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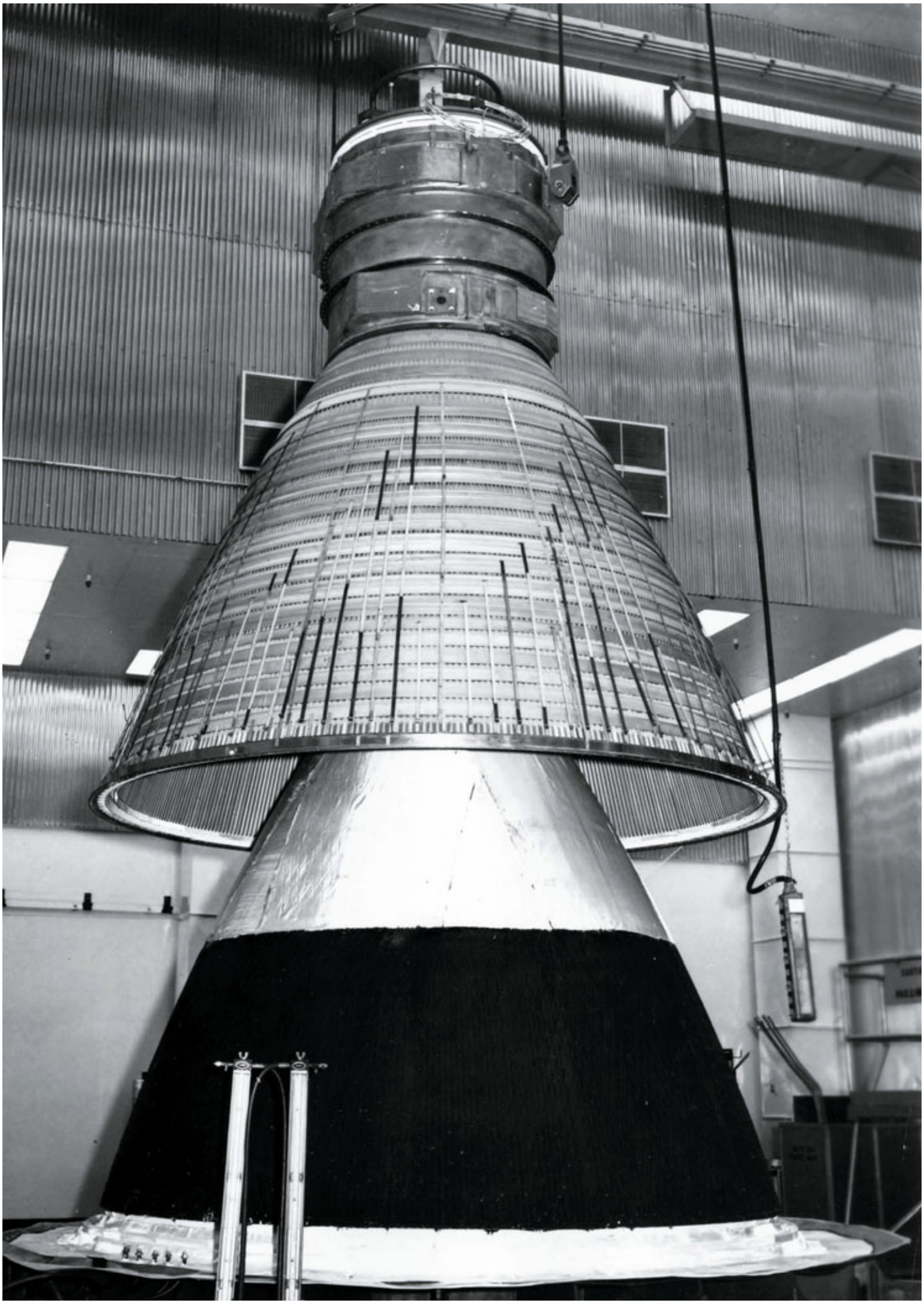
Manufacturing the F-1 engine at Rocketdyne

North American Aviation (NAA) was a prime contractor to NASA during the Apollo program. It was responsible for building the S-II stage of the Saturn V as well as the Apollo Command and Service Modules, and its Rocketdyne division manufactured the F-1 and J-2 rocket engines that, between them, powered all three stages of the launch vehicle. Rocketdyne also manufactured smaller rocket control and ullage (propellant settling) engines. As a result, NAA experienced phenomenal growth during the 1960s. In particular, employment at Rocketdyne's Canoga Park, California plant boomed. With the award of the initial F-1 production contract on July 2, 1962 for 55 engines, Rocketdyne had to expand its manufacturing and assembly facilities. The nature of the business required ongoing research and development of materials, manufacturing, inventory control, quality control and, of course, testing.

ROCKETDYNE IN THE 1960S

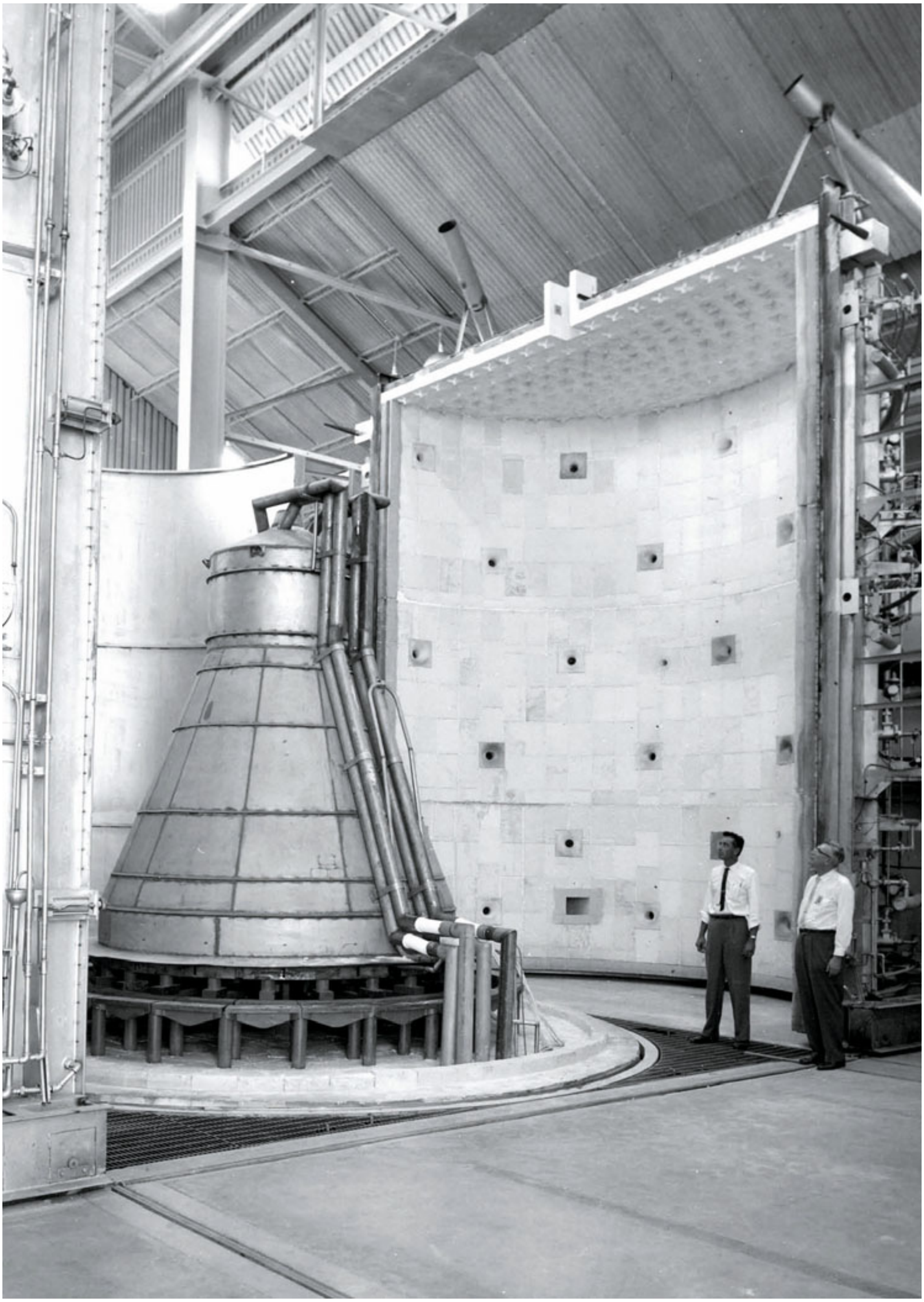
In fulfilling government contracts for the Navaho, Atlas, Jupiter, Redstone, Thor and Saturn I (H-1) rocket engines Rocketdyne had built up a capable and efficient manufacturing capability, and this was brought to bear on the F-1 engine program, which involved a rapid pace, frequent design changes and usually short production runs. Often, even as production hardware was being manufactured and delivered, design changes resulting from ongoing development were being implemented. The organization of Manufacturing was structured specifically for such conditions. The Factory Manager headed the Manufacturing Team, and the superintendents of the Fabrication and Assembly and the Manufacturing Support line sections



5-1 Prior to furnace brazing, the F-1 was placed over a pressure bag designed to support the thrust chamber during the brazing procedure. (Rocketdyne, Vince Wheelock Collection) reported to him. He was assisted in a staff capacity by Engine Program Representatives whose function was to ensure conformance to the plans and schedules of the company's various programs. Each Program Representative was dedicated to a specific engine program, and monitored it throughout its manufacturing phases, both experimental and production programs.

To expedite design and development programs, the manufacturing of production engines was separated from the experimental work in Fabrication and Assembly. The most experienced machinists in the experimental shop worked closely with the engineering groups, often making experimental hardware from simple sketches or rough mockups. The Sheetmetal and Processing Unit did metal fitting, welding and processing for experimental work. The Prototype Machine Shop took detailed dimensional drawings and created exact prototype hardware for fabrication by the production units, which used subsystem manufacturing operations. For example, one production unit would have primary responsibility for producing the complete turbopump—from the arrival of the raw aluminum castings to the final assembly and test of the component. This was facilitated by requiring all the equipment and machinery necessary to accomplish this to be physically located in that specific unit's manufacturing area. This saved time, improved production control, ensured that schedules were met and simplified the process of inventory management. The various components were brought together on a moving line in the Final Assembly Department. During final assembly, test cells that accommodated complete engines were utilized for high pressure checkout, with the turbopumps being calibrated and the flow through thrust chamber injectors checked.

