Apr 3rd, 12:00 AM

Applying the Ablative Heat Shield to the Apollo Spacecraft

B. V. Coplan
Materials Technology Directorate, Space Systems Division, Avco Corporation Wilmington, Massachusetts

R. W. King
Materials Technology Directorate, Space Systems Division, Avco Corporation Wilmington, Massachusetts

APPLYING THE ABLATIVE HEAT SHIELD TO THE APOLLO SPACECRAFT

B. V. Coplan
R. W. King

Materials Technology Directorate
Space Systems Division
Avco Corporation
Wilmington, Massachusetts

INTRODUCTION

The Apollo program to land men on the moon is administered by the National Aeronautics and Space Administration. Production of the spacecraft command module has been assigned to the North American Aviation Company. As a subcontractor to N.A.A., the Avco Corporation is carrying out the design and fabrication of the ablative heat shield for this module. Avco has the responsibility for the complete thermal design of the heat shield and for the analysis of any structural effect of the ablative material on the total vehicle. The environmental requirements which the heat shield must satisfy are determined by North American.

The Apollo spacecraft command module houses the three-man crew during flight and is the only part of the spacecraft to re-enter the earth's atmosphere at the completion of the lunar mission. It is a cone-shaped vehicle with a blunt base and is composed of an airtight aluminum inner crew compartment suspended within a stainless steel outer shell.

The outer stainless steel shell acts as a heat shield and is the support structure for the external ablative heat shield. It is composed of three mating sections: the forward compartment which is the pointed end of the cone, the crew compartment which forms the midsection, and the aft section which forms the rounded blunt section. The aft section or blunt end becomes the forward part of the module during earth reentry. The forward and crew compartments are made of 0.6-inch-thick stainless steel honeycomb panels with face sheets from as thin as 8 mils to a maximum of 40 mils. The aft section is made up of thicker stainless steel honeycomb with a corrugated section forming the rounded portion of the section adjacent to the crew compartment.

Ablative material is applied to the entire surface of the stainless steel structure except over the windows and exhaust ports. The thickness of the ablative material varies from approximately 3 inches on the aft section to less than 1/2-inch on a portion of the side, the thicknesses being varied to meet the calculated reentry heating loads over the various sections of the module.

This description of the module structure is deliberately brief and is meant to serve solely as a background for a discussion of the ablative heat shield. A complete description of the Apollo spacecraft structure appeared in the 5 October 1964 issue of the "Aviation Week and Space Technology."

I. DESCRIPTION OF HEAT SHIELD

The ablative heat shield structure is composed of a fiberglass honeycomb, impregnated with a phenolic resin and bonded with an epoxy-based adhesive to the cleaned, stainless steel shell. The honeycomb structure is composed of a number of pieces formed on molds to the proper curvatures. The honeycomb is cut to size during a prefit operation with a narrow gap left between pieces. The bonding is accomplished by vacuum bagging with a thermal cure of the adhesive. At edges of compartments and at all doors and entries through the stainless steel shell, epoxy-fiberglass edge members protect the heat shield and prevent erosion by shear forces during reentry.

The fiberglass honeycomb is used to create a structural base for anchoring the ablative material firmly to the stainless steel shell. The bond of the honeycomb to the stainless steel is verified by ultrasonic testing. This ensures that the ablator will form a monolithic structure properly bonded at all points to the substructure.

Forming tiles of the ablative material and cementing the tiles to the vehicle was another method considered. While the small cells of the honeycomb created a potential filling problem, it was felt that use of a honeycomb base increased reliability of the ablative shield. Using bonded tiles, failure of a local bond area could cause loss of a tile and exposure of an appreciable area of the steel shell. Failure of a local area of honeycomb bond is far less likely to cause loss of material because of the restraint exerted by adjacent bonded material. In addition, bond failure of any area is less likely to occur because the bond of the honeycomb is verified at all points before the cells are filled.

After the prefit operation, the stainless steel surface is thoroughly cleaned and the honeycomb and edge members bonded to the vehicle. The bond is tested for proper adhesion over the entire surface. To save weight, the required thickness of ablator is established by thermal and structural calculations. Using numerically controlled machining, the calculated profile is produced by precise grinding on a vertical turret lathe. The honeycomb cells are then filled with the ablative material. The cell is a hexagon of nominal 3/8-inch width. The depth to be filled ranges from 1/2-inch to slightly over 3 inches, depending upon location on the vehicle (Figures 1, 2, 3, 4).

