SPACE FABRICATION & ASSEMBLY OF GRAPHITE COMPOSITE TRUSSES

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GENERAL DYNAMICS
Convair Division

BASELINE SYSTEM CONCEPT (Figure 1)

A baseline LSS concept is shown in the facing illustration. In mid-1982, fabrication/assembly systems and prepackaged raw materials are delivered by Shuttle to a 300 nautical mile (556 Km) circular orbit.

Upon system deployment from the stowed position, a beam-builder, moving to successive positions along a Shuttle-attached assembly jig, automatically fabricates four triangular beams, each 200 meters long. Retention of the completed beams is provided by the assembly jig.

The beam-builder then moves to the position shown and fabricates the first of nine shorter, but otherwise identical, cross-beams. After cross-beam attachment, the partially completed assembly is automatically transported across the face of the assembly jig to the next cross-beam location, where another cross-beam is fabricated and installed. This process repeats until the "ladder" platform assembly is complete. The cross-beam installation process represents an opportunity for development/evaluation of EVA-assisted/partially automated techniques as shown.

Upon platform assembly completion, both structural and thermal response tests are conducted and RMS/platform release/recapture techniques are developed, thus completing the seven-day mission cycle. Soon after, a revisit mission installs experimental and functional subsystem equipment for an initial application and further testing.

BASELINE SYSTEM CONCEPT

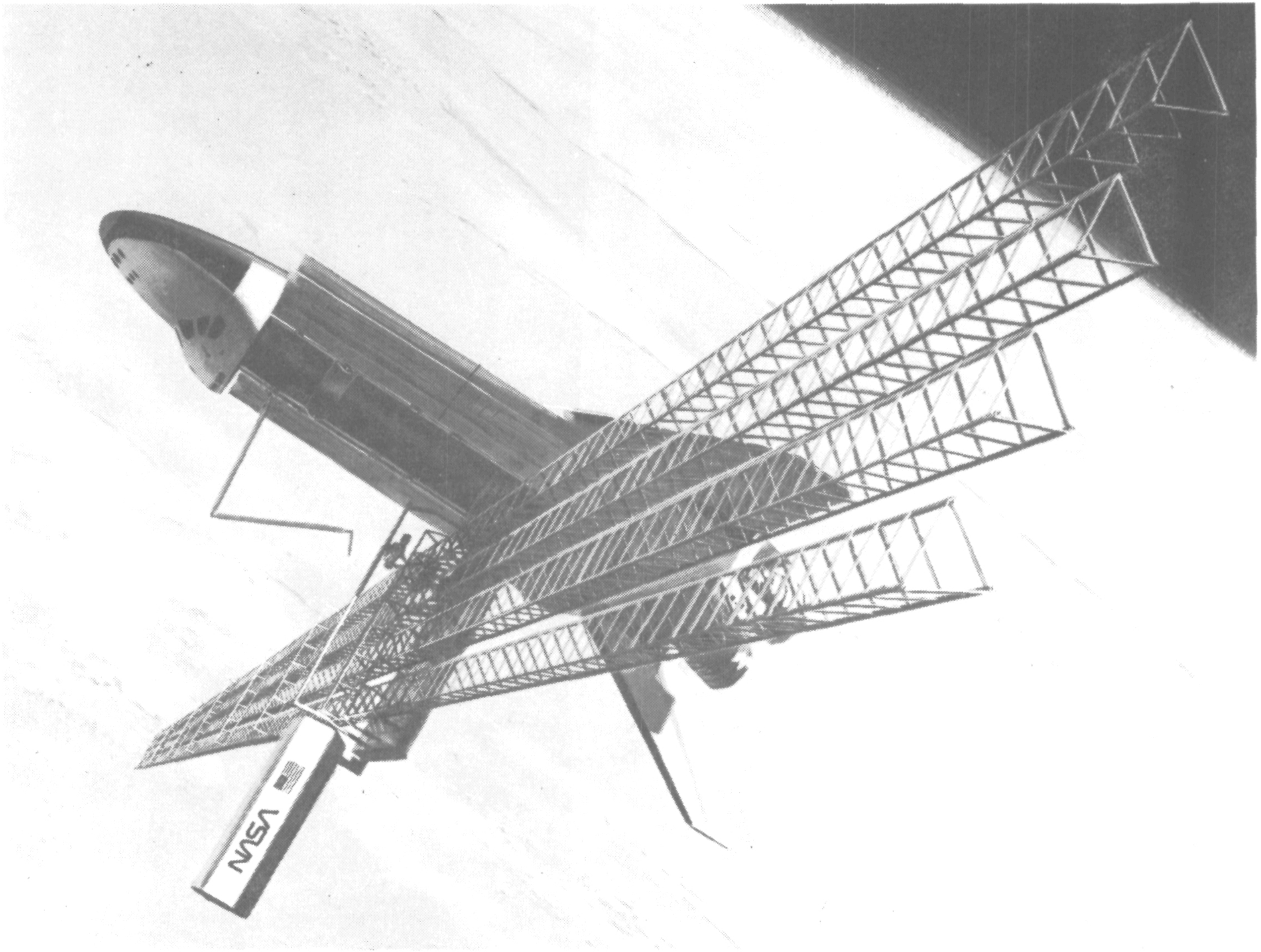


Figure 1

MATERIALS AND PROCESSES REQUIREMENTS (Figure 2)

The structural elements which we wish to fabricate on-orbit for eventual use in large space structures applications must be very light and adequately rigid. In addition, the material from which they are made when of the graphite thermoplastic type must be formable and assemblable into appropriate structural elements on orbit. The material is carried to orbit compactly packaged on reels, formed into structural sections of indefinite length and assembled into workable trusses. The use of graphite thermoplastic materials enables the designer to take advantage of the designed low coefficient of thermal expansion. Because of the eventual extensive use forseen for this application,it is also necessary that the material should be of low cost. Pitch fiber graphite is expected to have this characteristic during the time frame under consideration, possibly due to extensive use of the material in automotive weight-saving applications. For operational reasons, it is necessary to minimize the amount of energy needed to do the forming of the structural members. This is particularly true for applications depending on the Shuttle power supplies. It is also necessary that the processes do no harm to the material during forming so that full material properties are available to the designer. The beam fabrication process should also produce elements which are as straight and twist-free as possible. The requirements in these latter areas have yet to be formally established.