Other departments at Rocketdyne were a vital link to the smooth flow of engine production. The Scheduling Department provided support to Manufacturing for pricing, the control of work hours and budgets. The Planning Department handled normal planning and production control operations. It also contained a specialized planning group which performed the Process Control function. Manufacturing Analysis prepared specialized manufacturing reports on new techniques and their application and serviceability, and in order to pinpoint and eliminate inefficiencies made time and motion, and tooling rate studies. A vital manufacturing department was Tooling Design, which fabricated both experimental and production tooling. It also supervised the procurement of outside vendors and services in support of basic tooling design. Since Rocketdyne could not perform 100 percent of the work to manufacture its rocket engines, it drew on the manufacturing Purchased Labor Unit to use the abilities of many outside suppliers and vendors in the greater Los Angeles area. The Tooling Department, which was separate from Tooling Design, assisted all of the company's departments. Its tooling engineers were experienced in solving manufacturing problems, and they worked together with Engineering to improve manufacturability. To ensure the performance and reliability of its rocket engines, Rocketdyne implemented procedures and operations which it referred to as Process Control. Although these were vital elements in the control of the entire manufacturing process, they were just part of the overall manufacturing strategy. Additional steps had to be considered when establishing product reliability and repeatability in manufacturing.



5-2 The F-1 thrust chamber was placed inside a cupola and then placed inside the furnace for the brazing procedure. (Rocketdyne, Vince Wheelock Collection)

Mechanized production control

The first step in the complete quality control of a rocket engine was procedural. At Rocketdyne in the Apollo era, this was known as Mechanized Production Control (MPC). It was a comprehensively planned system composed of subsystems which integrated all phases of the plant operations. At its core was Mechanized Inventory Control (MIC), where information was made available on demand. Data collecting networks transmitted simple inputs to the magnetic disk file that updated company intelligence of any new requirements such as: the status and location of parts and tools, progress in procurement action, materials availability, status on completion of assemblies and details, parts quality, direct labor and accounting changes across the company. Continuously updated information was also used to produce weekly and monthly tabulated reports for distribution to supervisors and managers. The company upgraded its central computer systems several times during the 1960s as part of the ongoing process of improving the MPC process.

Process control

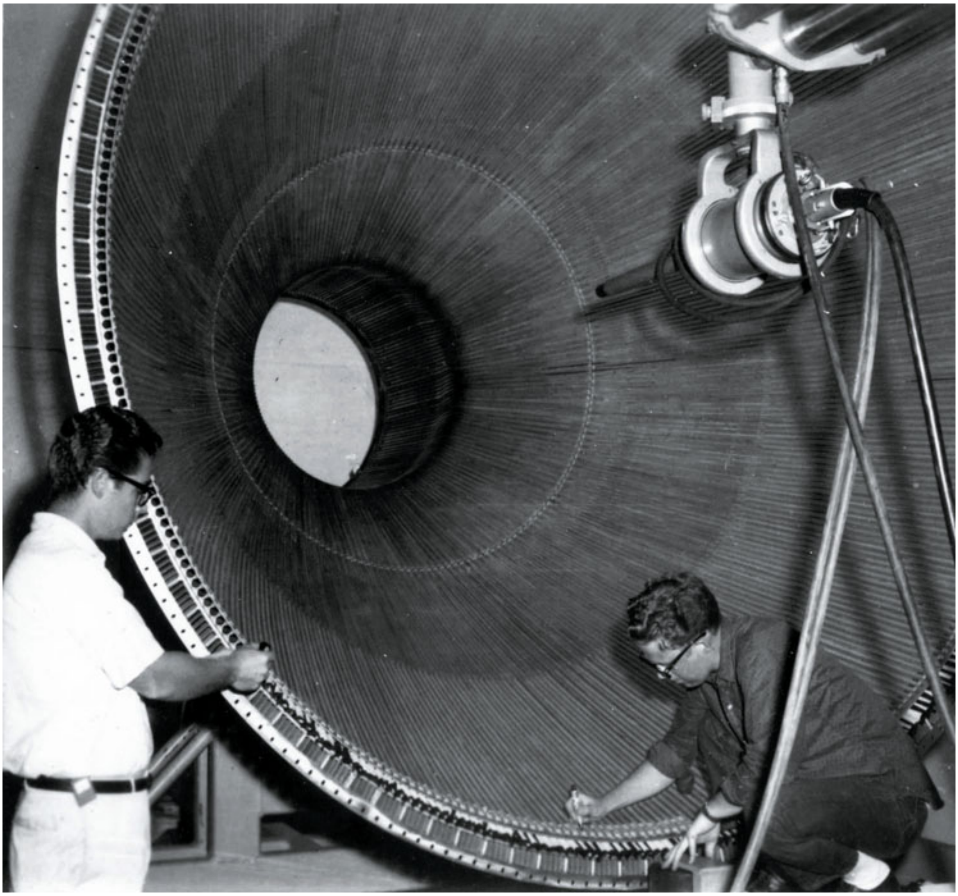
Rocketdyne's way of controlling operations by documentation, drawings, sketches and specifications was known as Process Control. This was conceived and initially used to guide and control certain critical manufacturing operations, involving only about 10 percent of the parts. But then the company converted all its tooling setup sheets to assembly operation books. These served the shop areas as required, and were vital aids to the engineering drawings. Manufacturing process specifications were created to define the correct manufacturing description of the many different and complex engineering process specifications involved. These were used either alone or as interpretive instructions in the assembly operation books.

The briefing program

In a design and development program as vital as the F-1 engine, revisions were to be expected, new materials would be introduced and new manufacturing processes incorporated. Every effort had to be made to keep all employees fully informed of such changes. In addition to training courses run by the Education Department at Rocketdyne, auxiliary training was provided which included the briefing program. This took the form of regularly scheduled meetings or courses using audio/visual materials on the entire range of manufacturing operations—including, to give just a few examples, the theory and operation of new sophisticated equipment, control methods, and department operation.

The manufacturing development operation

The manufacturing development operation at Rocketdyne during the 1960s was a vital part of manufacturing process control. Composed of a balanced admixture of technicians and experienced shop personnel, the department which carried out this



5-3 Inspecting a brazed F-1 thrust chamber. (Rocketdyne, Vince Wheelock Collection)

operation performed a variety of tasks, including: research and developmental and support functions to bridge the gap between theory and practical applications in relation to upgrading conventional equipment; establishing operating parameters for new equipment; and the design or discovery of new equipment and processes. In the early 1960s, at least 40 such programs were successfully completed with the goal of improving the company's rate of achievement during the rest of the decade and into the 1970s. At all times, Rocketdyne used state of the art manufacturing technology, including electrical discharge machining, electrochemical machining and electron beam welding. It also pursued solid-state oscillators that were capable of carrying high peak currents at repetition rates exceeding those common in then-current electrical discharge machines. At pulse rates as great as 100 megacycles, rotating graphite electrodes operated in much the same fashion as end mills, giving better surface finish than was attainable by previous equipment. A high pulse rate used in combination with a high current density could vastly improve machining rates whilst upholding surface finish. The effort on the electrochemical machining process centered on improving both cutting rates and accuracy by means of much greater current densities and improved electrolytes. Additional improvements in this area centered on the development of sensors to pre-arcing, programmed short duration peak-reverse charge to deplete the electrode, and the adaptation of the electrochemical process to conventional equipment. In the area of electron beam welding, equipment was upgraded to improve weld repeatability, provide better tracking capability and reduce machine downtime.

The machinability index

In 1956, just five percent of a rocket engine's total weight was comprised of exotic materials which required special machining or fabrication. However, by the end of the decade the proportion of such materials had increased to about 90 percent. The machinability index introduced by Rocketdyne to reflect the increases in materials strength and hardness, showed that conventional apparatus could barely cope with the super alloys and refractory materials that were being used in hardware for the F-1, J-2 and H-1 engines. To cope with this, the company installed more robust equipment having greater power and more accuracy, and replaced machining tools more frequently. In the case of the F-1 engine, the use of Inconel-X in the thrust chamber required the creation of new forming techniques, much harder tooling and special furnace techniques. The propellant injectors also required more refractory alloys—migrating from 4130 through 347 stainless steel and ultimately to Inconel, which required unconventional machining equipment and procedures. In fact, due to its size and power, the F-1 pushed the technological envelope in practically all areas of its manufacture.

NON-DESTRUCTIVE TESTING

A cornerstone of quality assurance, reliability and performance of Rocketdyne's liquid propellant rocket engines was the use of non-destructive testing (NDT) of the materials in addition to the components that went into its engines. This was an essential phase of the manufacturing process, because a defective material or part could result in component or subassembly failure that could, in turn, result in the destruction of the engine. Each part had to pass rigorous testing and inspection. At Rocketdyne, NDT involved the Engineering Development Laboratory, the Quality Assurance Laboratory, and Production Inspection. The Engineering Development Laboratory (EDL) was responsible for design review specification and revision, failure analysis material evaluation, research and development into test methods, and the introduction of new test methods into production inspection. The Quality Assurance Laboratory (QAL) was responsible for NDT drawings, the training of inspectors, supporting production inspections, in-house and supplier surveillance, the support of field tests and the introduction of new test methods into production

5-4 A close view of the tube bundle and bands around an F-1 thrust chamber. (Rocketdyne, MSFC History Office)

inspection. The main function of the Production Inspection Department (PID) was to evaluate engine components, materials and processes in relation to engineering drawing requirements and specifications in support of manufacturing. Rocketdyne inspectors using advanced instruments and test equipment ensured both the rapid flow of hardware and reliable test evaluation. The PID also was responsible for the planning and sequencing of the test methods during fabrication.

