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APOLLO

FINAL STUDY REPORT

VOLUME V IMPLEMENTATION PLAN

BOOK 4 MANUFACTURING PLAN

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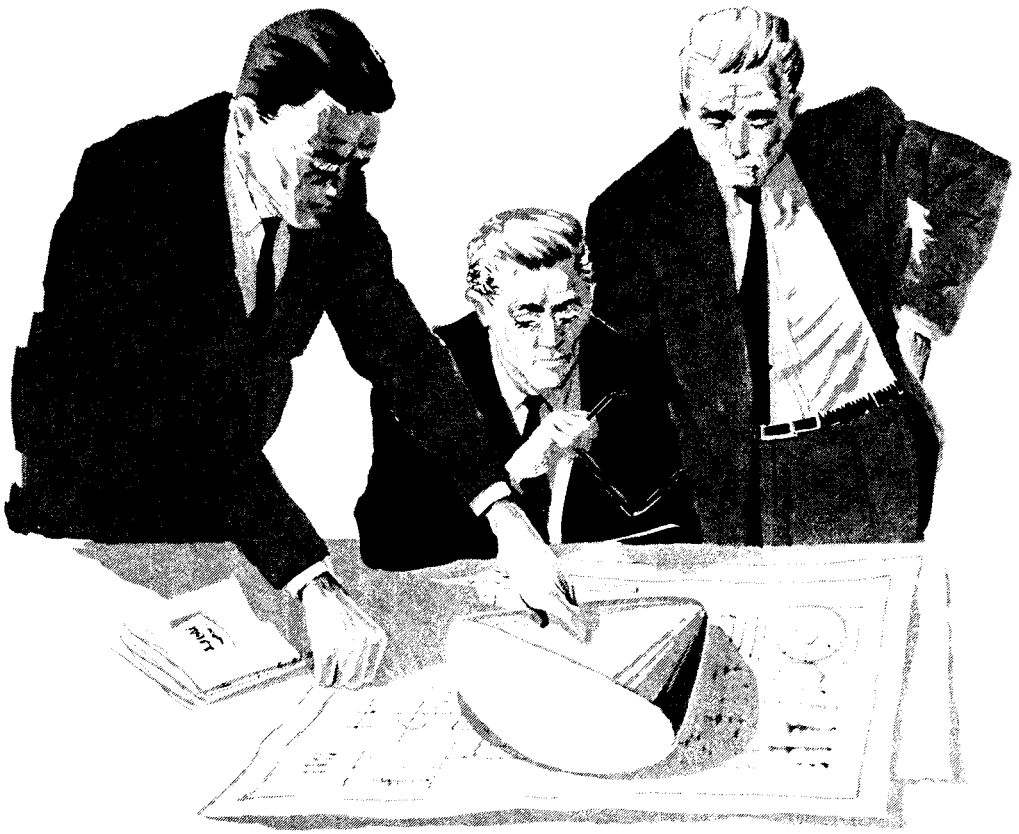

APOLLO
FINAL STUDY REPORT

Report No. AE61-0363

15 May 1961

Contract NAS 5-304

Volume V
IMPLEMENTATION PLAN
Book 4
MANUFACTURING PLAN

Prepared by:

CONVAIR (ASTRONAUTICS) DIVISION
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VOLUME I | SUMMARY

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VOLUME III | SUPPORTING DESIGN ANALYSES

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BOOK 2 | HEAT CONTROL SYSTEMS

BOOK 3 | STRUCTURAL ANALYSES AND MATERIALS

BOOK 4 | PROPULSION AND AUXILIARY POWER

BOOK 5 | TRACKING, COMMUNICATIONS AND DATA SYSTEMS

BOOK 6 | GUIDANCE AND CONTROL

BOOK 7 | AEROSPACE MEDICINE AND RADIATION

BOOK 8 | ENVIRONMENTAL CONTROL AND LIFE SUPPORT

BOOK 9 | HUMAN FACTORS

BOOK 10 | RELATED CONFIGURATION STUDIES

VOLUME IV | GROWTH AND ADVANCED CONCEPTS

VOLUME V | IMPLEMENTATION PLAN

BOOK 1 | SYSTEMS ANALYSIS, SCHEDULES AND COSTS

BOOK 2 | RELIABILITY

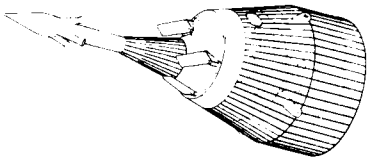
BOOK 3 | DEVELOPMENT PROGRAM

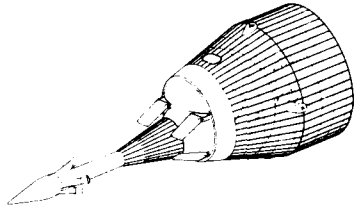
BOOK 4 | MANUFACTURING PLAN

BOOK 5 | SUPPORT OPERATIONS

FOREWORD

This book presents a manufacturing concept for the Apollo vehicle. A broad picture of the manufacturing operation is developed. Investigation of detail items and reference to them is purposely avoided except in area which may present fabrication difficulty or excessive costs. In most discussions, administrative, tooling or manufacturing principles are highlighted. The entire concept was developed to obtain maximum quality and minimum cost within a minimum time.





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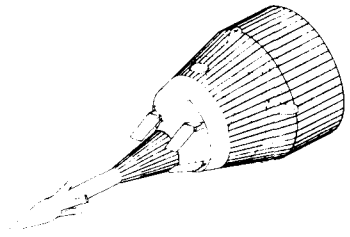

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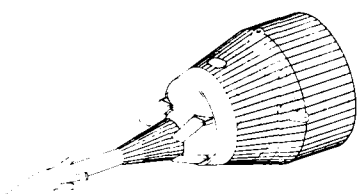


1 SUMMARY

1.1 GENERAL. This summary is presented to give a thumbnail sketch of the manufacturing concept. This concept is more fully presented in the remaining sections of this book.

A careful analysis of the current preliminary design has been made with a view in mind to answer the questions: 1) Can the design be produced and 2) Is the production feasible and are the production problems relatively proportional to the value of the unit's function.

As the design now stands, all components can be produced with contemporary facilities. An outline of how the unit can be produced is given in Section 3. Major tools for this concept are listed and consist of the minimum requirements to support a yearly production rate of seven units per year on a single shift basis.

The design engineers, industrial engineers and tool engineers collaborated frequently to obtain maximum coordination. The resulting design proved to be both producible and commensurate with its function. In no case has quality or reliability been sacrificed to facilitate production.

1.2 POLICY SUMMARY. The contractor's general policy must be to control the program to a degree that the desired quality is achieved within the contractual time limit and cost restrictions. This would be accomplished through administrative control, quality control, production control, tool control, purchasing control and cost control. Each control group must administer its portion of the program, keeping in mind the general management policy.

The administrative control is established through the development of a separate organization within existing lines. A Project Manager must be appointed. His staff would consist of the leaders of the other control groups. All groups would be completely divorced from other company activities, and would be responsible solely for the Apollo Project.

1.3 GENERAL MANUFACTURING CONCEPT SUMMARY. The general manufacturing concept develops the most feasible parameters by which management may convert the engineering concept to useable and deliverable hardware. As the engineering concept advances into a firm design the manufacturing plan converts the manufacturing concept into detail outlines of how, when, and where each piece and assembly will be produced.

The Apollo space vehicle as conceived in previous volumes of this report can be built as outlined in this plan. The complexity of the program demands close control and support of direct and indirect operations.

The fabrication area for the mission module will be very similar to existing machine tool, sheet metal, and processing areas. Deviation from contemporary practices will be in the areas of size and materials. Maximum part sizes vary from 12 feet to 18 feet in diameter. This will pose slight difficulties in isolated areas. The problem of large sizes can be overcome by reducing large component parts to several smaller pieces, and later assembling them, thereby achieving the same end results. Only a small weight penalty will be inflicted.

Titanium materials have been selected for construction of the mission module structure assembly. The major difference in handling between the use of this material and the use of other materials, such as stainless steel, aluminum, etc., is that titanium materials must be formed in the heated condition. A recommended solution for forming detail parts is to use heated shell-die stretch presses. This method is not only more economical from the standpoint of initial cost, in setting up a manufacturing process, but it will reduce costs in operation and in materials by reducing material scrappage. Welding will make a major contribution in the fastening area. Spotwelds, buttwelds and lap welds will be adopted to join materials as required.

The design of the command module vehicle dictates the use of brazed stainless steel honeycomb in the manufacture of the major structure assembly. In an effort to reduce the transfer and handling of critical material, and keep the high percentage of rejection of defective parts to a minimum, it is proposed to establish a separate fabrication and major component assembly line, completely divorced from other forms of manufacturing processes. For a more detailed discussion of the manufacturing processes and problem areas, see Section 3.2, Fabrication and Processes.

Separate assembly lines will be established for each unit within a common area. Checkout and validation of the various airborne systems will be performed with the vehicles in the mated condition. High-pressure testing of the Apollo pneumatic and hydraulic systems, and proof testing of the module cabin structure will be performed in an area isolated from populated areas for safety reasons.

1.4 SUMMARY OF SPECIAL CONSIDERATIONS. New processes, advanced manufacturing techniques, advanced equipment, and stringent tolerances require technical services before they can be readily used in production areas.

A manufacturing research analysis of the Apollo system, relating to new or advanced manufacturing requirements, indicates special areas of study. These are discussed in the following paragraphs.

1.4.1 Inboard Profile. The special requirements of several items as shown in configuration drawings are well within the state of the manufacturing art. Attitude and midcourse fuel and oxidizer pressure bottles, and helium high pressure bottles are in current production. The materials have included high strength steel, filament wound fiberglass, and titanium.

1.4.2 Command Module. The major requirements are for honeycomb sandwich made of brazed stainless steel structure and composite insulations. The primary structure is approximately 1/4-inch thick stainless-steel brazed honeycomb sandwich with frame stiffeners. The ability to manufacture such assemblies is indicated by many thousands of square feet of brazed honeycomb panels of various configurations which have been produced within the past five years. Several manufacturers have this capability.

The process uses conventional cleaning procedures similar to those used for spot and fusion welding. Pre-fit of parts is an extremely important phase, because of the accuracy required. From the time parts are cleaned and ready for brazed assembly, white glove cleanliness must be maintained with parts, tools, and work area. The parts are assembled in fixtures comprised of metal and castable ceramics to hold alignment during the brazing cycle. All panels must be held in place in an inert atmosphere. Pressure created by evacuating all internal air must be held until the unit is chilled at the completion of the brazing cycle. Heat is obtained from either of three common methods: 1) heating blankets, 2) quartz lamps, and 3) electric furnaces (and possible combinations).

There are several existing methods of panel joining such as secondary brazing, using various edge members for fusion welding, and mechanical attachments. This allows selection of a method which is satisfactory for a particular requirement. High re-entry temperatures (up to 5000° F), combined with other severe environmental conditions, will require the development of manufacturing capability in composite structures, which combine metallics and non-metallics ranging from hot structures to ablating devices.

The general assembly methods follow conventional missile and aircraft procedures.

1.4.3 Mission Module. Metallurgy is the key to production of the mission module. Metallurgy must be related to the selection of suitable materials, manufacturing techniques and tools essential to forming and assembly. Specifically, this involves: 1) decisions for types and gages of titanium, 2) development of joining techniques, particularly fusion and spotwelding, and 3) quality control methods for materials, processes, and related equipment. Additionally, structures which combine fiberglass and titanium require research to improve bonding methods, tools, and material applications.

While design utilizes conventional structures, the extensive use of A110-AT(5AL-2.5Sn) titanium involves development of new manufacturing capabilities. Many fabricators are familiar with titanium. In particular, one company has used one and one half million pounds of various types of titanium in the manufacture of production articles since 1953. Another has used 423,500 pounds in six years of production manufacturing. Many other contractors have done considerable titanium fabrication. All this work has resulted in accomplishing the following: 1) a working familiarity with most types of titanium, 2) a capability for proper design of hot and cold tooling for all types of forming, 3) the establishment of useful materials to be used for these tools, particularly in very hot forming ranges, and 4) the establishment, through extensive tests, of A110-AT (5AL-2.5Sn) titanium as a structural design material for temperature ranges of -423°F to 900°F. Reliable welding methods are established for both fusion and resistance processes. When titanium gages less than 0.020 thick are used, the mills will have an increasingly difficult problem to maintain widths of more than 24 inches and lengths of more than 10 feet. There are several ways of avoiding this problem satisfactorily: 1) with fusion welded joints capable of 100 percent joint efficiency (for yield and tensile strength; 90 percent efficiency for ductility), flat sheet can be welded to any desired width; 2) use the heavier gages that are available, and, as last operation of the fabrication procedure, chemically mill the excess material. Titanium chemically mills very satisfactorily, with a good surface finish of from 60 to 100 micro-inches.

The sandwich construction of complex shapes using fiberglass core utilizes routine bonding processes resulting in moderate fabrication costs. Past experience can be cited for bonded sandwich made throughout many areas on the B-58, the Convair 880-990, the Boeing 707 series, and a wide variety of similar work.

One problem area will be the refinement of the higher temperature adhesives now in use to bond outer layer skins to ablation insulation coatings. Many of these do very well on a short term basis, but may require an extension of their capability if units are to be reused.

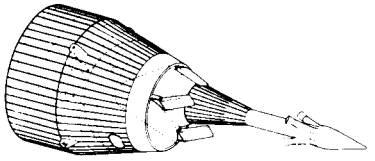
The aft skirt assembly may be titanium, but because it is lightly stressed, it may be possible through further structural analysis to use 2024 aluminum alloy. The use of conventional skin stringer construction is indicated.

1.4.4 Propellant Tanks. Titanium A110-AT(5AL-2.5Sn), as noted for the mission module, is used here also. The extremely thin gages are the biggest problem. The tank sections require hot forming by creep form techniques for minimum uniform thinning and best uniformity between longitudinal and transverse mechanical properties.

Support tubes of titanium would be formed by conventional manufacturing practices. All joining of tank segments is by resistance seamwelding and inert gas fusion welding. Attachment of support members may be either by spotwelding or by inert-gas fusion welding.

Chemical milling may be used on tank segments to achieve easier formability in heavier gages, minimum weight, and/or utilization of integral doublers at support attachments.

Propellant tank insulation for use at -423°F involves development of manufacturing procedures and processes.



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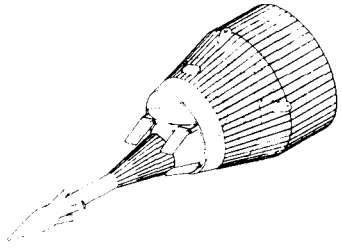

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2 POLICY STATEMENT

2.1 GENERAL. Although the time in which a unit is produced must be considered, it is second in importance to the quality of the product during the manufacture of initial units. Acceptable quality is obtained early in a program and is then retained. At this point, the schedule becomes the main concern. Attention must be focused on delivering the article at the time promised; neither an earlier nor a later time is acceptable. When production is on schedule and yet an acceptable quality level is being maintained, costs become the major consideration. This is not to be construed that each item is ever forgotten. Cost is certainly a consideration at all times, likewise, so is the schedule and the quality. To summarize the basic policy: first quality is achieved, then schedules, and finally costs. As each is achieved, it is retained at the desired level throughout the contract.

2.2 Control Policy. The degree of success that management has in obtaining a profit is directly proportional to the degree of control it exercises over its operations. The more control an organization keeps over its activities, the greater its chances are of achieving its ultimate goals. For these reasons, management must maintain maximum control over all areas.

2.2.1 Managerial Control. Sheer organizational magnitude increases the difficulty of the control task. As an organization grows, the number of relations increases and the difficulty of communications compounds. A size increase therefore increases the difficulty of directing the normal operation pattern. Integration of a product such as Apollo into existing systems tends to decrease the effectiveness of control.

To overcome this communications problem and simplify the control of the project, the program must be maintained as a separate entity as nearly as possible. The project concept supplies this need. This concept attempts to keep all portions, support as well as direct activity, isolated from existing systems. The separation must be physical as well as organizational. Existing facilities must be utilized, yet normal chains of command must be severed. The organization chart in Figure 1 illustrates the project organization. Note the absence of such functions as Contracts, Long Range Planning, etc. These functions will operate within the existing organization and will supply the project needed material through the Program Director. The normal functions shown in Figure 1 are directly responsible to the Program Director and are responsible to their parent counterpart for applicable guiding policy only.

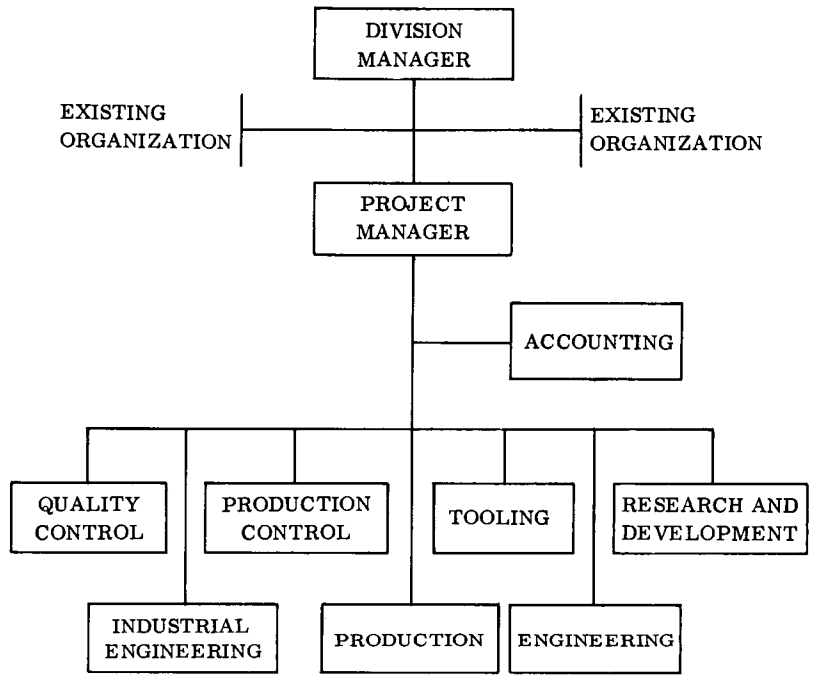


Figure 1. Project Organization

Project personnel should be grouped in three separate areas: 1) production, 2) material, and 3) support. The production area will support all fabrication and assembly operations not requiring special existing equipment. In this case, the parts will be routed to the machines in lieu of the machines being placed in the project area. The material area will house raw stock and purchased parts, as well as material control personnel. The support area will be used as the administrative and support headquarters for the project. Engineering, Tooling, Industrial Engineering, Quality Control, Production Control, Purchasing, and Accounting will occupy the area.

2.2.2 Control During Manufacture. The achievement of complete directing and restraining power over quality, schedules, and costs shall be accomplished through groups established for this purpose.

2.2.2.1 Quality Control. Engineering's concept is established on the blueprint which shows dimensions, tolerances, materials, and specifications. When management accepts the engineering concept, it acquires a responsiblity to direct manufacturing activities to convert the drawing into hardware. Management, having accepted the engineering concept, must be assured that it will be accomplished as indicated on the drawings. This is best performed by a control group exercising directing and restraining power through tests, checks, and verifications of the product excellence.

Execution of control will be performed by inspecting and monitoring parts, assemblies and tests. The authority to reject any sub-standard item is essential. This group will be an integrated part of the project team. Material and subcontracted items would pass through the parent organization in order to use special equipment for testing.

2.2.2.2 Manufacturing Control. Manufacturing control assures management of timely delivery of the end product through:

a. The development, issuance and posting of a production schedule,

b. The issue of tools, materials, parts and subassemblies to manufacturing according to schedule,

c. The stocking of materials, finished parts and assemblies, and

d. The timely delivery of the end item for shipment.

The steps in executing the control over fabrication and assembly are shown in Figure 2. Basic activity is coordinated with other service functions such as Tooling, Industrial Engineering and Material to obtain input for schedule adherence.

2.2.2.3 Factory Labor Cost Control. The cost control in the project concept requires the assistance of many support functions, such as Industrial Engineering, Data Processing, Manufacturing Control, and Accounting. These functions join efforts to obtain, compile, and present cost data to the Program Director for his information and subsequent action. The data will be presented in the form of performance reports which present:

a. The comparison of actual hours spent to measured standard hours earned,

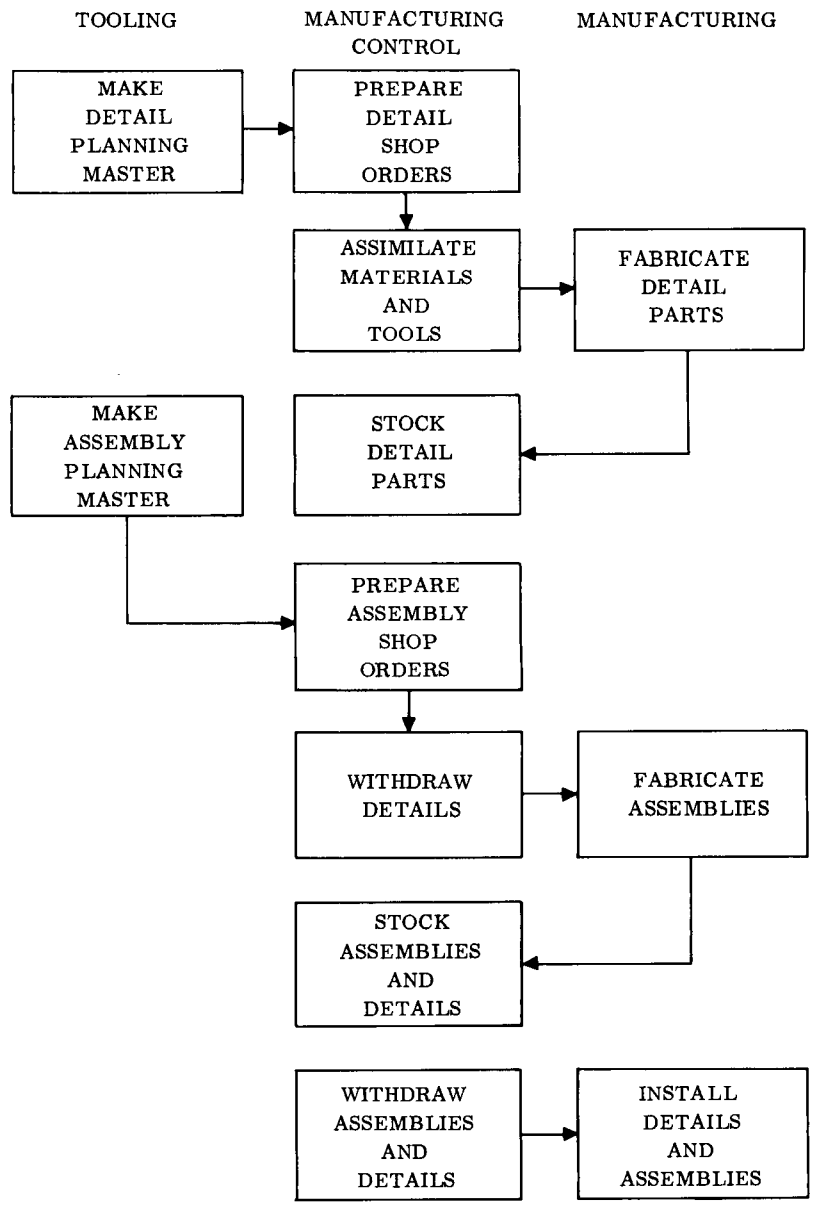


Figure 2. Manufacturing Control Operations

b. The schedule conditions, and

c. The cost to complete (projected).