MATERIALS & PROCESSES REQUIREMENTS

MATERIALS

- FORMABLE & ASSEMBLABLE ON ORBIT
- LOW COEFFICIENT OF THERMAL EXPANSION
- LOWEST COST FOR EVENTUAL LARGE SCALE USE

PROCESSES

- MINIMUM ENERGY NEED
- NO HARM TO MATERIAL
- STRAIGHT, TWIST-FREE BEAM

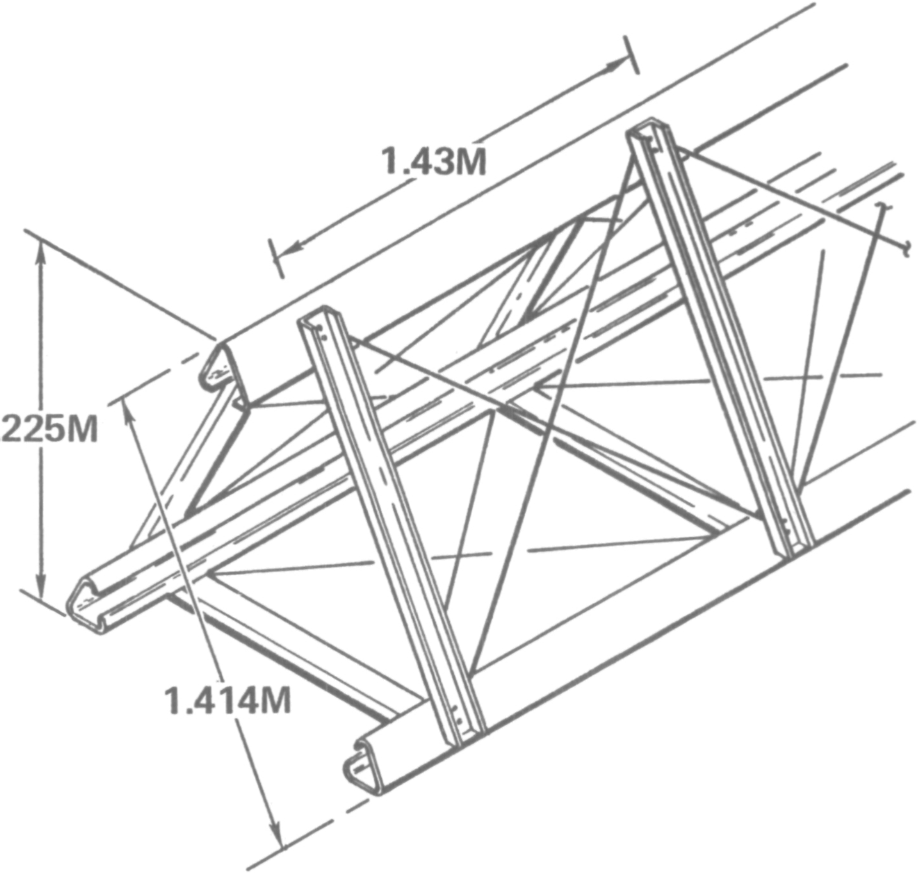


Figure 2

LAMINATE CROSS SECTION (Figure 3)

Three forms of laminate design are under consideration for large space structures use. All three forms have the promise of doing the job efficiently. Each has pros and cons.

1. Sandwiched 0° Tape

   This concept uses several plies 0° pitch graphite sandwiched between single plies of 104 or 120 glass cloth. The number of 0° plies and the thickness of cloth are determined by structural requirements (loads and stiffness).

2. Woven Fabric

   This concept uses a single ply of a fabric woven such that 0°, 90°, and ± 45° fibers are present; the amounts of each are dependent on the structural requirements. The fabric would necessarily be thicker than that presently used in aerospace applications and would have to be specifically designed to meet space platform or other specific load requirements.

3. Multi-ply Laminates

   Multi-ply laminates are the traditional form of laminate used in composite structures. They consist of several layers of 0° graphite plies orientated in the directions best suited to meet the requirements of a particular structural element. As such, they can be optimized for each application.

For near term development, the most flexible, least cost, and least risk approach appears to be the sandwiched 0° tape. A typical generic laminate which is weight effective is $(120/0_2/120)_T$ glass/VSB-32T graphite/glass in a polysulfone (P-1700) matrix. HMS fiber could be considered if VSB-32T pitch fiber in polysulfone is not available for early development. The chart illustrates the laminate construction. For longer term development, more investigation of a tailored, single-ply fabric should be conducted.

LAMINATE CROSS SECTION

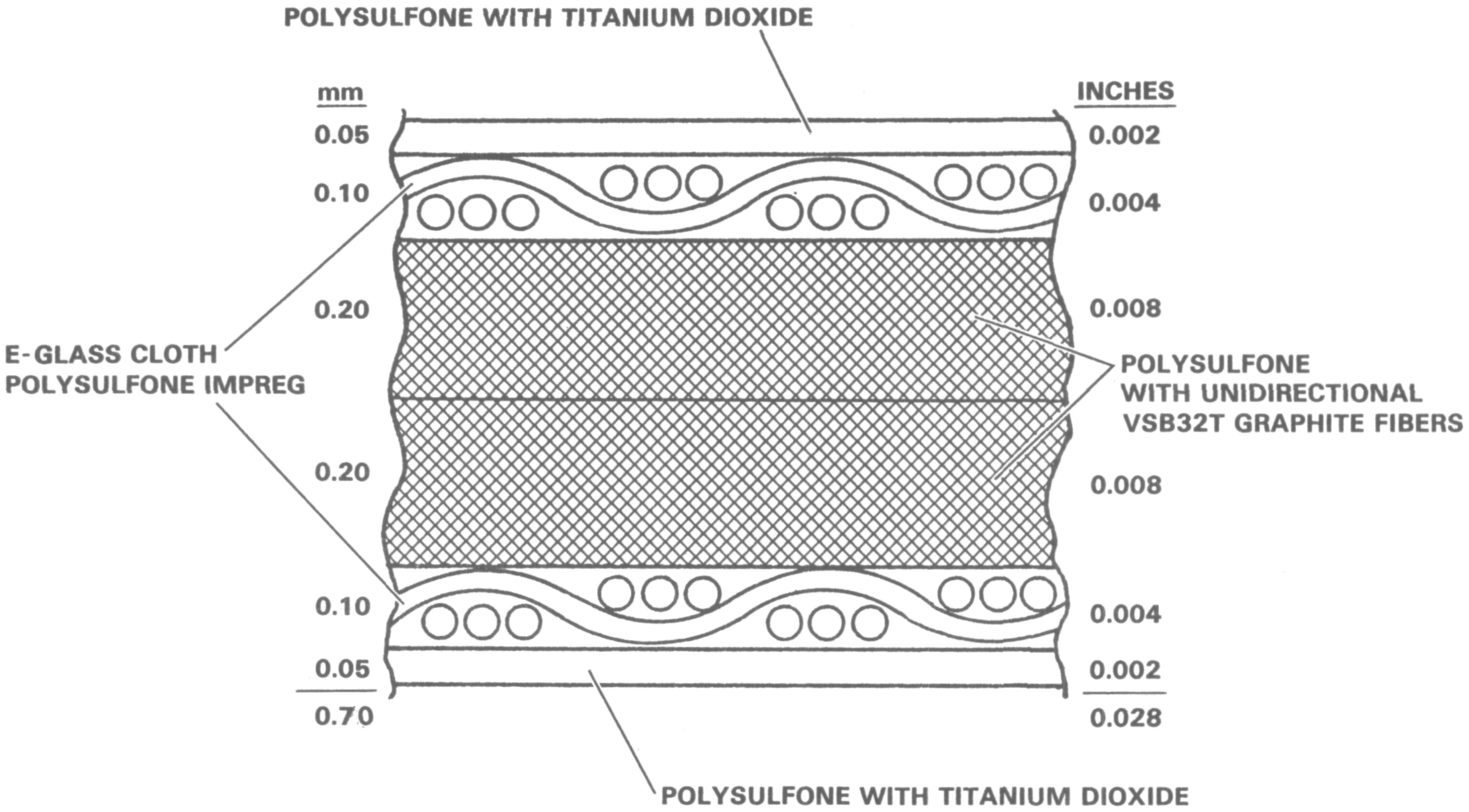


Figure 3

CAP SECTION ROLLTRUSION HEAD (Figure 4)

The machine element for forming the cap section consists of a long box frame with the reel for the laminate strip mounted at one end and the drive for pulling the laminate through the machine mounted at the other end. The reel (Section A-A opposite) has an adjustable drag brake on one hub and is hooded to contain the "clockspring" tendency of the laminate in the event of drag brake malfunction. A set of rollers that maintains a minimum bend radius of 300 mm from full to empty reel is located on the frame adjacent to the reel. Next to the rollers is the heating module (Section B-B) which is one beam bay (1434 mm) in length. The heat is confined to the bend zones in the laminate by using linear resistance heaters in parabolic reflectors.