Rocketdyne used a variety of NDT methods to evaluate materials and processes, encompassing both the entire electromagnetic spectrum and various other means to provide a qualitative or a quantitative evaluation of the material or process without altering the item being tested. Its engine reliability program began with design and manufacturing to ensure accurate, high strength hardware that would not fail while it was operating within the specified conditions. Extensive inspection to make sure that a part met its specified tolerances, finishes and manufacturing processes were integral steps. After individual components had been tested, an assembly could be subjected to extensive testing during development in an effort to discover inherent weaknesses. Successful development testing paved the way to a repeatable process for the production of an engine to acceptance testing. All of the NDT procedures developed for earlier engines were applied to the F-1, although in some cases they had to be modified to take account of the new engine's unprecedented size.

Radiographic inspection

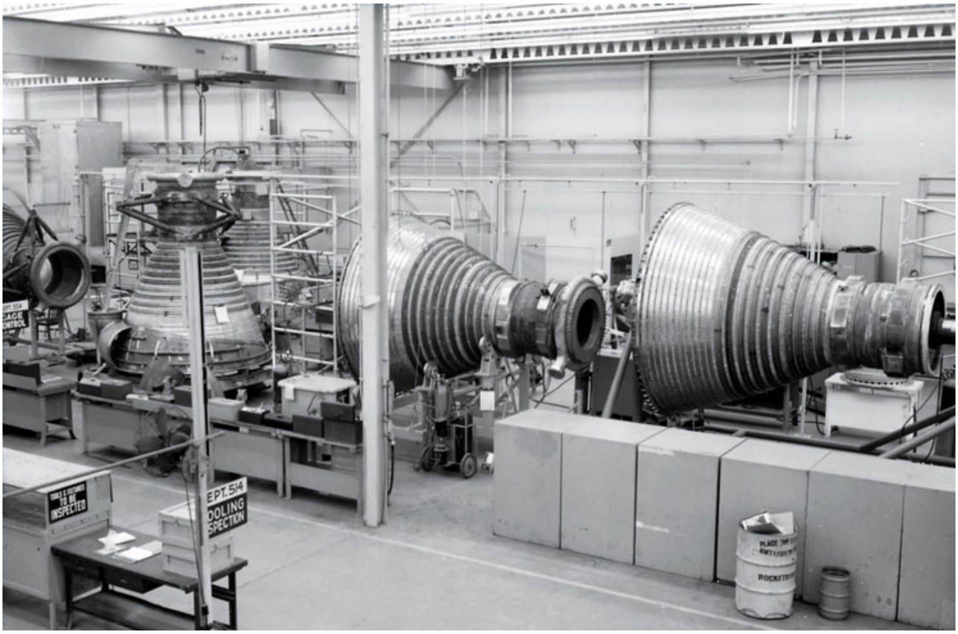
For the F-1 engine, radiography was used to detect internal defects in all of the Class-I weldments and high strength castings; to determine braze alloy distribution in the brazed thrust chamber and components; and to internally inspect electrical assemblies for missing or broken components. Inspection labs were located in each of the manufacturing buildings, as well as at the Santa Susana Field Laboratory. Parts and components were inspected in a specialized enclosure by placing film in a light-tight holder, positioning this closely beneath the item to be inspected, then beaming radiation from a radioactive isotope of Iridium-192 toward the target. The exposed film was processed and dried, and the negative image evaluated to pass or fail the inspected part or component.

Liquid penetrant inspection

Rocketdyne used a number of liquid penetrant methods in performing inspections. The penetrant could either be a dye, or a fluorescent type consisting of oil-based or water-based constituents, and it could be applied by dipping, spraying or brushing. The water-based penetrants were used on parts that would come into contact with liquid oxygen or other active oxidizers. Before a part could be inspected, it had to be cleaned of scale, dirt, oil, paint or any impurity. Leak testing was accomplished by applying penetrant to the inner surface and a developer to the outer surface. All Class-I and Class-II weldments, tubing, castings and forgings required inspection in this manner, as did machined parts having a non-magnetic finish. Rocketdyne also devised a special high resolution fluorescent penetrant inspection procedure to reveal very fine cracks.

Magnetic particle testing

This was used to detect discontinuities in ferromagnetic materials. The procedure involved establishing a suitable magnetic field in the test item, applying magnetic particles to its surface, and inspecting for accumulations of particles. This method could also reveal discontinuities beneath the surface. The magnetic field could be



5-5 This photograph dated December 7, 1961 shows thrust chambers which have been through the furnace braze operation. (Rocketdyne, Harold C. Hall Collection)

oriented longitudinally or circumferentially. After inspection, a part had to be demagnetized prior to further processing.

Ultrasonic testing

Ultrasonic inspection was performed by either transmission or pulse-echo. Testing was performed at frequencies between 1 and 25 megacycles per second. Ultrasonic testing and inspection was used to detect flaws in thin or thick plates, bars, rods, forgings, tubing and weldments. Thicknesses ranging from less than a millimeter to several meters could be ultrasonically tested, but most tests were on thicknesses up to 15 centimeters in accordance with ASTM E-113. This means of inspection had the advantages of:

1. High sensitivity, permitting detection of minuscule defects.
2. Great penetrating power.
3. Accuracy in the measurement of flaw position and estimation of flaw size.
4. Fast response, permitting rapid and automated inspection.
5. Need for access to only one surface of the specimen.

The application of ultrasonic testing for inspection of weldments and brazed assemblies grew considerably at Rocketdyne during the F-1 engine program. Some welded assemblies were not inspected by radiography owing to their thickness or the geometry of the part, and were inspected ultrasonically instead. This method was used extensively to detect defects in brazed injectors, exhaust gas generators, stators and thrust chamber tube-to-jacket and tube-to-band braze joints. It was used with all forgings, Rene 41, Inconel-X and Hastelloy-C plate stock. All Inconel-X thin-wall seamless thrust chamber tubing was inspected for longitudinal defects. Rocketdyne built an automated system for inspecting straight and straight-tapered tubing.

Eddy current testing

In eddy current testing, an alternating magnetic field induced eddy currents in the test object, in turn making an electromagnetic field in the immediate vicinity of the test object. The range of physical properties that could be measured included alloy variation, heat treatment, hardness, the magnitude of defects, dimensional changes, conductivity and permeability. It was effective in sorting out different alloys, or a single material of different tempers. It was helpful in testing thin, nonferrous metal tubing or sheets.

Infrared testing

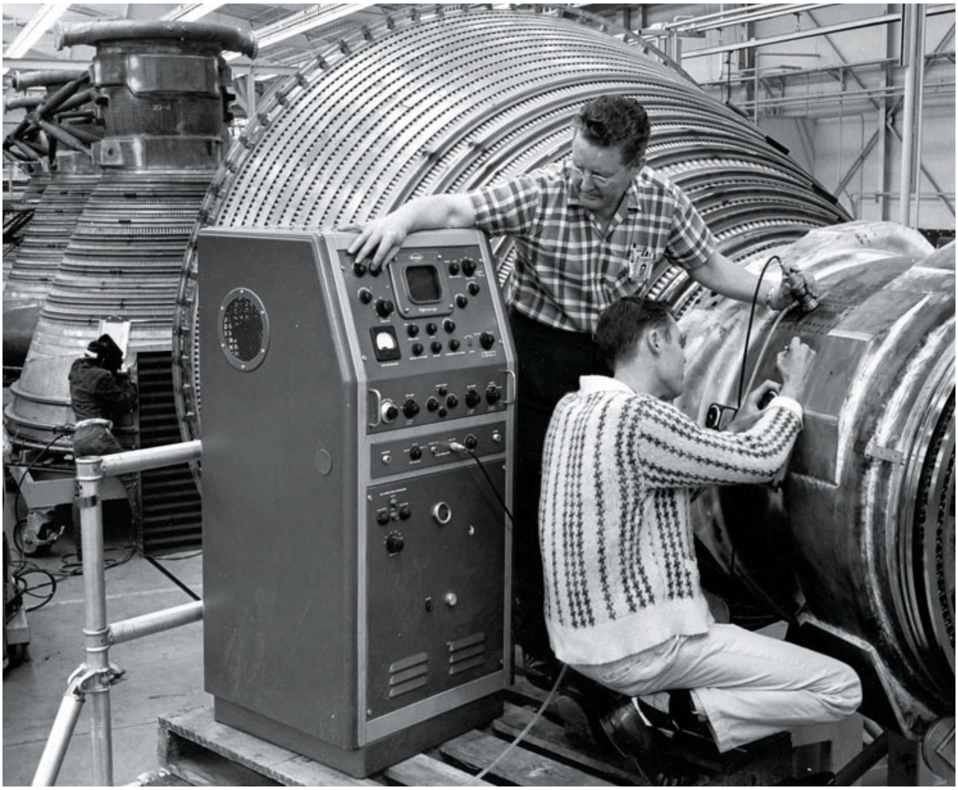
Infrared testing was done on selected components of the F-1 engine. Every object radiates heat at some range of wavelengths. When a component was altered by the manufacturing process, or there was a defect present, the heat that it emitted would vary across its surface. Heating a part and then scanning it for variations during the cooling process could reveal such flaws. Infrared testing could also be done while the part or component was in the process of being heated. Because Rocketdyne did not have the equipment to do these tests, the task was contracted to a company in Boulder, Colorado.

Kinefluorography and cinefluorography

These methods of inspection beamed X-rays through the test object, and observed it with a fluoroscopic image intensifier. Electronic components and thermocouples were inspected using kinefluorography. Cinefluorography using motion picture cameras were used at Rocketdyne to evaluate failure modes in small ablative thrust chambers during hot firing tests.

Thickness testing devices

Rocketdyne used several different instruments to measure the thickness of plating or materials: including the Permascope, which measured nonmagnetic coatings on a ferric substrate; the Dermitron, which operated by setting up an eddy current and measured either anodize on aluminum or nonconductive coatings on nonmagnetic substrates; the Betascope, which measured the thickness of a coating of either gold on copper or chromium on aluminum; and the Process Nucleonics Thickness Gage that



5-6 The F-1 thrust chamber underwent many non-destructive testing inspections during engine assembly. Here, technicians are ultrasonically inspecting tube-to-shell brazing bonds. (Rocketdyne, Vince Wheelock Collection)

utilized the gamma ray backscatter principle to measure the thickness of small diameter, tapered, thin-wall thrust chamber tubing.