The means of developing this information for installations will differ slightly from the means used for parts and subassemblies. Figure 3 illustrates the system for control of parts and subassemblies. Figure 4 illustrates the system for control of installations.

2.3 Tool Policy. The tooling function establishes the hardware by which the production function builds the deliverable item. The quality and reliability of the tooling is directly related to the quality and reliability of the Apollo vehicles. The requirement for high reliability demands the construction and maintenance of tools of the highest quality. Since the engineering design permits the use of tried and proven fabrication techniques, tools will be the same type as those utilized in current production.

General tool design and tool manufacturing policy will be based on limited production requirements and rapid incorporation of engineering changes. The planning and tooling approach will be guided toward achievement of production schedules through minimum planning and tooling; it will make use of worker skills rather than depend upon a completely tooled production line. The following tooling policies and procedures must be established to remain within the restrictions dictated in the engineering design concept:

a. Tools designed for the Apollo system shall be developed to satisfy all engineering specifications.

b. Optical measuring instruments shall be used extensively throughout both tooling and production programs to establish and maintain maximum efficiency of dimensional control.

c. Master tooling shall be provided for all interfaces where interchangeability is required.

d. Plaster masters will be used to control contours.

e. Normal engineering design and development requires that a full-scale mockup be used to determine electrical harness lengths and routing, tube bends, configuration and placement, and the development of brackets and supports on complex surfaces. A full scale, partially-operational metal mockup, in addition to a wood mockup of the vehicle interiors is planned to support design engineering. The wood mockup will have its prime value in support of human engineering studies and the development of customer design criteria. Original engineering design and proposed changes will first be mocked-up in wood and studied from the human engineering viewpoint. Upon approval, changes will be mocked-up and installed in the metal mock-up.

f. Tools will be designed to maintain the production rate, quantity, and tolerance applicable to the Apollo vehicle.

g. A tool maintenance program will be established to assure continued function of all tooling hardware.

h. Tooling will prepare a components breakdown and determine the assembly sequence.

i. Alignment control shall be maintained and accomplished in the major assembly fixtures, and shall be verified by optical tools.

j. Interchangeability shall apply to all completely finished assemblies, parts, or equipment which will require only the application of attach hardware (bolts, screws, clamps, etc.) for their installation. Interchangeable parts shall be capable of being readily installed, removed, or replaced without harm, injury, or misalignment to themselves or adjoining parts.

k. Detailed parts tooling generally shall be confined to forming tools and templates.

2.4 SUBCONTRACT POLICY. Selection of all subcontractors should be based on their historical performance of producing high quality and reliable products within a reasonable pre-determined cost, and maintaining schedule commitments to the prime contractor. Other factors must also be considered in determining outside procurement:

a. When subcontractors are available with a proven history of competitive development and production of quality products in a particular field (i.e., resistors, transistor, etc.).

b. When the development and production of a component requires specialized facility investment which can only be amortized by the production of similar system components, and a subcontractor has specialized equipment to support the development and production of a selected component (i.e., waveguides, filament winding, etc.).

c. When an item is a standard "produced for stock" item with existing suppliers (i.e., nuts, bolts, couplings, etc.).

d. When a component or process is related to proprietary patent rights (i.e., ablative material, etc.).

In addition to the above factors, this policy shall consider the governmental policy which provides for competive distribution of production throughout private industry. This shall provide small businesses the opportunity to compete with large firms for the items they are capable of producing.

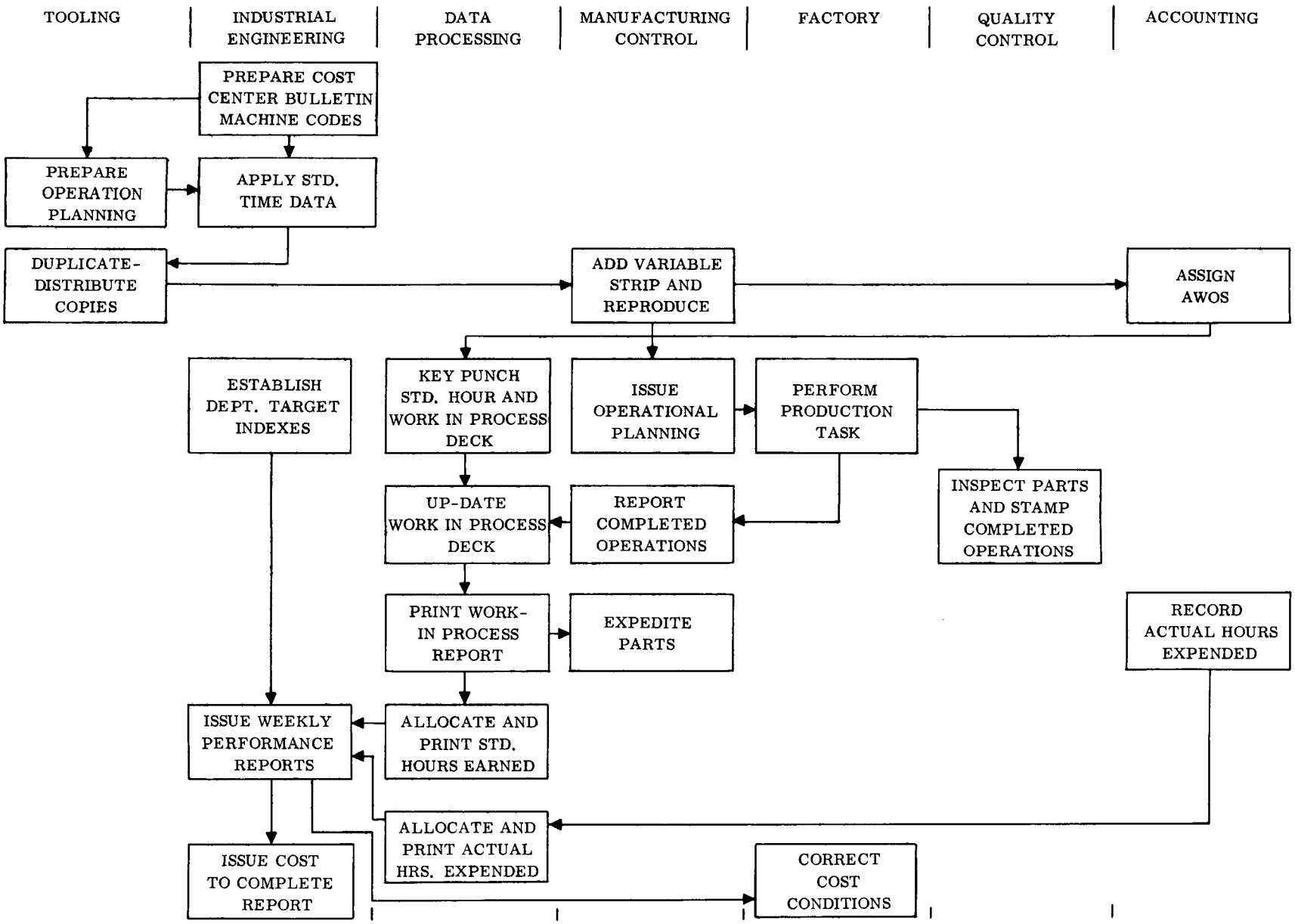


Figure 3. Factory Direct-Hours Cost Control System - Parts and Subassemblies

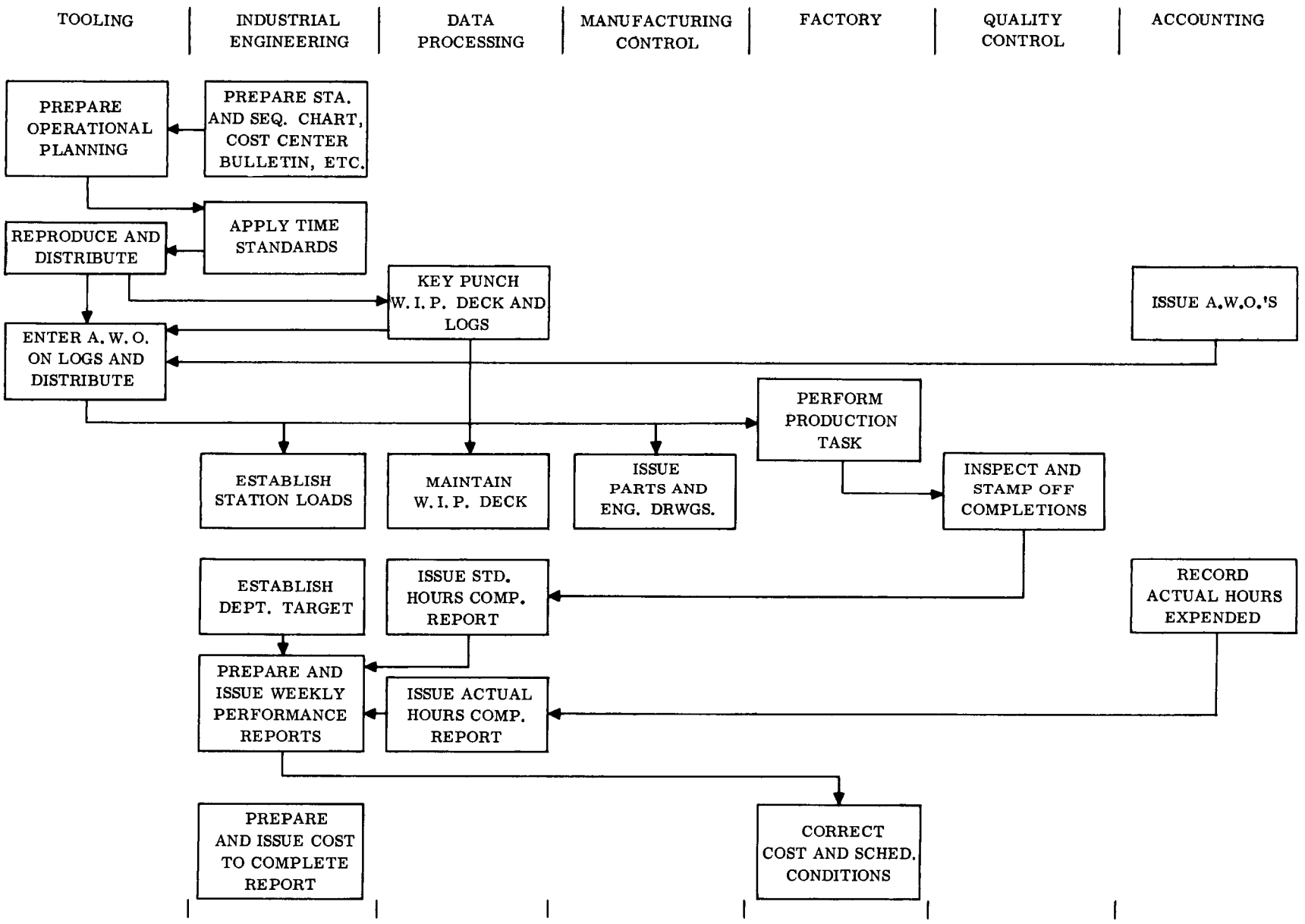
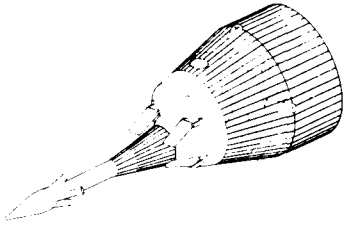


Figure 4. Factory Direct-Hours Cost Control System - Installations



3 GENERAL MANUFACTURING CONCEPT

Fabrication and assembly activities will be covered generally except where problems are anticipated and facility requirements are considered non-standard. The Apollo Program is made up of four distinct vehicles; booster, mission module, command module and abort tower. Since the booster is not a part of this study, discussions will deal only with the latter three vehicles. An assembled view of the Apollo is shown in Figure 5.

3.1 MATERIAL FLOW. This section will familiarize the reader with the vehicle breakdown and the sequences of its assembly. The cutaway view (Figure 6) reveals the major systems and components of the assembled vehicle. Subsequent illustrations and discussions will present an overall picture of the manufacturing concepts of the program.

3.1.1 Major Component Breakdown And Assembly Sequence. Figure 7 shows the production breakdown and the sequence of assembly. Only the major or larger components are indicated. Detail parts and subassemblies are not shown since they would add nothing to the assembly concept. The production breakdown and assembly sequence has been carefully planned to reflect a workable compromise between engineering requirements and manufacturing economy. The flow presents the maximum economy considering tooling cost, assembly time and space requirements. This concept will be followed throughout this study.

Although the chart reflects the abort tower mated to the Apollo space vehicle, each item will be delivered separately to the launch complex.

3.1.2 Manufacturing Sequence, Station and Flow Chart. The manufacturing sequence, station and flow chart (Figure 8) represents a major contribution to the manufacturing plan. It incorporates the production schedule, engineering design, production breakdown, production item numbers (at the hardware stage), and component analysis into a single descriptive chart that presents a bird's-eye view of the manufacturing task.

The chart is a one-view orthographic breakdown showing work position, work description, item and station numbers, indentures, manufacturing component sequence and flow, installation and mating points of all

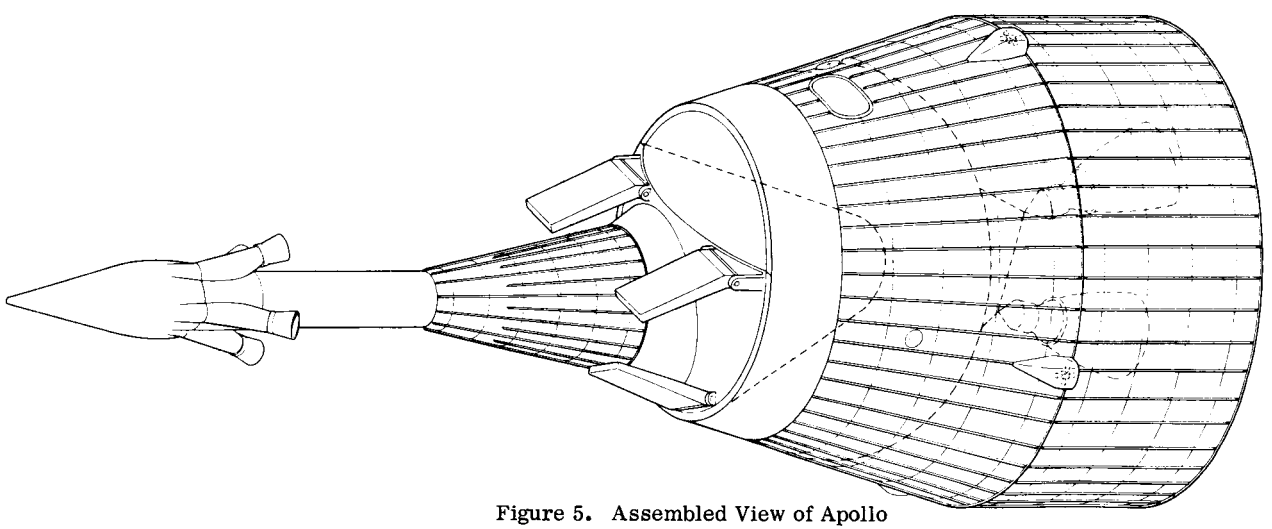


Figure 5. Assembled View of Apollo

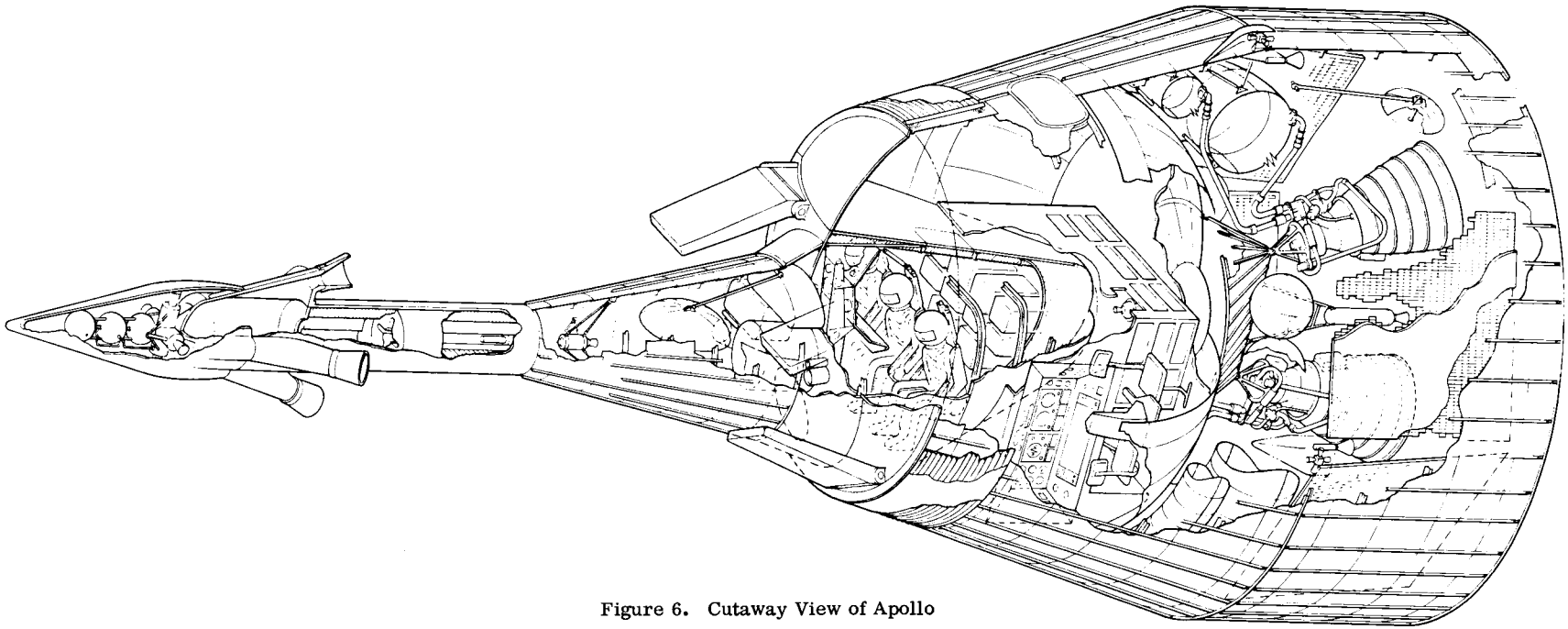


Figure 6. Cutaway View of Apollo

scheduled components. It provides a visual presentation of a production program in terms of the number of stations and/or fixtures, the quantity of component banks, and the flow times for a given manufacturing rate. The chart provides the basis for a manufacturing plan and serves as a guide to all departments in the execution of their assigned tasks.

The initial manufacturing sequence, station and flow chart is developed at the preproduction level - preferably at the predesign level. This first chart is rough and undergoes many refinements as the design becomes firm prior to production of the first article. The parameters established are proofed on the first production units, amended as required, and thereafter kept current with production rate increases, design changes, improved factory methods, etc.

3.1.2.1 Operation Process Chart. Figure 9 portrays graphically the manufacturing operations required to fabricate a single brazed stainless steel honeycomb panel for the command module. Standard A.S.M.E. symbols and vertical flow lines portray the various operations or activities in the proper sequence in which they are performed.

The operation process chart reflects the multiple activities by relating the details of the flow of each process to another to provide an overall picture of the entire manufacturing cycle. It provides a convenient device for organizing facts so they can be quickly analyzed and evaluated.