Coolant flowing through four passages in each heater block carries away the small amount of heat absorbed in the reflector ($\approx 6\%$).

Temperature sensors are installed on the opposite side of the laminate to provide feedback to the temperature control system. Coolant flowing through two passages provides thermal control of each sensor to assure a stabilized temperature reference.

A forming module consisting of a series of rollers and guideshoes interspersed with heaters is located immediately downstream of the heating module. The components in this module are placed on a curvature that has been carefully developed to coincide with the natural flow of the laminate during the forming process to avoid any wrinkling/malformation in the plastic bend zones that would damage the graphite fibers in the laminate. The laminate is first formed to a Vee shape, then the flanges are formed. Heaters and temperature sensors are interspersed between each stage. The heaters in the heating and forming sections are controlled to provide a bend zone temperature of 425 ± 25° F in the forming section. The plastic bend zones are protected from scuffing by relief cuts in the guide shoes and teflon coating on the idler rollers.

CAP SECTION ROLLTRUSION HEAD

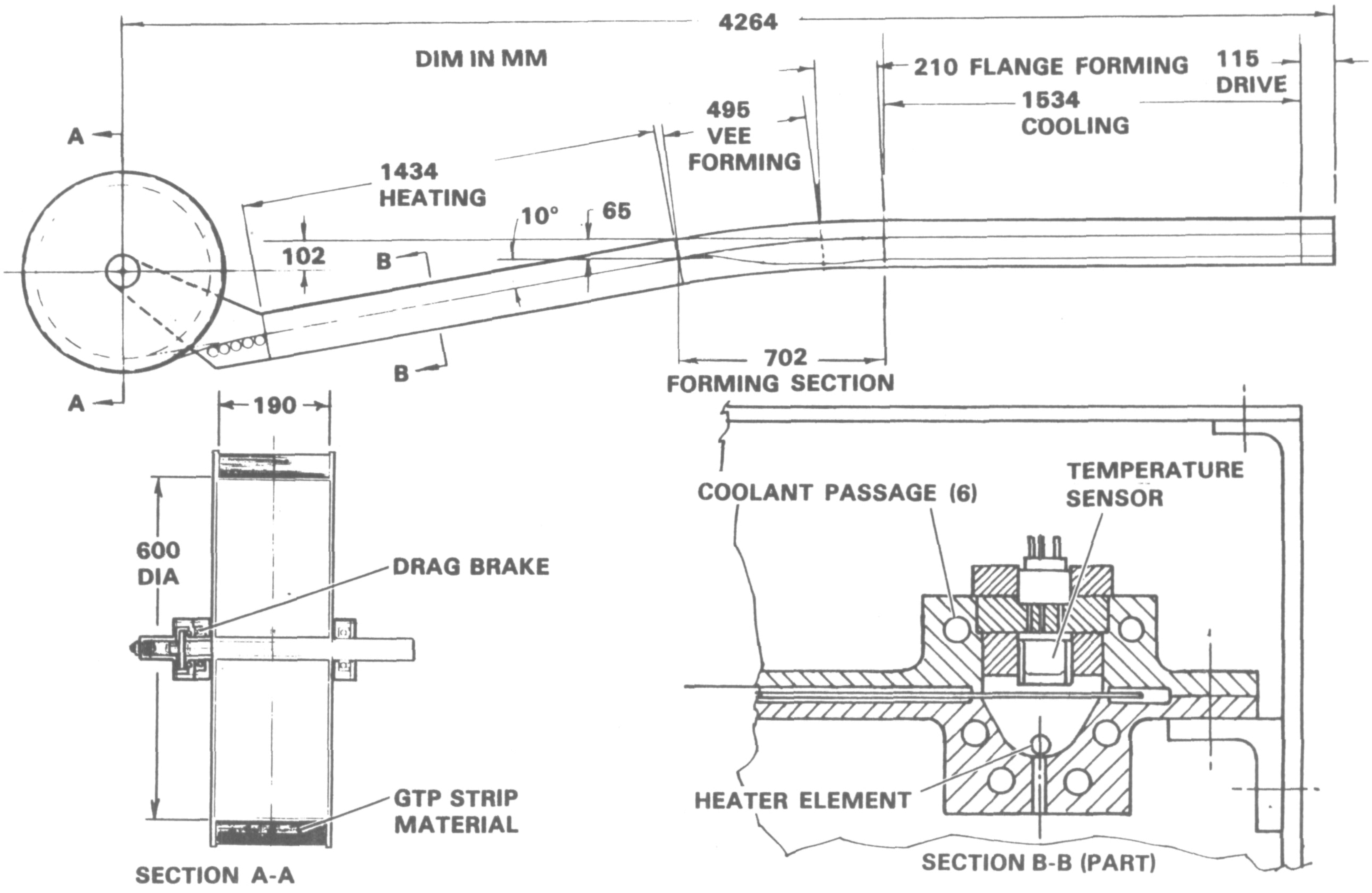


Figure 4

RADIANT HEATER PARAMETRICS AND DESIGN (Figure 5)

The recommended energy transfer mechanism is radiation from rod heaters. The radiation is directed at the fold areas to be heated, the other areas being masked. This method is used for primary operational heating, auxiliary start-up heating, and temperature maintenance. Parametric design data for the heater elements is given opposite.

Certain factors of uncertainty exist with regard to the emittance values used. A figure of 0.20 is available for non-oxidized nickel-chrome (80%, 20%) wire alloy and parameters in the region of 0.80 have been determined and reported for the alloy, when oxidized for 15 minutes at a temperature of 2100° F. The published emittance figures are closer to 0.86 at the temperature levels found herein. Emittance is significant with regard to definition of the stable operating temperature level of the nickel-chrome element wire.

Calculations showed that a wound heating element is feasible and applicable. What must yet be determined is the material which, both electrically and thermally non-conductive, can be formed or shaped to the established requirements. The chart illustrates these requirements, and also shows the relative arrangement/scale of the nickel-chrome wire lay. This basic design was found applicable to each of the strip heating applications.