Hardness testing

Rocketdyne used several different machines to check hardness of heat-treated parts to ensure that they conformed to the specifications on the drawing. In addition to the industry standard Rockewell hardness tester, Rocketdyne employed Brinell and Riehle testers. It had a sizable metallurgical laboratory to test the surface finishes of specific F-1 engine components.

Visual inspection

Visual inspection has always been a key aspect of quality control. At Rocketdyne, visual inspection of machined parts and manufactured components was aided by optical magnifiers, boreoscopes and fiber-optic scopes. Inspected components had first to pass a visual inspection prior to being subjected to further testing.

Selection of the test method

The method of non-destructive testing to be used for a given part or component was stated on the drawing or other documentation, based on Rocketydne's years of manufacturing experience. All forgings required ultrasonic and penetrant testing or magnetic particle inspection. Class-I weldments needed radiographic or ultrasonic and penetrant or magnetic particle inspection. If a new part could not be tested by established NDT means, then the design engineer, materials and process engineers and Manufacturing and Quality Control departments had to coordinate to develop a new means of testing. Research and Development hardware naturally underwent the same NDT tests as were to be applied to the production hardware. The completed development components or assemblies were statically and dynamically tested to ensure conformance to design specifications, with failed components undergoing a failure analysis which included metallurgical evaluation. Inspection of production hardware required the consistent application of NDT methods every time for every part and component.

F-1 engine reliability and NDT

The non-destructive testing of essentially every manufactured component that was integrated with other components into subassemblies for the F-1 was crucial to the engine's reliability and performance—as indeed it was for every rocket engine that the company made. The failure of a single part could trigger a chain of events that ended in the automatic shutdown of the engine or its destruction, in either case jeopardizing the mission. Rocketdyne strove to avoid the catastrophic failure of a crucial component by using the most stringent NDT. This, coupled with rigorous development testing, and then by production engine acceptance tests, resulted in the flight F-1 engines having a 100 percent success rate.

THE F-1 THRUST CHAMBER

Rocketdyne's early studies of the F-1 engine established that it would present no insurmountable problems in either its manufacture or its ability to generate a thrust in excess of one million pounds. But its size did present manufacturing challenges unlike any the company had faced with its previous engines. The F-1 was the first engine to use extremely hard Inconel-X in the thrust chamber components, posing difficulties in the fabrication and brazing processes of the tube bundles. Combined with this, was the unprecedented size of the thrust chamber. Early tubular-wall regeneratively cooled rocket engines had used high heat transfer pure nickel tube bundles which were brazed by hand using low melting silver-based brazing alloys.

These conventional materials and processes could not be applied to the F-1 thrust chamber.

The furnace brazing decision

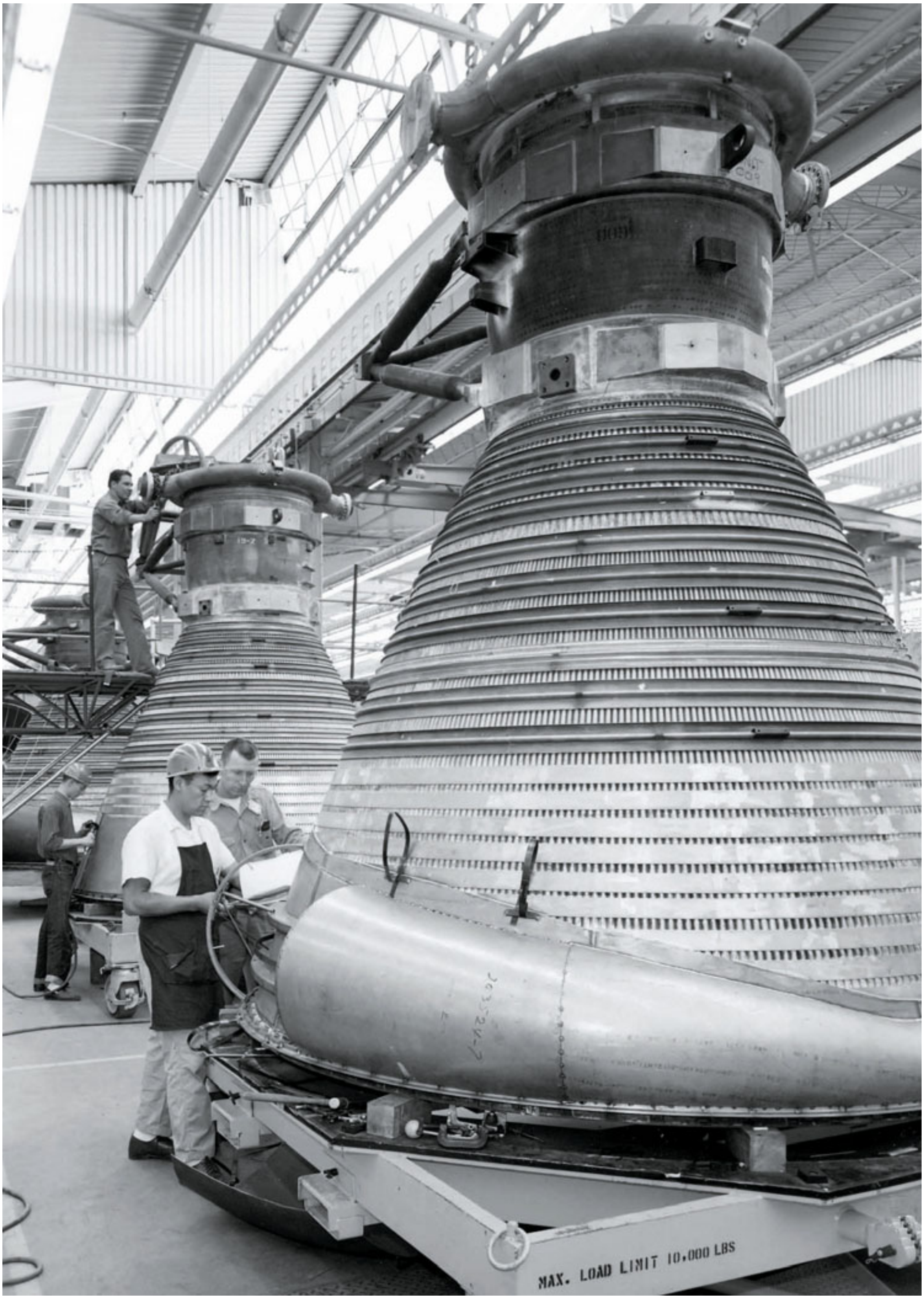
Initial development work on joining processes established that conventional torch brazing techniques used on pure nickel would not work on Inconel X-750 owing to the characteristic low ductility of high-nickel alloys in the temperature range of most silver-base brazing alloys—i.e. 1,200 to 1,500 degrees F. Brazing specimens with Inconel X tubes and conventional brazing alloys revealed liquid metal stress cracking using low melting silver-based brazing alloy. After many specimen tests and analyses, it was realized that the only viable method of joining the tube bundle would be furnace brazing with high temperature brazing alloys. But the aluminum and titanium in Inconel X-750 tended to form refractory oxides which made the surface resistant to effective wetting by most brazing alloys. The metallurgists at Rocketdyne eliminated this issue by a means of electrolytically depositing a layer of nickel that was 0.0010 to 0.0014 inch in thickness on the surface of the Inconel X tubes and other parts.

The furnace built by Rocketdyne for brazing the F-1 thrust chamber was the largest of its kind. The decision to use furnace brazing gave additional advantages over traditional torch brazing by a human operator:

1. Minimizing thermal stresses resulting from differences in heating and expansion rates.
2. Uniform temperature applied over the entire surface of the thrust chamber during the brazing process providing consistency for each thrust chamber.
3. The opportunity to combine the brazing process with the age hardening of Inconel X-750.

Selection of a thrust chamber brazing alloy system

Rocketdyne's decision to use Inconel X-750 for the thrust chamber, and furnace brazing as the primary method of joining the thrust chamber components, led to careful evaluation of potential alloy systems. Among those considered were silver-based, nickel-based and gold-based brazing alloy systems. Analysis of the thrust chamber brazed joint reliability requirements led to the decision to use a three-step brazing process. In the first brazing operation, the pair of smaller thrust chamber tubes would be joined to the larger primary tube by using induction heating. This subassembly would then be stacked and furnace brazed as part of the overall thrust chamber assembly. In the second brazing operation, all the thrust chamber parts, including the tube subassemblies, jacket, bands and engine rings, would be joined. In the third brazing operation, the thrust chamber would be partially re-alloyed in certain vital joint areas and then subjected to another furnace brazing operation. At each stage, the temperatures had to be carefully controlled in order not to melt the previously brazed components.