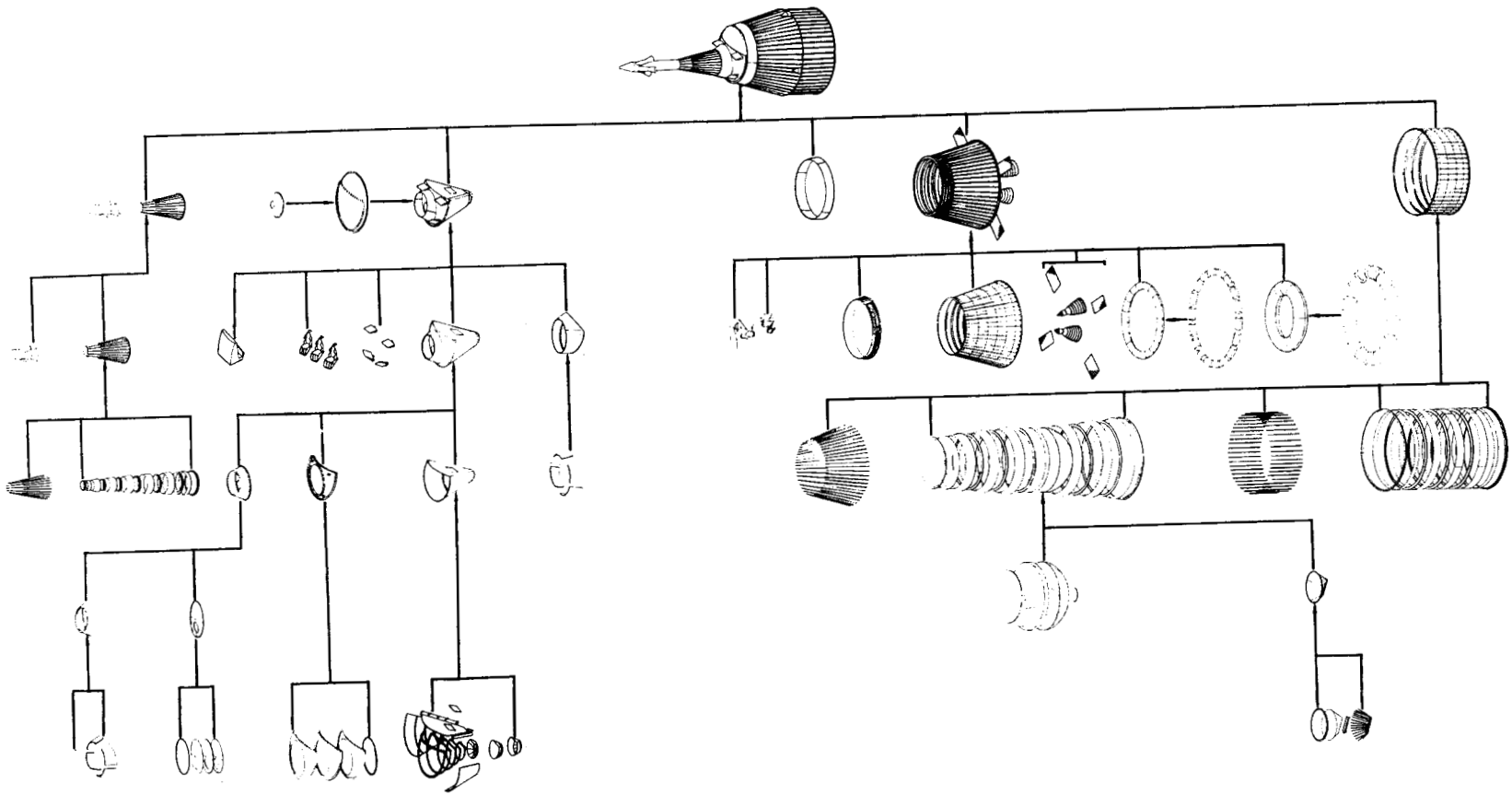
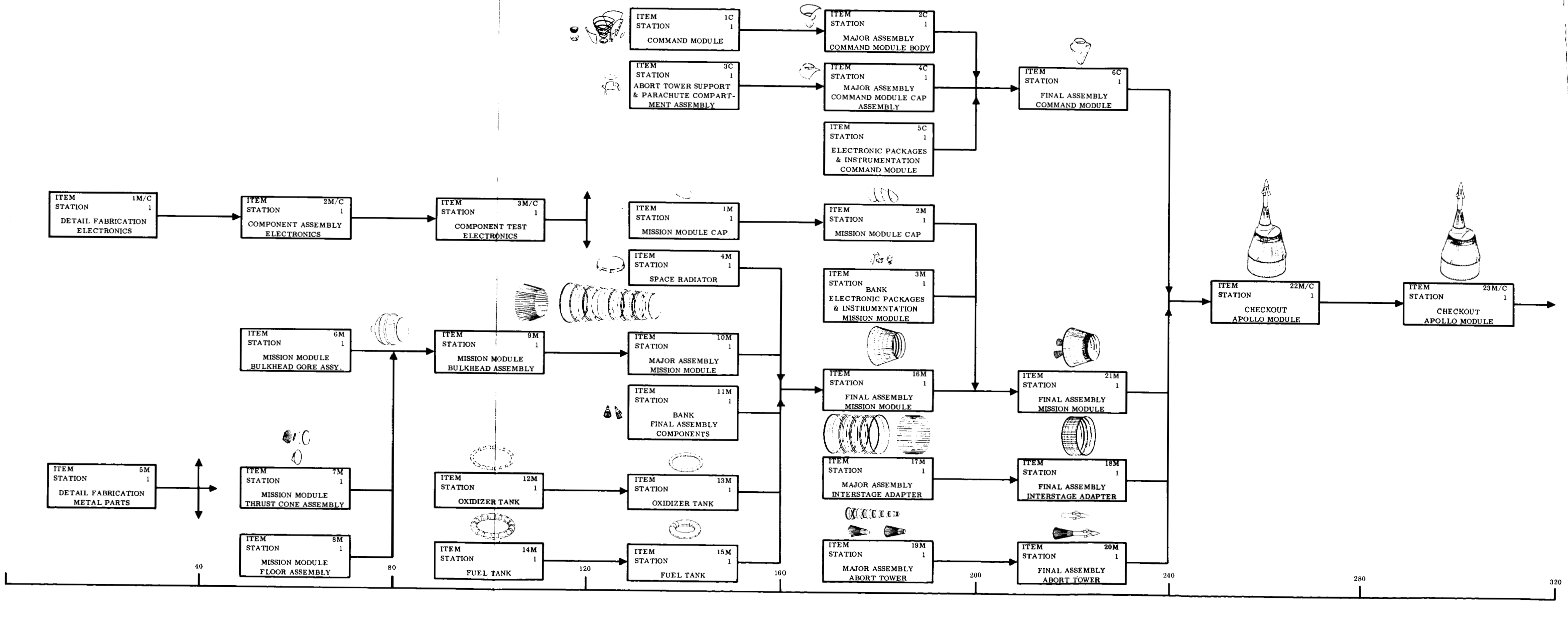


Figure 7. Major Component Breakdown and Assembly Sequence


ITEM 1C STATION 1 COMMAND MODULE
ITEM 3C STATION 1 ABORT TOWER SUPPORT & PARACHUTE COMPARTMENT ASSEMBLY
ITEM 2C STATION 1 MAJOR ASSEMBLY COMMAND MODULE BODY
ITEM 4C STATION 1 MAJOR ASSEMBLY COMMAND MODULE CAP ASSEMBLY
ITEM 5C STATION 1 ELECTRONIC PACKAGES & INSTRUMENTATION COMMAND MODULE
ITEM 6C STATION 1 FINAL ASSEMBLY COMMAND MODULE
ITEM 1M/C STATION 1 DETAIL FABRICATION ELECTRONICS
ITEM 2M/C STATION 1 COMPONENT ASSEMBLY ELECTRONICS
ITEM 3M/C STATION 1 COMPONENT TEST ELECTRONICS
ITEM 1M STATION 1 MISSION MODULE CAP
ITEM 2M STATION 1 MISSION MODULE CAP
ITEM 4M STATION 1 SPACE RADIATOR
ITEM 3M STATION 1 BANK ELECTRONIC PACKAGES & INSTRUMENTATION MISSION MODULE
ITEM 22M/C STATION 1 CHECKOUT APOLLO MODULE
ITEM 23M/C STATION 1 CHECKOUT APOLLO MODULE
ITEM 6M STATION 1 MISSION MODULE BULKHEAD GORE ASSY.
ITEM 9M STATION 1 MISSION MODULE BULKHEAD ASSEMBLY
ITEM 10M STATION 1 MAJOR ASSEMBLY MISSION MODULE
ITEM 11M STATION 1 BANK FINAL ASSEMBLY COMPONENTS
ITEM 16M STATION 1 FINAL ASSEMBLY MISSION MODULE
ITEM 21M STATION 1 FINAL ASSEMBLY MISSION MODULE
ITEM 5M STATION 1 DETAIL FABRICATION METAL PARTS
ITEM 7M STATION 1 MISSION MODULE THRUST CONE ASSEMBLY
ITEM 12M STATION 1 OXIDIZER TANK
ITEM 13M STATION 1 OXIDIZER TANK
ITEM 17M STATION 1 MAJOR ASSEMBLY INTERSTAGE ADAPTER
ITEM 18M STATION 1 FINAL ASSEMBLY INTERSTAGE ADAPTER
ITEM 8M STATION 1 MISSION MODULE FLOOR ASSEMBLY
ITEM 14M STATION 1 FUEL TANK
ITEM 15M STATION 1 FUEL TANK
ITEM 19M STATION 1 MAJOR ASSEMBLY ABORT TOWER
ITEM 20M STATION 1 FINAL ASSEMBLY ABORT TOWER
40
80
120
160
200
240
280
320

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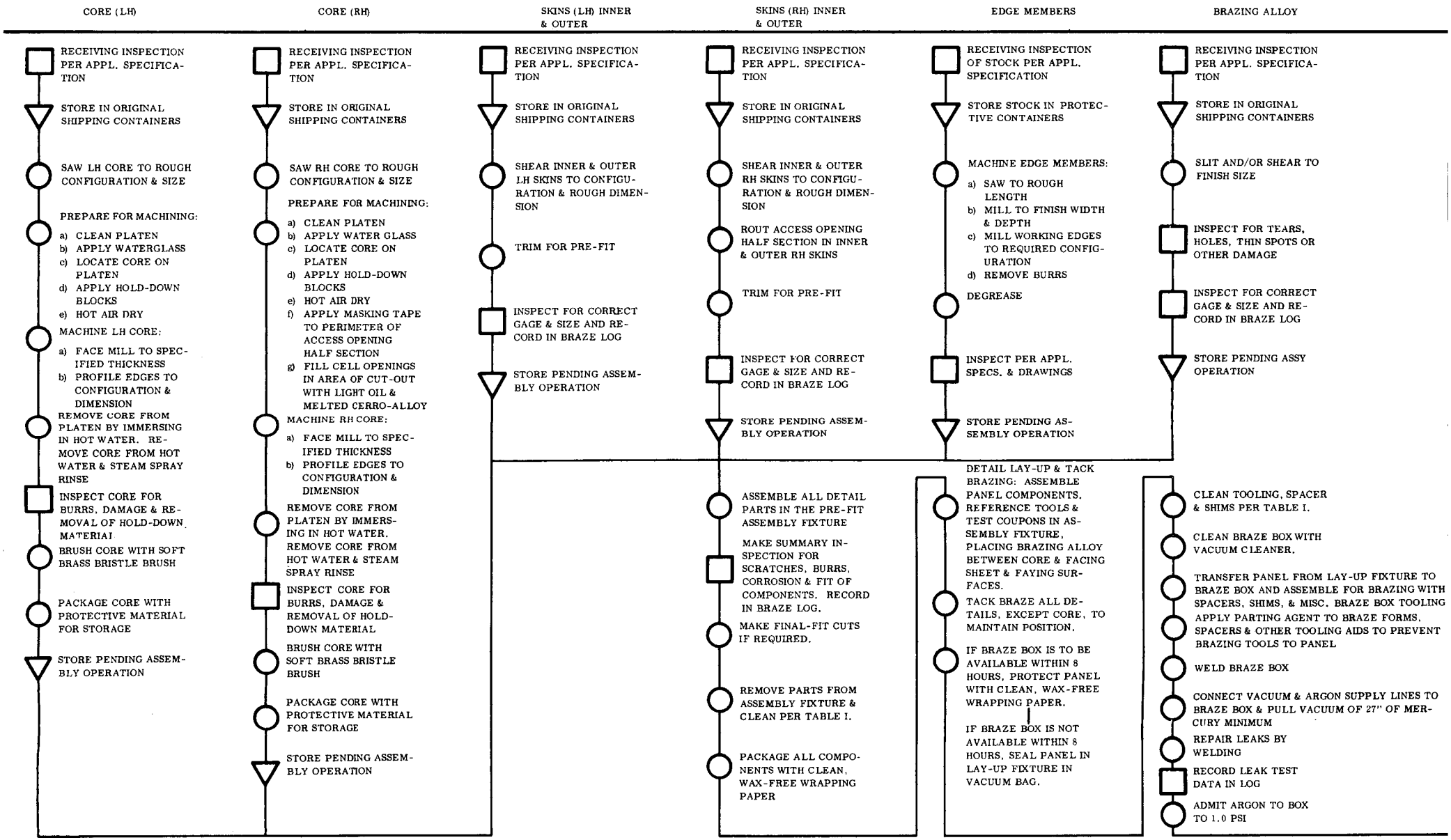


Figure 9. Manufacturing Operations for Stainless Steel Honeycomb Panel

CONFIDENTIAL

CYCLE PURGE:

a) PULL VACUUM TO 27" OF MERCURY
b) CLOSE VACUUM VALVE & ADMIT ARGON
c) CLOSE ARGON VALVE WHEN VACUUM GAGE READS 5"
d) OPEN VACUUM VALVE UNTIL READING REACHES 27"
e) REPEAT OPERATIONS a) through d) 10 TIMES
f) ON LAST CYCLE ADMIT ARGON TO 5" AND CLOSE ALL VALVES

ATTACH THERMO COUPLES TO BRAZE BOX

BRAZING & TRANSFORMATION PROCEDURE:

a) ATTACH ARGON & VACUUM LINES, PRE-SET GAGES & VALVES & ATTACH THERMOCOUPLES TO RECORDER
b) INSERT RETORT INTO 1400°-1700° BRAZING FURNACE.
c) MAINTAIN "BRAZE LINE" TEMPERATURE OF 1615°-1635° FOR 9 TO 11 MINUTES
d) ALLOW TO COOL TO 1000°
e) ALLOW TO COOL FROM 1000° to ROOM TEMPERATURE USING FORCED AIR AND MAINTAINING CONTINUOUS ARGON FLOW & VACUUM PURGE
f) REMOVE FROM FURNACE

REFRIGERATION CYCLE:

a) REMOVE ALL BRAZING THERMOCOUPLES
b) LEAVE ARGON & VACUUM LINES INTACT & CLOSE VACUUM LINE
c) ATTACH THERMOCOUPLE
d) PERFORM LEAK TEST
e) LOWER RETORT INTO LIQUID COOLANT WHILE MAINTAINING A VACUUM OF 20" OF MERCURY & HOLD AT -100° FOR 5 HOURS
f) REMOVE RETORT FROM REFRIGERATOR & ALLOW TO RETURN TO ROOM TEMPERATURE WHILE STILL UNDER VACUUM.

AGING CYCLE:

a) REPLACE THERMOCOUPLES
b) INSERT IN FURNACE USING CONTINUOUS ARGON FLOW & VACUUM
c) AGE AT 950° FOR 1 HOUR MINIMUM
d) REMOVE RETORT FROM FURNACE & COOL TO ROOM TEMPERATURE WHILE MAINTAINING MAX.
e) REMOVE PANEL FROM RETORT

INSPECT FOR WARPING

CLEAN ALL SURFACES BY DUST BLAST AND/OR MEK

ELECTRO-ETCH IDENTIFICATION

PERFORM X-RAY INSPECTION OF PANEL

WEIGH PANEL

PACKAGE COMPLETED PANEL WITH PROTECTIVE MATERIALS

TABLE I

CLEANING PROCEDURES
CORES, SKINS & DETAIL PARTS

STEP	PROCESS	SOLUTION COMPOSITION	SOLUTION TEMP.	IMMERSION TIME
1	VAPOR DEGREASE			
2*	ALKALINE CLEAN	OAKITE #90: 8-10 OZ. PER GAL.	180° TO 190°F	20-30 MIN.
3**	RINSE (CONSTANT OVERFLOW)	TAP WATER	120° TO 140°F	10 MIN (MIN.)
4*	ACID CLEAN	SULFURIC ACID (15-22% VOL.)	ROOM TEMPERATURE	10-20 MIN.
5*	RINSE (CONSTANT OVERFLOW)	TAP WATER	120° TO 140°F	3 CYCLES - 2 MIN. EACH
6	SPRAY RINSE	DISTILLED OR DE-IONIZED WATER	ROOM TEMPERATURE	30 SECONDS (MIM.)
7	DRY	ROOM TEMP. OR HOT AIR	140°F MAX.	UNTIL DRY

NOTES:

* CORES SHALL BE SUBMERGED IN SOLUTION FOR 15 SECOND AND WITHDRAWN, THEN REIMMERSED AND ALLOWED TO REMAIN FOR THE SPECIFIED TIME.

** CORES SHALL BE IMMERSED AND WITHDRAWN 8 TO 10 TIMES WITHIN THE 10 MINUTE RINSE CYCLE, AFTER WHICH TIME THE CORE SHALL BE RAISED AND DRAINED.

NOTE: A TEST PANEL IS FABRICATED CONCURRENTLY WITH THE PRODUCTION PANEL, FROM THE SAME MATERIAL LOTS. THIS TEST SPECIMEN UNDERGOES DESTRUCTIVE TESTS THAT SERVE AS A BASIS FOR CERTIFICATION OF THE PRODUCTION PANEL

1C FABRICATE S.S. HONEYCOMB PANELS FOR BODY, NOSE & CAP OF COMMAND MODULE. MACHINE TO EXACT REQUIRED DIMENSIONS. LOCATE AND JOIN METAL EDGE FERRULES, INSERTS, BRACKETRY & PORT FRAMES.

2C ASSEMBLE & JOIN PREFABRICATED S.S. HONEYCOMB PANELS, INCLUDING NOSE SECTION, TO FORM MODULE BODY. INSTALL INTERIOR INSULATION, RETAINING SKIN RINGS & HATCH FRAME. DRILL ATTACH HOLES. APPLY ABLATION COATING.

3C POSITION PRE-FORMED SKINS, BELTFRAMES, INTERFACE RINGS, BRACES & BRACKETRY & WELD COMPLETE. DRILL ATTACH HOLES IN INTERFACE RINGS.

4C ASSEMBLE PRE-FABRICATED S.S. HONEYCOMB CAP WITH INTERFACE RING, HATCH FRAME, HATCH DOOR & ABORT TOWER SUPPORT ASSEMBLY. INSTALL INTERIOR INSULATION & RETAINING SKIN. DRILL ATTACH HOLES. APLY ABLATION COATING.

6C INSTALL AIR CONDITIONING, PRESSURIZATION & WATER SYSTEMS. INSTALL FURNITURE & ELECTRONIC COMPONENTS, IN CAP SECTION & BODY SECTION OF MODULE. MATE CAP & BODY. COMPLETE INSTALLATIONS. PRESSURE TEST MODULE.

1M/C CIRCUIT BOARDS

HI-DENSITY MODULES.

CIRCUIT COMPONENTS

ENCAPSULATION

PACKAGE HARDWARE

1M MOULD FIBERGLASS CAP WITH METAL EDGE FERRULES. INSERTS AND BRACKETRY POSITIONED IN MOULD.

2M INSTALL INTERIOR INSULATION & RETAINING SKIN. DRILL INTERFACE ATTACH HOLES. APPLY ABLATIVE COATING AS REQUIRED. DELIVER TO MISSION MODULE FINAL ASSY. STATION #2.

4M SCRIBE, TRIM & BUTT WELD TAPER SKINS. MATE INNER & OUTER SKINS & JOIN BY WELDING. LOCATE IN HYDRAULIC PRESSURE FIXTURE & EXPAND WELDED SKINS TO REQUIRED CONFIGURATION. INSTALL FITTINGS & DRILL ATTACH HOLES.

5M GORE SECTIONS

STIFFENERS

SKIN BLANKS

BRACKETRY

MACHINED RINGS

DELIVER TO USE POINTS

6M SCRIBE & TRIM GORES & WELD COMPLETE. LOCATE CAP, DOUBLERS, BRACKETRY & CLIPS & WELD COMPLETE. PRESSURE TEST.

7M SCRIBE & TRIM SKINS & WELD. LOCATE & WELD SPLICE RING, DOUBLERS, STIFFENERS AND BRACKETRY.

8M LOCATE & WELD SUPPORTING STRUCTURE & HATCH FRAMES. SCRIBE & TRIM PANELS & WELD COMPLETE. LOCATE & WELD DOUBLERS & BRACKETRY.

9M MATE & WELD BULKHEAD GORE ASSEMBLY, THRUST CONE ASSEMBLY & FLOOR ASSEMBLY. INSTALL & WELD INTERNAL & EXTERNAL BRACKETRY. DRILL ATTACH HOLES FOR ENGINES.

10M PROGRESSIVELY POSITION & WELD RINGS, SKINS, BELTFRAMES & BRACKETRY UP TO BULKHEAD MATE LINE. MATE & WELD BULKHEAD ASSY & BALANCE OF SKINS, BELTFRAMES, BRACKETRY & STIFFENERS. PRESSURE TEST.

12M SIZE AND FORM TANK QUARTER SECTIONS. DELIVER TO TANK SUBASSEMBLY.

13M SCRIBE & TRIM PREFORMED TANK QUARTER SECTIONS. POSITION & WELD QUARTER SECTIONS TO HALF & HALF TO FULL. POSITION & WELD BRACKETRY & FLANGES POSITION FULL SECTIONS IN RING & WELD. PRESSURE TEST.

14M SIZE & FORM TANK QUARTER SECTIONS. DELIVER TO TANK SUBASSEMBLY.

15M SCRIBE & TRIM PREFORMED TANK QUARTER SECTIONS. POSITION & WELD QUARTER SECTIONS TO HALF & HALF TO FULL. POSITION & WELD BRACKETRY & FLANGES. POSITION FULL SECTIONS IN RING & WELD. PRESSURE TEST.

16M INSTALL TOROID TANKS PRESSURE SPHERES. FUEL & OXIDIZERS FEED SYSTEMS, HYDRAULIC & PNEUMATIC SYSTEMS. ENGINES, CONTROL ROCKETS, SOLAR PANELS, SPACE RADIATOR & ANTENNA.

17M SCRIBE, TRIM & WELD CONSTANT SKINS. PROGRESSIVELY POSITION & WELD SKINS, BELTFRAMES AND BRACKETRY. DRILL STAGE ATTACH HOLES IN FORWARD & AFT RINGS.

18M INSTALL HARNESSES, INTERFACE CONNECTIONS & STAGE SEPARATION SYSTEMS. PERFORM CONTINUITY CHECKS.

19M SCRIBE, TRIM & WELD TAPER SKINS, PROGRESSIVELY POSITION & WELD SKINS, BELTFRAMES, HATCH FRAME, STIFFENERS & ALL BRACKETRY. INSTALL HATCH DOOR. DRILL INTERFACE RINGS.

20M INSTALL HARNESSES, SEPARATION SYSTEMS & UNARMED ABORT ROCKET. MATE WITH MAJOR ABORT ROCKET CASE & COMPLETE ELECTRICAL INSTALLATION. PERFORM CONTINUITY & FUNCTION ALL TESTS IN UNARMED CONDITION.

21M INSTALL INTERIOR INSULATION, AIR CONDITIONING, WATER & PRESSURIZATION SYSTEMS. INSTALL FURNITURE & CONSOLES. MATE TOP CAP ASSY TO BODY STRUCTURE. INSTALL ALL ELECTRONIC PACKAGES.

22M/C MATE MISSION MODULE WITH COMMAND MODULE, INTERSTAGE ADAPTER & ELECTRICALLY MATE TO ABORT TOWER. PERFORM INDIVIDUAL SYSTEMS CHECKOUT AND START COMPOSITE SYSTEMS CHECKOUT.

23M/C COMPLETE COMPOSITE SYSTEMS CHECKOUT. INSPECT FOR DAMAGE. WEIGH & BALANCE. CUSTOMER ACCEPTANCE. PREPARE FOR SHIPMENT.