RADIANT HEATER PARAMETRICS & DESIGN

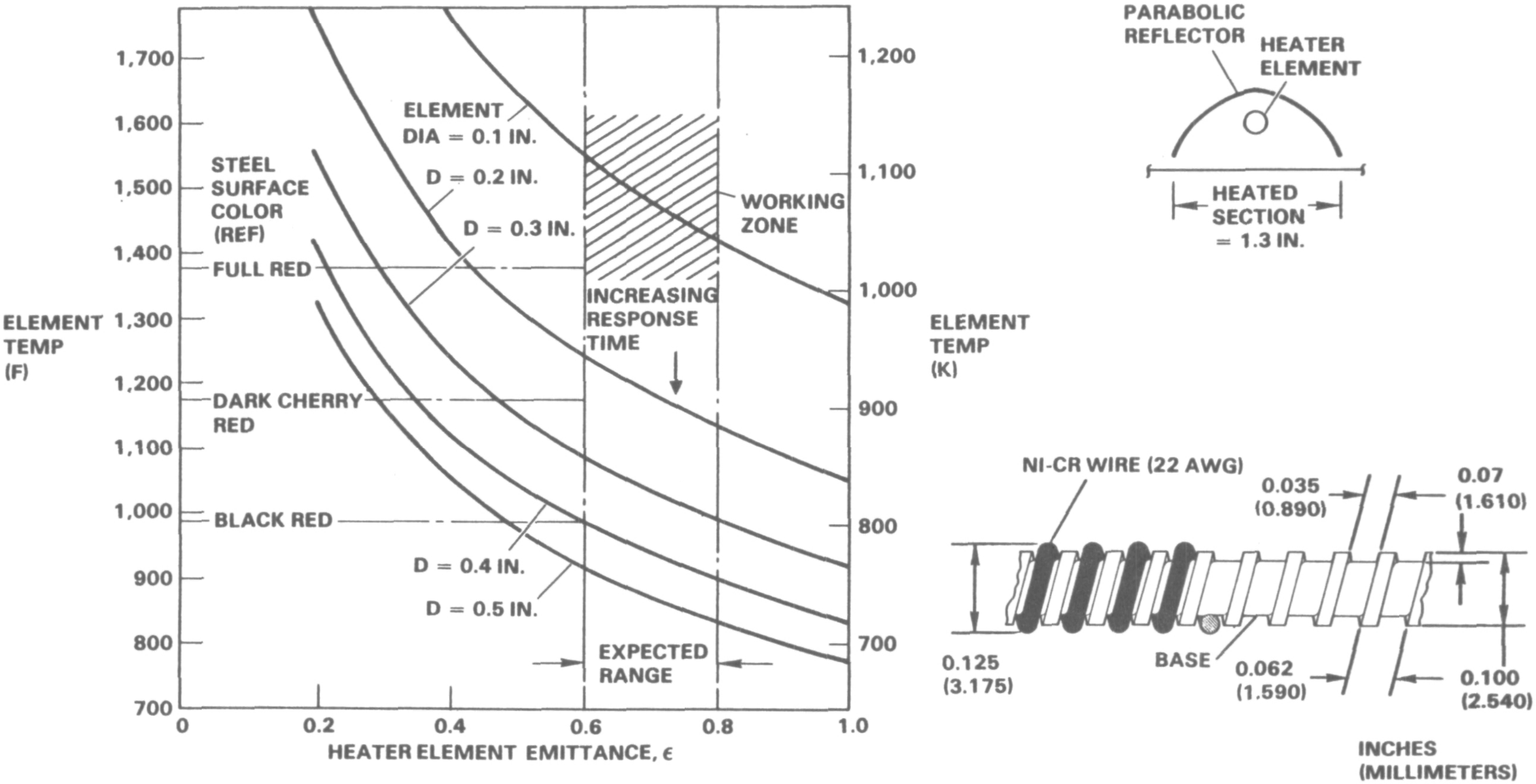


Figure 5

CAP SECTION FORMING (Figure 6)

The key feature of unidirectional graphite composite laminates is the inextensibility of the graphite fibers themselves. Even when the matrix is softened by heat, the fibers retain their original inextensible property; and in passing from Section A to Section F, shown in the chart opposite, they must maintain a conservatism of length. Experimental investigation shows that the free form between Section A and Section F of the material for a given length is explicit. By observation, the original shape-taking of the section shown in Section B is convex and there is a tension force applied at the softened apex of the section up to about 60% of the travel (i.e., Section C). The straight sections of the material pass through a point of inflexion, and, beyond there they become concave, giving rise to a compression at the softened apex. At Section B, the main apex angle of 60° is fully formed; and, between Sections E and F, the flanges may now be turned. Any attempt to turn the flanges at the same time as the apex angle is being formed will give rise to buckling of the softened material with a consequently greater probability of extensive delamination.

CAP SECTION FORMING

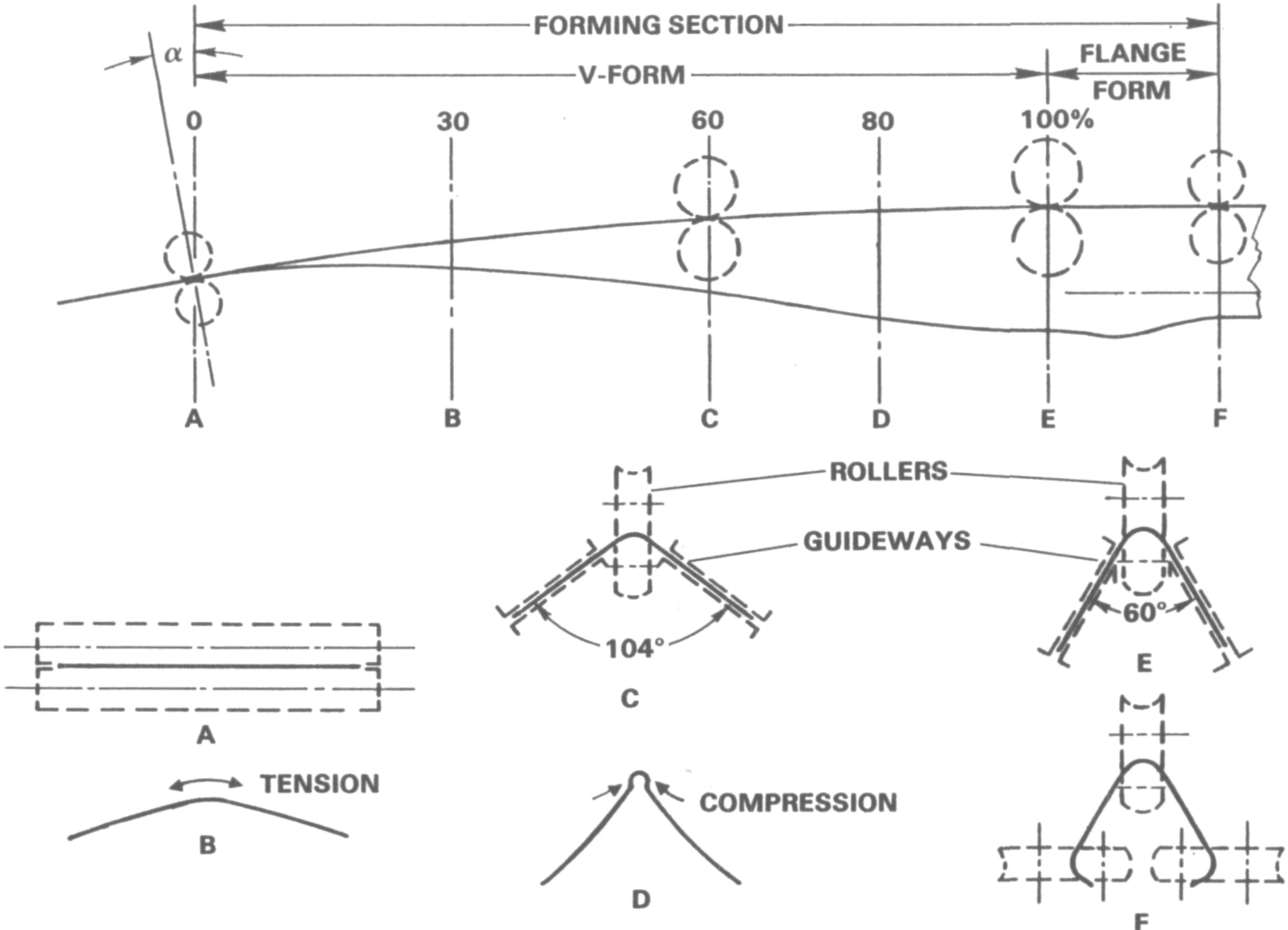


Figure 6

COOLING PARAMETRICS (Figure 7)

