 lbs (2.7 kg)		7.9 lbs (3.6 kg)		11.2 lbs (5.1 kg)	16.1 lbs (7.3 kg)		23.0 lbs (10.4 kg)
Lamp (one required but not included)	Type	Q500 T3/CL	Q1000 T3/4CL	500 T3/CL	1200 T3/CL	Q1250 T3/CL	Q1500 T3/CL	1000 T3/2CL/HT	2000 T3/CL/HT	1600 T3/CL	2500 T3/CL	5M T3/1CL/HT	3800 T3/CL
	Lighted length, in	2.4" (6.1 cm)	2.6" (6.6 cm)	5.0" (12.7 cm)	6.0" (15.2 cm)	6.0" (15.2 cm)	6.75" (17.2 cm)	10.0" (25.4 cm)	10.0" (25.4 cm)	16.0" (20.3 cm)	25.0" (63.5 cm)	25.0" (63.5 cm)	38.8" (118.7 cm)
	Rated Voltage	120	120	120	144[3]	208	240	240	240	240	480	600	570
	Current, Amps	4.17	8.34	4.17	8.34	6.04	6.25	4.35	8.70	6.96	5.32	8.33	6.67
	Rated Power, KW	.50	1.00	.50	1.20	1.25	1.50	1.00	2.00	1.60	2.50	5.00	3.80
	Power at 2x Rated Volts, KW	NA[1]	NA[1]	1.4	3.4[3]	NA[1]	NA[1]	2.8	5.7	4.5	7.0	14.0	10.6
Cooling Water Flow,[2] GPM		.05	.10	.05	.12	.13	.15	.10	.20	.16	.25	.50	.29
Heat Flux at Focus, Watts/Linear Inch, at Rated Voltage		133	254	59	128	133	144	65	130	67	68	138	69
at 2x Rated Voltage		NA[1]	NA[1]	167	406	NA[1]	NA[1]	183	373	190	114	394	191

NOTES:
[1] Do not exceed rated voltage on quartzline lamps.
[2] Flow at long term steady state conditions.
[3] At 240 volts, the 1200T3/CL dissipates 2.6 KW, pro[illegible]s 312 watts/linear in.
[4] Except 5193-2

ORDERING EXAMPLE: 5193 (Basic Model) -10 (Lighted Length) -R (Ceragold End Reflectors (Optional)) -W (Quartz Window (Optional))

PERFORMANCE DATA

HEAT FLUX DENSITY—High density radiant heat flux up to 406 watts per linear inch (based on calorimeter tests) on a narrow (.08-.18 inch) focal line can be generated.
POWER RATINGS—See table. Units may be operated at up to double rated voltage for short duty cycles provided the lamp envelope and reflector are not permitted to overheat. When operating Model 5193-25 at twice rated voltage, special electrical insulator considerations must be made.
EMITTER CHARACTERISTICS—Emitter is a tungsten filament in Argon atmosphere enclosed in a 3/8 inch (O.D.) clear quartz tube. Operates at approximately 4000 degrees F at rated, and 5400 degrees F at 2X rated voltage, with 1.1 and .85 micron spectral energy peak, respectively.
REFLECTOR—The reflector used to focus the energy radiated from the linear emitter filament is a two-dimensional ellipse of specular aluminum with provisions for water cooling and lamp envelope gas cooling.
MODULAR CONSTRUCTION—Line Heater construction consists of an electro-polished stainless steel backbone to which aluminum end covers and reflector are attached.
MOUNTING PROVISION—Four No. 10-24 N.C. threaded holes are provided on the main frame for mounting and for attaching various accessories such as a handle.
SERVICES—Power is applied to lamp through ½" NPT holes at each end of main frame. Clean water at 70 degrees F or less for reflector cooling should be supplied to the reflector through two No. ⅛ NPT ports provided. Gas for purging the work-piece heated area or for cooling lamp envelope can be introduced through the No. ⅛ NPT port centered on the main frame.

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Fig. 13 Comparison of Elliptical/Parabolic Heaters (Sheet 2 of 2)

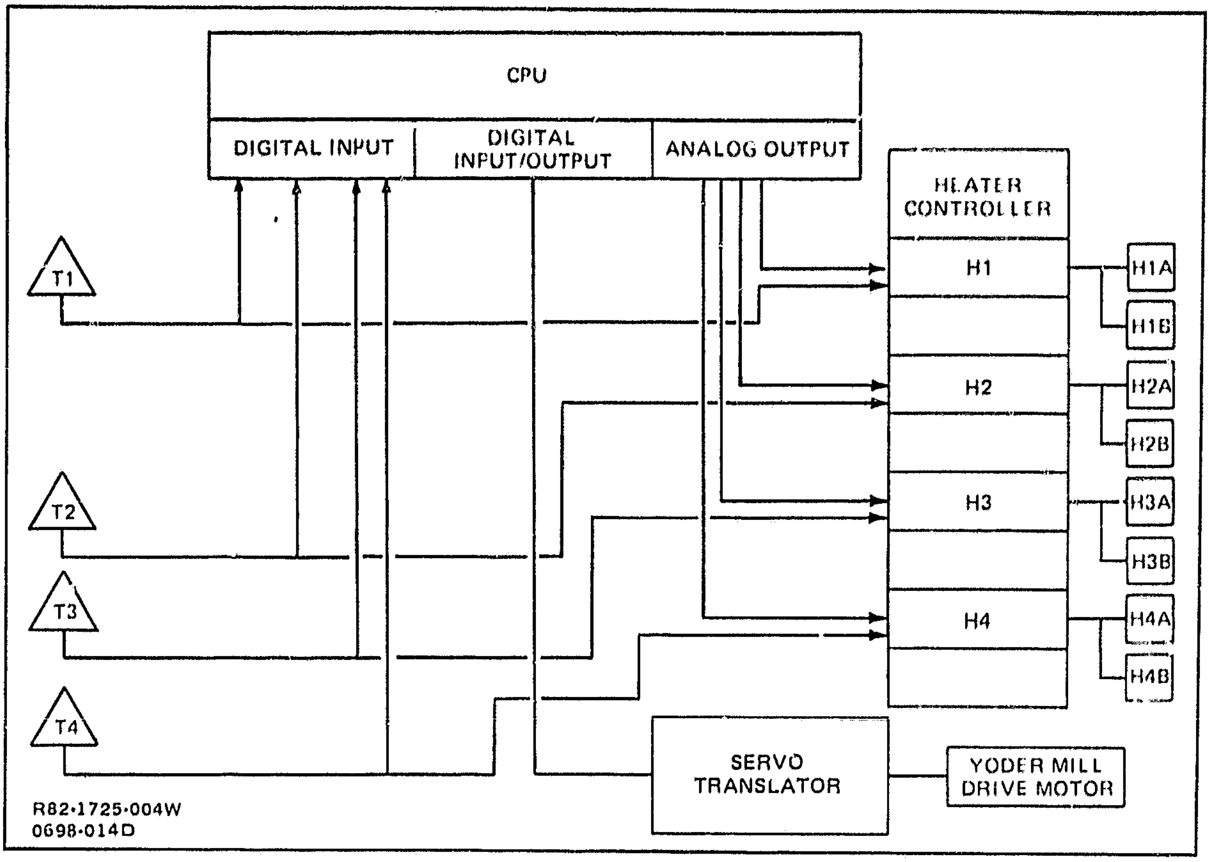

Fig. 14 Temperature Control System

- Four proportional infra-red quartz lamp controllers, which provide a closed-loop servo-control for each of the rolling mill heating stations. Local setpoints on each controller provide for experimental determination of average forming temperatures. Remote setpoints, generated by the microcomputer via its control algorithm, permit optimization of heating and forming rates
- Four optical pyrometers and displays for non-contacting temperature measurements at each heating station; these provide the feedback signals necessary for the proportional controllers, and the microcomputer. Optimum target size for each heating station has been established as a function of lens type and viewing distance.

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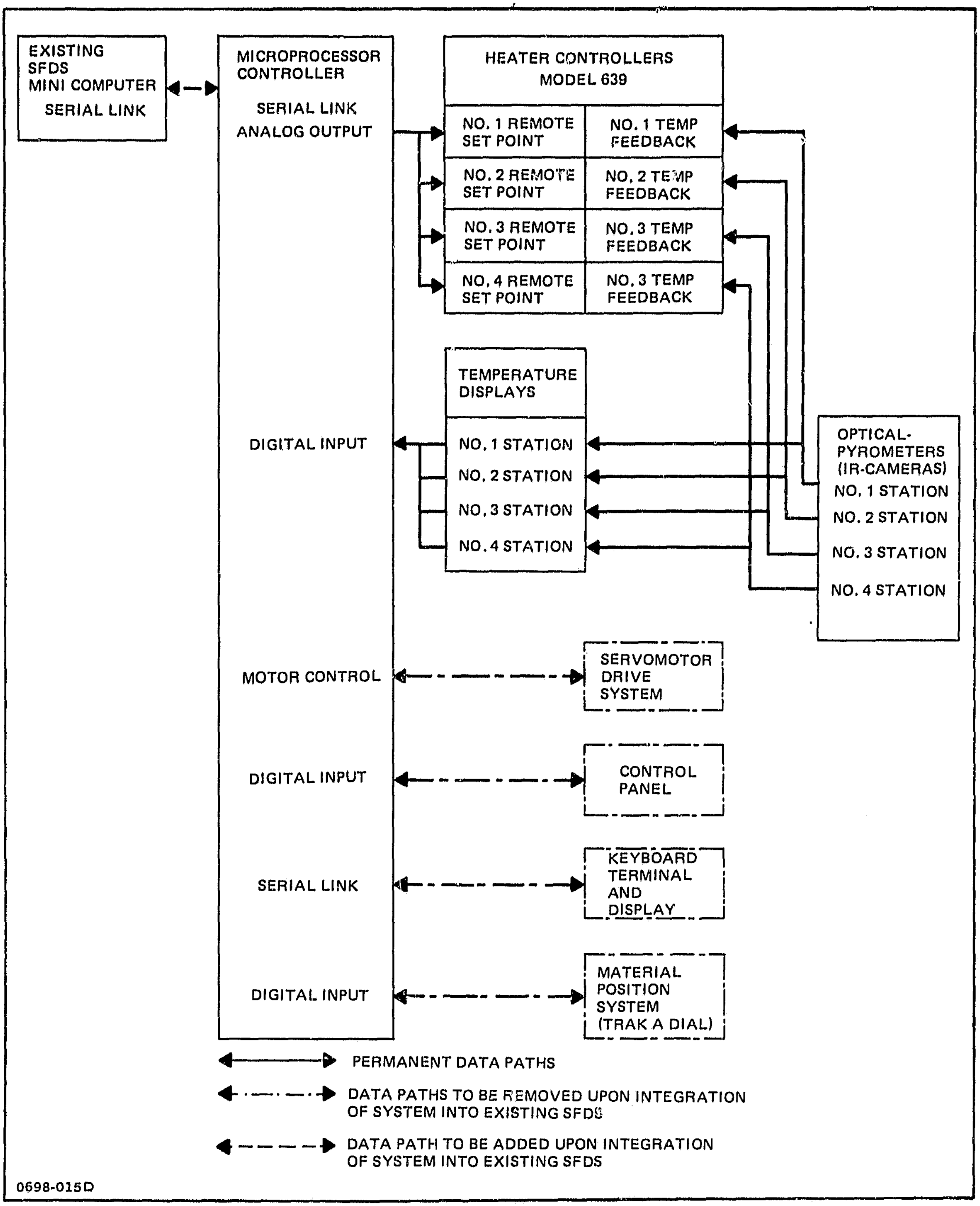

Fig. 15 Control System Block Diagram

The following components are included in the stand-alone bench model but would be removed upon integration into the completed beam builder:

- A custom-designed control panel, and a keyboard terminal and display. These provide both manual mode operations and digital entries into the microcomputer for simulated bay section fabrication. Various control system parameters can be displayed for system optimization as a function of the composite material type

  The digital constants and mode commands, which at present come from the control panel and terminal, would, when integrated into the beam builder, come from a central minicomputer via a serial link

- A servo-motor drive system, including microcomputer interface, necessary for driving the rolling mill
- TRAV-A-DIAL material position system for feedback to the microcomputer for controlling the rolling mill during simulated bay section fabrication.