ELECTRONIC PACKAGES
AND INSTRUMENTATION
COMMAND AND MISSION MODULES

UHF TRANSPONDER & RN CODERS	M
UHF POWER AMPLIFIER	M
UHF HR BEACON	C
UHF XMTR. RCVR	C
HF XMTR. RCVR	C
VHF XMTR. RCVR	C
DME EQUIPMENT	C
VOR CONVERTER. INDICATOR	C
MARKER BEACON RCVR	C
TLM SYSTEM	C
TAPE RECORDERS	C
COMMAND DECODER	C
LO-GAIN UHF ANTENNA	M/C
LO-GAIN VHF ANTENNA	M/C
LO-GAIN HF ANTENNA	M/C
CO-AX SWITCHES	M/C
DIPLEXER	M/C
COMMUNICATION CONTROL & DISPLAY	M
RCVR COMBINER	M
AC-DC CONVERTERS	M/C
CLOCK TIMER	C
DATA PROCESSOR	C
HARNESSES	M/C
ALTIMETER ANTENNA	C
ALTIMETER	C
INSTRUMENT PLATFORM	C
PLATFORM ELECTRONICS	C
ACQUISITION BEACON	C
COMPUTER	C
PERISCOPE	C
AUTOPILOT ELECTRONICS	M/C
BACKUP INERTIAL REFERENCE	C
SUN TRACKER	M
SEXTANT	M
TV CAMERA & LENS	C
TV ELECTRONICS	C
COMMUNICATION ANTENNA	M

Figure 8. Manufacturing Sequence Stations and Flow Chart

3.1.3 First Article Flow Times. In order to determine facility installation dates, work station installation, tooling activation, and facility quantity requirements, it is necessary to know the flow time for the first production unit. When the new unit to be produced is similar to units produced in the past, historical flow time information can be used for an estimating base. Past information can be altered by a predetermined factor of difficulty to produce usable planning estimates. This technique can be performed relatively quickly and gives results which are generally within the tolerances demanded. A more accurate and reliable means is possible when sufficient design information is available, namely standard data application. The time required to obtain usable information is considerably longer, but the results are extremely useful in many areas. Standard data application requires the breakdown of each task into its basic elements. The standard times applied to each element are summed for each operation; the operations are summed to give the total standard hours required to perform the task. These data can then be placed on a learning curve to determine the estimated actual time for the first unit. By closely determining the delays and waiting periods, the flow time for each article can be accurately determined.

The flow times for this report have been determined by the first method. The results are shown in Figure 10. When sufficient design information is available, the latter method will be applied to revise estimated flow times and serve as a base for controls

3.1.4 Learning Curves. Empirical evidence clearly indicates that manufacturing, as will be conducted on this system, is performed in less time on subsequent units than on earlier units. Investigation into this phenomenon has shown that the degree of time reduction is dependent upon many diverse factors - tooling, percentage of human operation, complexity, etc. The degree of time reduction is commonly noted by the percentage of reduction between doubling units. Because of various factors, curves sometimes must be defined as composites of several simple curves.

Figure 11 shows the anticipated learning curve for the Apollo command and mission modules, respectively. Note that these are compound curves. They were developed from empirical evidence of similar programs and are designed to be realistic. The ordinate of these curves is in percent, not hours, as is customary. The abscissa is designated in units, as is customary. Note the thirtieth unit will require 35 percent of the time required by unit one. The percent of unit one for the Nth unit (any unit) can be read directly from the ordinate. This is done by selecting the unit on the abscissa and projecting a vertical line to intersect the curve. At this intersection, project a horizontal line to the abscissa. Where this line crosses the abscissa is the percentage of that unit of unit one. Information obtained from these curves is extremely useful in planning operations.

3.1.5 Block Layout. The detailed layout is one of the master blueprints of the manufacturing plan. Organization, flow, methods, facilities, factory, and support space and operational planning all add information for the detailed layout. It is through the detailed layout that the manufacturing complex is developed. Detailed layouts are not included in this plan. However, Figure 12 shows a block plan layout of the manufacturing complex at the major component manufacture, final assembly, and systems checkout level.

A block layout of the detail fabrication and warehouse areas will be omitted in this report. Proposed schedules relative to quantities of vehicles required and the rate of production proposed, makes it a more economical to integrate the Apollo fabrication task within present detail fabrication and warehousing facilities.

3.2 FABRICATION AND PROCESSES

3.2.1 Parts Fabrication. Standard machine tools and fabrication techniques will find many applications in the manufacture of this vehicle. Titanium A110-AT (5Al-2.5 Sn) material in the form of bar stock, sheet stock, and thin gage coil stock will be used exclusively in the structural manufacture of this vehicle. Standard milling, boring, and drilling operations will be performed at the detail parts level. Numerical control machines will be used where numerous or complex machining tasks are evident. Forming of small detail parts and large thin gage gore skins will be performed with heated shell-die stretch presses. This method of forming is particularly advantageous for forming titanium alloys. Some of the advantages in using this method of forming are: 1) gases are easily ported, 2) physical and mechanical properties of the metal are retained, 3) springback is negligible, 4) scrap is reduced and 5) manpower is reduced. One employee having little or no previous experience in this method of forming can successfully operate one or more of these presses at one time. No insurmountable problems are created by the size of the parts to be made. Handling of thin gage parts and materials does present a problem, however. This can be overcome by providing specially designed containers and handling aids for movement of material from one station or operation to the next. All fabrication and processing operations are well within the present knowledge and capability of the missile and aircraft industry.

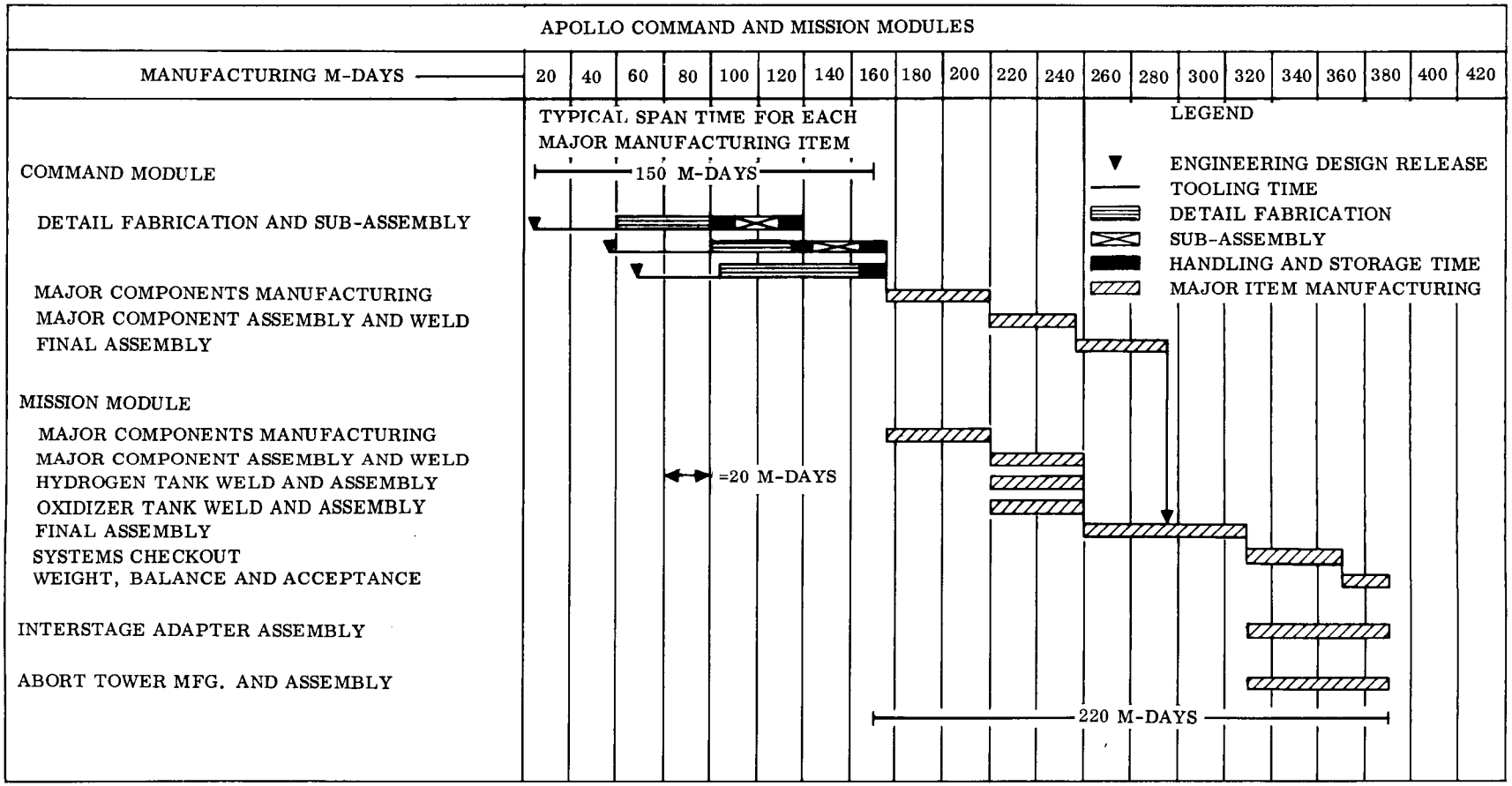


Figure 10. Manufacturing Times for the First Command and Mission Modules

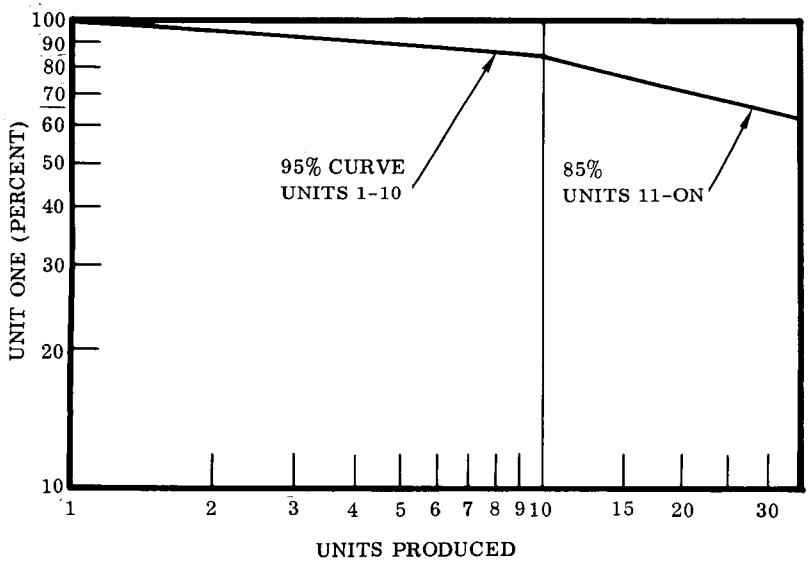


Figure 11. Anticipated Learning Curve

3.2.2 Electronics Assembly. Electronics manufacturing is to be located in a building apart from other types of manufacturing, so as to conform to the latest accepted practices and requirements for this type of work. A facility, other than one built especially for electronics manufacturing, is not satisfactory.

Separate departmental areas must be constructed herein for capabilities as follows:

3.2.2.1 Encapsulation, Potting, and Conformal Coating. In this area, electronic components are encapsulated fully or partially to insulate or protect parts from moisture and to stabilize them against vibration. Plugs on electrical harnesses are potted to insulate, strengthen, and seal. Electrical wire harnesses and plug ends are completely or partially encapsulated as a protective covering against heat, wear, water, for insulation, and for bonding. Assembled circuit boards are conformally coated with a thin spray or a dip coat to lessen vibration, to insulate, and to prevent corrosion.

3.2.2.2 Printed Circuitry, Manometers and Mandrels. In this area, electrical circuit paths are photographed onto thin boards of phenolic or fiberglass, which have been prepared with a bonded conductive foil and sprayed with a photographic emulsion. These then are processed through developer and etching tanks, which produces the desired circuit paths on the boards.

Manometers and mandrels herein described are used for gaging the fullness of propellant tanks. The fullness of the tanks is read as current which indirectly controls the flow of the propellants in proper proportion to promote the emptying of both propellant tanks simultaneously. Certain manometers use the photo etch process for producing the electrically conductive circuit paths while others use cemented foils or a metal deposition process.

In these manometers the solution (representing tank fullness) is conductive, as is the simulated metal foil tank shape on the side walls. A dielectric material separates one from the other. Tank volume is translated from indicated capacitance and bridge unbalance to propellant control-valve movement.

Another type of mandrel is a precisely turned metal shape that represents the tank shape. A dipped and baked dielectric plastic material is used on its surface as a partial dielectric insulator. The dip tanks are automatically controlled to remove the mandrels from the dip solution at a controlled rate which will produce a precise thickness of coating material. Several successive dips and cure operations are required for each mandrel.

3.2.2.3 Electronic Subassembly and Final Assembly Area. In this area, materials (transistors, diodes, condensers, capacitors, tubes, printed circuit boards, etc.) are assembled into subassemblies and components, which are later finally assembled in another area into the final end unit.

All operations are done from beginning to end by trained specialists who perform their respective operations in planned sequence. The materials are made, purchased, and stored. These materials will be drawn out later and delivered for assembly according to an engineering bill-of material and engineering drawings. All assembly work is performed and inspected in accordance with manufacturing engineering planning sheets and engineering parts and assembly drawings.

3.2.2.4 Scope of Items to be Produced "In-Plant" for Apollo. Items to be produced in-plant are as follows:

a. Checkout sets (for manufacturing test and maintenance checkout).

b. Circuit boards.

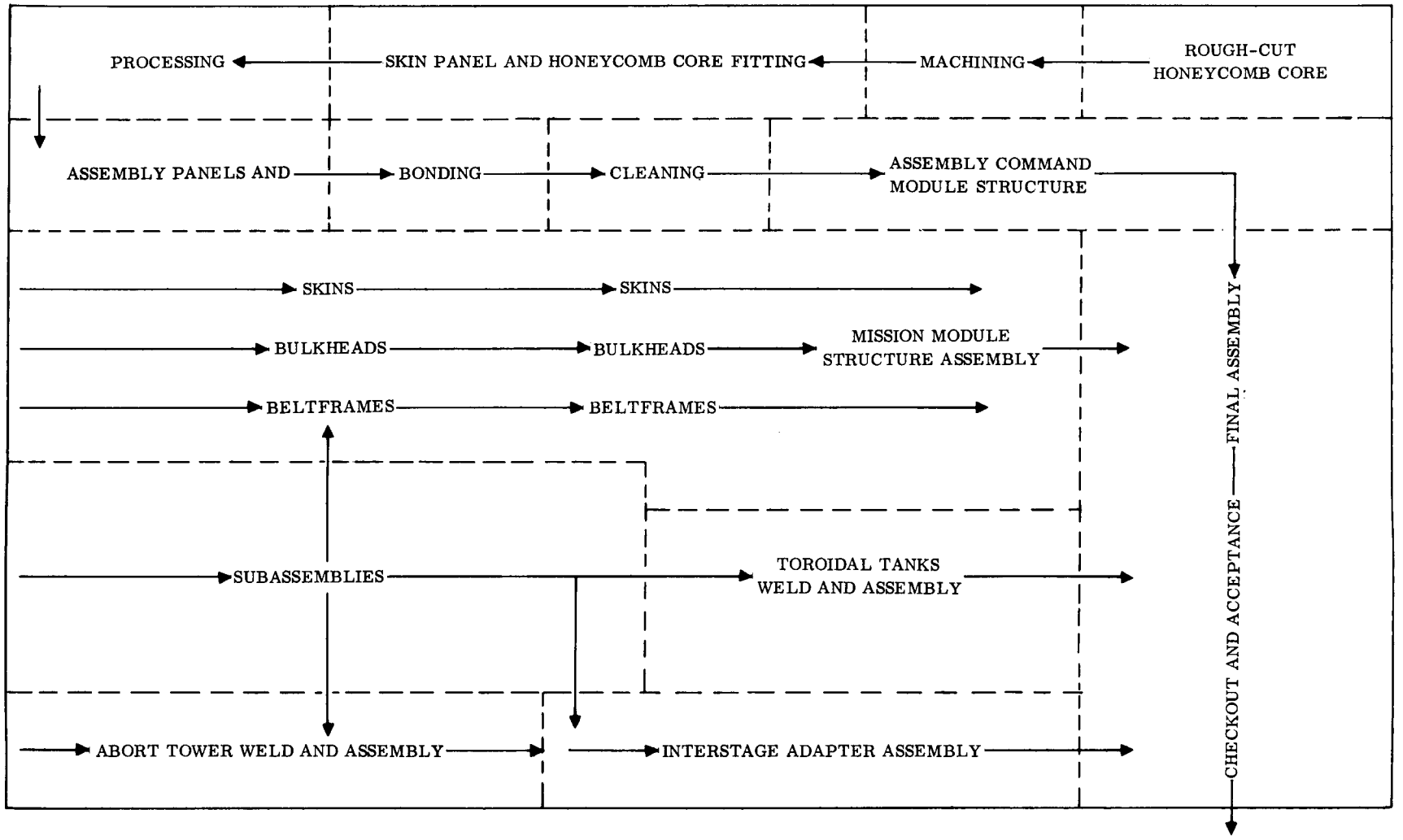


Figure 12. Material Flow Diagram for Major Components

c. Autopilot electronics.

d. Communications antenna.

e. Altimeter antenna.

f. Back-up inertial reference.

g. Lo-gain UHF antenna.

h. Lo-gain VHF antenna.

i. Lo-gain HF antenna.

j. Diplexer

k. Harnesses (electrical).

l. Manometer (propellant utilization).

Certain other electronic packages are to be subcontracted to recognized system specialists for design, development and manufacturing. Selected "in-plant" electronic designs shall also be produced by acceptable and appropriate subcontractors, to satisfy production schedule conditions. In all subcontracting outlined, conformance to Apollo manufacturing standards is obligatory.

3.2.2.5 Assembly Materials Control. Inspection procedure requires that all purchased materials are to be inspected and checked at Receiving Inspection. All material is checked prior to use, in assembly, during appropriate phases of assembly, and upon completion of assembly. In addition, spot checks are made beyond the final acceptance of the assembly for assurance of functional reliability.

Quality control records are maintained on all rejections. Remedial action is taken when repetitive rejections occur in quantities beyond acceptable levels.

3.2.2.6 Manufacturing Area Environmental and Material Cleanliness Control. The manufacturing of electronic components is to be accomplished under controlled conditions.

Manufacturing specifications shall appropriately establish controls to produce the environment and cleanliness necessary to conform to the latest state of the art. This will assure that the reliability of the end assemblies will not be affected by the results of contamination

Conformance to the required specifications will mean automatic regulation of the air temperature and humidity. Air is filtered to extract dust, lint and other debris to an established level of acceptance. Lint-free wearing apparel is required. Hair is appropriately covered, and gloves are worn as is applicable to the area. Unclean processes producing smoke, fumes, acid, dust, or lint are vented or excluded from this area. All materials delivered to the assembly area for storage or distribution for assembly shall be cleaned and free from contaminants to the degree which meets the standards maintained in the assembly area.

Commercially acquired electronic packages are to be modified and/or reworked where necessary for conformance to standards which will assure reliability.

3.3 ASSEMBLY AND TESTS

3.3.1 Mission Module. The mission module will consist of six major structural components and subassemblies, tapered skins, bulkheads, internal beltframes, engine thrust cone, hydrogen storage tank and oxygen storage tank. The configuration and size of these components and support tooling fixtures dictates that the manufacturing be accomplished in an area having an overhead crane support with a minimum capacity of 10 tons and a minimum unobstructed clearance of 36 feet from crane hook to floor level. Specially designed handling tools will be required in conjunction with the overhead crane facilities for line movement of these components. Fusion and resistance welding will be the principal method of fastening. Fusion welding will be accomplished with automatically controlled heliarc welding equipment. The power source will be a standard 300-amp AC/DC rectifier facility with argon and water saver controls, and high-frequency control panels. Crater eliminators will be utilized, in conjunction with power sources and heliarc spot guns, for performing heliarc spotwelds. Use of this type of weld will be limited to tackwelding operations.

Modern resistance welding facilities of various configurations and capabilities will be utilized throughout the manufacturing processes. During a resistance welding operation, it is difficult to detect where or when a variation occurs in the quality of a weld. This is due to possible variations in parameters such as current, resistance, time, and pressure which must be accurately controlled throughout the complete welding cycle. Variations in any one of these parameters is not necessarily caused by improper functioning of the welding facility, but could be the result of a sudden loss or a variation in the factory air and/or electrical supply systems. To overcome these changes, it is proposed to equip each resistance type welding facility with a "Monautronic" control system. This unit automatically produces welds to standards of acceptance by monitoring resistance and voltage, regardless of metal thickness variations and

mushrooming of the electrodes, thereby assuring that each weld is of the highest quality. Layouts will reflect straight line flow and proximity stocking of materials for each of these components.

3.3.1.1 Skin Assemblies. Approximately six developed conical skins will be required for each mission module vehicle. Skins will be fabricated from 36 inch wide titanium coil stock. Each skin will be made up of approximately five skin segments, using mark templates for sizing and scribing each segment from flat stock material. Skin segments will be trimmed to the scribe line with portable power trim shears, and will be butt-welded end to end to form a complete skin assembly. Plastic sizing fixtures will be used for final width and length sizing of the skins. A dye penetrant inspection will be performed on each fusion weldment to verify the quality of the weld. Tool accessory locators will be used to assure accurate location of all external and internal bracketry. The brackets will be fastened to the skin assemblies with standard vertical type resisance welders. Portable carts with protective material will be used to transport the skin assemblies between manufacturing operations.

3.3.1.2 Aft Bulkhead. The aft bulkhead will be fabricated from pre-formed titanium gore segments. Gore skins will be progressively located in a precision bowl-type weld fixture and will be joined together by an automatically controlled heliarc weld. Final sizing of the bulkhead will also be performed at this station. A dye penetrant inspection will be performed on each buttweld to verify the quality of weldment. An inverted bowl-type fixture, supported by a portable resistance spotweld transformer and a hydraulic expansion weld gun, will be utilized for attaching all external and internal bracketry. At the conclusion of all weld operations, rigid inspection will be performed on all weldments, and the bulkheads will be pressure tested above operating pressures. Special handling facilities will be used in conjunction with overhead cranes for line movement of this assembly.

3.3.1.3 Internal Beltframes. Beltframes will be pre-formed in segments at the detail parts level. Each segment will be sized and positioned on a table-type fixture, and joined together by a resistance tackweld. Structural welds will be applied with a standard vertical-press resistance spotwelder. Beltframes will be installed on the tapered skin section during the mating and progressive assembly of the mission module major components.

3.3.1.4 Engine Thrust Cone. This unit will be fabricated from sheet stock titanium, stiffened with external hat-section stringers and internal doublers. The thrust cone skin assembly will be manufactured using the same procedure as in used for the mission module skins. A cone-type tool, supported by a resistance spotweld transformer, and a hydraulic expansion gun will be used for locating and tackwelding all stringers, doublers, etc., to the thrust cone skin assembly. Structural and finish welding will be performed with the thrust cone supported vertically by a head stock type tool which allows free rotation of the part in relation to the supporting welding facility. This same tool and welding facility will be utilized for spot and seamwelding the thrust cone to the aft-bulkhead gore assembly.