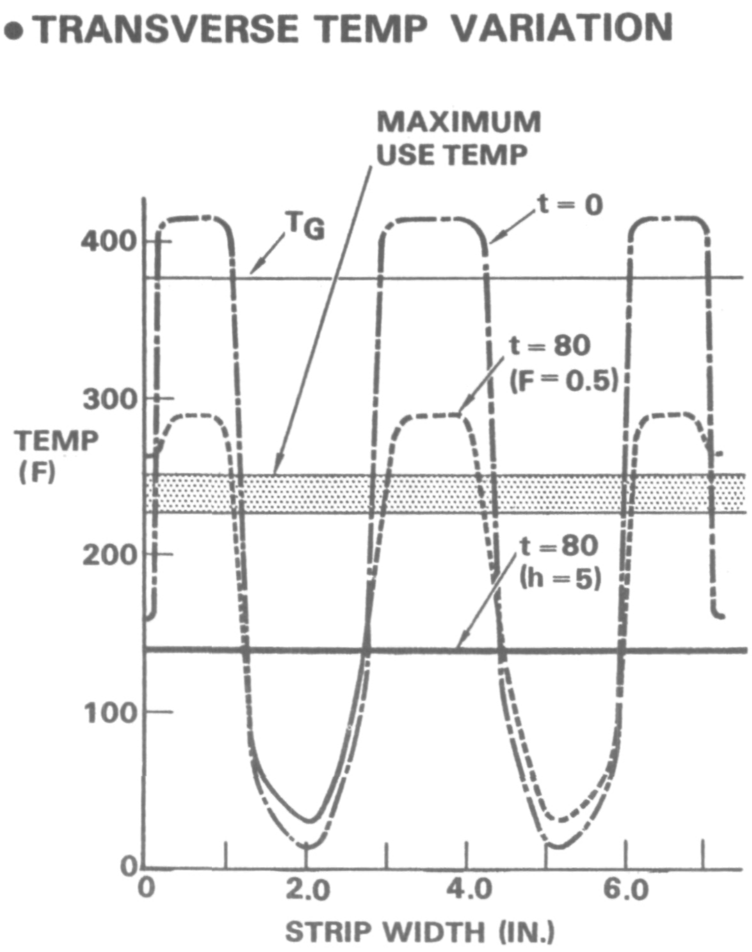
The characteristics of the temperature distribution in a hybrid laminate as it exits the beam builder forming section were investigated.

An analysis was conducted in which the strip was allowed to radiate (with a relatively optimistic deep space view factor, F, of 0.5) as well as conduct within itself over a complete 80-second machine cycle. As shown, the resulting peak temperatures still exceed the use temperature constraint, indicating that dedicated cooling is still required.

As seen in variations among key parameters controlling temperature decay rate, radiative/transverse conductive cooling is marginal even with a space view factor of 1.00.

Conversely, the platen cooling option permits significant reduction in pause cycle time (other processes permitting) even for a conservative contact coefficient of 5 BTU/hr-ft^2 °F.

COOLING PARAMETRICS



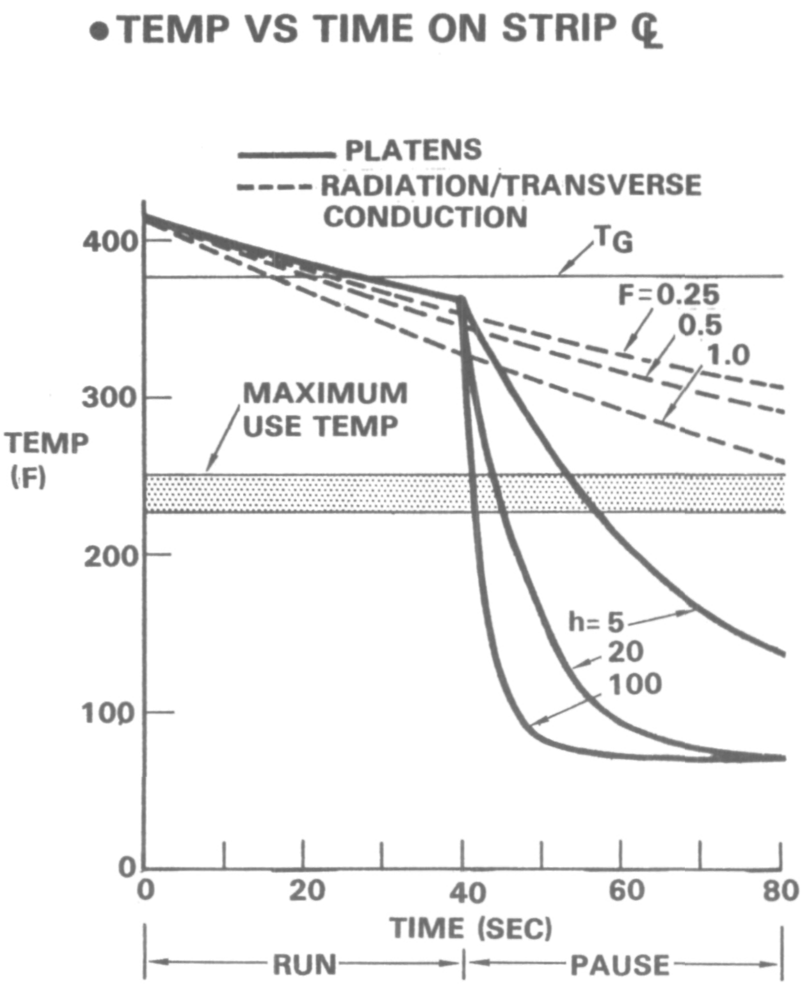


Figure 7

17018000H8729A

BEAM FABRICATOR GENERAL ARRANGEMENT (Figure 8)

This beam fabricator concept feeds and processes raw materials in the form of coiled graphite polysulfone laminate strip and polysulfone impregnated S-glass roving cord into a completed continuous braced triangular cross section beam of one meter depth. New technology in the rolltrusion hot forming of structural sections is combined with state-of-the-art mechanical and electrical/electronic design practices to effect straightforward flightweight product. Through an iterative design and trade study development approach, the machine shown in general arrangement opposite has been evolved.

Principal features of the beam fabrication machine are shown. Six reels of strip graphite/thermoplastic (GTP) material feed the rolltruder units which produce three continuous cap section members and the beam cross-members. The cross-members are cut to length positioned, and ultrasonically welded in place. Each bay of the beam is diagonally braced by crossing cords. These are dispensed and tensioned by an oscillating arm mechanism. The cords are fastened by welding them between the contact surfaces of cross-members and caps. Differential cord tensioning is used to correct any inherent twist in the beam. Straightness within construction tolerances is achieved by synchronized cap extension.