Design specifications for filling the honeycomb with ablative material include:

1. Every cell must be filled within a specified density range.

2. No void shall be larger in depth than 8 percent of the honeycomb depth or 3/32-inch normal to cell walls.

3. The plastic honeycomb must not be damaged.

Following filling of the cells, the total structure is X-rayed and any voids or defects repaired while the material is in the uncured state. The covered structure is then cured, machined to final thickness, and re-X-rayed. A tight seal is maintained around hatches, doors, and windows by use of silicone rubber gaskets. To ensure a perfect fit, these are cast in place using a room-temperature curing silicone rubber after the final machining. If necessary, repairs to the cured material are performed at this time, and the shield is finished by application of a moisture barrier sealing coat (Figure 5).

II. APPLICATION OF THE ABLATIVE HEAT SHIELD MATERIAL

The ablative material is a multi-component mixture of resins, fibers, and fillers. It is compounded a few days prior to use. Each batch is thoroughly tested and must meet rigid specifications before it is brought to the application area (Figure 6).

As mixed, it is a fibrous, sticky mass, nonflowing to the point where it holds its shape if a handful is removed from the mixer and lightly compacted into a ball.

The application of the ablative material is difficult because of the putty-like nature of the formulation, the irregular cross sections and sharp corners of the cells, and the relatively fragile plastic-fiberglass honeycomb. The honeycomb is strong in compression and forms a monolithic structure when filled with ablator and cured. Prior to filling, however, it can be separated at the node walls or can be torn fairly easily. The filling method must not cause any damage to the plastic honeycomb and must fill the cells with no voids within a specified density range.

The objectives were achieved by the development of an air-injection system. This is not simply extrusion by air, pushing the material out of the injection gun; filling is achieved by blowing air through a cartridge of the material contained in a gun barrel and injecting the air stream with accompanying material into the cell. The air vents from the cell, leaving the ablative material behind, well packed into the cell. The components of the material are not separated by the air stream and uniform composition is maintained.

By controlling the air pressure, the time cycle for air on-off and the temperature of the gun and contents, operator technique is reduced to a minimum and density of material in the cell is made uniform. An automatic gun is used for undistorted cells, up to 1-1/2 inches in thickness. For cells distorted by bending to a short radius, for thicknesses above 1-1/2 inches, and for special splice areas, a more manual gun is used. Both of these guns are described in detail in the following section.

The nozzle of the automatic gun is put at the top of the cell and all compaction is accomplished by the selected air pressure. The hand gun is used with a nozzle which is inserted into the cell and withdrawn gradually as material is injected. The operator uses the nozzle to compact the material and to ensure that the cell is void free.

III. DESCRIPTION OF THE GUNS

A. Manual

The manually operated gun is of the standard pneumatic caulking type. Its main body is a steel cylinder completely open on one end and swaged to a smaller diameter on the other end. A plastic valve head inserts into a holding and clamping bracket which can be twisted to fit and lock onto lugs which are riveted on the larger end of the cylinder body. Inside this steel cylinder is inserted a removable plastic tube with a molded lip on one end which forms an air-tight seal between the cylinder and valve head. A solid plastic insert is pressed into the other end of the cylinder. This insert is tapered on its inside surface to form a streamlined flow pattern from the inside of the plastic tube to a small opening in the other end of the insert. The small end of the insert protrudes from the steel cylinder in the form of a cylinder, the outside of which contains machine threads for attaching various shapes and sizes of nozzles.

The plastic tube inserts are filled with ablative material immediately following compounding of the ablative mixture. They are fluoroscoped and stored in a freezer pending results of fluoroscopy and other material quality control checks. When approved and ready for use, the frozen cartridge is dielectrically heated and stored in an oven about 10 minutes to attain temperature equilibrium. When required, the heated tube of ablator is inserted into the steel cartridge, the valve head is locked in place over a cloth filter, and the gun is ready for use. By depressing a trigger mounted on the handle of the gun, air is admitted through the valve head and into the plastic cartridge containing the ablator.