The primary task of the control system is to provide remote setpoints (desired temperatures) to the four closed-loop proportional controllers. The microcomputer changes the setpoints as a function of material type (e.g., graphite/acrylic, Gr/PES) and the measured material temperatures at each station. Narrow bandwidths (high gain) on the proportional controllers are used for better temperature stability. In addition, overheating of the material surfaces is prevented by the computer which increases the setpoints to the controllers in small increments until the desired temperatures are obtained. The incremental changes in the setpoints for each station are calculated dynamically to prevent full power from being used on any of the heaters. Electrical integration requirements are listed in Appendix B.

Material Feed and Entry Table - The material feed subsystem consists of the material storage reel, which supplies the thermoplastic strip material to the entry table, and the entry table, which properly aligns the material before it enters the first roll-forming station. The entry table was designed to be basically similar to that of the existing SFDS aluminum beam builder. Some alterations were made to accommodate the heating and temperature-sensing system. The feed-roll assembly for this stand-alone unit was designed to be assembled to the support structure to simplify alignment and installation. A braking mechanism is used to prevent the coil of material from unwinding as a spring. This is accomplished by applying drag to the coil as it unwinds into the machine (Fig. 17).

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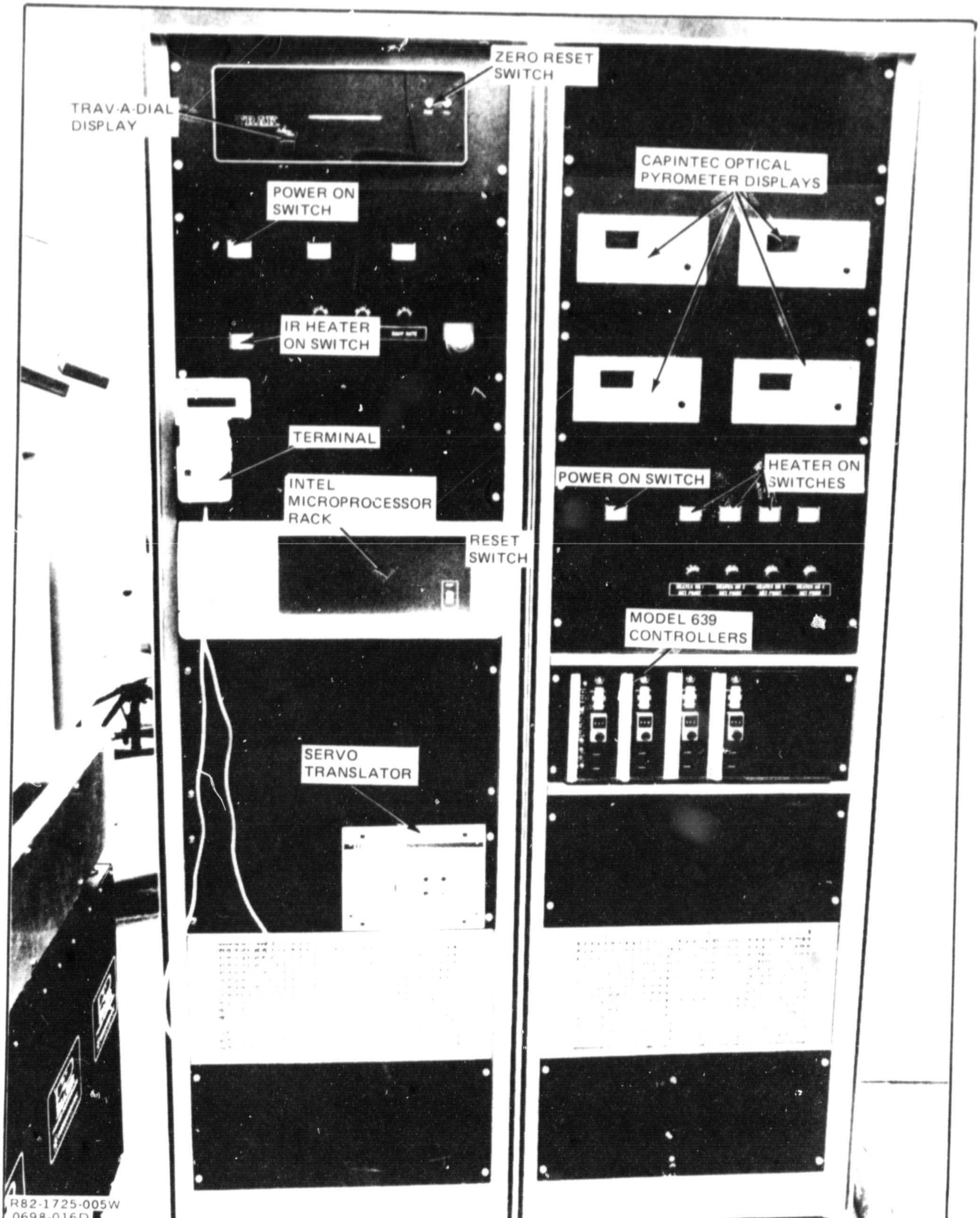

Fig. 16 Composite Cap Fabricator Control System

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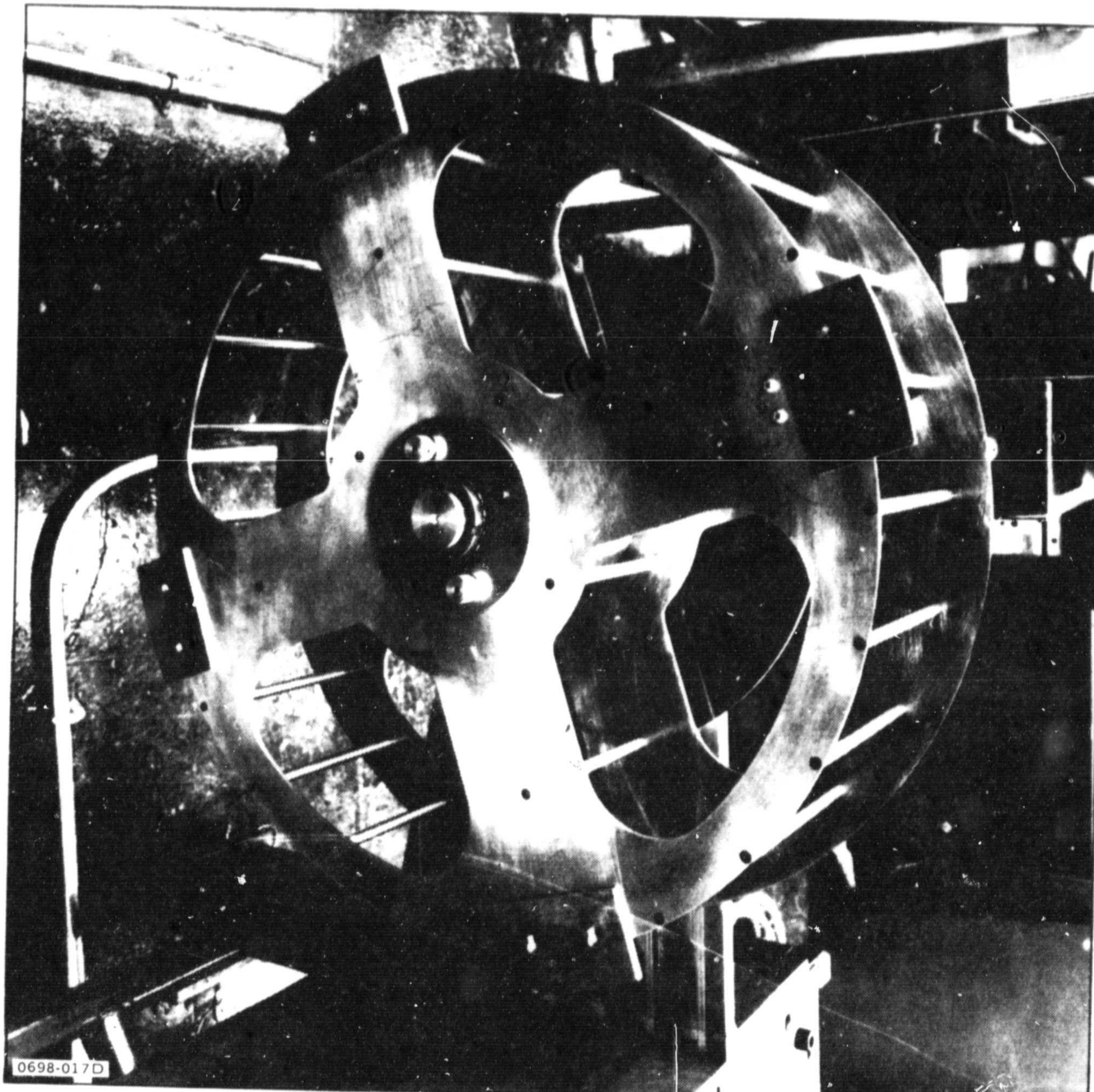

Fig. 17 Material Feed Spool

Servo-Drive System - The drive subsystem consists of a servo-motor, controller and gear box manufactured by Control Systems Research, Inc. (Ref. Fig. 11). This unit is identical to the unit used on the SFDS aluminum beam builder except for the gear ratio.

Support Structure - A support frame was designed for mounting the stand-alone cap fabricator unit and feed roll mechanism. In the interest of economy, this structure was designed as a simple, welded structural steel assembly that required no machining (Ref. Fig. 10).

3.2 TASK II - FABRICATION OF COMPOSITE BEAM CAP FORMING MACHINE

3.2.1 Approach

This effort was devoted to detailed fabrication of the composite, cap member forming machine (Section 3.1) that was approved by an MFSC/Grumman Critical Design Review (CDR). This machine represents a complete stand-alone, forming subsystem consisting of the following:

- Feed roll
- Aligning devices
- Forming equipment
- Heating and temperature-measuring devices
- Drive system
- Controllers
- Power supplies, electrical interface and miscellaneous electronics, as required.

The primary goal of complete interchangeability and compatibility with the existing SFDS aluminum beam builder was met, except for location of the feed-roll mechanism. This could not be achieved because the feed-roll mechanism on the SFDS was located on the superstructure of the beam builder.