BEAM FABRICATOR GENERAL ARRANGEMENT

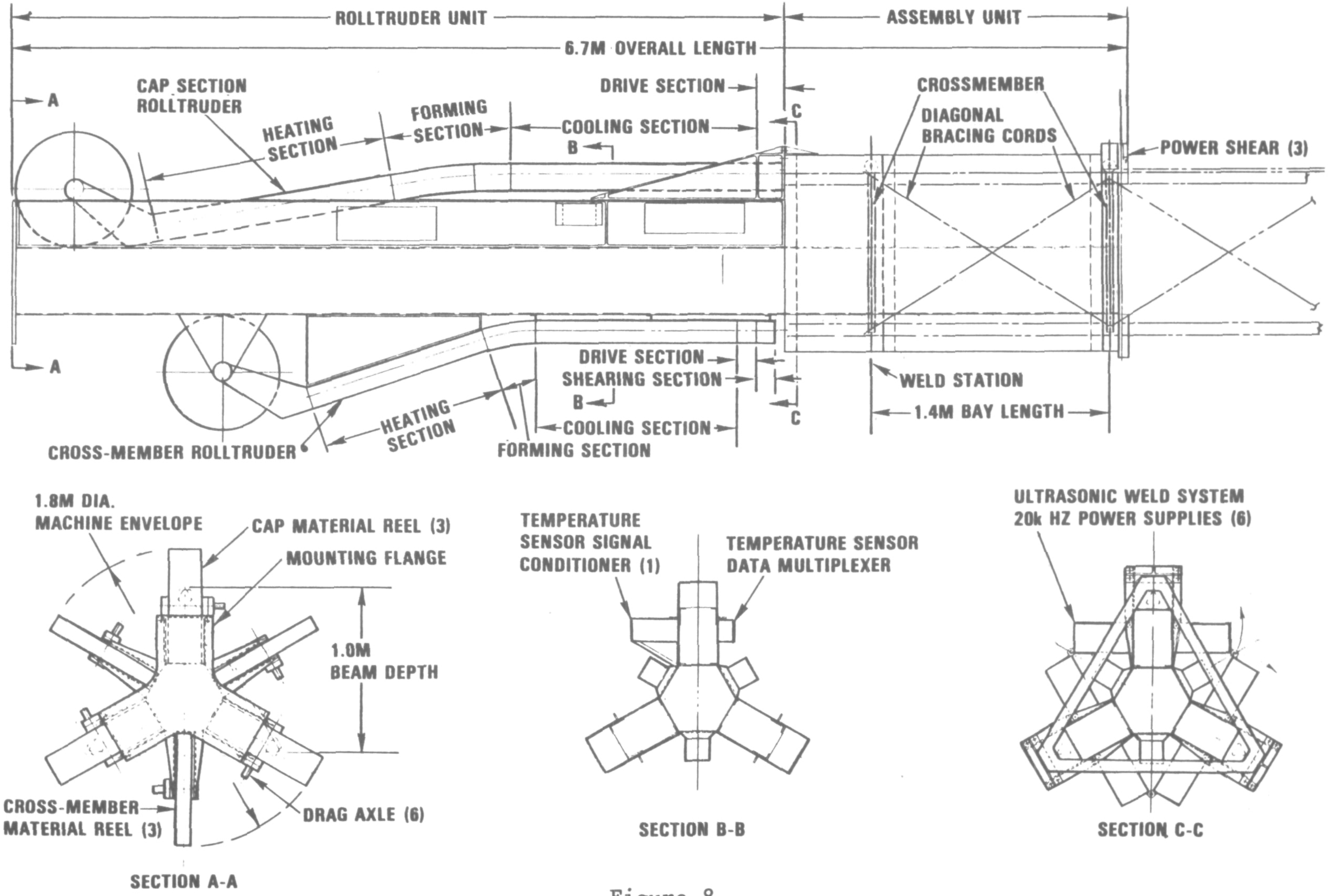


Figure 8

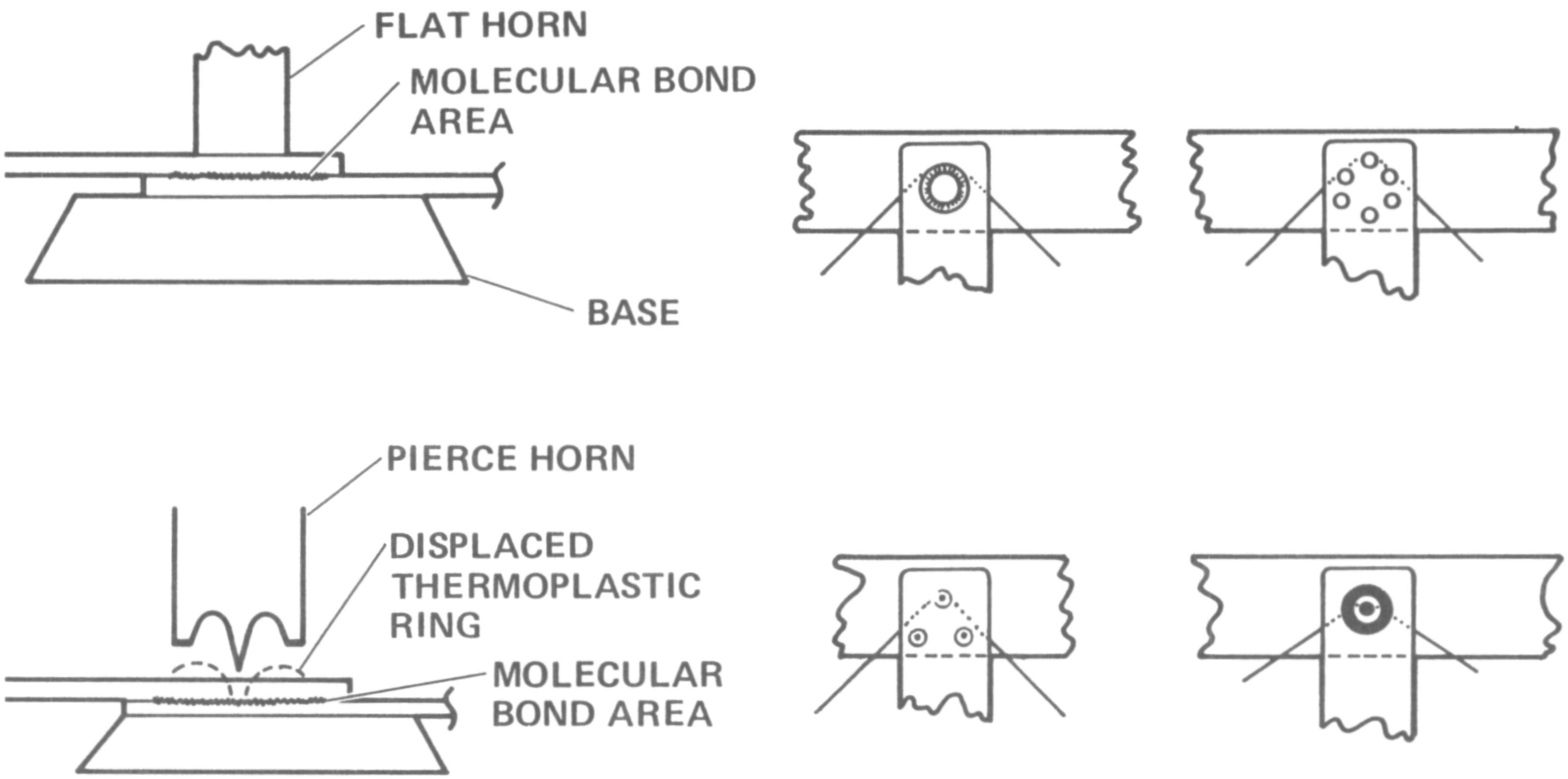
ULTRASONIC ASSEMBLY WELDING (Figure 9)

In a spot weld, the horn normally used contains a "piercing tip" or pilot which penetrates through the top sheet. The molten plastic displaced on the spot weld surface is shaped by a radial cavity in the tip and forms a raised ring of thermoplastic material simultaneously, energy is released at the interface, producing essential frictional heat to cause a thermoplastic melting and flowing to form a permanent molecular bond.

The chart shows a cross section of a flat weld and a typical piercing spot weld.

The ultrasonic spot weld method is the most attractive joining system investigated for our beam-building system. It is rapid, uses a minimum amount of energy, can be designed in an acceptable size and weight package, and produces excellent welds using a variety of weld tips. The type of tips and supporting mechanical and electrical combinations are numerous and varied. The chart illustrates several possible weld configurations. The selection of any weld configuration should be based on design requirements and energy limitations.