3.3.1.5 Fuel and Oxidizer Tanks (Toroid Shape). In an effort to conserve floor space and keep facility support to a minimum, it is planned to establish one assembly line to support the manufacture of both tank assemblies. In most instances, separate tooling will be required for each tank because of differences in the diameter and design of each tank. However, fixtures performing similar type of manufacturing operations can be located adjacent to one another allowing utilization of one welding power source for both fixtures. This will also allow maximum utilization of specialized skills related to a particular manufacturing operation. It is planned to manufacture the toroid shape tank in sections. Each section will be assembled from two pre-formed half skin sections by butt fusion welding and will be mated end to end by lapped joints (resistance roll welded) to form completed tank. At the conclusion of the weld and assembly operations, each tank will be hydrostatically tested at pressures above normal tank operating pressures to verify that the assembly is leak proof. Each tank will be surgically cleaned and sealed. Immediately following leak-test and cleaning operations, insulation material will be applied to the outside of each tank in accordance with engineering specifications. Assembly of these tanks to the mission module will be performed as part of the final assembly operations.

3.3.1.6 Major Component Assembly Area. In this area, the mission module major structural components (skins, bulkheads, beltframes, etc.) are mated to form the complete module structure assembly. A major precision type tooling fixture, with a power-driven head stock synchronized with the drive unit of the welding facility, will be utilized for the progressive assembly task. External and internal tooling rings are used to maintain true circular shape during the joining and welding of these components. Optical tooling will be used to locate the station line for each component. All brackets, clips, and boss assemblies will be installed as required during progressive assembly of the module.

3.3.2 Command Module. Layout of the manufacturing area shall reflect straight line production flow. Wherever possible, all phases of the manufacturing process will be self supporting. Each area of manufacture, such as machining, pre-fitting processing, panel assembly, furnace area, etc.,

will be developed to support all manufacturing requirements. Based on applicable schedules, approximately 14,500 square feet of floor space will be required to support the structural manufacturing task. Final assembly of the command modules airborne parts and components will be accomplished in the area designated for final assembly and checkout of the mission module.

3.3.2.1 Quality Standards. Rigid inspection will be required for each process during all phases of manufacture. Incoming materials must be identified as to manufacturer's specification, heat number, and batch number so that proper information can be reflected on the inspection log covering each part or assembly. Splices and repairs to the honeycomb core must be recorded and attached to the core history sheet. Caution and care in the handling, storage, and cleaning of all materials shall be strictly enforced. Circumstances that require changes to applicable procedures, materials, equipment, time and temperatures, and tooling changes that affect established manufacturing processes, must be approved by process control functions.

3.3.2.2 Facilities. Building requirements are not critical for the manufacture of honeycomb structure. Standard manufacturing areas applicable to aircraft and missile parts are suitable for the manufacture of honeycomb panels. Weight factors, and restrictions in the size of the panels that can be successfully manufactured, eliminate the need for overhead crane requirements. Production facilities required for brazing stainless steel honeycomb panels will include equipment such as the following:

a. Brazing oven having a temperature range up to 2000°F with automatic temperature and recording controls. This unit is required for brazing the facing panels to the honeycomb core and aging of the finished parts

   Note: Unless this facility exists within present complement of facilities, it is considered more practical, economically, to utilize an electrical blanket which will satisfactorily perform the same task.

b. Vapor degreasing equipment for removing oils from parts.

c. Acid process and rinse facility, required for cleaning panels and honeycomb core.

d. Refrigeration equipment, required for cool-aging panels.

e. Resistance brazing (spot tack) equipment, required for tack-welding subassemblies.

f. Hot air dryer providing 140 to 160°F hot air, required for drying waterglass solution used to secure honeycomb core to platen.

g. Vertical mill with tracer attachment, required for milling honeycomb core.

h. Bandsaw (special design), required for making rough cut operations on honeycomb core and for miscellaneous sawing tasks.

i. Heated platen, producing temperatures in ranges of 140°F to 160°F, required as a medium for securing honeycomb core using waterglass solution for machining operations.

j. Miscellaneous hand tools such as feeler gages, shears, seals, brushes, and special handling devices.

k. Dust free room, required for final assembly of the panels just prior to brazing operations.

l. Other miscellaneous type equipment would include such things as work benches, portable power tools, stock racks, etc.

3.3.2.3 Material Handling. Extreme caution shall be exercised in the storage and handling of all materials related to the honeycomb structure assemblies. Shipping containers shall be retained and utilized for storage of bank stock stainless-steel honeycomb. Adequate support must be provided during the transfer of parts by using support materials with proper stiffness, such as plywood, masonite, or corrugated cardboard. Stainless steel facing panels must be stored or transported in the flat position to prevent deformation. Clean waxfree paper shall be used to protect parts after cleaning. Sudden jars or shocks must be avoided when handling unbrazed assemblies.

3.3.3 Final Assembly Area. The mission module will be structurally complete at the time it is received in the final assembly area. All mechanical, electrical, harness, pneumatics, propulsion, and electronic airborne packages are installed in this area. The mission module will be supported by a tool handling cradle that will allow positioning of the module horizontally or vertically during assembly operations. After all internal installations have been completed, the command module will be mated to the mission module. Work platforms will be required for access of personnel to the work areas. Systems and cabin pressure testing will be performed outside the factory area in a pit or in a concrete walled area isolated from populated areas. At the con-

clusion of the high-pressure test operations, vehicles will be transported to the factory area where a complete systems checkout will be performed. In-factory handling of command module and mission module prior to and after mating will be accomplished with specially designed load bars and overhead crane facilities. The mated Apollo vehicle will be transported to and from the high-pressure test area with an in-plant handling trailer to support the vehicle horizontally.

3.3.4 Systems Checkout And Acceptance. In the final checkout stage, completely integrated systems are tested to verify operating characteristics under simulated flight and environmental conditions. These tests must be lengthy to assure the highest possible reliability. Systems checkout operations will be performed in special test stands or docks which support the vehicle. Complex checkout equipment used in the checkout and validation of the various systems will be installed in the area below, or immediately adjacent to, the checkout test stands. Close inspection will be maintained during all test evaluations to assure that all functional tests and checks are conducted in accordance with applicable specifications, test procedures, planning, etc. Plate fulcrum scales will be used in conjunction with special tooling for recording weight and balance data. Quality Control will audit all pertinent vehicle records, reports, logs, data sheets, planning paper, etc., for completeness and accuracy, and will prepare reproducible inventory records for each Apollo vehicle prior to acceptance by the customer. Following customer acceptance, the vehicle will be shrouded and prepared for shipment to its destination.

3.3.5 Major Tools And Operations

3.3.5.1 Mission Module (Structure). A rotating, power driven headstock type holding tool with a C-frame type welder mounted on a power driven carriage which is rolled on tracks will be used for weld assembly of the module capsule. Starting from the large or skirt end, pre-sized tapered skin assemblies, stiffeners, frames, attach rings and the aft bulkhead will be progressively spot and seam welded to form the capsule assembly.

A precision internal form will be used to trim the titanium skin segments to the net size prior to automatic fusion buttwelding which joins skin ends to form a truncated cone section.

Circular frame stretch forms, with provisions for hot forming (1150°F), will be used with a radial draw forming machine to fabricate the titanium one-half segments. Segments are spliced together to form complete rings prior to installation.

Pre-formed titanium gore segments will be sized, final trimmed and fusion buttwelded in this fixture (see Figure 13). Gore skins are positioned in the fixture, over a weld gas backup bar, held in position by a series of pneumatically operated clamps and fusion buttwelded complete by a semi-automatic weld head traveling on a contoured track. The gores are progressively welded until all have been joined together except one seam which is trimmed on the edge after sizing then welded, forming the complete bulkhead.

The aft bulkhead weldment is handled with the aid of a special handling tool(see Figure 14).

When the bulkhead buttwelding is finished, the bulkhead cap is spot welded and seamwelded in a special welding fixture (see Figure 15).

An internal form type fixture with a universal sweep arm type positioner for external brackets, and fixed locators for internal brackets, will be used for precision location and tack spot welding outlet ducts, brackets, floor frame, etc., on the aft bulkhead (see Figure 16). Engine support structure will be located with a special tool accessory.

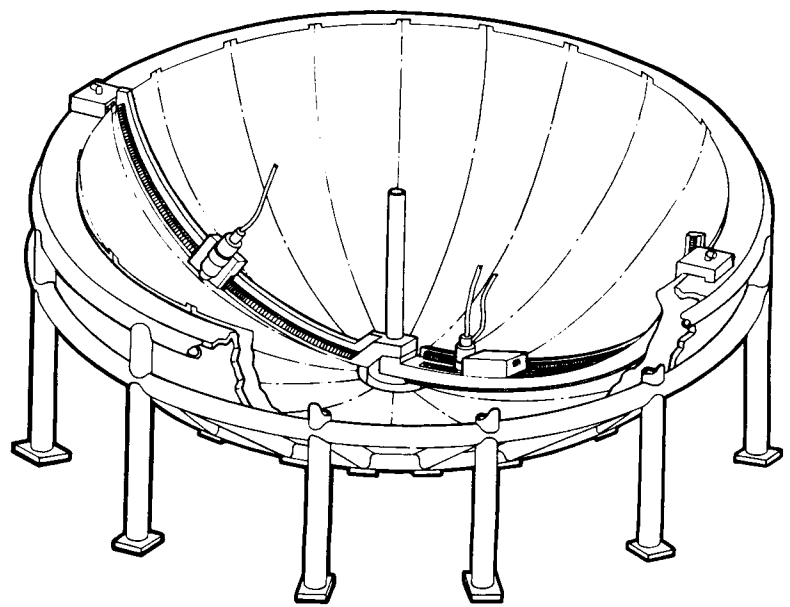


Figure 13. Fixture for Sizing and Buttwelding Aft Bulkhead

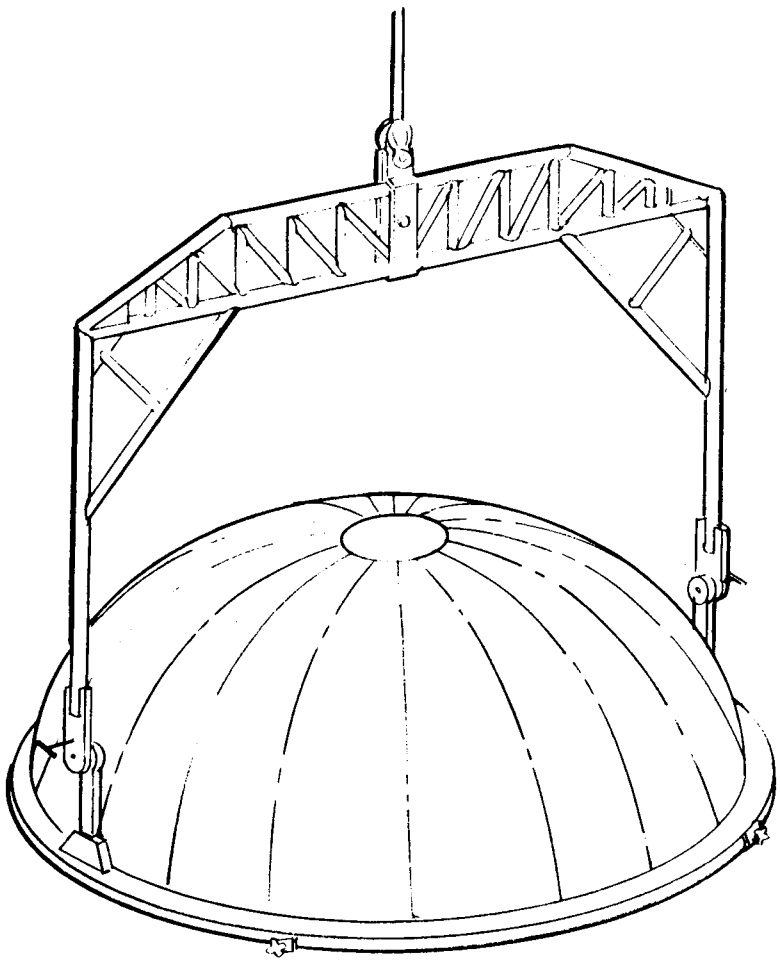


Figure 14. Handling Tool for Aft Bulkhead

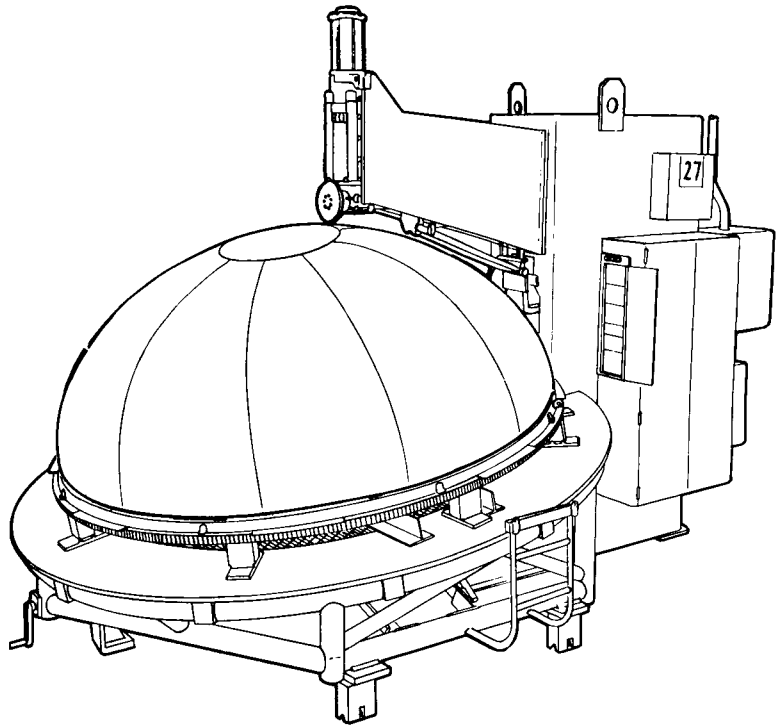


Figure 15. Fixture for Spotwelding and Seamwelding Aft Bulkhead

A wheel type tool supporting the bulkhead from its rim, plus a special deep throat, heavy capacity C-frame spotwelder will complete all spotwelding on the aft bulkhead (see Figure 17).

A contoured heated (1150°F) form, mounted on a hydraulic stretch press, will form the individual titanium bulkhead gore segments, employing the hot creep forming method.

When the weld operations have been completed, a cover type test tool, simulating the forward bulkhead, will be installed to seal the capsule. A special tooling handling tool which provides support for the capsule and access for subsequent final assembly operations, will then be bolted to the aft skirt attach ring. The capsule will then be transported to the

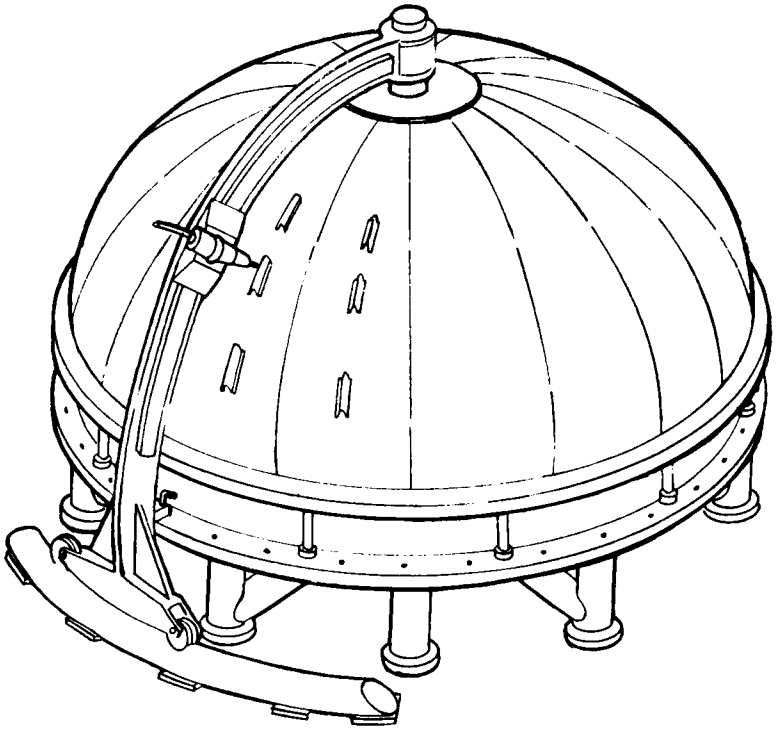


Figure 16. Fixture for Precision Location and Tack Spotwelding of Aft Bulkhead

hydrostatic test area. The capsule, resting on the handling tool, will now undergo hydrostatic proof pressure tests to insure the quality of all weld joints. When the tests have been completed, the cover will be removed, the capsule will be dried out, and it will be returned to the final assembly area.

Equipment and hardware installation will be performed with the capsule still mounted on the handling tool used during the hydrostatic test, with the forward (open) end up. Interior insulation panels will be installed first, followed by the floor panels, and then the pre-assembled and tested electronic components, controls, electrical harnesses, etc. Exterior equipment, radiator, fuel and oxidizer tanks, solar cells, engines, engine actuators, propellant lines, and associated equipment will also be installed at this time.

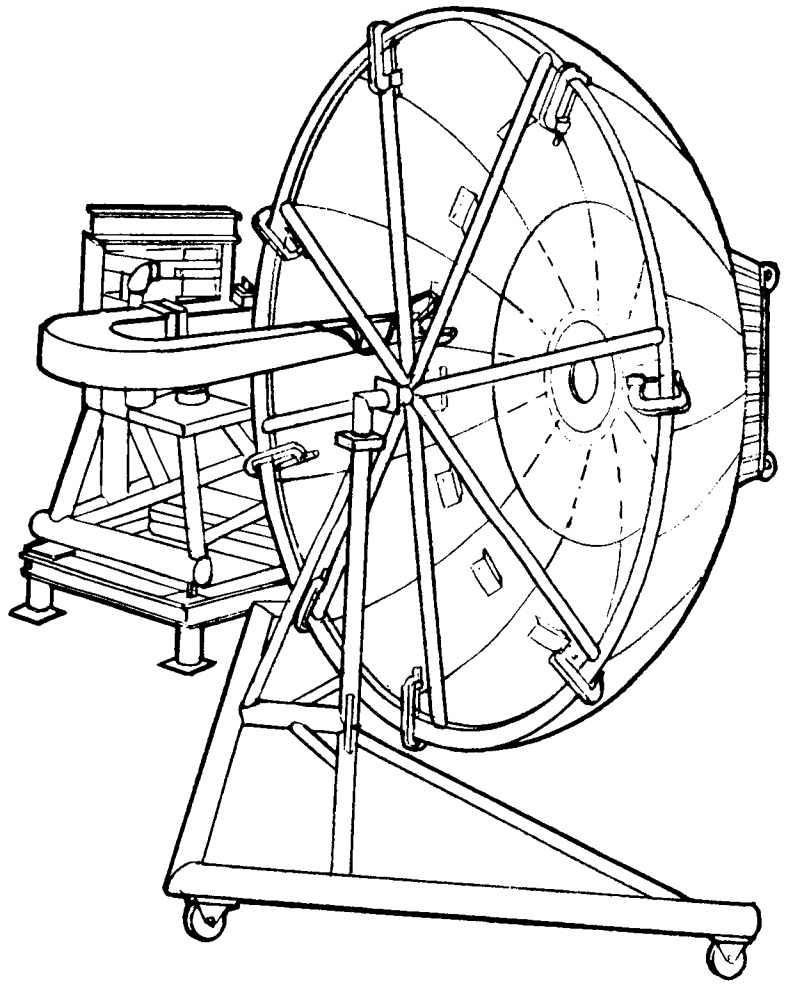


Figure 17. Holding Fixture and C-Frame Spotwelder for Aft Bulkhead

3.3.5.2 Mission Module - Toroid Fuel and Oxidizer Tanks. Individual tank segments, consisting of pre-formed halves joined together with a longitudinal fusion buttweld, will be progressively stovepiped together and then resistance seamwelded until the tank is complete except for final weld. The welder will use specially designed roll weld equipment which will employ a "planetary" exterior weld wheel with a stationary interior wheel just slightly smaller than the inside diameter of the tank. Both diameters of tanks will be welded on this fixture after suitable changes have been made to accommodate the different sizes. The final weld, closing the tank, will be an argon gas-shielded fusion weld. The gas backup and chill bar, required for a quality fusion weld, will be installed in the tank through the outlet port which will be adjacent to the last weld.

When the welding operations are complete, all openings will be sealed and the tank will be placed in a special handling tool supporting the tank from the normal attach point for test and final installation. It will then be transported to the test area and hydrostatically proof-pressure testec to verify the quality of weld joints.

When the pressure tests are complete, the tanks are returned to the factory area for extensive cleaning operations to remove any possible propellant contaminate. After cleaning, the tanks which are still in the handling tool are sealed and pressurized for shop handling. The external insulation is then applied and the completed tanks are forwarde to final assembly.

The above method of tank assembly provides for individual testing of tank segments prior to final seamwelding. It will also allow replacement of any section being seamwelded to form the tank that does not meet weld quality standards.

3.3.5.3 Mission Module - Engine Thrust Structure. The attach ring, skin, stiffeners, and machined engine attach fittings will be assembled, drilled, and riveted complete in a locating and handling tool.

3.3.5.4 Mission Module - Interstage Adapter. Pre-drilled adapter rings and frames will be positioned in an assembly fixture. The adapter skin and stiffener panel sub-assemblies are then wrapped around the frames and rings, and are drilled and riveted complete.

3.3.5.5 Mission Module - Radiator. A male-type forming mandrel will be used to maintain contour during the forming operation. Fabrication of the radiator will start with automatic fusion buttwelding of the sheets into the large developed flat pattern of top and bottom halves of the radiator. Inlet and outlet ports will then be welded into the top half.

Top and bottom halves will now be furnace-brazed together in a brazing fixture using thin copper sheet to bond the areas between ducts. The brazed assembly is then rolled into a truncated cone.* Next, the cone is placed on a forming mandrel that has the inside radiator contour on it. An external collar, relieved in the areas where the ducts are to be formed, is placed over the radiator mandrel. The ducts will then be hydraulically expanded by pumping water into the inlet ports, forming the ducts. After forming, the radiator ends are trimmed to size. The manifolds are then welded to the radiator, completing the assembly.

3.3 5.6 Mission Module - Forward Bulkhead Segment. Pre-formed inner and outer titanium skins for the forward bulkhead segment, with the pre-drilled attach ring spot and seam welded to the outer skin, plus preformed fiberglas honeycomb cores, are assembled in a high temperature cast bonding tool, vacuum bagged, and placed in an autoclave and bonded under heat and pressure.

Inner and outer titanium skins for the bulkhead segment will be stretch formed on heated forms employing the hot creep forming method.

3.3.5.7 Command Module Abort Tower. A rotating headstock type tool, mounted on tracks, will be used with stationary, floor-mounted spot and seamwelder for the progressive spot and seamweld assembly of the abort tower skin segments, stiffeners, frames, and pre-drilled attach rings.