5-7 Fabrication and installation of the turbine exhaust manifold at the base of the F-1 thrust chamber. (Rocketdyne, Vince Wheelock Collection)

Detail part preparation

All of the thrust chamber components, including the jacket, injector ring and exit ring, were precision machined. The forged and welded construction of the Inconel X-750 jacket was subjected to rigorous process requirements and quality control during fabrication. The thrust chamber tubes of Inconel X-750 were made to tight tolerances, and then induction brazed using a semi-automatic process. The bands which surrounded the thrust chamber nozzle extension were also precision formed. This precision in manufacturing was essential to ensuring that the entire chamber assembly was capable of satisfying the minimum clearances necessary to establish capillary joints and good brazing alloy flow. To achieve this, it was necessary that all parts received proper surface preparation. In order to ensure successful brazing of the Inconel X-750, the thrust chamber jacket and tube bundle were nickel plated by the electrolytic process. All thrust chamber components, included those which had been plated, were subjected to a succession of cleaning operations involving degreasing, alkaline cleaning, and a final rinse using deionized water to optimize brazing conditions. The thrust chamber components were then ready for assembly. In order not to jeopardize the strict requirements for successful brazing, the thrust chamber was assembled and alloyed for furnace brazing in a 'white room' that was used only for this purpose. The assembly of the thrust chamber tube subassemblies into the jacket and end rings, referred to as the 'stacking operation,' was done in a stacking fixture—a precision tool that established the initial alignment between the tube bundle, jacket and end rings prior to the brazing alloy application. The high precision in manufacturing and assembly prior to brazing is apparent from the fact that there was about 3,000 feet of tube-to-tube joint length to be sealed against the gases of the combustion chamber, and there were about 7,000 tube-to-band joints to be bonded. The gases were at a temperature of about 5,000 degrees F, and containing them in the combustion chamber was a significant accomplishment for the brazing process. For the first cycle brazing operation, the brazing alloy was in powdered form and was applied by a proprietary Rocketdyne spraying process. All phases of the thrust chamber furnace brazing process were controlled by the company's F-1 Furnace Brazing Process Specification. In the spraying process, alloy was applied to the tube-to-tube joints on the interior and exterior of the thrust chamber. The chamber was then ready for the furnace braze tooling setup.

The brazing retort and high temperature pressure bag tooling

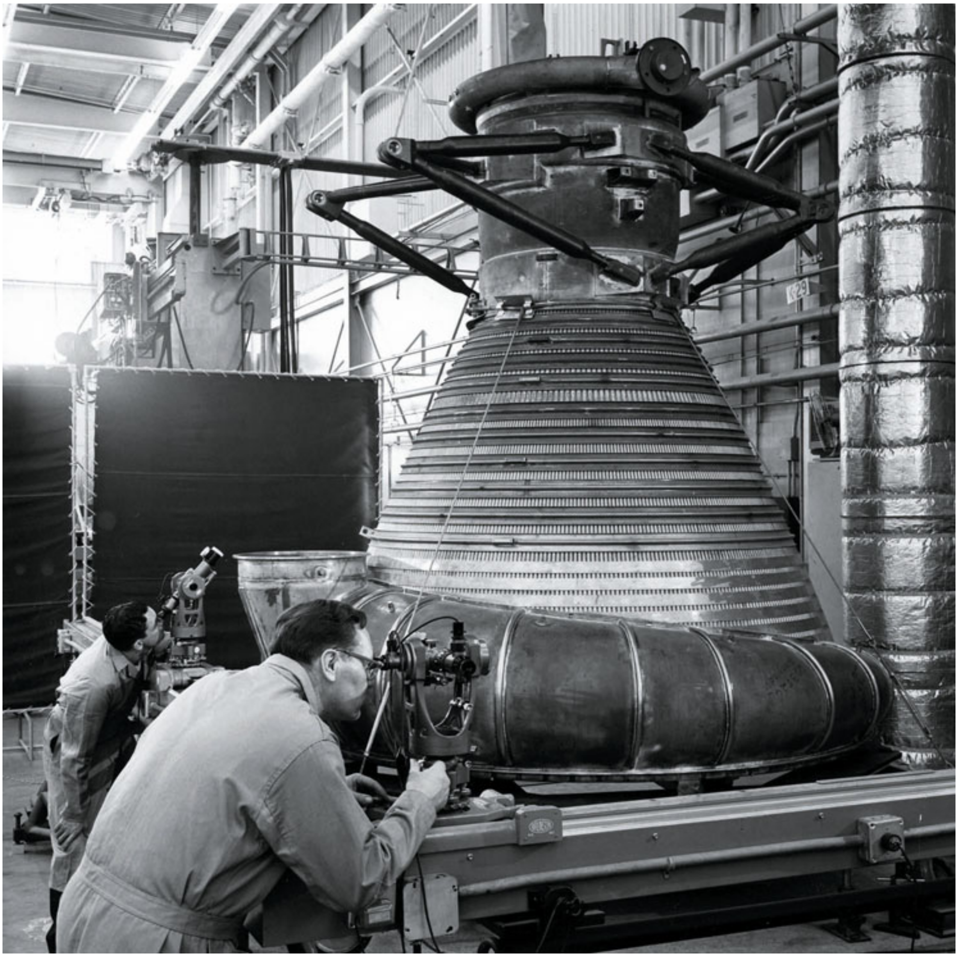
The unprecedented size of the F-1 thrust chamber had a primary requirement in the ability of the tooling to support the interior of the thrust chamber tube stack at temperatures in excess of 2,000 degrees F for successful brazing. This was done using a device called a 'pressure bag', which consisted of a flexible heat-resistant alloy skin, shaped to the interior contour of the thrust chamber, which, when it was inserted and pressurized, supported the tube stack. This technique was a significant departure from earlier concepts, which had employed a high mass rigid mandrel of heat resistant alloy. The good internal support characteristics and low mass of the pressure bag tooling were the primary factors in establishing a relatively rapid and economically feasible furnace brazing cycle. The brazing retort fulfilled a second requirement in the furnace brazing operation: the elimination of oxygen from the atmosphere surrounding the brazed assembly. This required the containment of an extremely pure protective atmosphere around the thrust chamber. The retort was constructed of a high nickel-chromium oxidation resistant stainless steel developed for this purpose. Its form was designed to maintain a protective atmosphere around and within the thrust chamber throughout the brazing cycle. Prior to initiation of the heating cycle, a gas line fed argon gas into the bottom of the retort to displace any residual air.

Furnace brazing: the first cycle

The furnace brazing operation represented the final step in which all the hundreds of parts and subassemblies became a complete thrust chamber. In many respects it was similar to the launch of the Saturn V itself, as the failure of any of the many numerous control exercised during the furnace brazing operation could produce an unacceptable result. Consequently, the entire process was a highly developed and closely controlled operation. The furnace designed for the F-1 thrust chamber was unique in its design and performance. Its low mass construction provided a design with minimum heat capacity, and rapid response to the heating requirements of the thrust chamber during the brazing cycle. Its ability to provide uniform heating and rapid response was aided by that fact that it had three zones of temperature control. These performance characteristics made it possible to initiate the furnace brazing cycle with the furnace at room temperature, thereby eliminating the thermal shock that the thrust chamber would otherwise have been subjected to by being put into a furnace at its operating temperature. This cold-start capability helped to limit the gradients of the thrust chamber to 150 degrees F as the temperature was raised for brazing. Since thrust chamber component wall thicknesses varied from as little as 0.020 inch in the tube wall, to as great as 0.500 inch in portions of the jacket, large temperature gradients in a conventional furnace could have produced unacceptable thermal stresses and dimensional variations of parts. Following the first brazing cycle in the furnace, the thrust chamber was prepared for the first tube-to-tube leak test. Incomplete joints discovered during these tests or by radiographic inspection, were realloyed prior to the second cycle furnace brazing.

Cleaning and alloy application for the second furnace brazing cycle

After the first brazing cycle, the thrust chamber was thoroughly cleaned and rinsed to remove any post-brazing residue and loose alloy particles, then returned to the white room in order for selected areas to be realloyed. The second cycle alloying process was accomplished using a slurry of gold-18 nickel alloy with a paste flux and alcohol. To optimize the flow and sealing capability of the brazing alloy, the thrust chamber was inverted with the jacket down for the second furnace brazing cycle. The second cycle differed from the first in that: because the thrust chamber was now self-supporting there was no requirement for internal support tooling; to preclude remelting the



5-8 A turbine exhaust manifold undergoes inspection in the optical tooling dock in November 1962. (Rocketdyne, Vince Wheelock Collection)

first braze, the brazing temperature was 1,800 degrees F, which was considerably lower than the first brazing cycle; and the Inconel X-750 had aged during the cooling cycle.

Furnace brazing instrumentation

Thrust chamber temperature measurement was accomplished with chromel-alumel thermocouples, with calibrated checkpoints throughout the chamber to monitor its temperature. Thermocouples were also emplaced at each point where the thickness of a section, or its proximity to the furnace wall, might cause a variation from the average chamber temperature. To maintain the required highly pure atmosphere in the brazing retort, the thermocouple cables were fed through a line from the retort to a cool location at the base of the furnace, and then through a hermetic seal to the recording instruments. Because the most significant cause of surface oxidation and poor brazing was likely to be the presence of water vapor, the argon for furnace brazing the F-1 thrust chamber had less than four parts per million of water vapor. Any moisture entering or leaving the retort during furnace brazing was monitored by an electrolytic hygrometer, which measured the dew point of the argon in the retort. A cold cup containing dry ice and acetone was used as a low-tech backup to this instrumentation. The gas in the retort was also monitored for oxygen content and specific gravity.

After the second cycle in the furnace brazing, the thrust chamber was subjected to a series of pressure, penetrant and radiographic tests to establish that its brazed joints did not allow any leaks of hot gas and fuel. Also, pressure tests for hot-gas leakage in the tube-to-tube joints were made, radiographic inspections of the tube joints in critical areas of the thrust chamber were made, followed by penetrant tests of joints for fuel leakage and a static hydraulic pressure test for fuel leakage.

THE F-1 MARK 10 TURBOPUMP

More design and fabrication time was spent on the Mark 10 turbopump of the F-1 engine than any other of its components. Simplicity and reliability were achieved by designing a direct drive unit with a single two-stage turbine driving both the fuel and oxidizer pumps. The material for the manifolds and rotors was selected for its high strength at elevated temperatures and mechanical properties in heavy sections. The turbine blade material was selected for its high strength at elevated temperatures, good mechanical and thermal fatigue resistance, and for being castable. The pump shaft material had to be readily fabricated, and have high strength and toughness at the operating temperatures. Oxidizer system components such as the inducer and impeller had to provide high strength at cryogenic temperatures. Weight reduction was always a prime consideration in evaluating materials. A number of the F-1 engine's cast aluminum components were cast by various foundries that had done such work for Rocketdyne over many years. Some of these cast components were delivered to Rocketdyne for machining and other manufacturing steps, but other aluminum components were delivered as finished parts. All such parts underwent inspection, and had to pass non-destructive testing procedures prior to assembly. All turbopump rotor components were either balanced as individual components prior to turbopump assembly, or thereafter by rotation in a spin pit. After assembly at Canoga Park, each turbopump was taken to the Santa Susana Field Laboratory for hot fire testing and then returned to Canoga Park for installation on an engine. This turbopump hot fire (and calibration if required) gave assurance that this key functional component would operate to specification during engine acceptance test hot fires. The oxidizer dome, propellant valve bodies and related components were also cast by outside foundries. Typically these were delivered to Rocketdyne in a rough cast or semi-finished state, and finish-machined to be certain of controlling all the vital precise machining steps to match the manufacturing drawings. The all-important injector was fully machined and finished at Rocketdyne, as was the F-1 engine gimbal assembly.