ULTRASONIC ASSEMBLY WELDING



TYPICAL WELDING ARRANGEMENTS

POSSIBLE WELD CONFIGURATIONS

Figure 9

BEAM FABRICATION MACHINE - ASSEMBLY SECTION (Figure 10)

This perspective view of the beam fabricator assembly section shows the major functioning mechanisms. The three cap sections emerge from their rolltrusion units. Cross members have been sheared at the exit from their rolltruders and are partially swung into position for welding. The dispensing arms have laid cord diagonals in position for cross member placement beneath the articulated ultrasonic weld heads. At the machine exit, locations of the beam cap shears are apparent. Shearing anvils are firmly supported from the hexagonal section structural spine.

BEAM FABRICATION MACHINE — ASSEMBLY SECTION

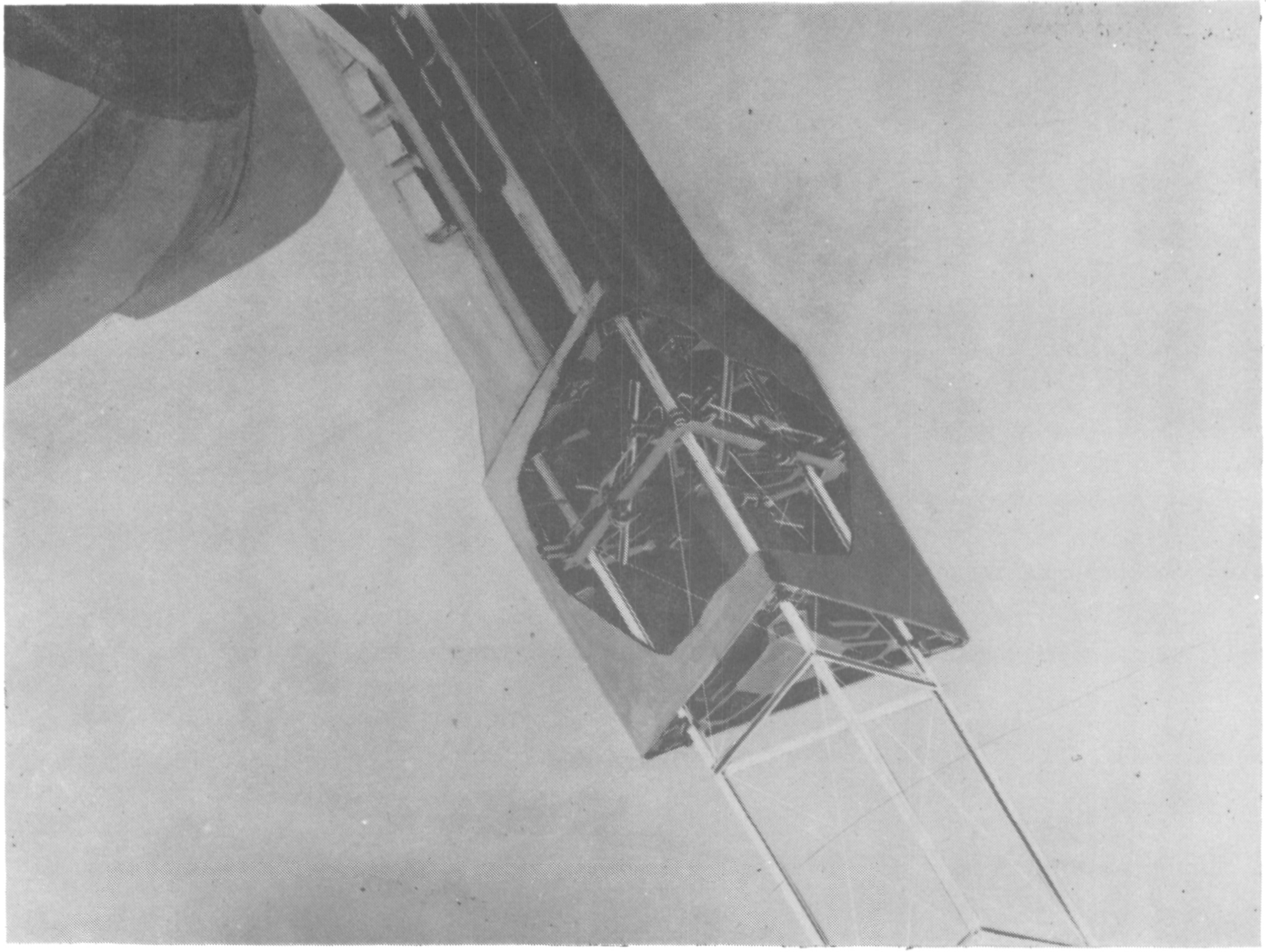


Figure 10

TYPICAL JIG & BEAM BUILDER DEPLOYMENT SEQUENCE (Figure 11)

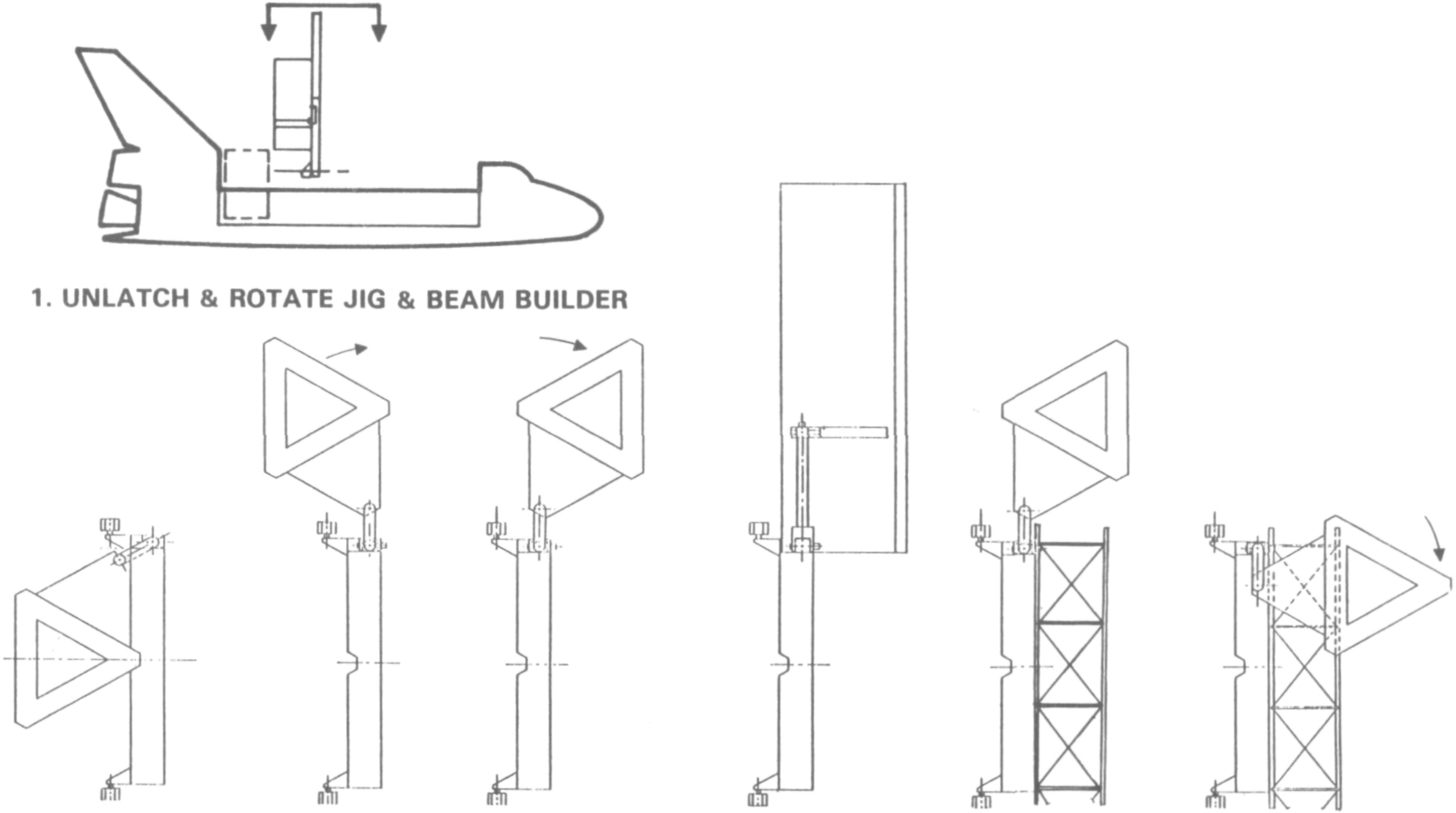
The assembly jig is deployed by unlatching the forward Z support pins and rotating the jig about an axis concentric with the aft X-Z trunion support pin.