A holding tool, bolted to the aft face of the abort tower, will provide support and access for final assembly of the rocket motor, electrical harness, etc.

A precision internal form will be used to size and trim skin segments prior to an automatic fusion buttweld which joins the skin ends to form a truncated cone section.

* An alternate fabrication plan is strongly considered where the upper and lower developed skins (including the manifolds, as well as the ducts) are resistance roll welded.

A contoured heated (1150°F) form, mounted on a hydraulic stretch press, forms the titanium frame sections in halves. The halves are spliced together to form complete rings, prior to installation.

3.3.5.8 Abort Tower - Inter and Outer Support Structure. Pre-formed net-trimmed inner and outer stainless steel skin panels, plus pre-formed inlaid panel edges, brazing alloy, and stainless honeycomb core, are assembled in a high temperature cast refractory holding tool and brazed to form a complete panel assembly. Brazed honeycomb panel subassemblies and the abort tower attach ring will be positioned in a tool holding them in the proper relationship, then joined together by fusion welding the edges of the panels and the ring.

3.3.5.9 Aft Bulkhead - Pressurized and Non Pressurized. Pre-formed gore segments will be sized, fusion buttwelded, and scribed for final trim in a size and buttweld fixture similar to the mission module aft bulkhead.

The attach ring, inner and outer skin, abort tower adapter structure rings, and the access door ring will be located, and spot welded and seam-welded complete in a wheel type weld fixture, using a special C frame spot welding machine.

Inner and outer bulkhead skins with attach rings, abort tower adapter rings, and door rings (previously spot and seamwelded to them) will be assembled with the brazing alloy and stainless steel honeycomb core in a cast refractory holding tool. They will then be brazed to form the inner pressurized and the outer non-pressurized bulkheads that make up the complete aft bulkhead. The abort tower adapter structure will then be welded to the inner pressurized bulkhead.

3.3.5.10 Capsule Shell. The following items are assembled in a cast refractory holding tool and brazed to form the capsule shell panels: 1) inner and outer skins which are trimmed to net in a flat development, 2) pre-formed frame ring segments (spotwelded previously to the inner skin), 3) stainless steel honeycomb, 4) brazing alloys, and 5) pre-formed inlaid panel edges.

Inner and outer structural bulkhead skins, consisting of pre-formed gore segments sized and buttwelded to form individual bulkheads, will be placed in a cast refractory holding tool along with pre-formed honeycomb core and brazing alloy, and brazed to form the structural bulkhead. The forward bulkhead outer shell, fabricated in the same manner as the structural bulkhead skins, will be placed in a cast refractory holding fixture along with the brazing alloy and a machined stainless honeycomb, and will be brazed. The forward structural bulkhead will then be brazed to the outer shell bulkhead. A lower temperature brazing alloy will be used so as not to disturb the original brazing. Brazed honeycomb panel sub-assemblies, the aft bulkhead attach ring, and the forward bulkhead brazed honeycomb sub-assembly will be positioned in a tool, holding them in the proper relationship, where they will be joined together by fusion welding the edges of panels, attach ring and forward bulkhead. Pre-formed internal frame segments are spliced together then riveted to the frame ring segments that were welded on the panel sub-assemblies. The non-pressurized aft bulkhead assembly and the abort tower support structure are then welded to the capsule shell as the final weld operation.

After all weld operations have been completed on the capsule shell and aft bulkhead, the pressurized bulkhead is bolted in place and the sealed capsule is forwarded to the pressure test area for hydrostatic testing to check the complete capsule for leaks. The capsule, upside down, resting on the abort tower adapter structure, is bolted to a holding tool which gives the necessary support, assembly access, and provisions for rotating the capsule for final assembly. When the leak testing is complete, the capsule is returned to the factory, still supported by the handling tool.

Application and baking of the ablative coating will be made at this point. When the coating is finished, the capsule is rotated, by means of the handling tool, to an upright position and placed in a padded, final assembly handling cradle, where the aft pressurized bulkhead is removed.

Module final assembly is performed with the capsule resting in the handling cradle. First the pressurized bulkhead is removed, and internal insulation is applied. Pre-tested packaged electronic components in the forward section are then installed, followed by all major items of equipment, console, wiring, tubing, seats, etc., which have been pre-assembled and tested. The aft pressurized bulkhead is now reinstalled and sealed. Balance of internal final assembly and hookup is performed using the escape hatch for access.

Installation of exterior equipment, including capsule adapter ring, control flaps, antennas, parachutes, etc., is then performed, including a trial fitting of the abort tower master to the command module. When proper interface match is verified, the abort tower master is removed and prepared for shipment to the launch sites.

3.3.5.11 Control Flaps. Pre-formed, net trimmed skin panels, stainless steel honeycomb, and required brazing alloy will be assembled in a high temperature cast refractory holding tool and brazed in a panel assembly

brazing fixture. Final spot welding and assembly of hardware will then be performed.

All internal flap members, where practical, will be spotwelded to the outer skin panel to aid in positioning components prior to brazing.

3.3.5.12 Adapter Ring. (Command Module to Mission Module). Laminated glass cloth laid on a plastic mold will be used for the adapter ring. When the required layers of cloth have been applied to the mold, it is placed in an autoclave and cured under heat and pressure. The cured ring is then removed, trimmed to net size, and drilled with a drill fixture that has been coordinated to the master tool.

3.3.5.13 Assembled Vehicle. Mating of the command module to the mission module will be accomplished by lifting the command module from its handling cradle, using an overhead crane and a special handling tool, then placing it in the mission module which is supported with its open end up by the pressure test handling tool.

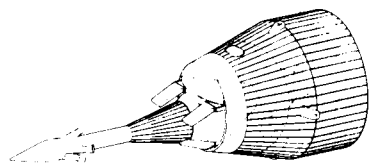
Final hookup of lines, harnesses, etc., is then performed, followed by extensive functional and systems checkout procedures, including a high pressure test in a special test pit outside the factory area.

Upon completion of vehicle checkout, special handling rings are installed on the abort tower separation face. The vehicle is then hoisted out of the final assembly holding fixture with overhead cranes and mated to the interstage adapter to which a special handling ring has been attached on the aft face.

The assembled vehicle is then placed on the weigh and balance fixture. This tool consists of special adapter provisions installed on a standard fulcrum plate scale to provide support on either end of the vehicle. This permits the assembled vehicle to be weighed through the two axes normal to each other for determining C.G., as well as gross weight.

When weigh and balance operations are finished, the vehicle is loaded on a standard trailer for transport to the launch site.

3.3.5.14 Apollo Major Tool List. Table 1 reflects the major tooling required to support the manufacture of the Apollo space vehicle. Quantities indicated are based on a maximum production rate of seven units per calendar year. Detail and subassembly type tooling requirements are not included.



4 AREAS OF SPECIAL CONSIDERATION

On this project, as in the past, Industrial Engineering has worked closely with Manufacturing Research, Tool Engineering, and Engineering Design areas in anticipating and coping with the manufacturing problems of product design. Discussions were held relative to manufacturing techniques for new materials, the producibility of the vehicle design and assembly, and the capabilities of new and unique facility items proposed for manufacturing. By this cooperation, particularly during the preliminary stages of engineering design, a producible end product is assured and design modifications are minimized.

In the Apollo design, thin, lightweight titanium is used which requires new techniques and processes to form and join. Unlike stainless steel, molybdenum steel, and aluminum alloys that can be fabricated and processed easily because of long experience with them in industry, the successful use of titanium is relatively recent. It therefore requires careful engineering, planning and manufacturing development to produce a vehicle design which uses this metal in thin gages, to the extent that it does.

4.1 FABRICATION AND PROCESSING CONSIDERATIONS

4.1.1 Metals - Forming and Welding. The greatest percentage of material designed to be used for Apollo part fabrication is A110-AT-5AL-2.5Sn titanium alloy. It has good forming and welding qualities under controlled conditions. The fabrication and processing techniques for this alloy differs over those used for the remainder of parts made of aluminum and stainless steel. This alloy, when bent or formed without heat, requires subsequent stress relieving with heat; whereas no stress relieving is required when it is formed with heat.

4.1.2 Brake Forming. Aside from the mandatory differences in bend radii used for titanium sheet and the sometimes novel use of heat, the techniques are similar to those commonly used. Greater material hardness or brittleness requires a larger radius in bending to prevent metal deterioration or a weakness at the bend. More ductile materials than titanium can be bent to sharper radii.

4.1.3 Stretch Forming. In stretch forming sheet titanium, a technique identified as "creep forming" is employed (see Figure 18). In this system, a slow drawing action is used and the part is heated to 1100°F. by the punch over which is is being formed. The sheet is held by jaws placed around the perimeter at positions to be dictated by the finished

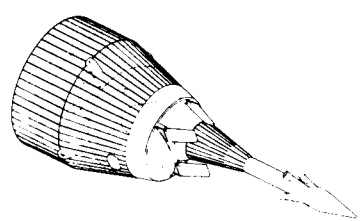


Table 1. Major Tooling Required for Apollo Manufacture

Area	Tool	Quantity
Abort Tower	Major Assembly Weld Fixture	1
	Final Assembly Holding Fixture	1
	Taper Skin Sizing Tool	1
	Frame Section Stretch Forms	5
Mission Module	Weld Assembly Pressure Test Tool	1
	Final Assembly Handling and Support Tool	1
	Major Assembly Weld Fixture	1
	Taper Skin Sizing Tool	1
	Frame Stretch Forms	5
	Aft Bulkhead Size and Buttweld Fixture	1
	Aft Bulkhead Cap Seamweld Fixture	1
	Aft Bulkhead Spotweld Assembly Fixture	1
	Aft Bulkhead Spotweld Holding Fixture	1
	Aft Bulkhead Gore Stretch Form	1
	Toroid Tanks Assembly Weld Fixture	1
	Toroid Tanks Segment Stretch Forms	2
	Toroid Tanks Segment Buttweld Fixture	2
	Toroid Tanks Handling Tool	2
	Engine Thrust Cone Assembly Fixture	1
	Interstage Adapter Assembly Fixture	1
	Radiator Panel Brazing Fixture	1
	Radiator Panel Forming Mandrel	1
	Forward Bulkhead Segment Bonding Fixture	1
	Forward Bulkhead Skin Stretch Form	2

Table 1. Major Tooling Required for Apollo Manufacture (Cont)

Area	Tool	Quantity
Command Module	Abort Tower Outer Support Structure	
	Weld Assembly Fixture	1
	Skin Panel Brazing Fixture	4
	Aft Bulkhead Size and Buttweld Fixture	1
	Aft Bulkhead Spotweld Fixture	1
	Aft Pressurized Bulkhead Brazing Fixture	1
	Aft Non-Pressurized Bulkhead Brazing Fixture	1
	Skin Panels Weld Assembly Fixture	1
	Skin Panels Brazing Fixtures	5
	Forward Bulkhead Size and Buttweld Fixture	2
	Forward Bulkhead Brazing Fixture	1
	Forward Bulkhead Outer Shell Size and Buttweld Fixture	1
	Forward Bulkhead Outer Shell Brazing Fixture	1
	Abort Tower Inner Support Structure	
	Weld Assembly Fixture	1
	Skin Panel Brazing Fixture	4
	Assembly Pressure Test Handling Tool	1
	Assembly Handling Cradle	
Assembled Vehicle	Final Assembly Handling Tool	1
	Weigh and Balance Fixture	1

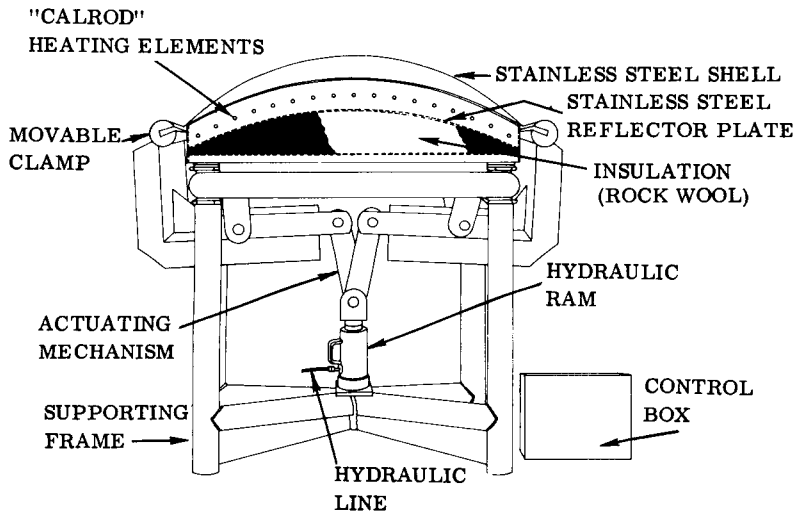


Figure 18. Tool for Creep-Forming Titanium

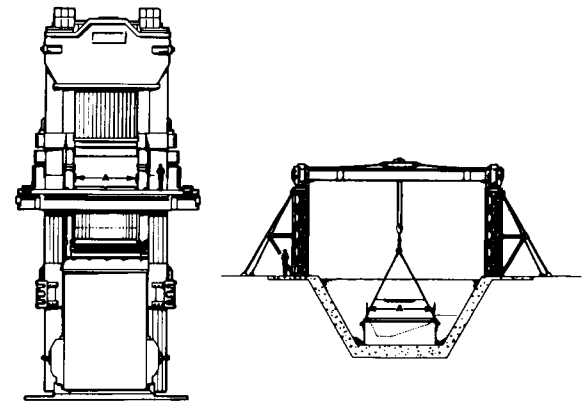


Figure 19. Hydrochemical Forming Facility

part shape. The edges of the shaped punch also closely follow the perimeter of the finished part. Forming is accomplished by slowly forcing the heated punch up into the sheet, hydraulically. Parts formed in this manner have negligible "spring back".

4.1.4 Hydrochemical Forming. Several facilities for this newly used technique are in existence and use. In this method, sheet metal parts are (cold) formed into a die shape which has been submerged in water. The die cavity is sealed off by the part blank and sealing compound which keeps the die free of water. The motivating force upon the water, which in turn moves the part as a punch, is by means of a well placed pyrotechnic charge which provides an instantaneous high-energy force. In this high-impact forming, a phenomenon occurs in that the parts form to depths heretofore deemed impossible. The yield strengths are beyond the limits which the materials are known to possess. In addition, spring-back from the die shape and thin-out which is uniform, is also negligible. Figure 19 shows a portion of a hydrochemical forming facility. The large press shown illustrates the approximate size that would be required for forming the maximum diameter parts required for this program.

4.1.5 Dynapak, High Impact Forming. "Dynapak" is a high-energy-rate machine tool. It produces high ram forces and speeds by pneumatics. Energy up to 1,500,000 foot-pounds and speeds up to 2,500 inches per second are currently available. It not only produces extrusions and forgings, but also draw-forms sheet metal to unusual depths and impacts powdered metals to high density for subsequent sintering. Part sizes are limited to date by machine capacities to approximately 12 inches or less.

Parts are formed in 2 to 10 milliseconds and this time is so brief that heat transfer to the die is minimized. The dynapak permits metal working of exotic metals at temperatures of 3500°F, and yields long die life. This machine (see Figure 20) produces forged die parts to such close finished dimensions that practically little machining is required to produce a finished part.

Sheet titanium parts have been drawn to three times the depth accomplished by other means without prior or subsequent heat treating. In this process, water again is used as the punch. The water is placed in a heavy retainer on the machine platen. The cavity die on the ram fits into the retainer immediately prior to impact, thereby acting as a water seal. The part blank is held against the cavity die by means of a putty used as a sealant around the perimeter to prevent water from entering the die during the forming operation (see Figure 21). Metal

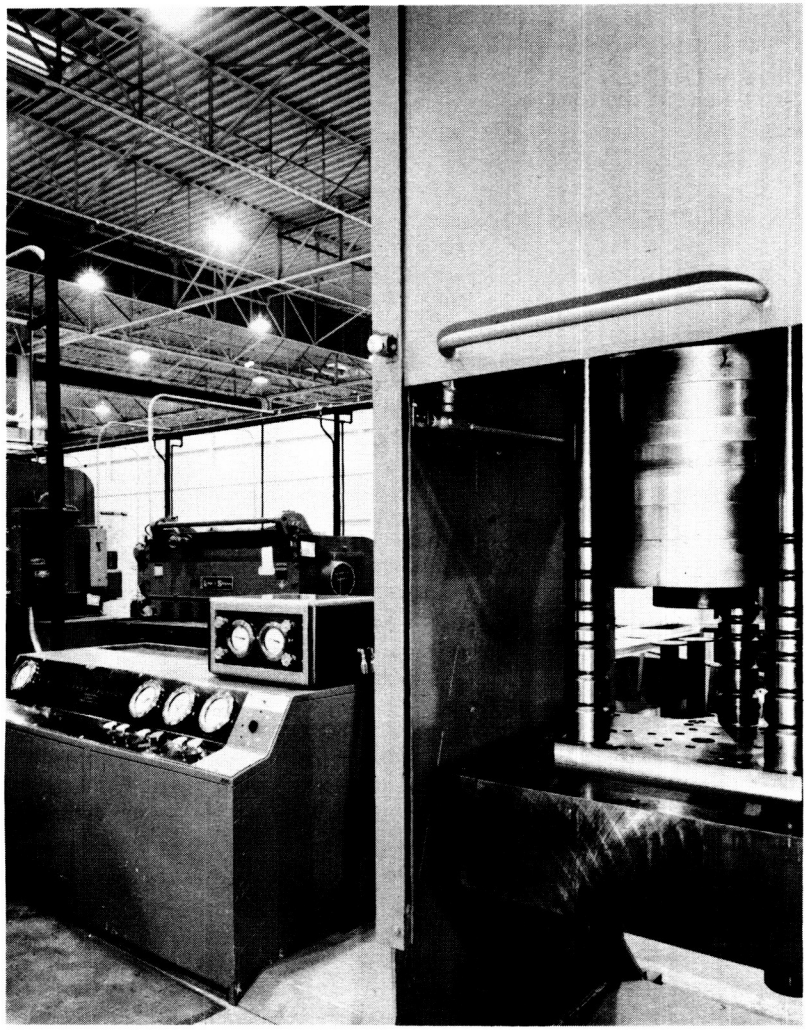


Figure 20. Dynapak Tool

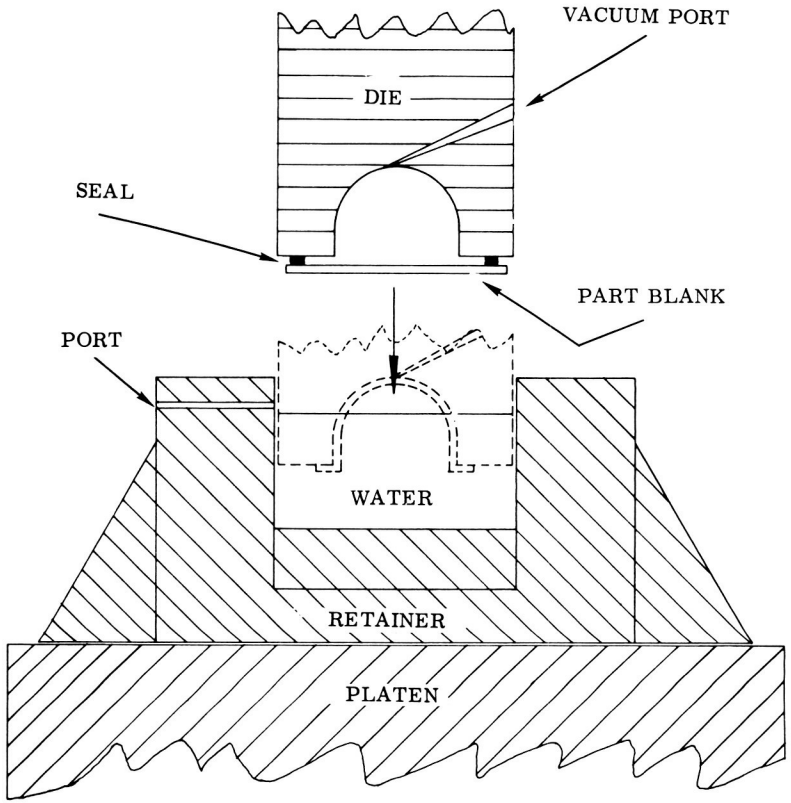


Figure 21. High-Impact Forming

"thin out" is negligible and uniform. In this ultra-high speed forming, a phenomena occurs which provides unexplainable but desirable drawing qualities.

4.1.6 Welding. In recent months great strides have been made in welding thin gages of sheet material. These are much improved over methods used currently in producing missile and space vehicles. In buttwelding thus far, with materials much heavier than those designed for Apollo, meticulous trimming and fitting is required in preparation for the skin and tank buttwelds (particularly where fusion welding is accomplished without the use of consumable rod).

In the Apollo design, titanium to a minimum thickness of .010 is used, which requires even greater care and precise alignment at the sheet butting interfaces for fusion welding. It also requires a shielding gas to prevent the contaminates in the air from being attracted to the molten weld area phenomena peculiar to titanium and certain other rare metals.

The problems of metal preparation and welding with the attendant potential scrap expense have caused new and unorthodox techniques to be developed. Through the cooperative efforts of Industrial Engineering and Manufacturing Research Departments, these newly developed techniques have made the use of this titanium alloy fully feasible.

Half of the welds on Apollo which, heretofore, would have been fusion welded, now are designed to be lapped at the joints and (resistance) roll welded, eliminating the meticulous fitting and shielding gas provisions. Material scrap will be minimized and many labor hours will be saved by reducing the complexity of the fitting and welding operations.

4.1.7 Space Radiator. In the fabrication of the radiator (see Figure V.4.22) the use of an outside and inside sheet welded together as an envelope, which in turn is wrapped around as a truncated cone or collar and welded end to end, was proposed (Figure 22). The envelope (in the flat) initially is to be seamwelded completely in the pattern of the radiator tubes and manifolds (to the developed pattern which evolves in true shape and dimensions when wrapped).*

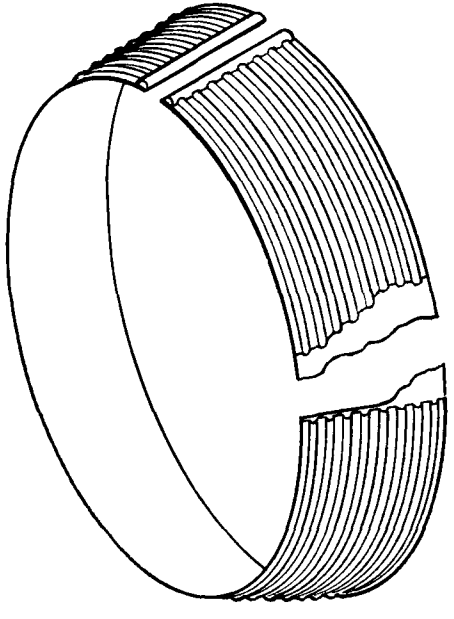


Figure 22. Space Radiator

As a collar, it is placed upon a male tool form representing the true inside dimensions of the finished collar. Hydraulic pressure then is applied to form the outer convolutions of the radiator to the full blown shape of the duct pattern and manifolds. Aluminum is the material to be used in the design.