HEAT EXCHANGER AND TURBINE EXHAUST MANIFOLD

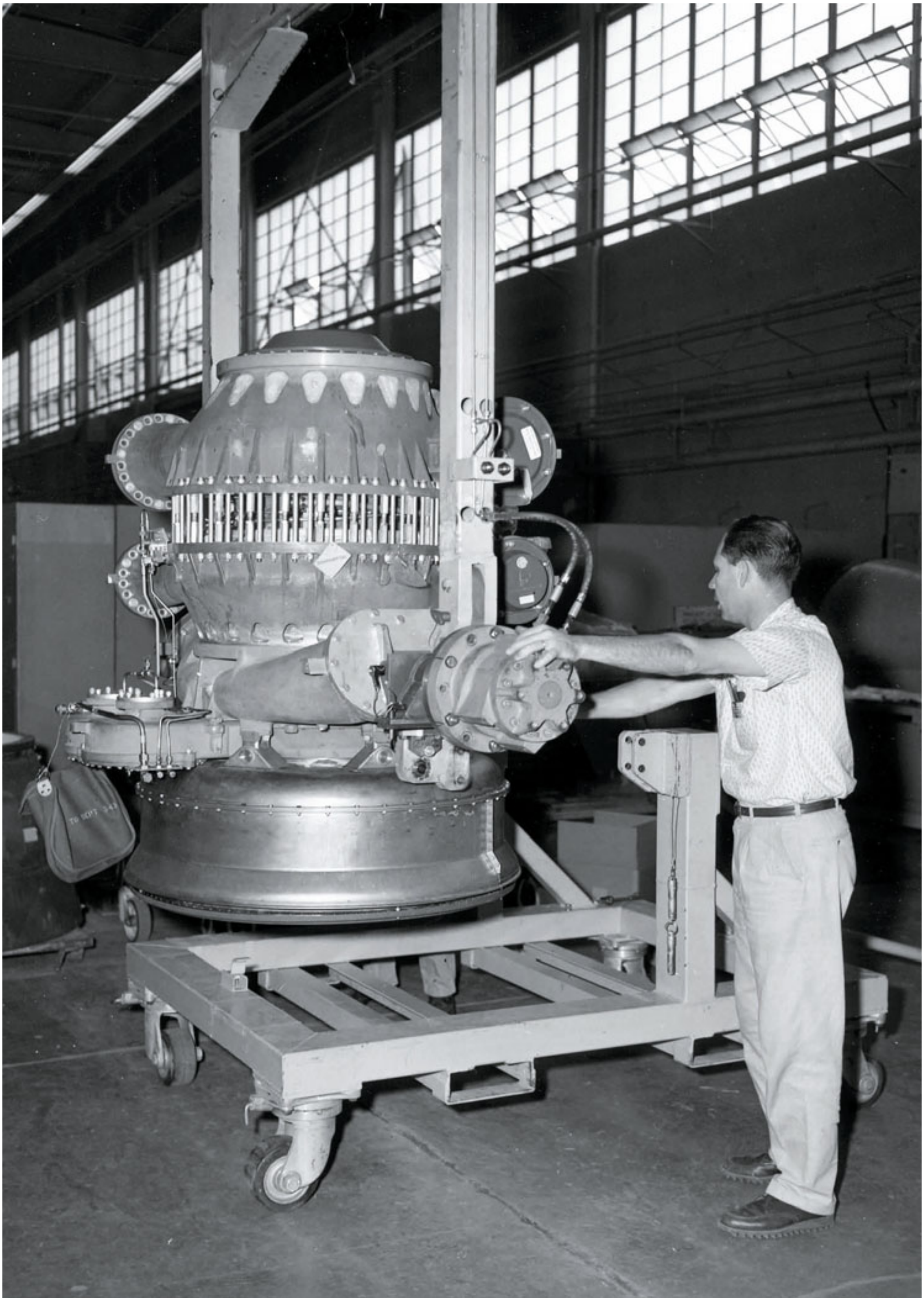
The heat exchanger and turbine exhaust manifold for the F-1 engine were made using high strength refractory alloy steel in Rocketdyne's own sheetmetal shops. Individually formed sheetmetal components were precision welded to produce the finished components. The task was complicated by the intricate compound curves, in particular on the turbine exhaust manifold, which had to be carefully produced using special die stamps or special sheetmetal roller equipment. The finish-formed parts were checked against templates prior to being mated in fixtures for welding. The assembled heat exchanger and turbine exhaust manifold were subjected to thorough inspections and non-destructive testing to check for component integrity.

HYDRAULIC LINES, HOSES AND WIRING HARNESSES

Rigid hydraulic lines were fabricated at Rocketdyne by precisely forming special stainless steel alloy tubing to pattern. Hydraulic or pneumatic hoses were produced by outside vendors that specialized in making such items for aerospace companies. Wiring or cable harnesses were generally fabricated by Rocketdyne, using pattern templates to assure correct cable and harness segment lengths, and terminated with Mil-Spec grade connectors. After all the connections were soldered, the connectors were often potted to ensure that they did not become contaminated and to prevent shorts. All finished cable assemblies or wiring harnesses were inspected and tested before being installed on the engine. One of the final engine assembly steps was to fit the protective covers, which, with other non-flight hardware, were individually designated and generally red in color to assist operations personnel in identifying items to be removed before assembly, test and flight.

F-1 ENGINE FLOW

Rocketdyne published seven technical manuals as field support documentation for the description, operation and maintenance of the F-1 engine. The first, R-3896-1, contained all the information for the individual engine system components, engine operation, mounting on the S-IC stage of the Saturn V, the F-1 engine flow from NASA acceptance tests at Rocketdyne right through to delivery of the S-IC to the Kennedy Space Center, and other information related to the F-1 engine. Below is the *verbatim* text on F-1 Engine Flow from R-3896-1.



5-9 An assembled F-1 turbopump is lowered onto a dolly for transport to the next engine assembly area. (Rocketdyne, Vince Wheelock Collection)

Section 1-135.

The following describes F-1 engine flow and events that take place from the time of Customer acceptance of the engine at Rocketdyne, Canoga Park, through Apollo/Saturn V launch at Kennedy Space Center (KSC). After official acceptance of the engine (signing of DD Form 250), modifications may be made or maintenance tasks may be performed, with Customer approval, before shipment. The engine, nozzle extension, and loose equipment are shipped to the Michoud Assembly Facility (MAF) by either truck or ship. (Thermal insulation (TIS) is shipped to MAF by truck.) At MAF the engine is inspected and then assigned to a stage, designated as a spare, or left unassigned. Spare engines and unassigned engines are processed to a specific condition and placed in storage until needed. The normal flow of assigned engines consists of installing loose equipment and TIS brackets, performing modifications and maintenance, and installing the thrust vector control system on outboard engines. Single-engine checkout is performed, wrap-around ducts and hoses are installed, and the engines are installed in the stage. The stage and nozzle extensions are then shipped to the Mississippi Test Facility (MTF) by barge.

Section 1-136.

The stage is installed in the static test stand at MTF where the engines are inspected, and the nozzle extensions, slave hardware, and static test instrumentation are installed. A pre-static checkout of the stage is performed, followed by a static test, to determine stage acceptability and flight readiness. After a successful stage static test, the engines are inspected, test data is reviewed, and the turbopumps preserved. The nozzle extensions, slave hardware, and static test instrumentation are removed; then the stage is removed from the test stand, and the stage and nozzle extensions are shipped to MAF by barge. During normal stage flow at MAF, the installed-engines are inspected and refurbished; then a post-static checkout and a pre-shipment (to KSC) inspection are performed. The stage may be stored at MAF after engine refurbishment, depending on the stage schedule. The stage, nozzle extensions, loose equipment, and TIS are shipped to KSC by barge.

Section 1-137.

At KSC the stage is erected onto the Launch Umbilical Tower (LUT) in the Vertical Assembly Building (VAB), where a visual inspection is performed.[1] Loose equipment is installed, modifications are made, and maintenance tasks are performed. Stage and engine leak and functional tests are performed, and final installation of the TIS is completed. While the first stage is being prepared, other

[1] Author's note: The stage was actually erected on the Mobile Launch Platform, inside the Vehicle Assembly Building (the initial term Vertical Assembly Building for this facility was superseded; although there *was* a Vertical Assembly Building for the S-IC at the Michoud Assembly Facility). In what follows these points will not be corrected.

tasks are being done to prepare the remaining stages and modules, and the spacecraft, to mate and assemble them into the complete Apollo/Saturn V Vehicle. The vehicle and mobile launcher are then moved from the VAB to the launch pad on the crawler transporter, where launch preparations and final checkouts are performed. With all preparations complete and all systems ready, the Apollo/Saturn V is launched. After launch, a post-flight data evaluation is made, to determine that the S-IC stage engines operated within the specified values during vehicle launch.

1-138. ENGINE FLOW BEFORE FIELD DELIVERY.

1-139. Customer acceptance inspection.

1-140. Customer acceptance inspection is performed when Contractor engine activity at Canoga Park is complete. The Customer reviews all documentation including Component Test Records, Engine Buildup Records, Engine Test Records, and Engine Acceptance Test Records in the Engine Log Book. The Customer verifies that the engine configuration information on the engine MD identification plate corresponds to that listed in the Engine Log Book, and upon acceptance of all records and documentation, signs DD form 250, which constitutes official acceptance of the engine by the Customer.