When the longitudinal axis of the jig is parallel to the Z axis, the jig is locked into position and the beam builder is unlatched for deployment.

Beam builder deployment and positioning is performed as a series of operations by the roll and turn mechanism. The beam builder is rolled 180° in two steps as shown in Steps 3 and 4. It is then turned 90° to the orientation required for longitudinal beam fabrication as shown in Step 5.

To reorient the beam builder for cross-beam fabrication, it is first turned back 90°. The roll link then rotates 180° as the beam builder counter rotates 120° resulting in a net rotation of the beam builder of 60° and a lateral translation to the desired position.

TYPICAL JIG & BEAM BUILDER DEPLOYMENT SEQUENCE


1. UNLATCH & ROTATE JIG & BEAM BUILDER

2. UNLATCH BEAM BUILDER

3. ROLL 120°

4. ROLL 60°

5. ROTATE 90°

6. PREPARE TO BUILD CROSS BEAMS ROTATE 90°

7. ROLL 60°

Figure 11

CROSS-BEAM TO LONGITUDINAL BEAM JOINING TECHNIQUES (Figure 12)

Use of EVA personnel for performing cross-beam to longitudinal beam joining is considered too time consuming and would interfere with other EVA activities where manual action is more advantageous; e.g., installing instrumentation or connecting instrument wires. Highly repetitive operations such as beam joining should be automated wherever practicable.

Automatic welding options considered are compared as follows:

Single Row Traveling Welder

- Greatest control complexity
- Slowest joining method (mission impact)
- Adds a special carriage mechanism
- Minimum number of weld heads for least power utilization

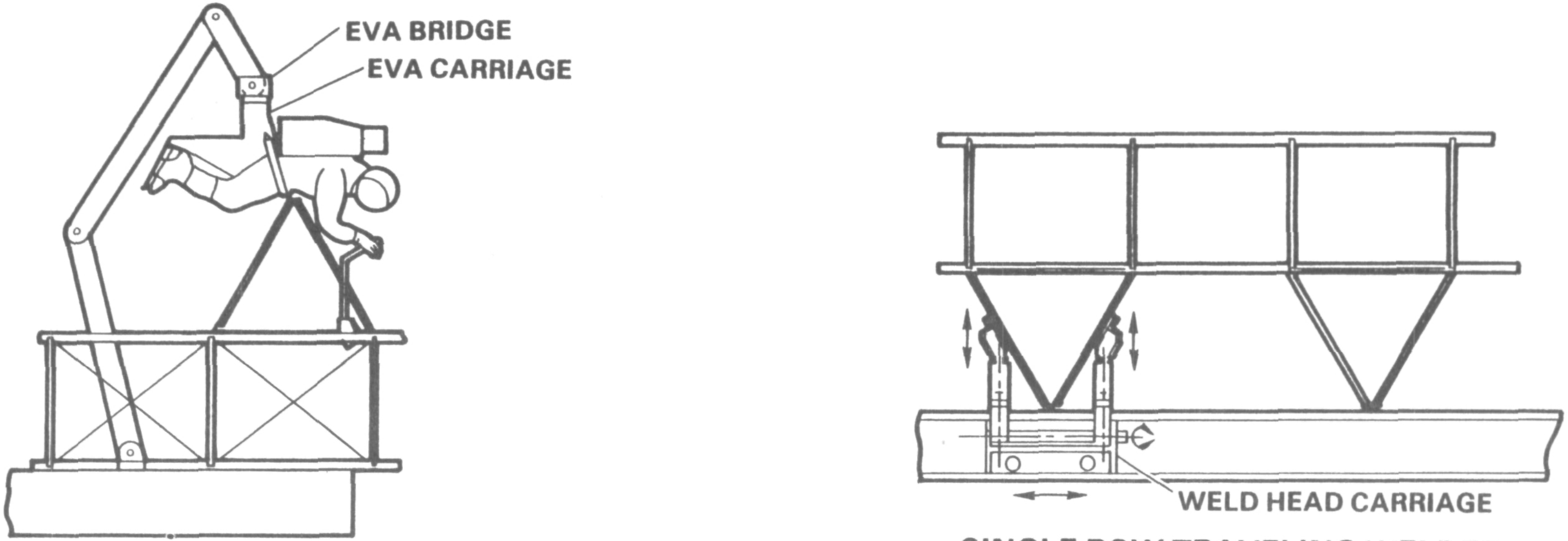
Double Row Fixed Welder

- Fastest joining method
- Maximum number of weld heads (16) increases power requirements
- Simplest welding mechanism
- Least number of control functions

Single Row Fixed Welder

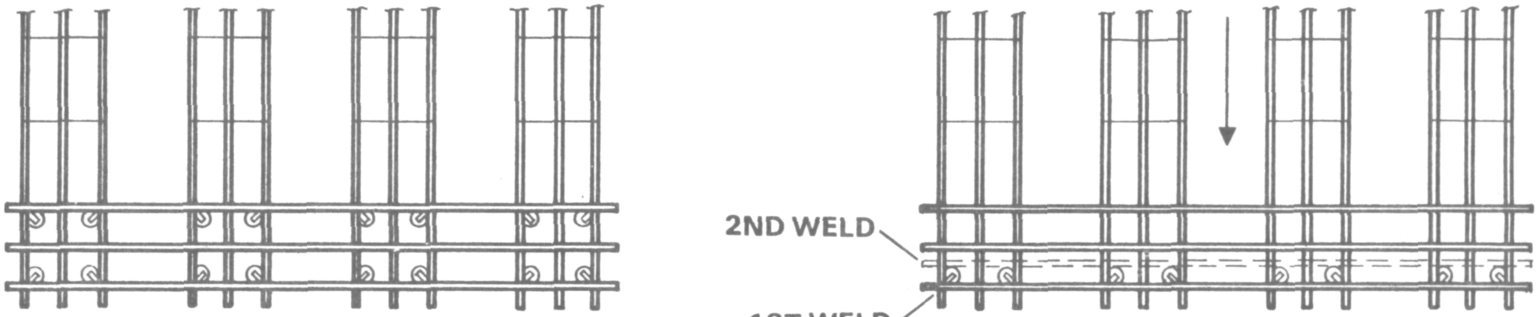
- Permits welding operations within reasonable time limits with fewer weld heads (8)
- Half the power usage of double row welders
- Adds index drive mechanism to welding mechanism
- Adds to complexity of platform drive control

CROSS BEAM TO LONGITUDINAL BEAM JOINING TECHNIQUES



HAND-HELD WELD HEAD

SINGLE ROW TRAVELING WELDER



DOUBLE ROW FIXED

SINGLE ROW FIXED

Figure 12