This plan has good producibility, in contrast to the original plan in which the cores or tubes on the top surface were made as a developed corrugated sheet, with the fore and aft, as well as the circumferential manifolds designed as separate parts, to be fitted and welded together subsequently.

In this cooperative effort with Engineering, a manufacturing plan evolved which produced a more reliable end item. With this plan a significant saving of both labor and material would be realized through fabrication processes and scrap reduction.

4.2 PLASTICS AND INSULATION. Much consideration has been given to the insulation of the toroidal propellant tanks (particularly for the liquid-hydrogen tank - 423°F). Heat conduction from radiation must be minimized in the cryogenic storage area by insulation.

Supporting struts from the vehicle mission module structure conduct heat through the tank insulation to the tank walls and to their termination in the propellant liquid. To prevent this end effect, Engineering has proposed that a layer of fiberglass mat be cemented to the inside tank wall with a sealed sheeting of Mylar cemented to the insulation in contact with the propellant.

This plan is to be replaced by an Industrial Engineering proposal which reduces the difficulties in installation, tearing, inaccessibility, and cementing. It is proposed (see Figure 23) that the insulation designed for inside the tank be redesigned to be completely enveloped in heat-sealed mylar, and evacuated of moisture and air. The developed envelopes would be made approximately 36 inches wide and long enough to reach around a radial segment of the tank circumferentially. Each point of intersection of pads would be taped with Mylar strip and heat sealed to the mat coverings.

*An alternate plan also exists for the fabrication of the envelope in that furnace brazing is used to accomplish the same end except that the manifolds are to be aluminum soldered on during a subsequent assembly.

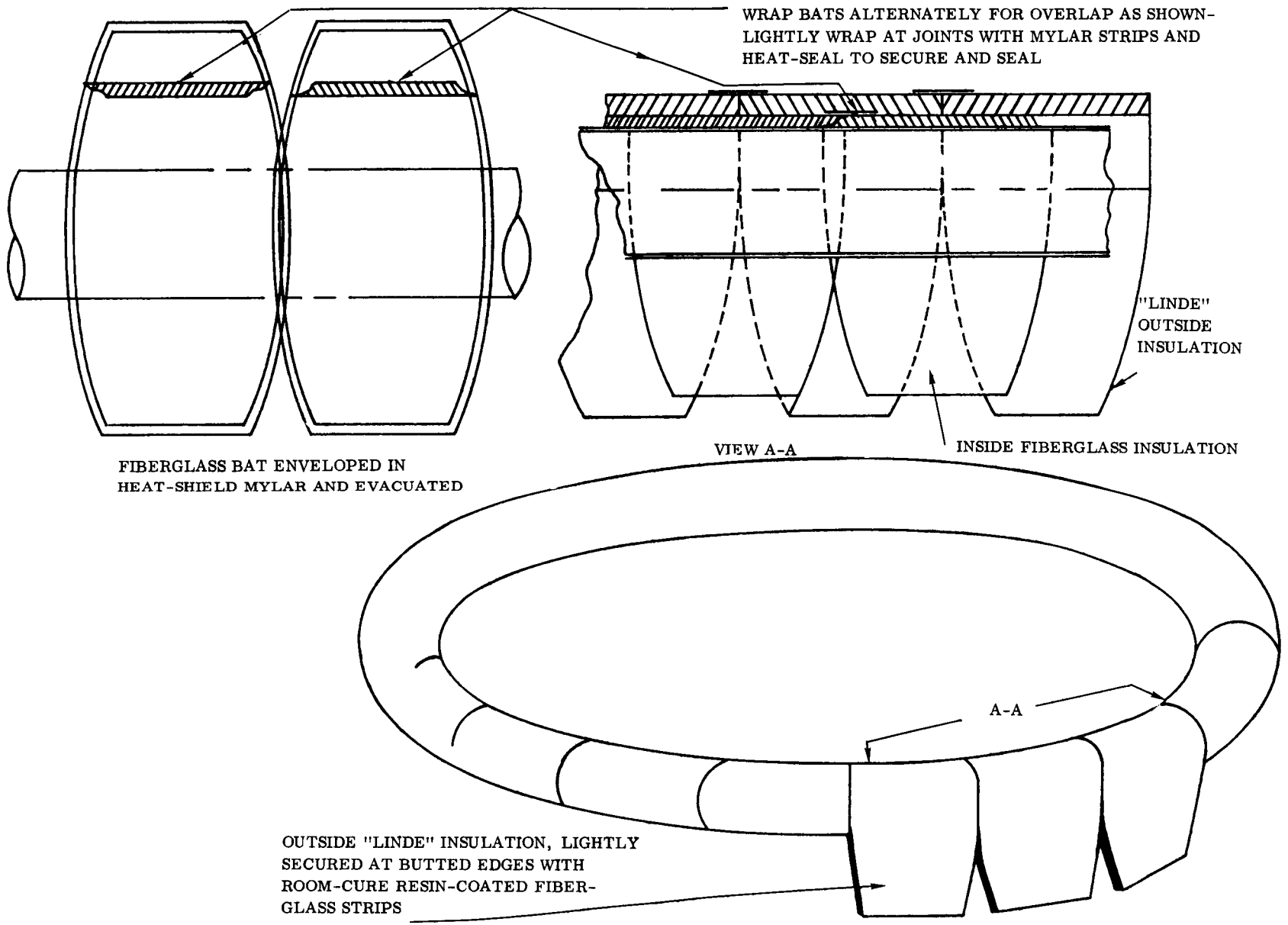


Figure 23. Toroidal Tank Insulation

This tape would also lightly bind the insulation to the tank in lieu of adhesive and prevent the liquid nitrogen which is used to cool down the vehicle prior to launch) from seeping into the cold tank wall and impairing the insulating value of the insulation.

It is also proposed to plane an envelope of insulation under the tank support strut bands at the tank inner faces to stop heat conduction and act as a chaffing pad for the tank walls (see Figure 23).

4.2.1 Ablative Material. The heat shield material is a dense epoxy-resin based plastic. Silica fiber and phenolic microballoons are milled into the resin to provide a uniform blended mixture. The resulting blend is very stiff with a dough-like consistency. The normal work life (shelf-life) at ambient temperature is a minimum of 24 hours.

There are two basic techniques by which this material may be fabricated into the heat shield:

a. Apply the mastic material directly to the vehicle and follow immediately by curing the entire unit.

b. Mold and machine ablative panels which are subsequently bonded to the vehicle.

The first technique is preferred.

For panel fabrication, the blend would be rammed into open-face molds. Production molds would be fabricated of aluminum and so designed as to minimize machining of the molded part. The filled mold would be vacuum-bagged and cured at approximately 350°F. The finished panels would be bonded to the metal honeycomb structure with epoxy based adhesives. Additional fastening may be required. This technique is an alternate method.

The preferred technique of heat shield application consists of applying the mix directly to the structure. Batches would be machine mixed and applied by hand to the unit. Confining molds may have to be applied to the unit to support the resin. When the vehicle is covered, vacuum bags would be applied and the entire unit would be oven cured. A dressing operation may be required after cure. This technique permits minimum time and assures minimum cost.

4.3 ELECTRONICS. A determined effort shall be made to promote techniques and procedures in the fabrication and assembly of the Apollo vehicle electronics which reflect the latest state of the manufacturing art. Manufacturing specifications shall provide controls regulating environment, dust, and cleanliness to a level that assures reliability by preventing deleterious contamination of the assembled components.

4.3.1 Component Parts. Parts shall be inspected at receiving, before assembly, during assembly, and functionally at completion of assembly. Component assemblies are to be functionally inspected before and after encapsulation. Every effort must be made to assure parts reliability.

Parts subject to damage or breakage during storage are to be meticulously packed and wrapped until time of assembly.

4.3.2 Encapsulation Dies. Dies are to be lined with resilient plastic for easier removal of the encapsulated items from the mold, particularly the shapes with negative draft and/or with protuberances. Molds produced in this manner can be made faster and duplicated precisely from the master plug for each assembly which simulates the connections and net shape of the finished component. See Figures 24 thru 28.

4.3.3 Encapsulated Wire Harness And/Or Plug Ends. A technique and process has been developed for either partially or fully encapsulating a wire harness and plugs for environmental protection, wear and bonding. The elements of the plugs are pre-assembled or soldered to the wire ends, then held in their relative positions by details of the mold for encapsulation. These plugs are molded into a configuration which laps over the mating plug end and produces a watertight seal.

The use of molded plugs in lieu of purchased plugs produces a significant dollar savings. Purchased plugs can also be used in place of the molded plugs encapsulated with the harness. Purchased plugs, however, require the confined and laborious soldering of the wires to the assembled plug elements. (See Figure 29). All completely molded plug ends are compatible with purchased plugs. See Figures 30 through 32 for illustrations on molded plugs.

4.4 HANDLING CONSIDERATIONS

4.4.1 In-Plant Handling. A basic policy in the manufacture of the Apollo will be to handle material as little as possible. Any handling which is not essential to the end article creates extra costs. These shall be held at a minimum.

Receiving, warehouse storage and transportation from the warehouse to the fabrication area present no difficult handling problems. Items to be received, stocked, and transported include such things as diodes, stainless steel sheet stock, instruments, titanium bar stock, titanium roll

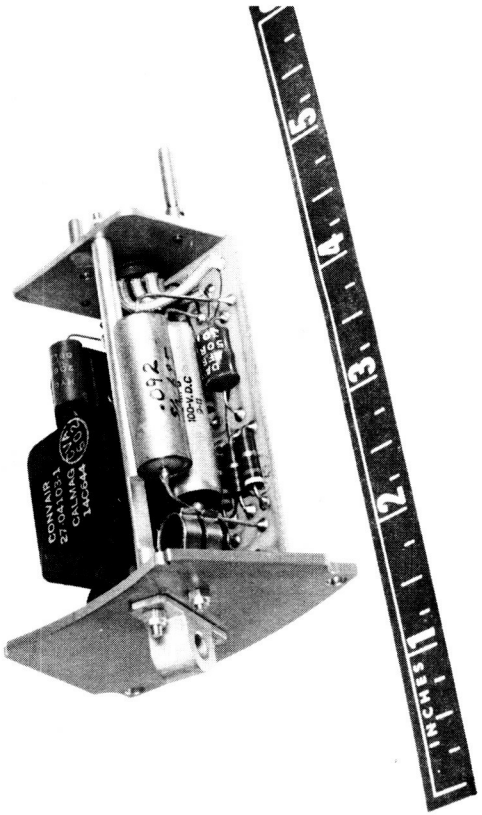


Figure 24. Amplifier Assembly Before Potting

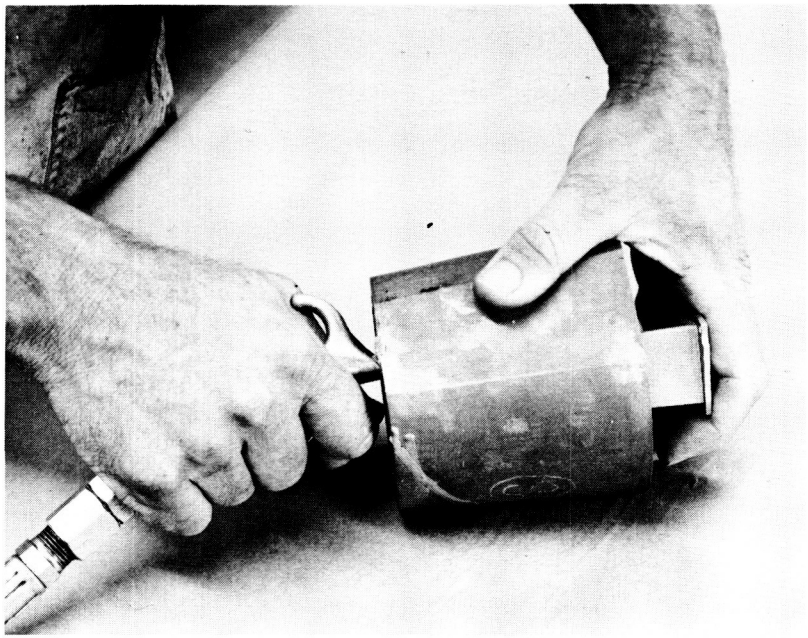


Figure 25. Potting Mold and Ejection of Part

stock, and adhesives. Care must be exercised in storing and handlaing the thin sheet stock (0.008 inch) and instruments. These and certain other items are highly subject to damage. Protective cushioning must envelop them to prevent scratches, jars, etc. Normal transporting and stocking practices should be followed, i.e., fork trucks, trailer trains, overhead cranes, and metal and/or wood shelving would be utilized.

Fabrication operations convert the raw stock into more valuable and more delicate parts which add to the complexities of handling. Special dunnage must be designed for standard trailers to individually hold and protect the thin (0.008-inch) sheet metal parts as well as the delicate machined surfaces of fittings. Once a part is completed and inspected, it should be wrapped in heavy kraft paper to protect its surface from scuffs and scratches and to maintain its cleanliness.

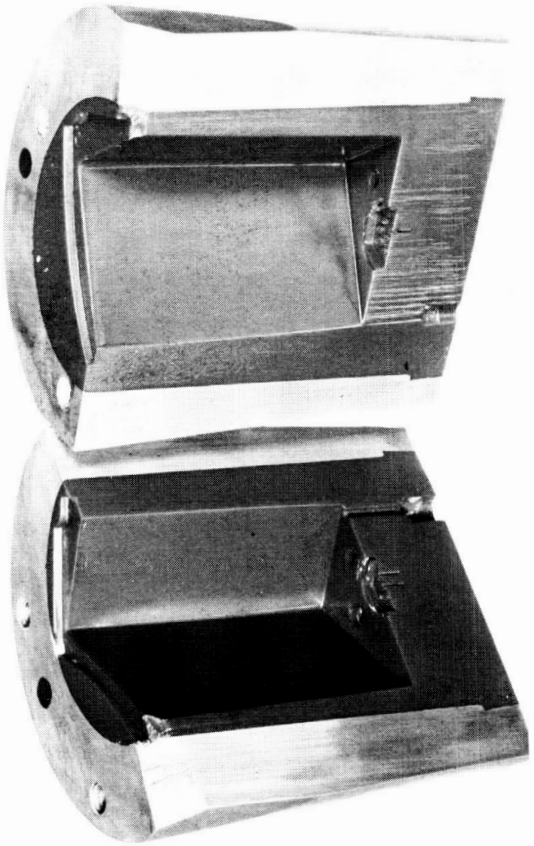


Figure 26. Potting Mold

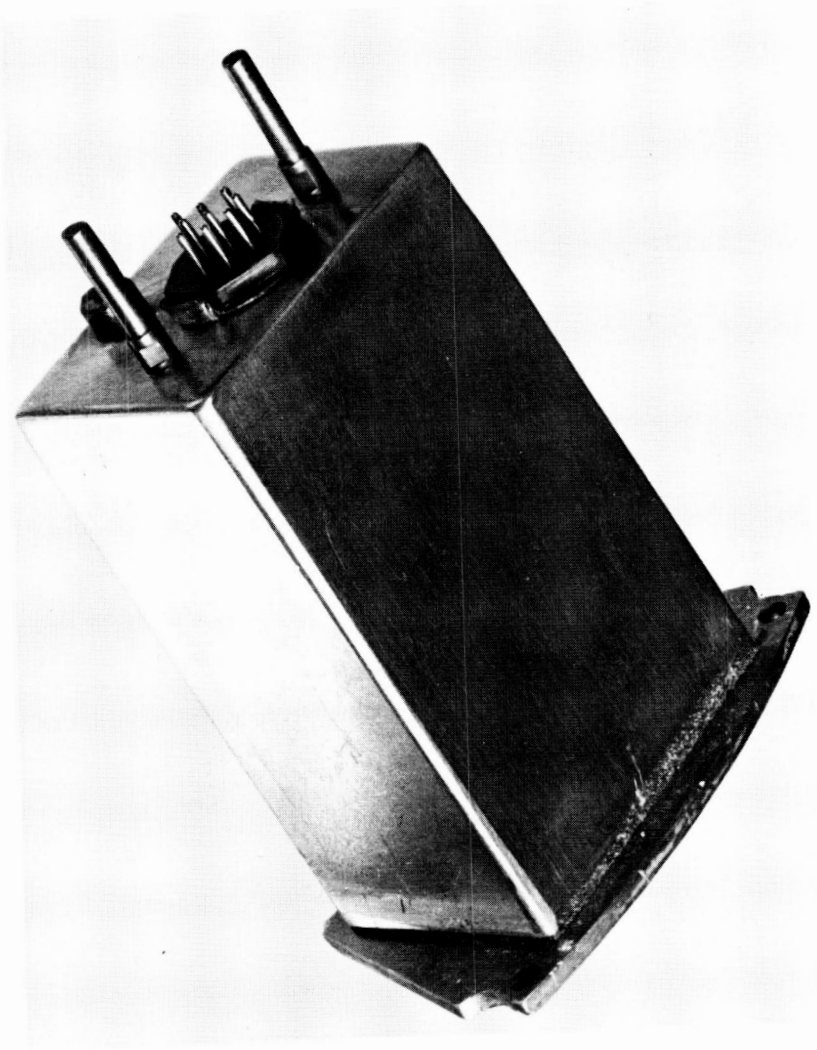


Figure 27. Potted Amplifier Assembly

This is particularly true of honeycomb core, and skine for honeycomb panels. The majority of the parts made are relatively small and will be handled by normal means, i.e., tote pans, racks, and special trailer dunnage.

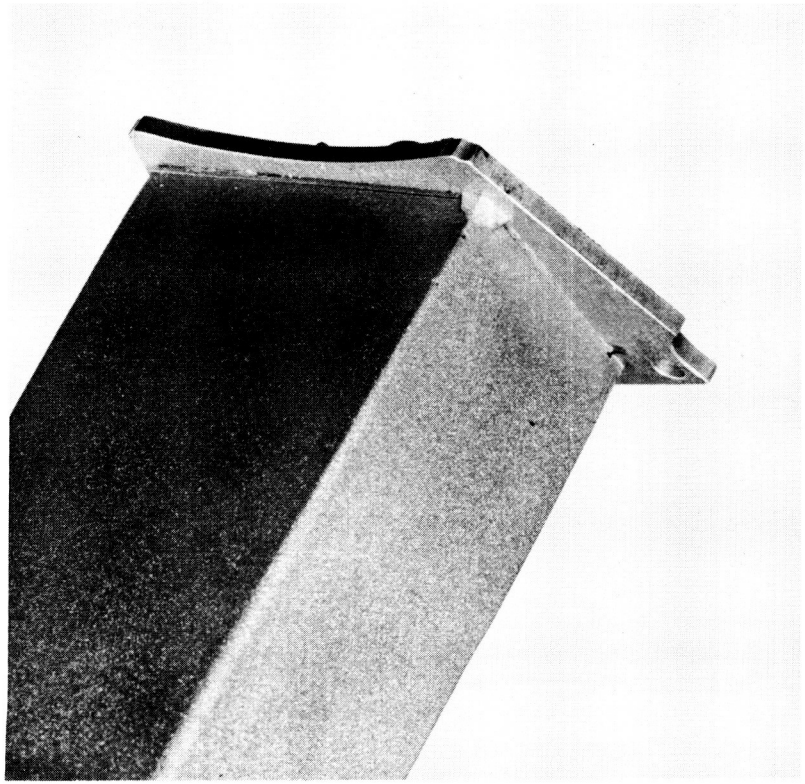


Figure 28. Trim Requirements for Amplifier Assembly

Because of the size and duration of the program, establishing a stock room for fabricated parts or assemblies is not recommended. All stocking shall be directly to the assembly line. Purchased items such as nuts, bolts, small assemblies, etc., will go directly to the assembly line in lot quantities. All fabricated parts will be sent directly to their point of use; no interim stocking area will be used. This conserves floor space and eliminates a handling operation.