The mechanism of material flow from the cartridge through the nozzle and into a cell of honeycomb structure is unique when compared to the mechanism involved when using a liquid or putty with this gun. With a liquid, the air acts like a piston on the surface and extrudes the liquid from the cartridge out through the nozzle. No air permeates through the liquid itself. In contrast, with the Apollo ablative mixture, air flow actually occurs through the material and even into the honeycomb cell. The air acts as a vehicle in this case and it literally transports the material from the gun into the cell.

B. Automatic Gun

The purpose of the automatic gun is to free the operator from the repetitive operation of pulling the trigger, thereby increasing production efficiency and producing a more uniform density of material from cell to cell. It is used for honeycomb thicknesses up to 1-1/2 inches. The automatic gun's operation, as far as material flow is concerned, is identical with that of the manual gun. The manual trigger for activating the inlet air valve is replaced by an electrically operated solenoid. The solenoid, in turn, is connected to a timing device such that the solenoid is consistently energized and de-energized at any desired repetitive sequence. This produces a constant length of time when air is admitted and material flow occurs, followed by a constant length of time when air is exhausted and material flow ceases. During this off period, the operator moves the gun from one cell to another. It can be seen, that a prediction of cells filled per given unit time can be made more certainly with this device than with the manual gun. The fact that the operator is relieved of the operation of depressing the trigger each time diminishes operator fatigue.

Both hand and automatic guns are kept at a constant temperature by wrapping with electric heating tape. This keeps the material at the proper viscosity during the gunning operation.

The forming of the honeycomb to fit the stainless steel structure causes cell distortion and creates varying shapes of cells. To adequately fill distorted cell shapes, the hand gun is used with nozzles of different cross section. The operator selects the type suitable for the specific area he is filling. A standard nozzle is used for the automatic gun which fits all regular and slightly distorted cells (Figures 7, 8, 9, 10).

IV. CONCLUSION

We have found that the air-injection guns described in this paper have enabled us to inject a putty-like, non-flowing, sticky material into irregular areas to form a sound structure meeting rigid specifications. The combination of the automatic gun for regular cross-section cells up to 1-1/2 inches high and the hand gun for deeper cells, gaps, and irregular cross sections has met the filling requirements. This gunning method, by controlling the injection pressure, minimizes the liklihood of damage to cells during production filling.

Other methods were tried, including rolling, tamping, extrusion, brushing, and ultrasonic vibration. No other method came close to air injection in uniformity of filling, protection of the honeycomb and meeting void-free specifications.

We have found it takes about 2 weeks to fully train and certify a gunner. Before a gunner is allowed to work on an Apollo vehicle, he undergoes a formal training period. At the end of this period he makes a qualification panel using both the automatic and hand gun. This panel must meet specifications as determined by X-ray examination before he is certified as a qualified gunner.