3.2.2 Detail Part Fabrication and Procurement

The basic program approach involved procurement of commercial hardware whenever practical. It had been originally proposed to use light-weight materials for the rolling mill base-plate, drive housings and roll-form tooling. However, because of budget restrictions, existing off-the-shelf hardware was utilized. The procured machine components are listed in Appendix C.

3.3 TASK III - TEST AND EVALUATION

3.3.1 Approach

Limited availability of Gr/PS and Gr/PES strip laminates made it necessary to perform machine testing under very constrained conditions. This material limitation was caused by vendor strip-fabrication difficulties with these state-of-the-art materials.

3.3.2 Functional Tests

The completely assembled, composite cap, roll-forming machine was debugged to achieve proper operation of the mechanical and electrical components, individually as well as part of an integrated unit. Demonstration testing involved fabrication of composite cap members from the several candidate materials to simulate full system operation. Processing and operating parameters were established on a very limited basis for each candidate material.

Strip-forming speed was maintained at 14 inches per minute (ipm) for each material evaluated. The heating system was calibrated using Gr/acrylic strip and reference thermocouples. After calibration, the temperature delays were used to indicate the forming temperature for each of the three primary materials. Forming temperatures for Gr/acrylic, Gr/PS and Gr/PES were 325°F, 490°F, and 590°F, respectively.

Power measurements were taken during the forming operations for the Gr/PS strip material. These measurements showed that the parabolic heaters were running at a power level of 562 watts, while the rest of the heaters were running at a power level of 354 watts. Total power consumption of the heaters for a forming speed of 14 ipm was 1,626 watts. As predicted, this power consumption level was considerably higher than the previously measured power consumption of 300 watts for the Gr/acrylic strip material.

3.3.2.1 Formed Part Verification. The formed parts were checked to verify their geometry relative to that for automated fabrication. Part geometries were dimensionally consistent for each of the demonstration parts fabricated and were well within engineering drawing tolerances. Of the two, 12-ft-long Gr/PS caps fabricated, longitudinal straightness was within 0.06 inch. One of these caps was cut to provide an axial compression test specimen; the other cap was delivered to MSFC.

3.3.2.2 Element Testing of Cap Section. One Gr/PS cap section was prepared for axial compression testing per the configuration shown in Fig. 18. This specimen was subjected to axial loading; it failed at an ultimate load of 490 pounds. This compares favorably to a cap load-carrying capability of 500 pounds for an aluminum cap. Analysis of the cap material indicated a resin content of 34 percent; the desired resin content was 40 percent. This lower-than-normal resin content is the result of the state-of-the-art of strip laminating. Improvement of the capability should enhance both roll-forming and structural efficiency.

3.3.3 Operating Procedures

The cap fabricator control system was designed to provide the features required to permit the overall system to be used as a research and development tool. These features allow a trained operator to vary system parameters (i.e., heating loop set point temperatures, rolling feed rates, and distances), which are dependent upon the unique characteristics of different composite materials, or potentially different cap configurations. In addition, both a strictly manually controlled mode of cap fabrication for setup and check-out purposes, and a simulated semi-automatic bay length fabrication cycle are included. The semi-automatic cycle closely simulates the expected operations to be performed if the composite cap fabrication were to be integrated into the aluminum beam builder. Where possible, commercially available electronic hardware was utilized to minimize potential development costs and risks.

3.3.3.1 Control System - Theory of Operation. The four major components of the control system are:

- Heating control loops - four identical systems control the amount of radiant heat applied to four distinct areas of the composite material
- Servo-motor control loop - provides the required electro-mechanical drive to enable the rolling mill to move and form material
- Microprocessor system - provides overall system-level control and parameter optimization
- Software system - programs required by the microprocessor to provide control functions.

Each major component is described in order to illustrate the overall capabilities of the control system.

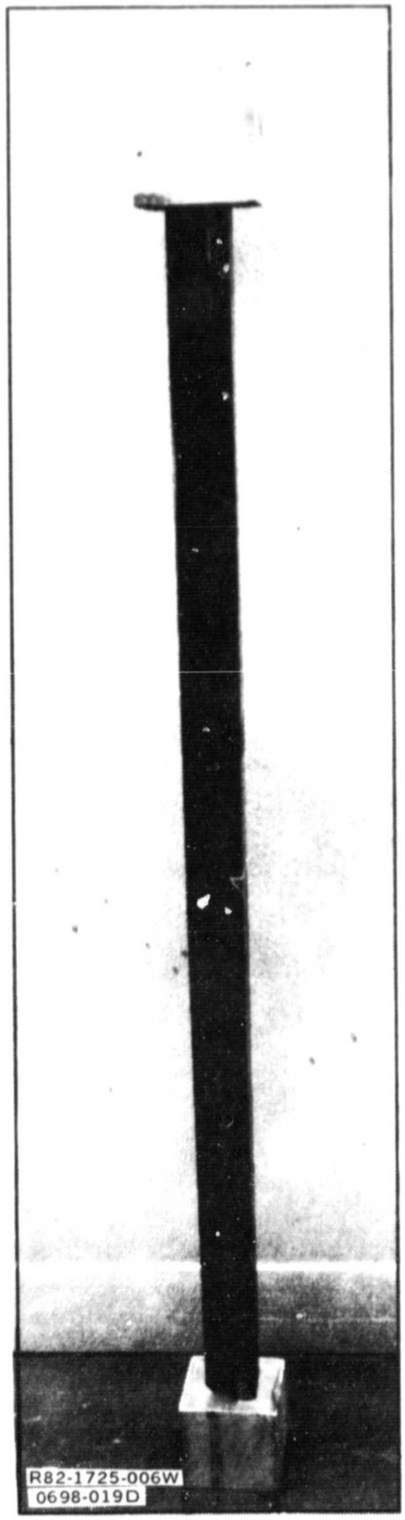

Fig. 18 Axial Compression Test Specimen

3.3.3.1.1 Heating Control Loops - Four heating stations were designed as shown in Fig. 19. Each station provides local radiant heating to both the top and bottom sides of the composite material. The actual area of material heated at each station is in the 0.75 x 6-inch range. An optical pyrometer (a non-contacting temperature probe) is mounted at each station to measure the surface temperature of the material leaving the heating station. Two quartz lamps at a station are mounted above and below the material at the focal length of the reflector assembly (nominally two inches). Fine adjustments were made to the mounting heights to optimize the actual heated area of the material as required.

A functional block diagram of the electronic hardware for a single heating station is illustrated in Fig. 20. The two 115-VAC quartz lamps at each station are wired in series for Station No's. 2, 3 and 4, and in parallel for Station No. 1. The lamps receive power from a Research Inc., Model 646 SCR power controller which is supplied with 115 VAC through a large contactor-type relay. The relay is controlled by a manual switch labeled "HEATER ON" in the right-hand control rack and a water flow switch. The water flow switch is used to verify that sufficient cooling water is supplied to the eight quartz heater assemblies. This prevents oxidation of the internal reflectors. Each Model 646 power controller has an associated set-point or offset potentiometer. The potentiometer establishes the minimum amount of power that will be delivered at all times to the quartz lamps. It is generally adjusted to provide a low orange glow on each of the quartz filaments in the heaters. This level allows longer filament life by minimizing the temperature cycling extremes of the filament.

The control signal to the Model 646 power controller is generally provided by the Research Inc., Model 639 single-loop controller. A relay, controlled by a manual switch labeled "IR HEATER ON/OFF" on the left-hand control rack, supplies either the Model 639 control signal or a zero-volt signal to the Model 646 power controller. The "IR HEATER ON/OFF" switch in the "OFF" position sets up the system initially and adjusts the heater set point potentiometers for the Model 646 power controller.

The temperature feed-back signal from each Capintec optical pyrometer to its respective Model 639 controller is generated by the pyrometer and displayed on a digital display. The Model 639 controller operates as a standard analog, closed-loop, proportional controller with temperature feed-back. Through a switch mounted in the Model 639 controller, labeled "LOCAL/REMOTE", the desired set point for the loop