1-141. POST-DD250 MAINTENANCE OR MODIFICATION.

1-142. If required before field delivery of an engine, post-DD250 maintenance or modification, as required by Engineering Change Proposals and Engine Field Inspection Requests can be done at Rocketdyne with Customer approval. Upon completion of maintenance or modification, the Engine Log Book is updated and the engine is accepted by the Customer.

1-143. ENGINE SHIPMENT TO MAF.

1-144. The engine, nozzle extension, and loose equipment is shipped to MAF by truck or ship as directed by the Customer. Detailed requirements for shipping the engine are in R-3896-9. Detailed requirements describing the use of handling equipment are in R-3896-3.

1-145. PREPARATION FOR SHIPMENT.

1-146. Preparation for shipment at the Contractor's facility consists primarily of removing the engine from buildup and test equipment, installing the engine and nozzle extension in shipping equipment, and packaging the loose equipment. Engine Rotating Sling G4050 is installed on the engine and a facility hoist lifts the sling and rotates the engine from vertical to the lowered (shipping) position. A gaseous nitrogen purge is applied to the oxidizer pump seal during the time the engine is being rotated to the horizontal or lowered position. The engine is then secured on Air Transport Engine Handler G4044 in the lowered position and the sling removed. If the engine is to be shipped cross-country by truck, the turbopump shaft preload fixture is installed. A check is then made to make sure that

Thrust Chamber Throat Security Closure G4089 is installed, that all desiccant is correctly secured, that the humidity range is acceptable, that openings are covered with suitable closures, and that the gimbal bearing is immobilized with Gimbal Bearing Lock G4059. The frame and Engine Cover G4047 are installed on the engine with the necessary forms sealed in the security pouch. Using a facility hoist and Engine Handler Sling G4052, the nozzle extension is installed on Nozzle Extension Handling Fixture G4080 and the loaded nozzle extension installed on Handling Adapter G4081. Because of shipping regulations governing transportation of ignition devices, the engine hypergol cartridge and pyrotechnic igniters are not shipped with the engine.

1-147. SHIPPING BY TRUCK.

1-148. Trucks are used to transport the engine, nozzle extension, and loose equipment, cross-country or to and from dock sites. Using a facility hoist and Engine Handler Sling G4052, the handler-installed engine and loaded nozzle extension (installed on the handling adapter) are loaded and secured on low-bed, air-ride-equipped trailer. Loose equipment is packaged in boxes, loaded by forklift, and secured. For cross-country shipping, a calibrated impact recorder is installed on the handler. A truck transport checklist is used as a guide to verify that specified procedures are performed before truck departure and during cross-country shipping.

1-149. SHIPPING BY SHIP.

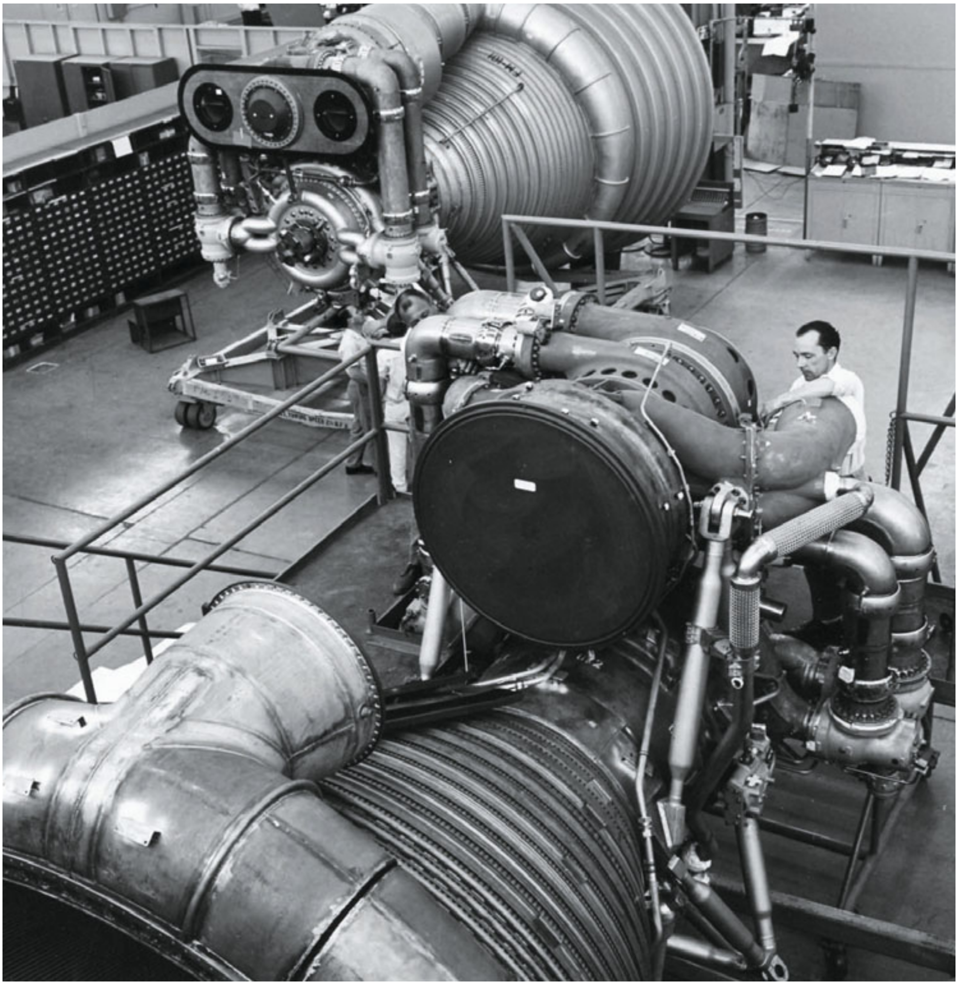
1-150. The engine, nozzle extension, and loose equipment are delivered to the ship by truck. The low-bed trailer is positioned on the ship's deck. Using a mobile crane, Engine Handler Sling G4052, and tractor, the Handler-installed engine is removed from the trailer, placed on the cargo deck, then moved forward and secured. The nozzle extension and loose equipment are removed from the trailer by mobile crane or forklift and secured to the cargo deck. The water transport checklist is used as a guide to verify that specified procedures are performed before departure, in transit, and after docking.

1-151. RECEIVING ENGINE AT MAF.

1-152. The Stage Contractor receives the engine and is responsible for engine flow at MAF. Detailed requirements for engine receiving by truck and ship are in R-3896-9. Detailed requirements describing the use of engine handling equipment are in R-3896-3.

1-153. RECEIVING BY TRUCK.

1-154. Engines, nozzle extensions, and loose equipment received by cross-country truck or by truck from the MAF dock are delivered to the Manufacturing Building where the equipment is visually inspected for shipping damage. If arriving at MAF by cross-country truck, the arrival time and date are recorded



5-10 An F-1 turbopump in the final stages of being mounted on the side of this development engine's upper thrust chamber. The heat exchanger will connect the turbine at the bottom of the turbopump to the turbine exhaust manifold, as in the case of the engine in the background. (Rocketdyne, Vince Wheelock Collection)

on the impact recorder chart. Using the facility hoist and Engine Handler Sling G4052, the handler-installed engine and nozzle extension are moved from the trailer to the floor. Loose equipment is removed from the trailer using a forklift. The nozzle extension is routed to the nozzle extension storage area, and loose equipment is routed to the Engine Support Hardware Center. The engine is routed to the engine area or to the bonded storage area (if unassigned), where the impact recorder and turbopump preload fixture are removed (if installed) and returned to Canoga Park.

1-155. RECEIVING BY SHIP.

1-156. When the ship arrives at the MAF dock, a tug, mobile crane, and low-bed trailer are positioned on the ship's cargo deck for the off-loading procedure. Using Engine Handler Sling G4052 and the mobile crane, the engine and nozzle extension are loaded and secured on the low-bed trailer. The loose equipment is loaded on the trailer by forklift. The trailers are moved into the Manufacturing Building, where the engine, nozzle extension, and loose equipment are inspected for shipping damage. Engine receiving then proceeds as described in paragraph 1-153.

1-157. UNASSIGNED-ENGINE FLOW AT MAF.

1-158. Unassigned-engine flow at MAF pertains to unassigned and spare engines. Upon receipt at the Manufacturing Building, unassigned engines are inspected for shipping damage, moved to the bonded storage area, inspected, and stored until scheduled for modification and/or assigned to a stage. Spare engines are processed through buildup and single-engine check-out, moved to the bonded storage area, and stored in a standby condition in case engine replacement is required. Single-engine checkout is required for all engines in storage over six months. If any discrepancies are observed during engine flow at MAF, Engine Contractor personnel perform unscheduled maintenance and repair or replace discrepant hardware on the engine. Discrepant hardware removed from the engine is routed to the CM&R area,[2] where it is repaired and tested.

1-159. STORAGE RECEIVING INSPECTION.

1-160. Unassigned engines are visually inspected in the bonded storage area. The engine cover is removed, and the engine inspected for damage, corrosion, residual fluid on exterior surfaces, and surface wetting on the hydraulic control system exterior. It is verified that specified areas of the engine are coated with corrosion preventive, that humidity indicators indicate blue, and that line markings are correct. The turbopump preservation status is checked in the Engine Log Book, and the turbopump is serviced if required. The engine cover is reinstalled. Detailed inspection requirements for engines in storage are in R-3896-11.

1-161. ENGINE FLOW AT MAF.