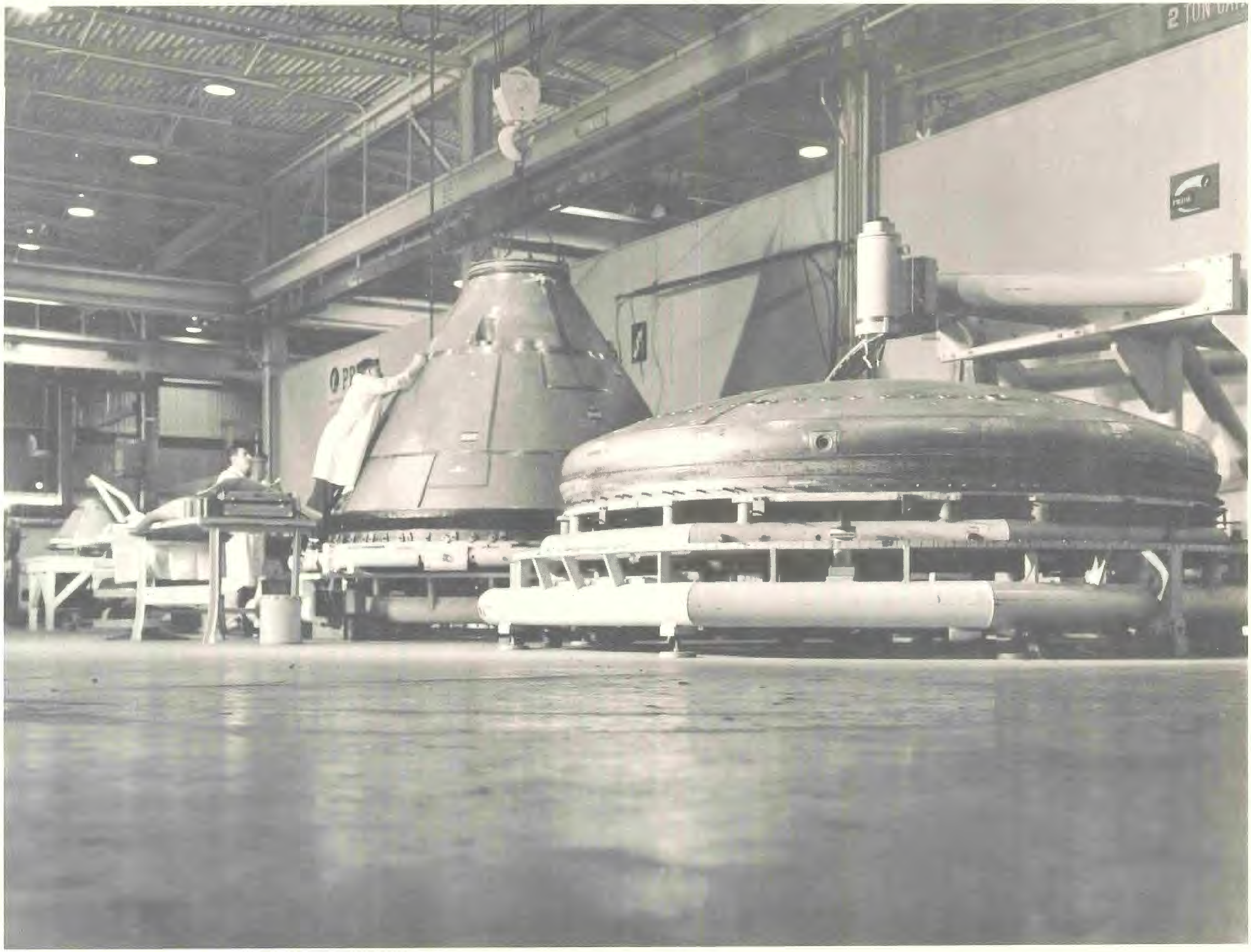

Figure 1   Stainless Steel Sections of Apollo Command Module

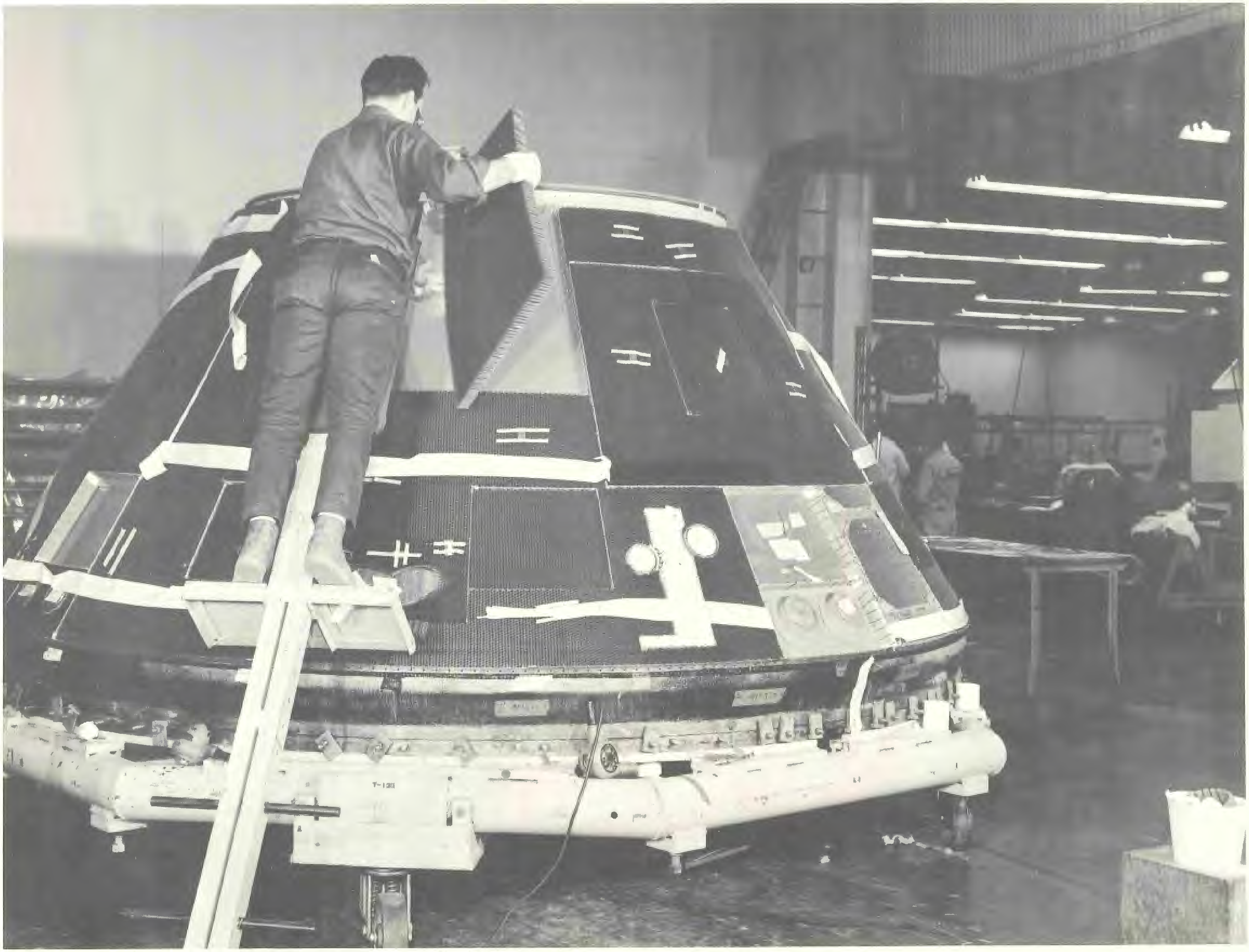