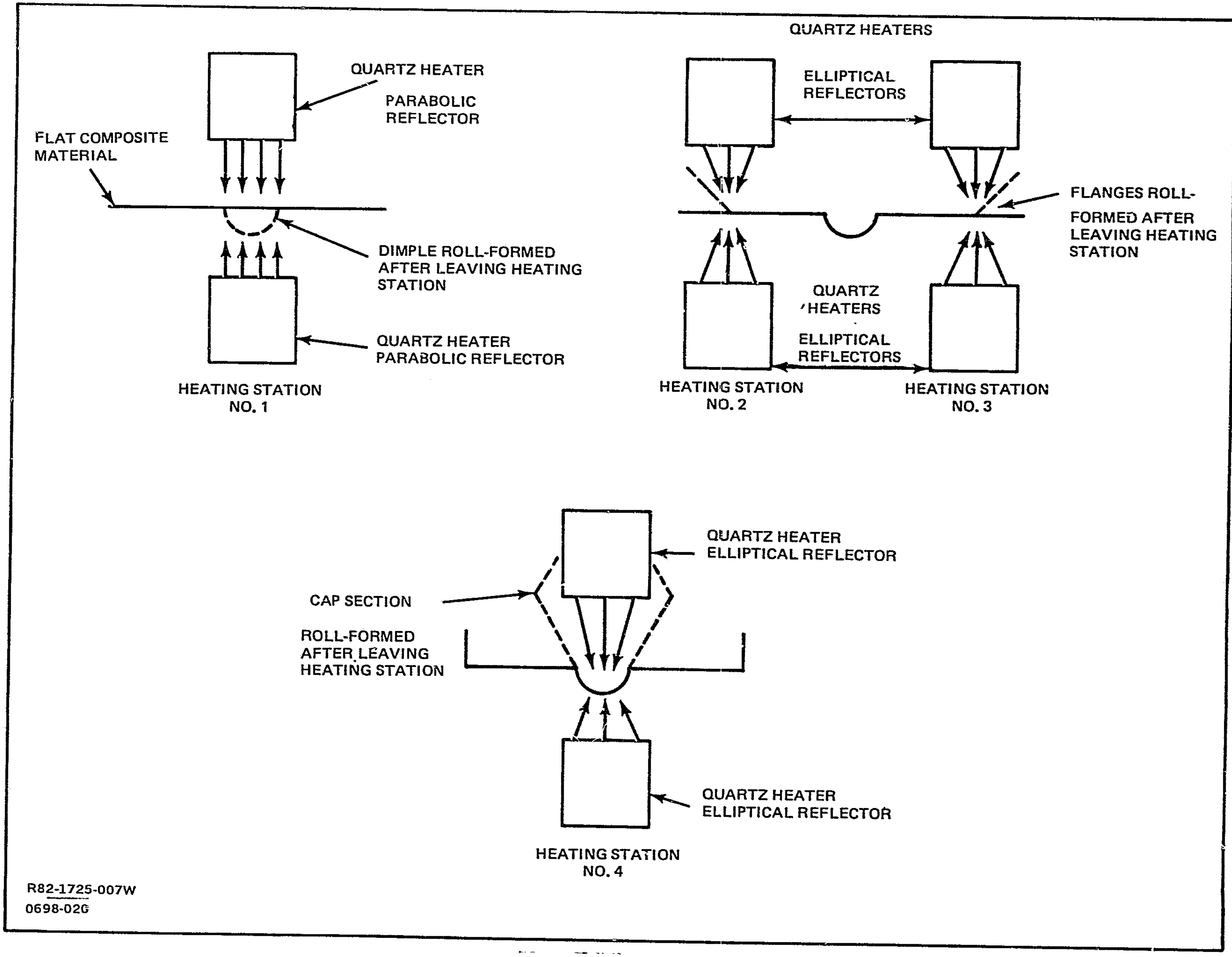

Fig. 19 Heating Stations

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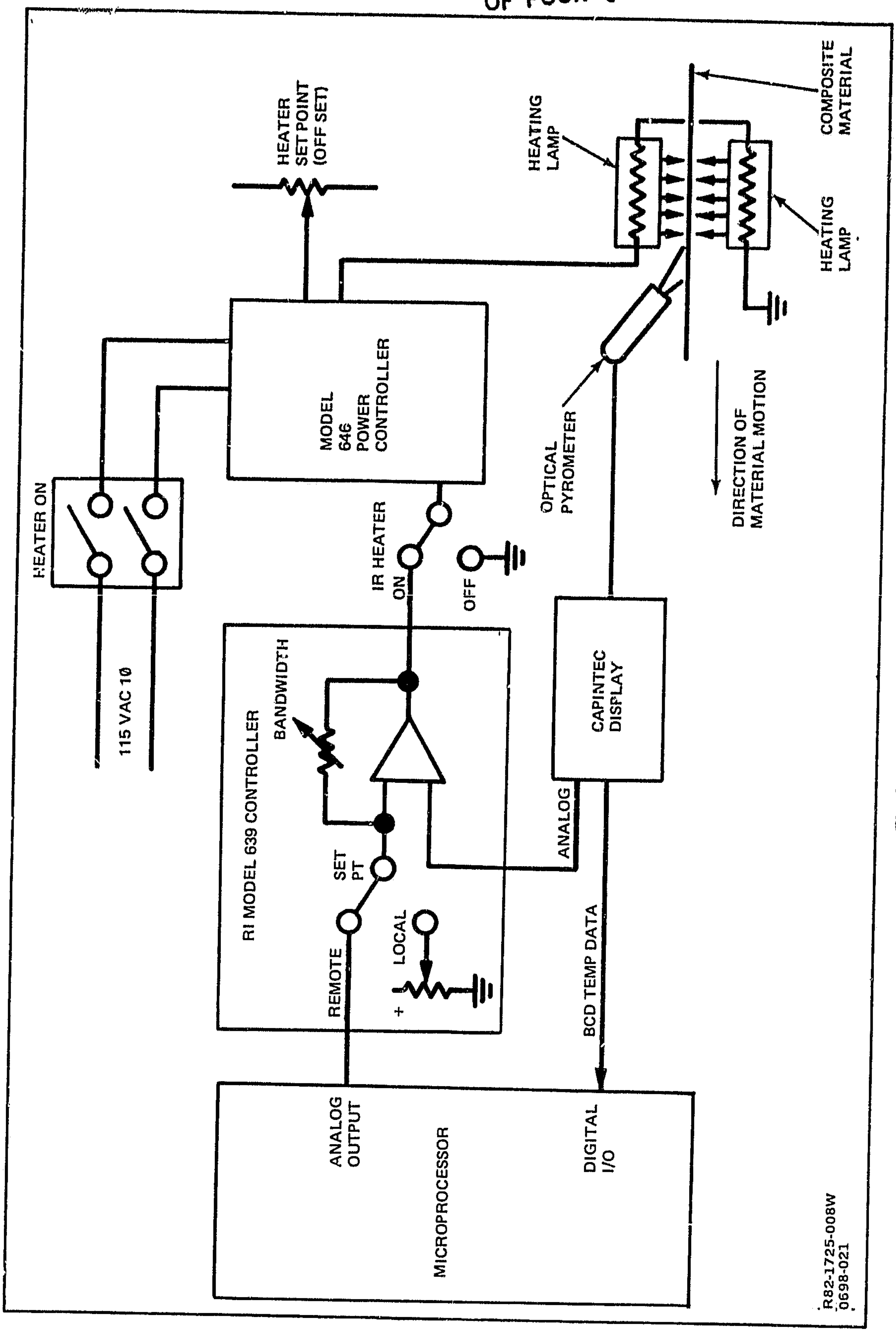

Fig. 20 Typical Heater Control Loop

can be selected to come from a local set-point potentiometer, or from the microprocessor. The temperature data from the Capintec display is also forwarded to the microprocessor in binary coded decimal format. This data is used when the machine is run in the semi-automatic mode.

3.3.3.1.2 Servo-Motor Control Loop - Electro-mechanical power to roll-form the heated composite material is provided to the rolling mill by a DC servo-motor and gear box assembly. The motor-drive feed-back loop is illustrated in Fig. 21. The servo-motor, which contains an integral tachometer and resolver, is powered by a Control Systems Research, Inc., Model ST703 servo-translator. The translator and motor were designed by the manufacturer to replace stepper-motor drive systems, but not to suffer any of the speed/resonance problems inherent in stepper systems. This requires that clock rate rpm and direction sense be fed to the translator from the control system. The translator contains various jumper-selectable options that fix the input clock rate to provide a maximum of fifteen different resultant motor speeds and resolutions. A custom-designed interface card was fabricated and installed in the microprocessor rack to generate the necessary command signals to the servo-controller under microprocessor command. To provide the maximum flexibility in forming speeds, the system was designed to permit the operator to set, via potentiometers on the left-hand control rack, the minimum and maximum roll-forming speeds of the drive motor. In addition, the rate at which the motor will accelerate from minimum to maximum speed, decelerate from maximum to minimum speed, is provided by the rate potentiometer. The microprocessor provides the necessary signals to start or stop the motor in either the forward or reverse direction, and to ramp-up to maximum speed or ramp-down to minimum speed. Two manual switches, "MILL ON/OFF" and "FWD/REV", located on the left-hand control rack, are interfaced to the microprocessor for operator inputs and control while in a manual mode of operation.

A standard, off-the-shelf position-measuring system, manufactured by TRAV-A-DIAL, is mounted on the rolling mill to measure the amount of composite material that is roll-formed. The data from the measuring system's display is input to the microprocessor system for control purposes during the semi-automatic mode of operation.

3.3.3.1.3 Microprocessor System - Overall control of the system is maintained by the Intel Model 80/30 single-board computer and its associated logic cards mounted in the left-hand control rack. A block diagram of this system is illustrated in Fig. 22.