The assembly operation will require some special handling tools to hold and handle assemblies during and after operations. The 17-foot diameter toroidal tanks present an example of peculiar assembly handling problems. Because of wall thickness and tank weight, the units must be moved in a horizontal position. If the units are to be moved by

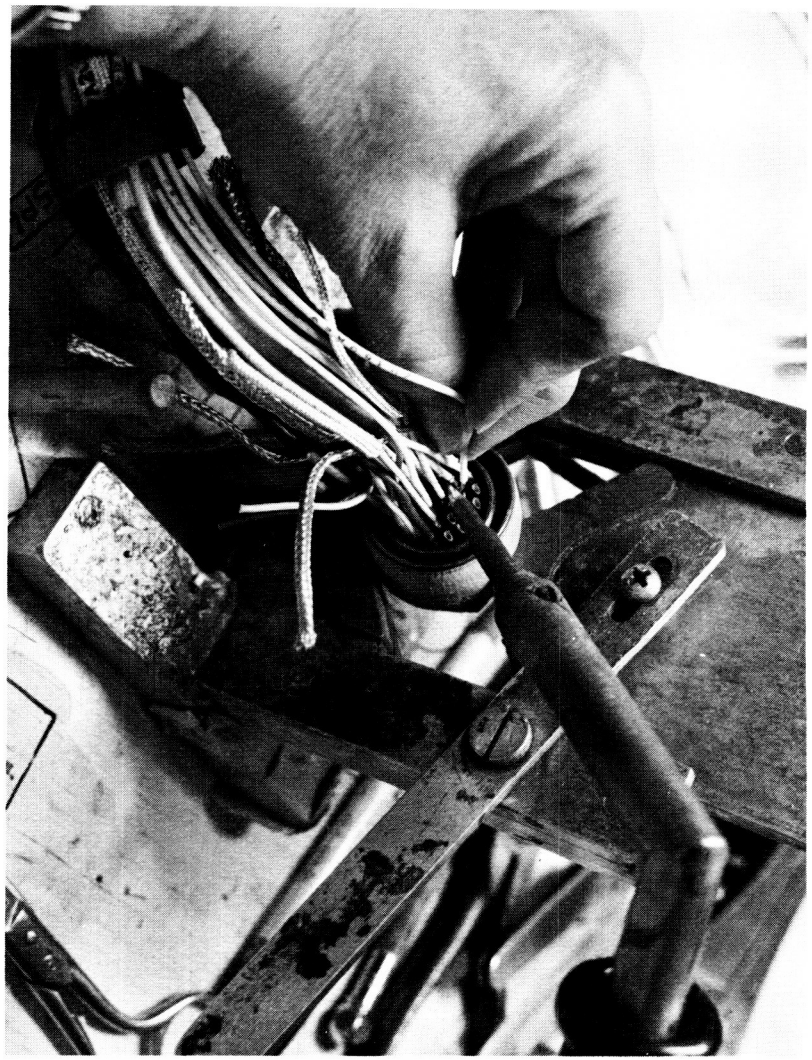


Figure 29. Soldering Wire to Pin in Conventional Connector

standard ground equipment (fork trucks or trailers), the aisles must accommodate this width (aisles must be a minimum of 21 feet). This is poor utilization of floor space and will require expensive handling cradles. A more feasible solution is to transport the tanks by overhead cranes and simple woven slings. The same principle applies to the

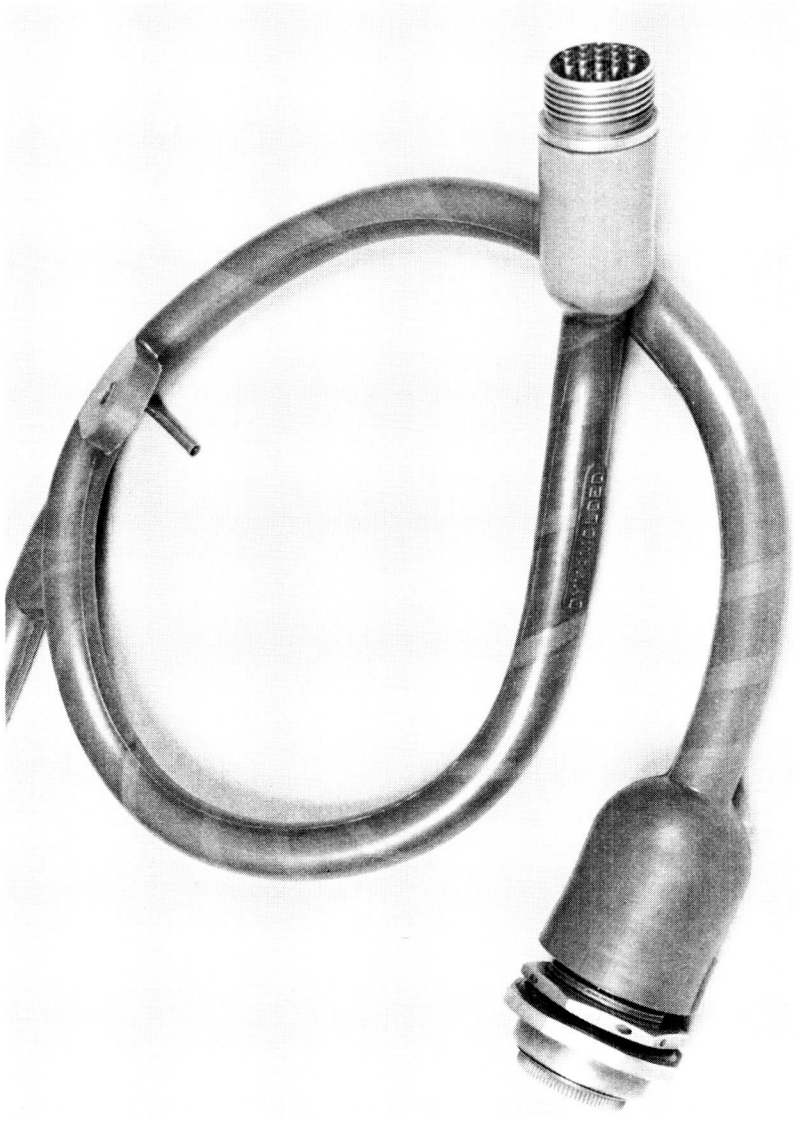


Figure 30. Molded Harness with Integrally Molded Connectors

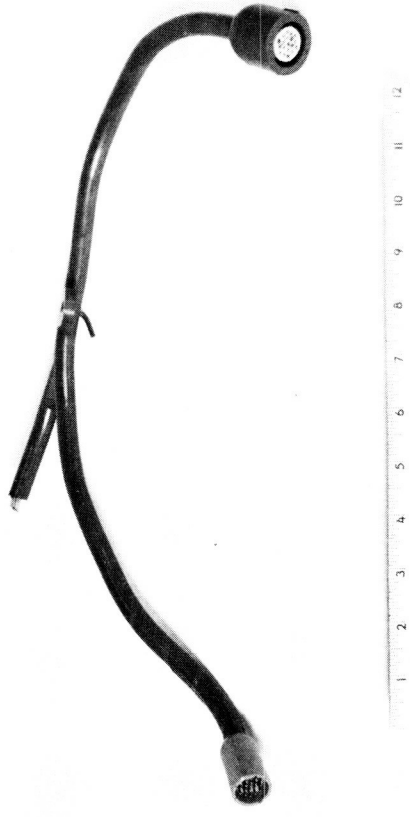


Figure 31. Molded Connectors Mated with Conventional Connectors

mission-module fore and aft bulkhead, the adapter skirt, and the assembled mission module. The crane load increases as the unit becomes more complete until the load it must carry approaches nine tons. Therefore the overhead crane used to transport the final unit out of the building must have a ten-ton capacity.

Figure 32. Precut and Tipped Wires Being Assembled in Mold

The mission module is built up of an aft bulkhead, skin and stringer assembly, forward bulkhead, engine and support installations, and internal installation. All operations except internal installations must be performed with the units lying on their side. If installations and assemblies are made in the normal or vertical position, the component handling and installation times become excessive. With units ninety degrees to normal, special holding and locating tools are required for the toroidal tanks, engines, and adapter skirt. However, the cost of these tools is far less than the cost of handling tools and special locators for installation in the horizontal position. The only feasible way to make the interior installations (consoles, chairs, etc.) is in the normal position.

Once the mission module has been raised to the normal position, it will remain in this attitude. A slight problem may be presented when the command module and mission module are mated. The mission module is approximately 25 feet tall; an additional 4 feet must be added for the holding fixture. Since the command module is approximately 13 feet long, the crane clearance must be approximately 39 feet from the building floor. A ceiling height of 50 feet is, therefore, required, As an alternate plan, the mating fixture can be constructed upon a base, which might be lowered to clear the command module as the crane moves in overhead.

The command module does not present any unusual handling situations from the standpoint of weight or size of components except in the structurally assembled condition. The structural unit will be assembled and the ablative material will be applied to the entire unit and cured. Curing will take place in a large over (10.5 feet long by 14 feet high by 14 feet wide.) The holding and handling unit for the structure assembly will be used during ablative coat application, transportation to and from the oven, and during the curing cycle (at approximately 375°F). The handling unit will hold the assembly in the normal position during these operttions by suspension from the aft attach ring.

4.4.2 GROUND HANDLING EQUIPMENT. Movement of the entire assembly to the test and checkout area will be by means of a special trailer designed to support the unit in an attitude of 90 degrees to normal. Removal from the trailer and erection to the test and checkout fixtures will be accomplished by cranes with spreader load bars. All handling of the complete unit prior to shipment will be on this handling trailer.

Critical review of the manufacturing schemes for ground handling equipment indicate no unusual fabrication and assembly problems. All proposed equipment is designed with standard industrial GSE

philosophy, and undoubtedly this equipment, for the most part, would either be directly purchased or sub-contracted. The majority of the handling equipments suggested are built-up of standard tubular or I-beam welded frames and trusses, which can be manufactured quickly and cheaply.

4.5 APOLLO MANUFACTURING AREA AND FLOOR SPACE REQUIREMENTS. The following considerations are based upon a maximum manufacturing capability of seven complete vehicles per year, for a total requirement of 30 vehicles. Additional units or tasks will require additional manufacturing area or additional shift work.

The manufacturing area is to be fully developed with electrical power adequate for lights, environmental control, small electrical tools for assembly, and large machines, such as welders. A 1500 KVA sub-station will suffice for supplying 115V AC and 220-440V DC and AC for these items, in addition to all weld equipment for part fabrication and assembly tooling. It will also supply the electronic test tools and checkout operations. The area must be adequately supplied with air lines that will maintain 90 pounds pressure under peak use. The air will serve in the operation of machine and fixture accessory tools, hand tools, and processing requirements.

Crane facilities are to be provided in the assembly areas to capacities as indicated in paragraph 4.3.

Floor area must include space for parts and assembly stocking and/or storage. A central stock room will not be used; all items will be stocked at the point of use. Racks, shelves, etc., will be adjacent to the benches and tools for this purpose.

Space shown will not include the following areas:

a. Machining tools for machined parts.

b. Sheet metal cutting and bending operations.

c. Hydrochemical forming facilities.

d. Electronics assembly area (except for auxiliary area).

e. Tooling functions (except for an auxiliary area).

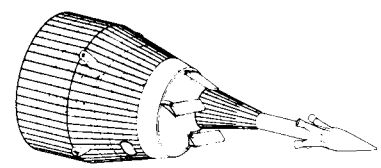
f. Receiving warehouse.

However, these must be considered in the total plan.

Clearance above the floor level to the crane hook is to be a minimum of 39 feet. The minimum floor weight-carrying requirement is 150 pounds per square foot. It is anticipated that this requirement will suffice for any fixture, assembly, or checkout dock to be designed. Any item in excess of this weight shall be suitably supported with additional reinforcement at its supporting points.

Figure 33 indicates by block layout the size and relationship of the various work areas.

4.6 MANUFACTURING ACTIVATION SCHEDULE. To sucessfully establish a facility for the manufacture of any given product, a thorough analysis of the task and the scheduling of the major events that must be performed is required. Each task must be properly timed and sequenced to successfully accomplish subsequent tasks and support the prime objective of delivering the finished product on schedule. An estimate of the manpower required, by fiscal year, throughout the Apollo program to fullfill the manufacturing task stated herein is presented in Table 2, which includes an assumed sub-contractor level and both direct and indirect programs support. Figures 34 and 35 reflect compressed yet workable schedules for the manufacture of the necessary tooling, and of the first production articles. Production and tool manufacturing tasks have been sequenced to allow an overlap of each task, so as to provide the maximum time for accomplishing each task. Task schedules are based on the progressive release of engineering design information, as shown by the start of tool manufacture prior to the release of 100 percent of the engineering design.



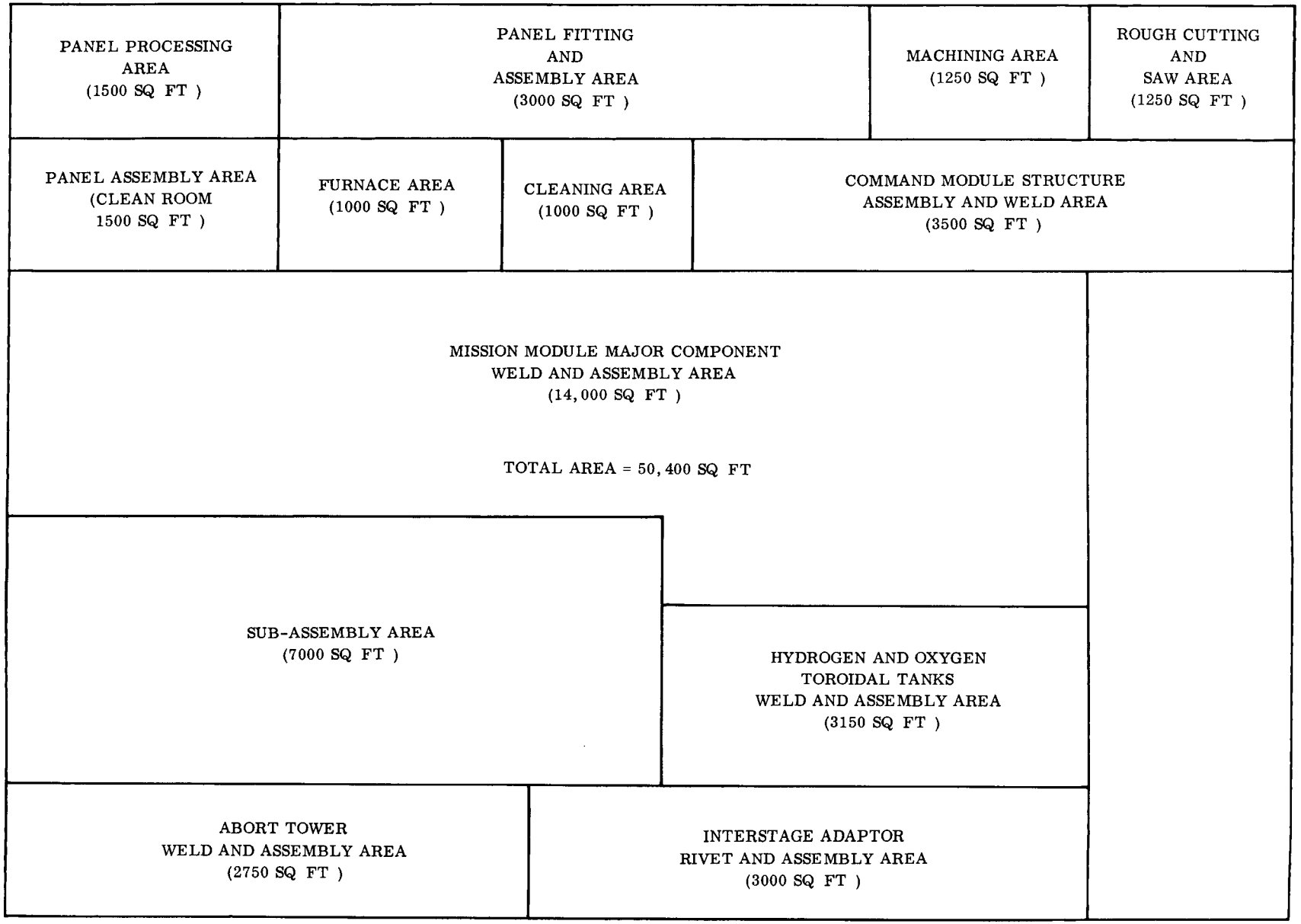


Figure 33. Manufacturing, Assembly, Checkout and Acceptance Areas for Major Components

TABLE 2. APOLLO CONTRACTOR MANPOWER (BY FISCAL YEAR)

Fiscal Year	1962	1963	1964	1965	1966	1967	1968	1969
ITEM								
Vehicle Contractor								
Design and Development	555	1860	1860	1120	760	555	405	25
Support Flight Program (AMR)	0	0	50	60	60	60	60	10
Manufacturing	210	670	1050	870	810	610	505	10
Direct Support Functions	55	55	70	65	60	55	55	10
Subtotal, Vehicle Contractor	820	2585	3030	2115	1690	1275	1275	55
Command Module Contractor	565	1050	950	770	640	455	310	35
Guidance Contractor	340	1000	1080	690	540	465	400	0
Tracking and Communications	125	310	310	410	375	350	320	170
Other Sub-contractors	370	850	1250	830	670	525	210	0
TOTAL Direct Manpower	2220	5795	6620	4815	3915	3070	2265	260
Allowance for Indirect (65%)	1440	3760	4300	3130	2540	2000	1470	170
TOTAL APOLLO MANPOWER	3660	9555	10,920	7945	6455	5070	3735	430

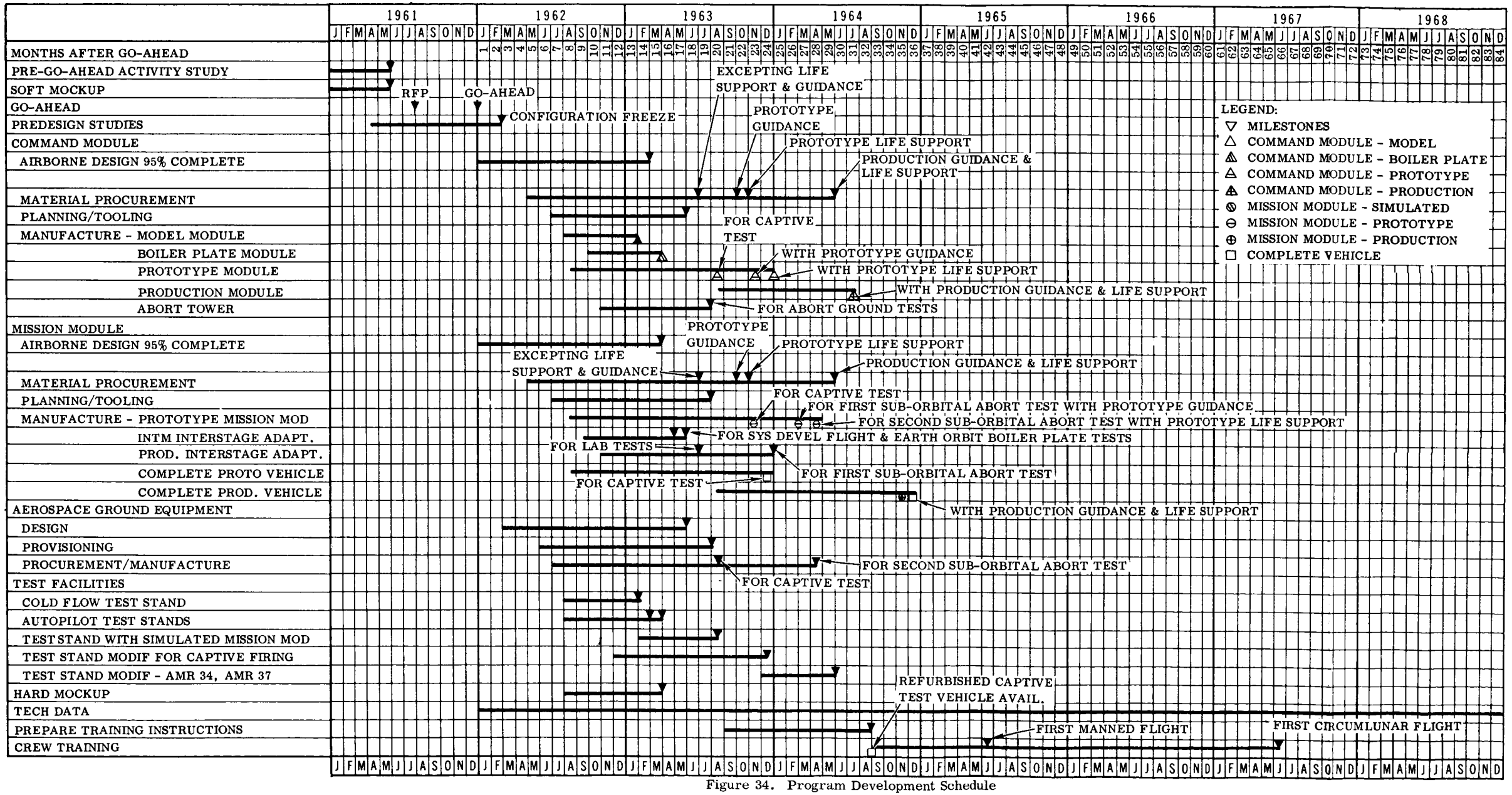


Figure 34. Program Development Schedule

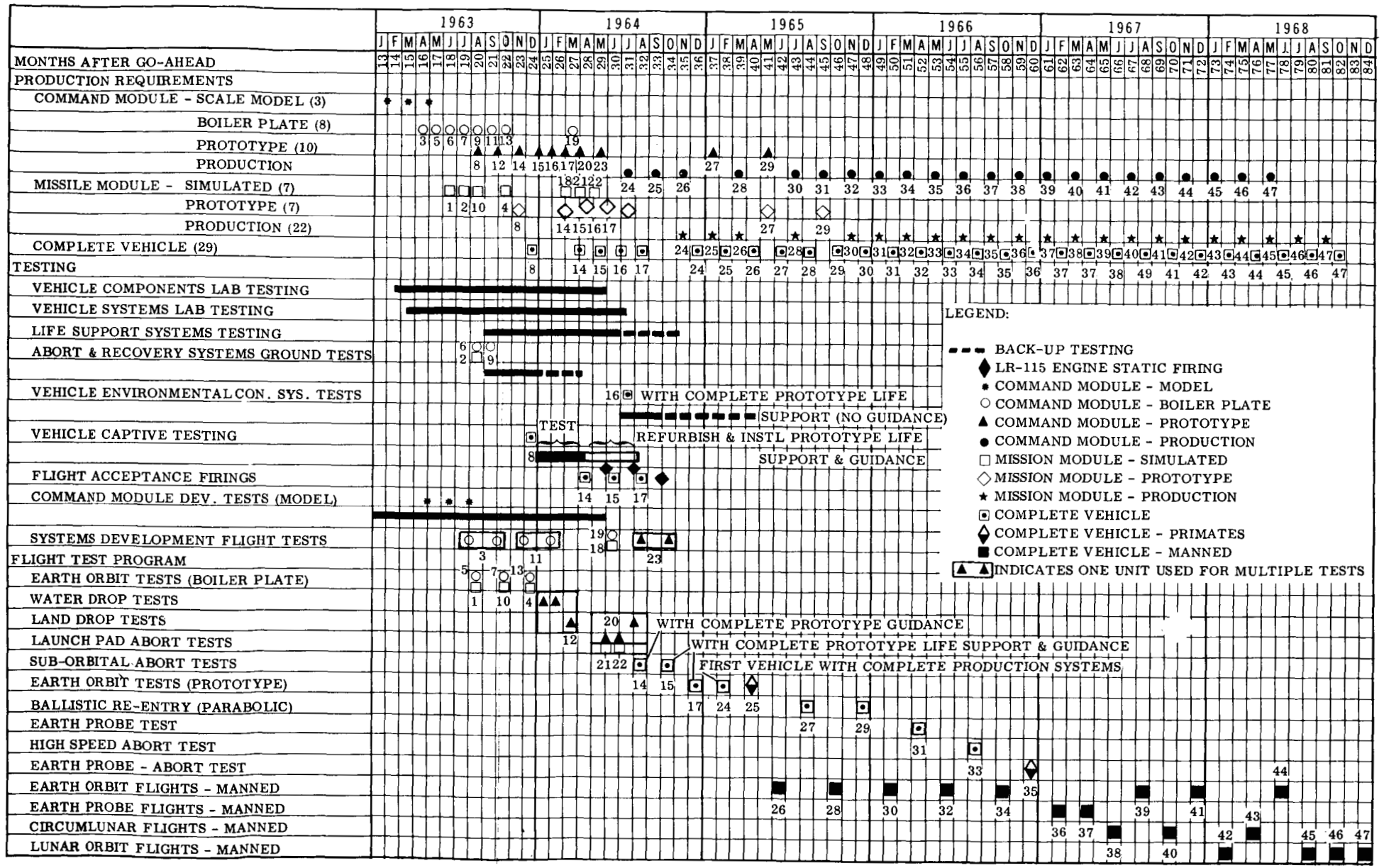


Figure 35. Master Schedule for Production Support of Test and Operational Programs