Figure 2 Prefitting Honeycomb

Figure 3 Prefitting Edge Members

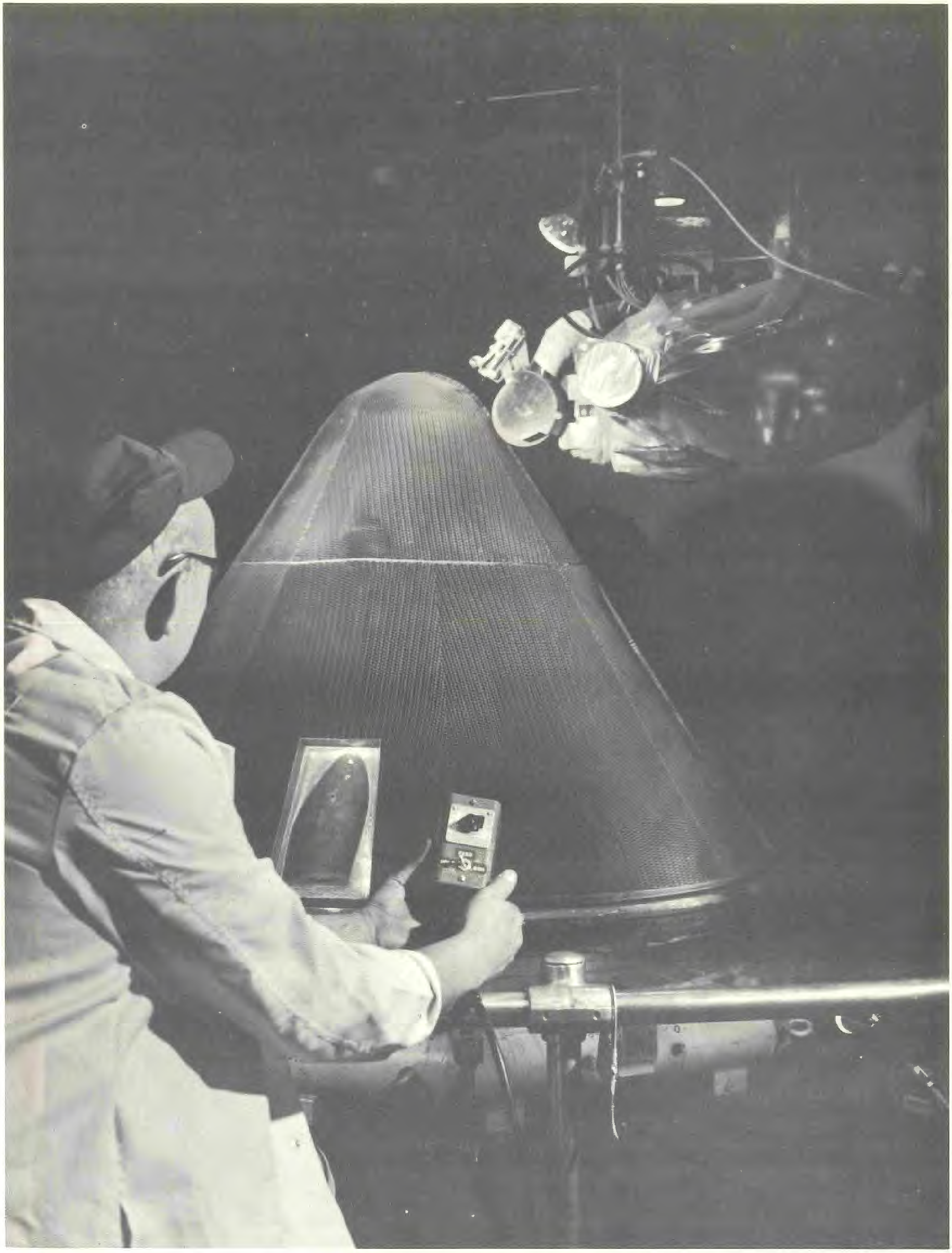

Figure 4 Machining Honeycomb

Figure 5 Shipping The Completed Crew Compartment