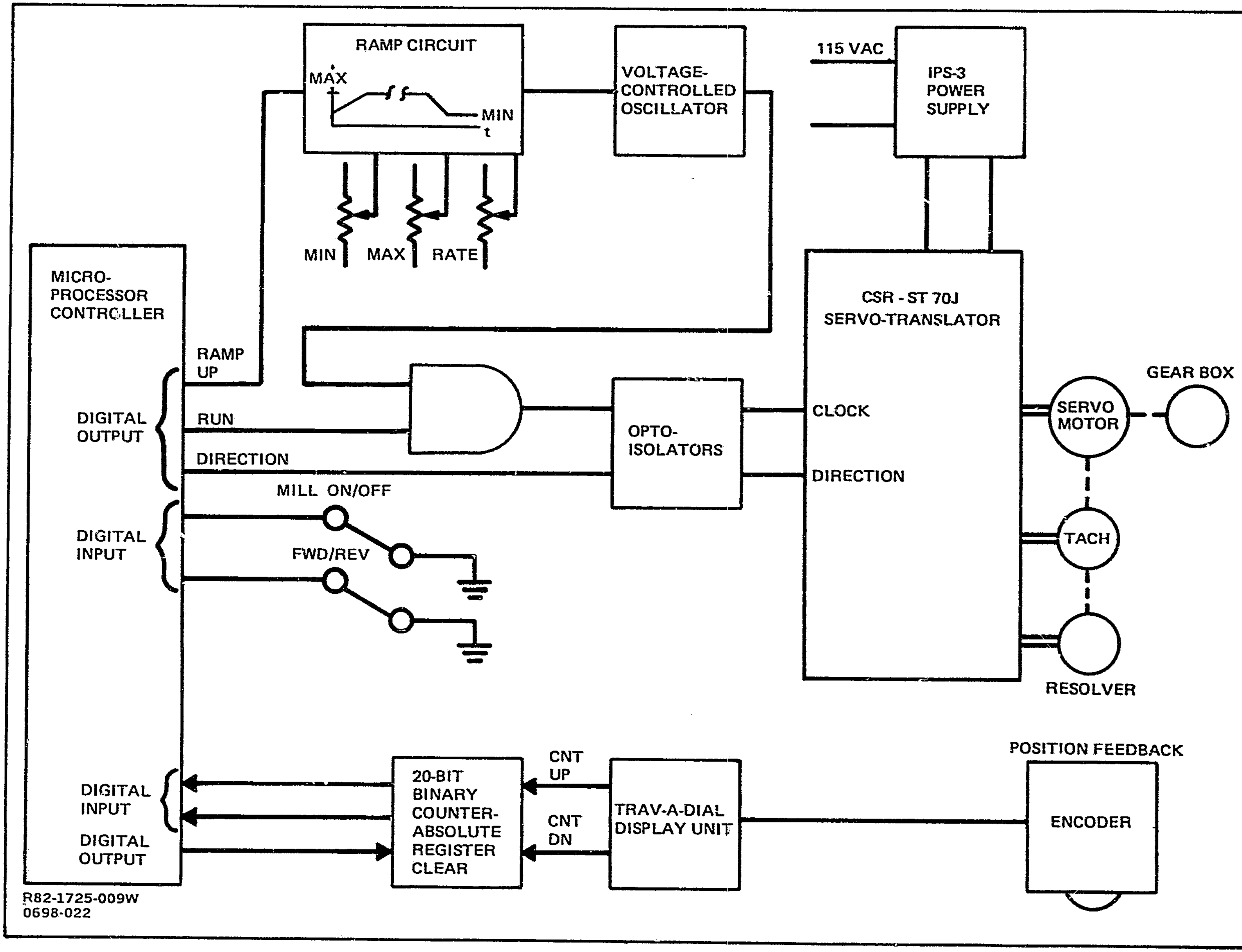

Fig. 21 Motor Drive-Feedback Loop

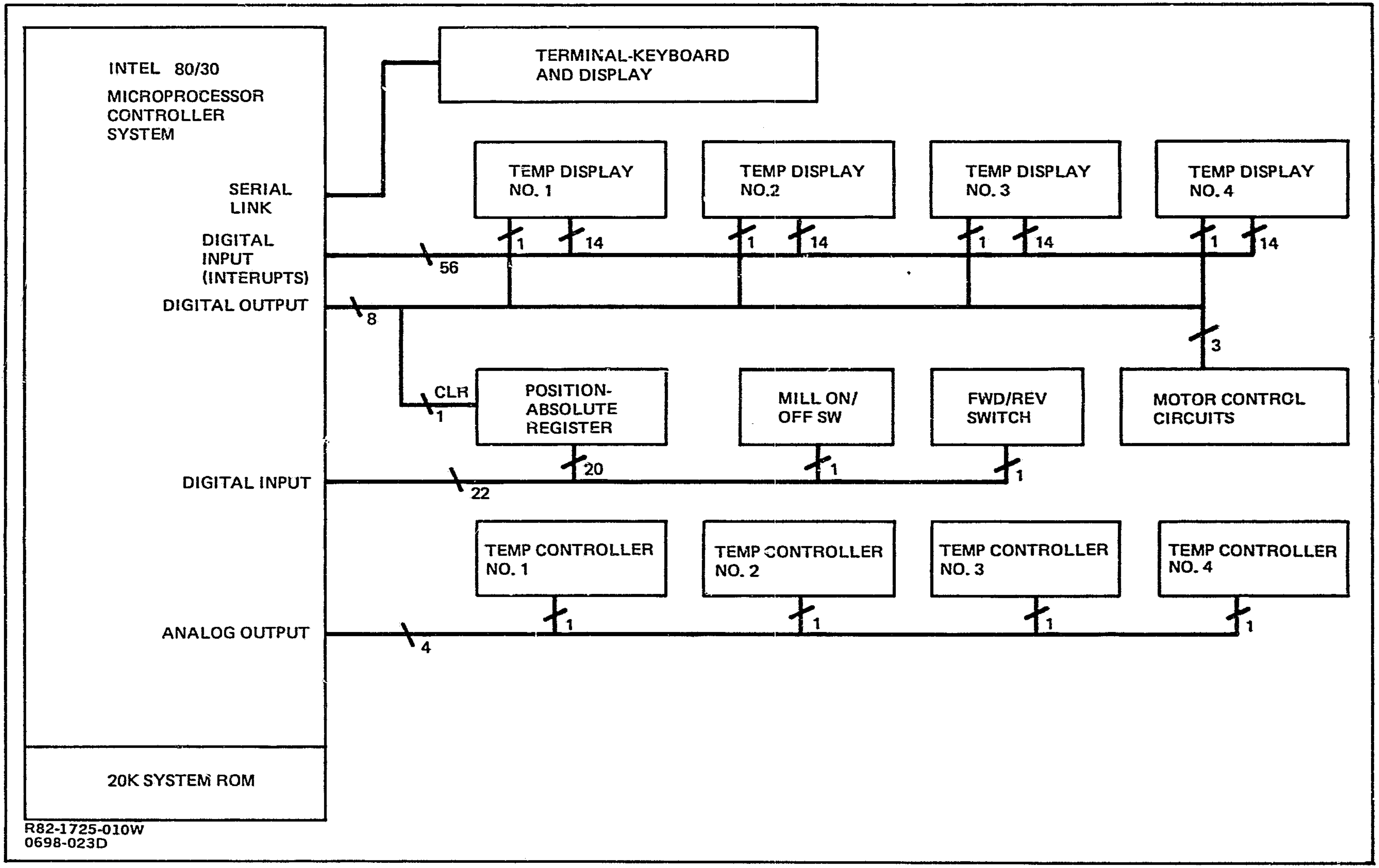

Fig. 22 Microprocessor Control System

Digital Input and output to the single-board computer is provided by standard Model 519 Intel multibus-compatible digital input-output cards. The analog outputs necessary for generating remote set-points for the four heat-loop controllers are also provided by a multibus-compatible Model DT 1843 digital-to-analog converter card supplied by Data Translation. The Termiflex hand-held terminal is interfaced to a standard RS232C port on the single-board computer card. This terminal is used to input the values necessary for the semi-automatic mode, or to display the data acquired by the microprocessor in real-time.

The four Captinec optical pyrometer temperature displays are interfaced to the microprocessor in such a manner that they generate equal-priority interrupts to the computer each time a new digital temperature value is available. To prevent loss of data, each display is prevented from being updated until the computer has read the previous data sample. This is accomplished by the hardware electronics on the digital input/output cards. Upon reading the latest data, the microprocessor permits the display to generate the next digital value. In parallel with digital data generation, analog output from the pyrometer is continuously fed to the heat-loop controllers for feed-back purposes. This prevents the digital data sampling process from influencing the closed-loop servo-operation of the heat-loops.

3.3.3.1.4 Software System - This provides all the functions considered necessary to use the cap fabricator for a research and development tool. A real-time multitasking executive with unique application tasks was designed and implemented. Figure 23 shows a conceptual view of the system. The application tasks indicated do not necessarily have a one-to-one correspondence to the tasks in the actual software system.

The multitasking operating system and executive is a standard Intel product configured to provide only those features necessary for a particular application. This results in a minimal PROM memory size requirement. This executive provides the necessary features of task scheduling, intertask communications, terminal input-output driver software, and interrupt handling.

The application tasks were written in a high-level language (INTEL-PL/M), and integrated with the executive. All software for the system is resident in PROM integrated circuits and located in either the microprocessor board or the system memory board in the microprocessor rack.

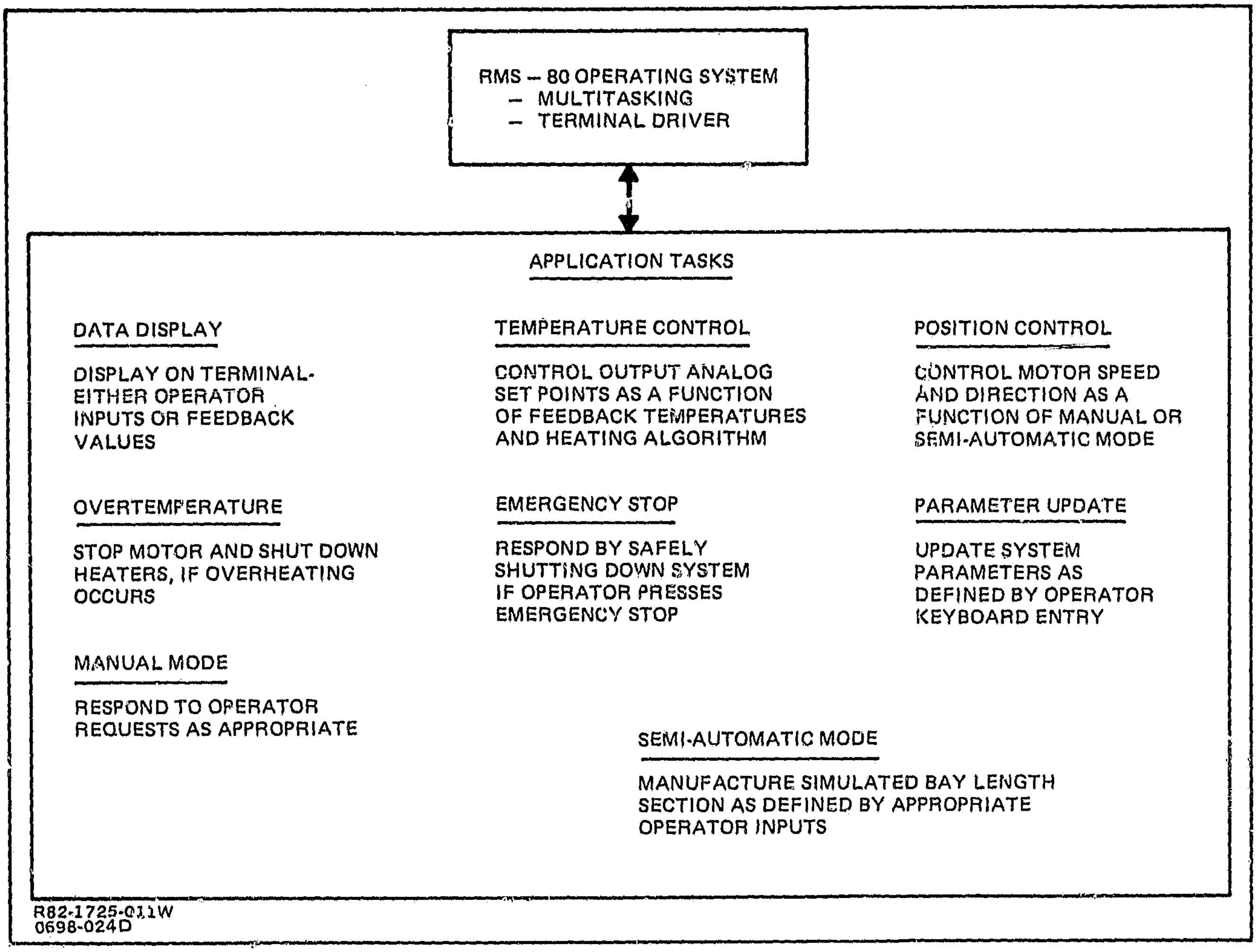

Fig. 23 Software System

Data Display Task - The Data Display Task displays the following on the hand-held terminal:

- Any of the parameters input by the operator
- Any of the four optical pyrometer feedback temperatures and the distance that the material position encoder wheel has rotated since the time the counter value was reset.

The counter is contained on the custom-designed motor control card in the microprocessor rack. In general, it only agrees with the value on the TRAV-A-DIAL display when both are reset simultaneously. Resetting of the TRAV-A-DIAL display is done via a pushbutton switch on the unit itself. The counter is reset by either the start of a semi-automatic mode operation or a unique keyboard entry by the operator.

Temperature Control Task - The temperature control task is utilized during a semi-automatic mode operation. When activated, this task determines four analog output voltages to be sent to the four Model 639 controllers for remote setpoints. Each voltage is generated based upon a linear equation ($y = mx+b$), in which "X" represents the desired setpoint temperature for a heating station. "M" represents the empirically determined slope of the heating station system in volts/°F, and "b" represents the empirically determined zero offset of the equation in volts.

The actual setpoint for a heating station used in the calculations is dependent upon several variables. The ability exists within this task to prevent large-magnitude step changes from occurring in the analog output voltages. This is done by restricting the setpoint used in the linear equation calculation. The setpoint may not exceed the present feedback temperature indicated by the heating station pyrometer by more than some predetermined value. This value is referred to as a delta temperature value. The operator must input the delta temperature values for each of the four stations to the control system. For example, if a value for a station was entered as 20°F, each time a new temperature is read from the corresponding heating station, the temperature control task would perform the following:

(1) The ultimate desired forward or backward rolling temperature target (as defined by the semi-automatic mode task) would be checked against the feedback temperature measured for the station.

(2) If the target temperature exceeded the feedback temperature by more than the delta temperature (20°F), a new temporary target temperature would

be established. Its value would be the feedback temperature plus the delta temperature. It is this target temperature that would be used in the linear equation calculation as the set point.

(3) If the target temperature does not exceed the feedback temperature plus the delta temperature, then the real forward or backward rolling temperature target would be used in the calculations as the set point.

(4) The linear equations are then evaluated and the resultant voltages are sent out to the heat loop controllers.

This philosophy of restricting the step change capability of the output analog voltages permits the system to potentially use a narrower bandwidth (higher gain) in the heat loop controllers than could normally be expected. In addition, the temperature control task will send out a negative voltage to the controllers when a semi-automatic operation is not being performed.