Figure 6 Mixing the Ablative Material

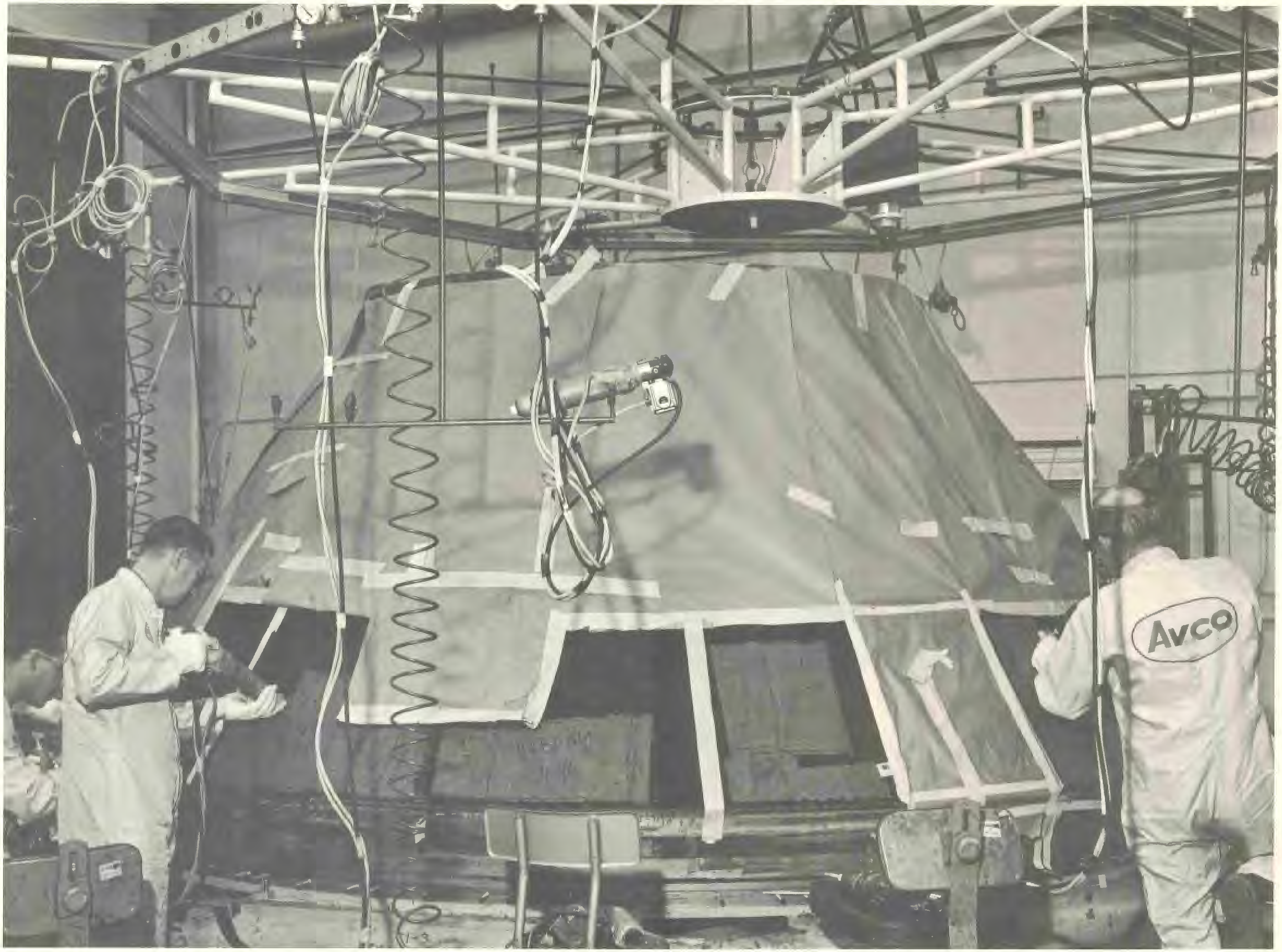

Figure 7 Gunning The Crew Compartment

Figure 8 Closeup of Automatic Gunning

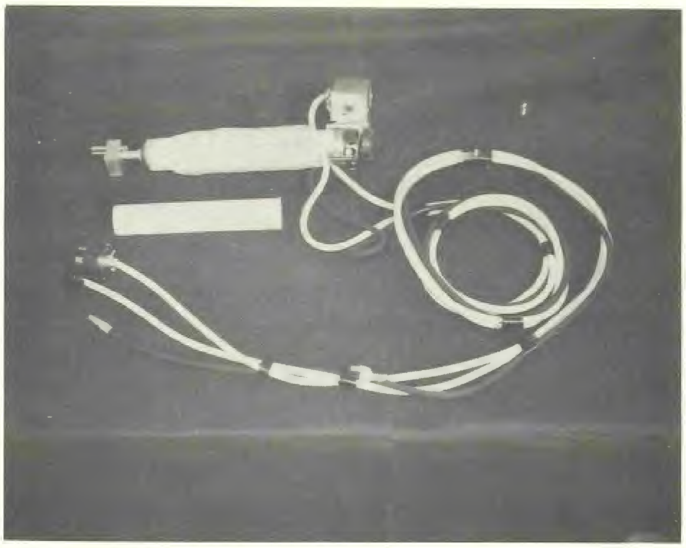

Figure 9 Gun Components

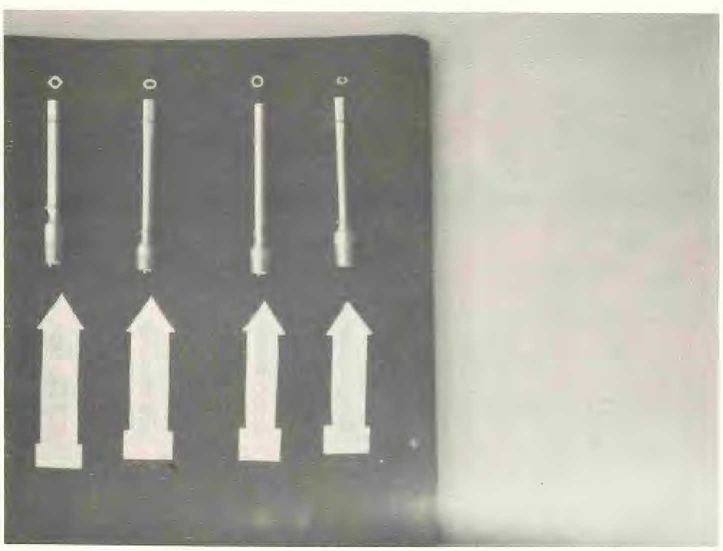

Figure 10 Nozzles For The Hand Gun