Position Control Task - The Position Control Task is used to command the motions of the servo-motor drive-system as a function of being either in the semi-automatic mode (keyboard control) or simply in manual mode (MOTOR ON/OFF, FWD/REV switches). In the semi-automatic mode, the task will start the motor if certain conditions are met. These conditions are specified by operator inputs via the terminal keyboard. The conditions are determined primarily by a parameter referred to as the roll flag. The state of this parameter (either set to a "0" value or a "1" value) determines whether the task will wait for a minimum material-temperature to be obtained at all four of the heating stations before starting the motor. If the roll flag is set to a "1" by the operator, then no roll-forming will take place until the minimum temperature is obtained. The value of the minimum temperature is specified by the operator via a terminal keyboard entry. If the flag is set to a "0", the motor will be started immediately, independent of the material temperature.

The amount of time that the task will run the motor in the forward direction is determined by the position information from the absolute register. This counting register is incremented from the position measuring encoder system (TRAV-A-DIAL) and periodically read by the microprocessor. An operator-entered parameter called forward rolling distance will be compared to the absolute position in the register. When they are equal, the motor will be stopped. In addition, if the operator entered a value for the reverse rolling distance, the task will again start the motor, but in the reverse direction. It will run the motor until the reverse distance has been accomplished, as read from the absolute position register, and then stop it.

There is another capability built into the position control task which may or may not be used in the semi-automatic mode. This is the ability to maintain the motor speed at its minimum value, or ramping it up to the maximum speed and then back down to minimum speed. Whether this ramping is to occur is determined by another operator-entered parameter which is referred to as a ramp flag. If the ramp flag value is set equal to a "0" value, the motor will always run at its minimum speed. If the parameter is set to a "1" value, then the motor will be ramped up to its maximum value at the beginning of the semi-automatic operation. When the motor speed will start to slow down towards its minimum value is determined by another operator-entered parameter called deceleration distance. When the deceleration distance remains to be roll formed in the forward direction, the motor control circuits are commanded to ramp the motor speed-down towards its minimum value. The actual rate of ramp-up or ramp-down is controlled by the rate potentiometer on the left control rack. When the complete forward rolling distance has been obtained, as indicated by the absolute register, the motor is stopped. Ramp-up and ramp-down are never done by the control system when it is running the motor in the reverse direction independent of the value of the ramp flag.

If the system is not performing a semi-automatic operation, the position task will run the motor forward or reverse, and start it or stop it based purely upon the status of the two manual switches located on the left control rack. Ramping, automatic starting, stopping, or reversing is never done independently of the values for ramp flag, or roll flag.

Over-Temperature Task - The overtemperature task is a safety monitoring task which continuously monitors the feed-back temperatures of heat loops. If any of the temperatures exceed an operator input parameter, referred to as maximum temperature, this task will abort a semi-automatic mode operation if it was in progress. An emergency stop message will be displayed on the hand-held terminal and a minus voltage will be sent to the heat-loop controllers. This is done to turn-off the servo-loop controllers.

Emergency Stop Task - The emergency stop task monitors the operator's EMERGENCY STOP switch which will remove power from both the servo-motor translator drive and the quartz lamps. In addition, the control system software will abort a semi-automatic run, if it was in progress, and display an emergency stop message in the display, if the switch is pressed in.

Parameter Update Task - The parameter update task is used by the control system to allow the operator to display current values of the various parameters and to change them as desired. The general format for displaying and/or changing a parameter requires that the operator enter a single character followed by a carriage return on the terminal keyboard. The exact character which must be entered for a particular parameter is given in Fig. 24. If an acceptable character is entered by the operator, the task will generally display a three- or four-character abbreviation for the parameter, followed by the value of the parameter. If it is acceptable, the operator then enters a carriage return to terminate that parameter update sequence. If the operator wishes to change it, he enters the new value for the parameter, via the keyboard, followed by a carriage return, which terminates the updating of that parameter.

Manual Mode Task - The manual mode task is used by the control system to respond to operator requests to run the motor forward or reverse. These requests are initiated by the "MOTOR ON/OFF" and "FWD/REV" switches on the left-hand control rack, as long as semi-automatic operations aren't being performed. In addition, any of the system's parameters can be updated, or feedback data values can be displayed on the terminal.

Semi-Automatic Mode Task - The semi-automatic mode task, when started, will control all the other tasks in the system to simulate the fabrication of a bay-length cap section. This task will use the various parameters that the operator has established, via the keyboard, to manufacture a single bay section. A typical sequence is as follows:

(1) The operator presses the "@" key followed by a return. This activates the semi-automatic mode task.

(2) The system turns on the four stations of heat lamps and attempts to use the setpoint values for each station that the operator had input as forward rolling temperature target. These setpoints can be adjusted, as discussed in the Temperature Control Task, depending upon the input value for delta temperature.

)	CLEARS KEYBOARD TERMINAL DISPLAY	
@)	START AUTOMATIC RUN	
A)	CONTINUOUS DISPLAY OF ACTUAL TEMPERATURE	1
B)	CONTINUOUS DISPLAY OF ACTUAL TEMPERATURE	2
C)	CONTINUOUS DISPLAY OF ACTUAL TEMPERATURE	3
D)	CONTINUOUS DISPLAY OF ACTUAL TEMPERATURE	4
E)	UPDATE FORWARD ROLLING TEMPERATURE TARGET	1
F)	UPDATE FORWARD ROLLING TEMPERATURE TARGET	2
G)	UPDATE FORWARD ROLLING TEMPERATURE TARGET	3
H)	UPDATE FORWARD ROLLING TEMPERATURE TARGET	4
I)	UPDATE REVERSE ROLLING TEMPERATURE TARGET	1
J)	UPDATE REVERSE ROLLING TEMPERATURE TARGET	2
K)	UPDATE REVERSE ROLLING TEMPERATURE TARGET	3
L)	UPDATE REVERSE ROLLING TEMPERATURE TARGET	4
M)	UPDATE DAC SLOPE	1
N)	UPDATE DAC SLOPE	2
O)	UPDATE DAC SLOPE	3
P)	UPDATE DAC SLOPE	4
Q)	UPDATE DAC OFFSET	1
R)	UPDATE DAC OFFSET	2
S)	UPDATE DAC OFFSET	3
T)	UPDATE DAC OFFSET	4
U)	HALT AUTOMATIC RUN	
V)	CLEAR ABSOLUTE POSITION REGISTER	
W)	UPDATE RAMP FLAG (0/1)	
X)	UPDATE DELTA TEMPERATURE FOR COLD START	
Y)	UPDATE MINIMUM ROLL TEMPERATURE	
Z)	UPDATE ROLL FLAG (0/1)	
<)	UPDATE AUTOMATIC FWD ROLL DISTANCE	
>)	UPDATE AUTOMATIC REVERSE ROLL DISTANCE	
;)	UPDATE MAXIMUM TEMPERATURE	
=)	UPDATE DECELERATION DISTANCE	
?)	DISPLAY ABSOLUTE POSITION REGISTER	

NOTE:) IS CARRIAGE RETURN ON TERMINAL

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Fig. 24 Composite Machine Keyboard/Terminal Code Functions

(3) The servo-motor may be initially started or delayed depending upon the state of the roll flag and the value of the minimum roll temperature, as discussed in the Position Control Task.

(4) The motor may be ramped-up in speed, or maintain a constant slow speed, depending upon the state of the ramp flag.

(5) The material will be roll-formed through the rolling mill for a distance that is determined by the automatic forward roll distance value input by the operation. The material will stop being roll-formed in the forward direction when the absolute position register contains a value equal to the forward roll distance. The heat lamps will then be turned off. If the motor had been ramped-up to a higher speed, a deceleration would have been started before the completion of the forward rolling. The distance at which the deceleration would have been started is specified by the deceleration distance parameter.

(6) Once the forward rolling is complete, a reverse-rolling operation may be performed. If an automatic reverse roll distance parameter, other than zero, had been input by the operator, then the following will occur after the forward rolling motion has stopped.

(a) The system turns on the four stations of heat lamps and attempts to use the setpoint values for each station input as reverse rolling temperature target. These setpoints may be adjusted as discussed in the Temperature Control Task.

(b) The servo-motor may be initially started in the reverse direction, or may be delayed, depending upon the state of the roll flag and the value of the minimum roll temperature. The motor speed will not be ramped-up.

(c) The material will be moved in the reverse direction through the rolling mill for a distance determined by the value of the reverse roll distance parameter.

(d) When that distance had been accomplished and indicated to the system by the absolute position register value decreasing appropriately, the motor will stop and the lamps will be turned off, The semi-automatic mode task would be completed at this point. Another bay-length fabrication cycle could be initiated by the operator by pressing the "@" key on the terminal, followed by pressing a return key. No additional operator entries would be necessary to fabricate the next bay-length of cap section.

At the conclusion of each semi-automatic mode run, if the operator had specified a reverse rolling distance of sufficient size, previously roll-formed composite material is left under the heat lamps at each station. This permits the next fabrication cycle to be started immediately, without having an area of the cap section not correctly formed. The previously roll-formed cap section would be heated at the beginning of the run. The previously run, not roll-formed material that follows it through the lamps, would have sufficient time to be heated and then be formed. This prevents areas of forming discontinuity from occurring.

3.3.4 Control System - Turn-On and Operating Procedures

Before attempting to operate the cap fabricator system, the operator must be familiar with the concepts and ideas presented in Section 3.3.3.1.

3.3.4.1 System Power-Up.

(1) Turn on facility 115 VAC voltage to the control system. The "MILL FWD/MILL REV" switch on the left control rack should be illuminated (either top or bottom half).

(2) Verify or set the four facility disconnect switches on the SCR power panel to the "OFF" position.

(3) Press the "POWER ON" switch on the left-hand control rack; it should illuminate. The TRAV-A-DIAL Display unit at the top of the rack should also indicate that it is being powered-up.

(4) Press the "RESET" switch located in the front of the TRAV-A-Dial display unit. All zeros should be displayed. As material is being roll-formed through the rolling mill, the data display should indicate a positive motion. If it does not, press the "+/-" switch to obtain the correct sign.

(5) On the "INTEL" microcomputer rack located in the left control rack, press the "POWER ON" switch; it should be illuminated. Press the "RESET" switch on the "INTEL" rack to reset the computer system.

(6) On the Control System's Research servo-translator, located at the bottom of the left control rack, place the "REMOTE/JOG" switch in the "REMOTE" position. Set the "POWER ON/OFF" toggle switch to the "ON" position. A slightly noticeable high-frequency oscillation should be evident at the servo-motor.

(7) Press the "POWER ON" switch in the right control rack; it should illuminate. The four Capintec display units should also begin displaying data. After a short warmup period, each display should indicate a value of less than 200°F. If they do not, press the "RESET" switch on the "INTEL" computer rack in the left control rack. The updating of the Capintec data displays is controlled by the microprocessor. The microprocessor must occasionally be reset to permit data display updating to occur.

(8) The four "HEATER ON" switches should not be lit up on the right control rack.

3.3.4.2 Quartz Lamp Power-Up. When power to the heating lamps at each station is desired, do the following:

(1) Turn on the facility water supply and insure that there are no restrictions on the water return line connections.

(2) On the base frame of the roll-forming machine, rotate the water flow valve to the "ON" position.

(3) On the facility disconnect panel, set the facility supply switch to the "ON" position for all or any of the heating stations required.

(4) On the left control rack, set the "IR HEATER ON" switch to the "OFF" position. This prevents the servo-controllers from commanding the lamps to the full "ON" condition.

(5) On the right control rack, set the "HEATER ON" switches to the "ON" position for those heating stations that are required. If there is sufficient water flow through the lamp assemblies (as measured by a water flow switch mounted on the base-frame of the rolling mill) each time a "HEATER ON" switch is pressed, a large contactor on the facility disconnect panel should audibly change state.

(6) The level of heat produced at each station, with the "IR HEATER ON" switch in the "OFF" state, is controlled by the "HEATER SET POINT"

potentiometer. There are four such controls located on the right control rack. Nominally, these should be set up such that a low orange glow is visible at each lamp when the station is powered-up and the "IR HEATER ON" switch is turned off.

3.3.4.3 Manual Mode of Operation. Under the manual mode of operation, the temperature for each heating station is controlled by a manually set potentiometer. The running of the servo-motor, either forward or reverse, is controlled by the "MOTOR FWD/MOTOR REV" and "MILL ON/MILL OFF" switches.

Each of the Research Incorporated Model 639 controllers, mounted in the right control rack, must be set up as follows:

(1) The "A/MAN" switch must be in the "A" or "OUT" position. This allows the servo-loop to function.

(2) The "LCL/REM" switch must be in the "LCL" or "OUT" position. This allows the local setpoint potentiometer on the front of the controller to determine the heating station's target temperature.

The "HEATER ON" switches on the right control rack, corresponding to the required heating stations, must be turned "ON". In addition, the "IR HEATER ON" switch on the left control rack must be turned "ON". This switch allows the Model 639 controller's command signal to reach the Model 646 SCR power controller and turn on the quartz lamps as required. Selectively, the "HEATER ON" switches can be turned "ON" or "OFF" to control the various heating stations. However, the "IR HEATER ON" switch must be on to permit any of the stations to function. The cooling water flow must also be turned "ON" to permit any of the "HEATER ON" switches to function. If the composite material is located in the pyrometer camera field of view at a particular station, the corresponding temperature display and Model 639 servo-controller will function correctly. If there is no material present in the field of view, the lamps will generally turn on to a high heating level; the camera display, however, will indicate a low temperature level (about 200°F). Since the servo-controller will not receive sufficient analog feedback voltage from the camera system, it will not control the lamp heating level.

To manually run material through the machine, do the following:

(1) Set the Model 639 control switches as indicated above.

(2) Place a small section of composite material at each of the heating stations, in the field of view of the camera.

(3) Turn off all the "HEATER ON" switches.

(4) Turn on the "IR HEATER ON" switch and the cooling water flow.

(5) For each of the stations, do the following:

(a) On the Model 639 controller, set the "SETPOINT" potentiometer to a low value, corresponding to a low setpoint temperature.

(b) Turn on the "HEATER ON" switch for the station of interest. Increase the "SETPOINT" potentiometer as required to obtain the desired setpoint temperature as indicated on the display.

(c) Turn off the "HEATER ON" switch for the station.

(6) Remove the composite material from each of the stations.

(7) Insert the flat composite material into the entry feed table until it starts to enter the first heating station.

(8) If necessary, adjust the TRAV-A-DIAL encoder mounting to obtain the correct preload. Press the "RESET" switch on the display.

(9) Turn the "HEATER ON" switch to the "ON" position for the first station.

(10) As the lamps turn on, slowly move the material by hand through the first station lamps. Minimize the amount of oxidation that occurs on the material surface by varying the feed speed.

(11) Press the "MILL FWD/MILL REV" switch to the "FWD" position.

(12) Press the "MILL ON/MILL OFF" switch to the "ON" position; the motor will run at its minimum speed setting.

(13) Slowly feed the material up to and then into the first set of dies. The material should be pulled through the die by the servo-motor system.

(14) As the material enters the second and third heating stations, press the corresponding "HEATER ON" switches.

(15) Do the same for the fourth station, as the material enters it.

(16) When the material has passed through the final die set and straightening roller assembly, turn off the four stations by setting the "IR HEATER ON" switch to the "OFF" position. Stop the motor by pressing the "MILL ON/MILL OFF" switch to the "OFF" position.

(17) To continue the forming process after having stopped, do the following:

(a) With the "IR HEATER ON" switch in the "OFF" position, start the servo-motor in the reverse direction by setting the "MILL FWD/MILL REV" switch to the "REV" position. Press the "MILL ON/MILL OFF" switch to the "ON" position.

(b) Run the material in the reverse direction to position roll-formed sections under each of the heating station lamps. Normally this requires a reverse motion of approximately five inches. Stop the motor drive by pressing the "MILL ON/MILL OFF" switch to the "OFF" position.

(c) Set the "MILL FWD/MILL REV" switch to the "FWD" position.

(d) Set the "IR HEATER ON" switch to the "ON" position and wait for all four displays to indicate that the material has been warmed to the correct rolling temperature.

(e) Press the "MILL ON/MILL OFF" switch to the "ON" position.

(18) Prevent overheating of the lamp assemblies during the forming process, when the material is no longer entering a heating station (that is, end of material is passing through the machine), by pressing the corresponding "HEATER ON" switched to the "OFF" position.

(19) When all the material has been processed through the machine, set the "MILL ON/MILL OFF" switch to the "OFF" position and set the "IR HEATER ON" switch to the "OFF" position.

(20) Turn off the cooling water flow to prevent condensation from forming on the lamp assemblies.

(21) Turn off the facility power disconnect switches when completed.

NOTE: During the roll-forming process, the actual material temperatures obtained at each of the four stations may be less than that obtained with the four small samples used during the setup steps. To compensate for this temperature drop during the actual forming steps, increase the "SETPOINT" potentiometer on the front of each Model 639 controller as required.

3.3.4.4 System Power-Down.

(1) Turn off all "HEATER ON" switches

(2) Turn off "IR HEATER ON" switch

(3) On the Control System's Research servo-translator in the left control rack, set the "POWER ON/OFF" toggle switch to the "OFF" position

(4) Turn off the cooling water

(5) Turn off the facility disconnect switches for the SCR power amplifiers

(6) On the right control rack, set the "POWER ON" switch to the "OFF" position

(7) On the left control rack, set the "POWER ON" switch to the "OFF" position

3.3.4.5 Semi-Automatic Mode of Operation. Under the semi-automatic mode of operation, the temperature for each heating station is controlled by the microprocessor via four analog outputs. The feedback temperatures from the optical pyrometers can be used by the microprocessor to modify those temperatures initially specified to the system by the operator. The running of the servo-motor to drive the rolling mill is also controlled by the microprocessor based upon data entered by the operator via the keyboard.

Each of the Research Incorporated Model 639 controllers, mounted in the right control rack, must be set-up as follows:

(1) The "A/MAN" switch must be in the "A" or "OUT" position. This permits the controller to function as a servo-loop using the temperature feedback from the cameras.

(2) The "LCL/REM" switch must be in the "REM" or "IN" position. This permits the microprocessors analog output to determine the heating station's target temperature.

Switch positions must be set as follows:

(1) Facilities disconnect power switches to the SCR amplifiers must be turned on

(2) "IR HEATER ON" switch must be turned on

(3) "HEATER ON" switches for the four heating stations must be turned on

(4) Control System's Research Inc. servo-translator power toggle switch must be set to the "ON" position and the "REMOTE/JOG" switch must be set to the "REMOTE" position

(5) "MILL ON/MILL OFF" switch must be turned to "OFF" position

(6) Cooling water flow must be on

Parameter values must be entered by the operator via the keyboard to permit the running of the semi-automatic sequence. There are several different types of entries required. The first is the slope and offset values for each heating station.

The microprocessor will generate an analog output voltage as a command signal to each of the Model 639 controllers. It will generate the voltage based upon a linear equation ($y = mx+b$), where "m" is the slope (volts per degree Fahrenheit) of the heating station, "x" is the desired temperature, and "b" is the offset value (volts). The slope and offset values were empirically determined, after all gains (bandwidth) and current limit settings were manually adjusted in the system.

The technique to determine the slope and offset for each heating station and its associated controller and camera is as follows:

(1) Place a small piece of composite material in each heating station in the cameras field of view.

(2) Set up the microprocessor to generate a command voltage to the controllers. Several different voltage levels (all under six volts) were available during the initial calibration.

(3) Measure and record the command voltage to each controller with a digital voltmeter.

(4) Turn the "HEATER ON" switch for each of the stations on. Also turn on the "IR HEATER ON" switch so that the lamps for each station warm up the material.

(5) When the display temperature on for each station has stabilized, record it together with the appropriate command voltage level.

(6) A different command voltage level is then generated by the microprocessor; record the stabilized temperature and command voltage level again.

(7) Approximately four temperature points (less than 500°F) are obtained for each station.

(8) For each heating station, an equation of the form, y = mx+b, is fit to the data previously taken. In this equation, "x" corresponds to the stabilized temperature and "y" corresponds to the related command voltage level.

(9) The results of typical calibration runs are presented in Fig. 25.

HEATING STATION NO.	SLOPE	OFFSET
1	0.01949	–4.667
2	0.02136	–5.176
3	0.021078	–5.0656
4	0.02039	–4.7898
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Fig. 25 Slope and Offset Constants from Calibration Run

(10) The data to be entered by the operator for the slopes and offsets are shown in Fig. 26. These are not the same values that are derived from the linear equation curve fit. The raw data (slope and offset) must be transformed as follows to be entered:

SLOPE (to be entered) = SLOPE (volt/°F) x 12.8
OFFSET (to be entered) = OFFSET (volts) x 12.8 + 128

These values (see Fig. 24) are typically entered as follows:

(a) To enter the slope for Heating Station No. 1, press the "M" key followed by the "CARRIAGE RETURN" key on the terminal

(b) The terminal will then display "SL1 = .xxxx", where .xxxx is the present slope value

(c) Type the new slope value, followed by a carriage return. For example, 0.2495

(d) The terminal display will then go blank.

(e) To verify the value entered, press the "M" key followed by a "CARRIAGE RETURN" key. The terminal will then display, "SL1 = 0.2495".

(f) To clear the display, press the "RETURN" key.

(g) The operator could then enter the next slope value or offset value by pressing the correct code key sequence as indicated in Fig. 24.

(h) All entries must be terminated by a carriage return.

HEATING STATION NO.	SLOPE	OFFSET
1	0.2495	68.26
2	0.2735	61.74
3	0.2698	63.16
4	0.2610	66.69
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Fig. 26 Slope and Constants to Enter Via the Keyboard

(11) If adjustments are made to any of the Model 639 control settings, the slope and/or offset values may have to be modified. This is necessary to permit the microprocessor to obtain the correct setpoint temperatures for each of the heating stations.

The next parameter entry the operator must enter are those which determine the desired temperatures and distances for roll-forming in either the forward or reverse direction. These are control codes "E" through "L", "<" and ">" as indicated in Fig. 24..

The final parameters which must be entered control either the motor drive characteristics (Codes "w", "x", "y", "z", and "="), or the emergency shut down temperature for the lamps (Control Code ";"). These codes are described in detail in Section 3.3.3.1.4.

Numerical values must be entered via the keyboard for all codes in Fig. 24, except for "A" through "D," "U," "@," "V", and "?". These codes are strictly used to display the various feedback temperatures seen by the microprocessor, to start and stop the semi-automatic run, or to clear and display the present material position as indicated by the absolute position register.

The operator must perform the following actions to produce a 60-inch long piece of composite cap section. It is assumed that the material has been manually loaded into the machine and is exiting through the straightening roller assembly (See Section 3.3.4.3). The material has been rolled in the reverse direction on a sufficient distance to have correctly formed sections under each of the heating station lamps. The desired forward rolling temperature for each station is 500°F. No heat is necessary during reverse rolling. No acceleration of the motor is required and no rolling will take place until the material at each station has been warmed to

300°F. It is also assumed that all "HEATER ON" switches are set to the proper condition. The operator then does the following on the terminal keyboard:

(1) Type "E" followed by a "CARRIAGE RETURN" (indicated as "↵") to enter the forward rolling target temperature for Heater Station 1.

(2) System will display "FT1 = XXX.X" on terminal display

(3) Type "500." on terminal followed by "↵"

(4) Type "F↵"; system will display "FT2 = XXX.X"; Type "500." followed by "↵"

(5) Operator does the same for the "G" and "H" codes

(6) Type "I↵" system will display "RT1 = XXX.X Type "/."↵

(7) Do the same for "J", "K", and "L" codes.

(8) Enter slopes and offsets using Codes "M" through "T", and data from Fig. 26.

(9) Since no acceleration of the motor is required, type "W↵"; system will display "RMF = X"; type 0↵"

(10) Since no requirement exists to minimize the heat-up rate at the beginning of the cycle, the permissable delta temperature value will be large. Type "X↵"; system will display "DLT = YY."; type "500.↵".

(11) To prevent rolling until all stations are at 300°F, type "Y↵"; system will display "MRT = xxx"; type "300.↵".

(12) Set roll flag so system will wait for minimum temperatures. Type "Z↵"; system will display "RLF = X"; type "1↵".

(13) To form a net length of 60 inches of material, enter a value which takes into account the amount of reverse rolling distance that will be done at the end of the cycle. Assuming this value to be five inches, type "<↵ ;" the system will display "FDD = XX"; type "65↵".

(14) To back up five inches at the completion of the operation, type ">↵"; the system will display "RVD = Y"; then type "5↵".

(15) To setup the emergency shut-down temperature of 800°F, type ";↵; the system will display "MXT = XXX"; then type "800↵".

(16) The operator can now verify all or any of his entries by entering the control codes as required.

(17) To start the forming process, type "@ ↵". The following will occur:

(a) The lamps at all stations will be turned on to reach the 500°F temperature at each station.

(b) When each station has reached at least 300°F, the servo-motor will be started and the material will proceed to be roll-formed.

(c) When 65 inches of material has been processed, as measured by the TRAV-A-DIAL encoder, the servo-motor will stop, and the lamps will be turned off.

(d) The motor will be turned on in the reverse direction for a total of five inches of reverse motion.

(e) The semi-automatic operation will now be complete.

(18) If at any time during the operation, the operator wants to stop the semi-automatic, he should type "U↵" on the terminal keyboard. This will stop the servo-motor and shut off all the lamps.

(19) If it is desired to process another length of material with the same parameters, type "@↵" on the terminal keyboard. The system will then use the previously entered parameters and perform another semi-automatic operation.

(20) If there is not sufficient material to be processed to accomplish the desired forward rolling distance, (that is, there will not be material under the encoder for the complete sequence), the operator will have to stop the automatic run by using the "U↵" code where appropriate.

NOTE: When the system is initially turned on (See Section 3.3.4.1), it may not be possible to use all the control codes in Fig. 24. Occasionally, "INVALID" may be displayed in response to a valid control code entry. This implies that the value of the parameter presently in the system is outside the allowable tolerance range. To recover from this situation, simply enter a correct value for the parameter. The system will accept a number from the terminal keyboard and update the parameter correctly. The operator must terminate the entry with a carriage return. He may verify the value of the parameter by re-entering the correct control code on the keyboard. The software system was written to permit pressing of a reset on the "INTEL" rack, but not to lose all the operator-entered parameters. The software does check to see whether the various operator-entered parameters are within acceptable ranges. During the rack power-on sequence, the microprocessor's random access memory will assume random values. Occasionally, one of these random values for an operator-entered parameter will appear not to be within the acceptable permissible range. This results in display of the "INVALID" message.

NOTE: If any of the Capintec displays stop updating at any time, the probable cause is the loss of an interrupt request pulse to the microprocessor. The Model 639 controllers and the heating lamps at the corresponding station will continue to function correctly. This occurs because an analog feedback voltage from the camera, which is independent of the digital data, is used for the feedback to the controller. To restart the display update, press the "RESET" switch on the "INTEL" rack located in the left control rack. The "RESET" switch should not be pressed during a semi-automatic mode operation. If it is, the operation will be immediately stopped and the lamps turned off.

Section 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Analysis of the results of the project to develop a Composite Beam Cap Fabricator (CBCF) under the Space Fabrication Demonstration System (SFDS) has led to the following conclusions:

- The CBCF is capable of stand-alone, automatic fabrication of composite beam caps from high-temperature, graphite-reinforced, thermoplastic materials (Gr/PS and Gr/PES) supplied as laminated strip stock
- The CBCF is interchangeable with elements of the aluminum beam builder
- Composite beam caps have cross-sections and strengths comparable to aluminum beams
- Production-quality, high-temperature, graphite-reinforced thermoplastic material is not currently available
- Limited testing and evaluation of the CBCF precluded optimization of machine operating parameters.

4.2 RECOMMENDATIONS

The following activities should be continued to complete development of composite beam cap fabrication technology:

- Formulate and implement a composite material development program to include the following:
  - Location and development of material supplies for laminated strip stock
  - Performance of material tests and analyze to determine physical and mechanical properties
  - Fabrication of composite beam caps with the CBCF
  - Evaluation of tests and analyses to select a material for further development and flight testing.

- Formulate and implement a ground evaluation program for the CBCF to include the following:
  - Selection, purchase, and preparation of test material
  - Performance of operational tests to determine range and optimum operating parameters
  - Compression testing of composite beam caps and comparison of test data with previous results
  - Evaluation of test program data to establish optimum operating parameters.
- Comprehensive evaluation of processing technology and machine behavior under several environments. Recent Grumman experience in developing high- and medium-technology commercial products has shown conclusively the need for extensive testing and evaluation. This will preclude unanticipated operating problems that might affect the credibility of a product
- Development of the CBCF should be conducted simultaneously with a materials evaluation program. Formability is an important characteristic for any material that will be used in a space environment. Consequently, evaluation of the behavior of a material while it is being formed by the CBCF is vital to both the search for an acceptable material and the selection of optimum material configurations.

APPENDIX A

DRAWING LIST

Drawing No.	Status	Description
RDM 447-951 (Sheet 1)	NC	Heater Water Supply Manifold
-951 (Sheet 2)	NC	Motor Safety Guard
-1999	NC	Station No. 6 Heater Assembly
-2148	B	Assembly
-2149	NC	Spool Assembly
-2150 (Sheet 1)	A	Base Frame Assembly and Servo-Drive
-2150 (Sheet 2)	A	Base Frame Assembly and Servo-Drive
-2151	B	Station No. 7 Roll Form Tooling
-2153	A	Station No. 2 Roll Form Tooling
-2154 (Sheet 1)	A	Station No. 4 Roll Form Tooling
-2154 (Sheet 2)	A	Station No. 5 Roll Form Tooling
-2155	NC	Material Feed Spool Subassembly
-2156	NC	Spool Adapter Housing
-2157	NC	Spool Support Shaft
-2158 (Sheet 1)	C	Station No. 1 Support Weldment
-2158 (Sheet 2)	NC	Spool Adapter Plate
-2159	B	Encoder Bracket Details
-2180	NC	Spool Outer Cover
-2181	NC	Alternate Drive Adapter
-2182	A	Station No. 3 Lower Heater Assembly
-2183	NC	Station No. 3 Details
-2184	NC	Station No. 3 Details
-2185	NC	Station No. 3 Details
-2186	NC	Spool Mounting Bracket
-2187	NC	Spool Mounting Plate
-2188	NC	Miscellaneous Spool Details
-2189	A	Station Nos 3.6 and 8 Support Weldments
-2192	NC	Station No. 3 Upper Heater Assembly
-2193	NC	Station No. 6 Pyrometer Details

APPENDIX A (CON'T.)

DRAWING LIST

Drawing No.	Status	Description
RDM 447-2194	NC	Station No. 6 Upper Heater Details
-2195	NC	Live Heater Rework
-2197	NC	Miscellaneous Brackets
-2198 (Sheet 2)	NC	Station No. 3 Material Guide Bracket
-2199 (Sheet 1)	NC	Station No. 1 Heater Subassembly
-2199 (Sheet 2)	NC	Station No. 1 Heater Brackets

APPENDIX B

ELECTRICAL INTEGRATION REQUIREMENTS

To interchange the composite cap-forming subsystem with the existing roll-forming system in the Aluminum Beam Builder, the following will have to be accomplished:

- Modifications to the SFDS software/hardware to provide:
  - Serial-data-transmission interfacing between the minicomputer and each of the three microprocessor-based composite control systems
  - Control algorithms for temperature set-point determination and minimum startup temperature requirements for each heating station as a function of the composite material utilized
  - Control algorithms and hardware modifications for the reverse-rolling sequence at the completion of a bay-length fabrication cycle
- Modifications to each of the microprocessor-based composite cap control systems to provide:
  - Serial-data-transmission interfacing to the microcomputer
  - Removal or disabling of the hardware/software that controls the servodrive system and encoder feedback measurement
  - Control algorithms to respond to commands from the minicomputer controller for the required set-point temperatures at each heating station
- Additions to facility power-distribution system to control the 115-VAC power needed for the quartz heating lamps on each cap subsystem.

APPENDIX C

PURCHASED PARTS

Part Description	Part No.	Supplier
Trav-A-Dial	ST-1-1 & F100B	Southwest Industries
Timing Pulley	24HB150/Bore 1.1240-1.1250	Browning
Timing Pulley	24HB150/Bore 1.4365-1.4375	Browning
Timing Belt	300H150	Browning
Lifting Eye	CL-25-5HR	Carr Lane Manufacturing
Servo-Motor	SM709	Control Systems Research
Reducer	HJ52AX	Sumitomo Corporation
Bearing	6210	Hoover
Bushing	2-1/2-in. DIA/1-1/2-in. LG.	Oilite
Retaining Ring	5100-196	Waldes Tru-Arc
Bearing	6209	Hoover
Locknut	N-09	New Departure
Locknut	W-09	New Departure
Spring	LC-0389-9	Lee Spring
Bearing	77R16	New Departure
Retaining Ring	5560-37	Waldes Tru-Arc
Pyrometer	1548	Capintech
Bearing	R4A	Hoover

Notes:

1. All aluminum details are made from commercial-grade 6061-T6 alloy
2. All spacers are made from A6 tool steel
3. All roll-form tooling is made from 4130 steel
4. All other steel details are made from either cold-rolled or drill-rod steel