1-162. When an uninstalled engine is received in the engine area, it is removed from Air Transport Engine Handler G4044, rotated to the vertical position, and placed on Engine Handling Dolly G4058 using Engine Rotating Sling G4050 and the facility hoist. The engine is then moved into a workstand where receiving inspection and engine buildup are accomplished. After engine buildup, the engine is placed into a test stand for single-engine checkout and installation of wrap-around lines. The engine is then removed from the test stand, rotated to the horizontal position and installed on Engine Handler G4069. The oxidizer pump

[2] The CM&R area is an environmentally controlled room set aside for component maintenance and repair of F-1 engines.

seal is purged with gaseous nitrogen during engine rotation to the horizontal position and for 30 minutes (minimum) thereafter. The engine is moved to the Stage Horizontal Final Assembly Area, where the engine is prepared for installation, installed in the stage, and inspected in preparation for shipment to MTF. Engine modifications are made as required during engine flow at MAF. If any discrepancies are observed, Engine Contractor personnel perform unscheduled maintenance, and repair or replace hardware on the engine. Discrepant hardware removed from the engine is routed to the CM&R area, where it is repaired and tested. Detailed requirements describing the use of engine handling equipment are in R-3896-3.

1-163. RECEIVING INSPECTION.

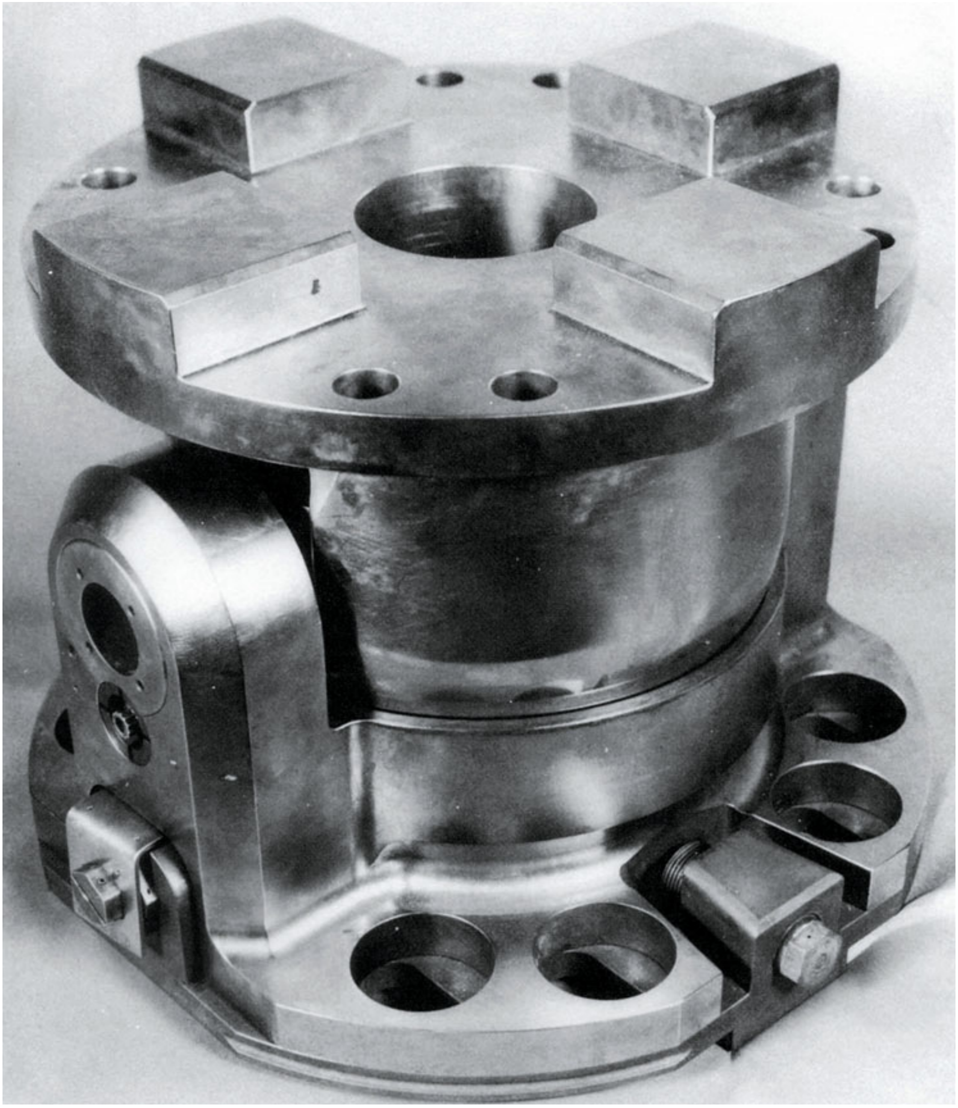
1-164. After installation in the single-engine workstand in the engine area of the Manufacturing Building, each assigned engine undergoes an overall visual receiving inspection. The engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits or on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, line markings are correct, humidity indicators indicate blue, and there are no voids in the turbopump housing cavity filler material. A clean polyethylene bag is installed on the fuel overboard drain line, the turbopump preload fixture is removed, and orifice sizes and serialized components are checked against those listed in the Engine Log Book. Detailed inspection requirements for engines received at MAF are in R-3896-11.

1-165. ENGINE BUILDUP, MODIFICATION, AND MAINTENANCE.

1-166. LOOSE EQUIPMENT INSTALLATION. Loose equipment that does not interfere with single-engine checkout is installed during engine buildup. The electrical cable support post is installed only on engines assigned to the outboard positions. The interface panel-to-oxidizer inlet insulation seal is installed on all engines. Wrap-around ducts and hoses are not installed at this time.

1-167. THERMAL INSULATION BRACKETRY INSTALLATION. The field-installed thermal insulation bracketry is normally stored at MAF until installation on the engine. All brackets are installed except for the bracket that attaches to the engine handling bearing. The engine handling bearing is an attach point for securing the engine onto Engine Handler G4069; therefore, the bracket is installed after the engine is installed on the stage. Requirements for installing thermal insulation brackets are in R-3896-6.

1-168. MODIFICATION AND MAINTENANCE. Modifications are made and maintenance tasks are performed during engine buildup, whenever possible. Engine modifications and special inspections consist of incorporating retrofit kits, as a result of Engineering Change Proposals (ECPs), and implementing Engine Field Inspection Requests (EFIRs). Engine maintenance involving component removal and replacement or turbopump disassembly, if required, is done



5-11 The gimbal bearing assembly was bolted to the top of the LOX dome assembly. (Rocketdyne, Harold C. Hall Collection)

in the engine workstands. Component modification, repair, and functional testing are done in the environmentally controlled CM&R area.

1-169. THRUST VECTOR CONTROL SYSTEM INSTALLATION. The thrust vector control system is installed by the Stage Contractor on engines assigned to the outboard positions. This system consist of two gimbal actuators, hydraulic supply and return lines, and a hydraulic filter manifold.

1-170. SINGLE-ENGINE CHECKOUT.

1-171. Single-engine checkout is done after receiving inspection and after engine buildup tasks are completed. The engine is installed in the test stand, where the ignition monitor valve sense tube is disconnected, Thrust Chamber Throat Security Closure G4089 removed, and Thrust Chamber Throat Plug G3136 installed. All connections are made between the engine and Engine Checkout Console G3142; facility electrical, pneumatic, and hydraulic sources are applied to the console; and the console is prepared for operation. Electrical system function and timing tests, a turbopump torque test, pressure tests, valve timing tests, and leak and function tests are done in accordance with the detailed requirements in R-3896-11. Upon completion of engine checkout, the ignition monitor valve sense tube is connected, Thrust Chamber Throat Plug G3136 is removed, and Thrust Chamber Throat Security Closure G4089 installed.

1-172. WRAP-AROUND DUCT AND HOSE INSTALLATION.

1-173. The loose-equipment wrap-around ducts and hoses are installed on the engine in the test stand after single-engine checkout. The helium, GOX, and hydraulic wrap-around ducts and the purge and prefill hoses are installed and connected to flanges used for test setups during engine testing. The ducts and hoses are aligned using alignment tool T-5041233 and supported with support set T-5046440 to prevent movement until the engine is installed in the stage and interface connections are completed. The engine is then removed from the test stand. Detailed requirements for installing and aligning wrap-around ducts and hoses are in R-3896-3.

1-174. ENGINE INSTALLATION AT MAF.

1-175. PREPARATION FOR ENGINE INSTALLATION. The engine is rotated to the horizontal position and installed on Engine Handler G4069 using Engine Rotating Sling G4050 and the facility hoist. The oxidizer pump seal is purged during engine rotation to the horizontal position and for 30 minutes (minimum) thereafter. After removing the interface panel access doors, the oxidizer and fuel inlet covers are removed, the inlets inspected for contamination, the oxidizer inlet screen and seal secured in place, and the inlets covered with Aclar film. The fuel overboard drain system is isolated using clean polyethylene bags. The gimbal boot cover is removed, and it is verified that the gimbal bearing locks are installed, the electrical cable support posts installed on engines assigned to outboard positions, and the engine gimbal wrap-around lines are installed and adequately supported. When ready for installation in the stage, the engine is moved to the Stage Horizontal Final Assembly Area and positioned under a mobile hoist. (A-frame). Thrust Chamber Throat Security Closure G4089 is removed and the thrust chamber inspected. The engine horizontal installation tool is suspended from the mobile hoist, prepared for engine installation, and then installed in the thrust chamber. The engine is then removed from Engine Handler G4069 and raised and rotated in the position required for engine installation.

Detailed requirements for fuel overboard drain system isolation and engine preparation for installation are in R-3896-11.

1-176. ENGINE INSTALLATION. When preparations for engine installation are completed and the engine is correctly positioned in the stage, the engine gimbal bearing is mated and secured to the stage attach point. On the outboard engines, the gimbal actuators are secured to the stage actuator locks, while on the inboard engine, the stiff arms are secured to the actuator locks. Gimbal bearing locks are removed, and the gimbal boot is reinstalled on the gimbal bearing. The engine horizontal installation tool is removed from the thrust chamber after the engine is secured to the stage; then the Thrust Chamber Throat Security Closure G4089 is installed. Aclar film is removed from engine oxidizer and fuel inlets, fuel inlet seals and screens are installed, and stage ducting is connected to the engine inlets. The interface electrical connectors and stage pressure switch checkout supply line are connected at the interface panel, and the wrap-around ducts and hoses are connected to the stage. The thermal insulation bracket that attaches to the engine handling bearing is installed as specified in R-3896-6. Detailed requirements for installing the engine are in R-3896-11.

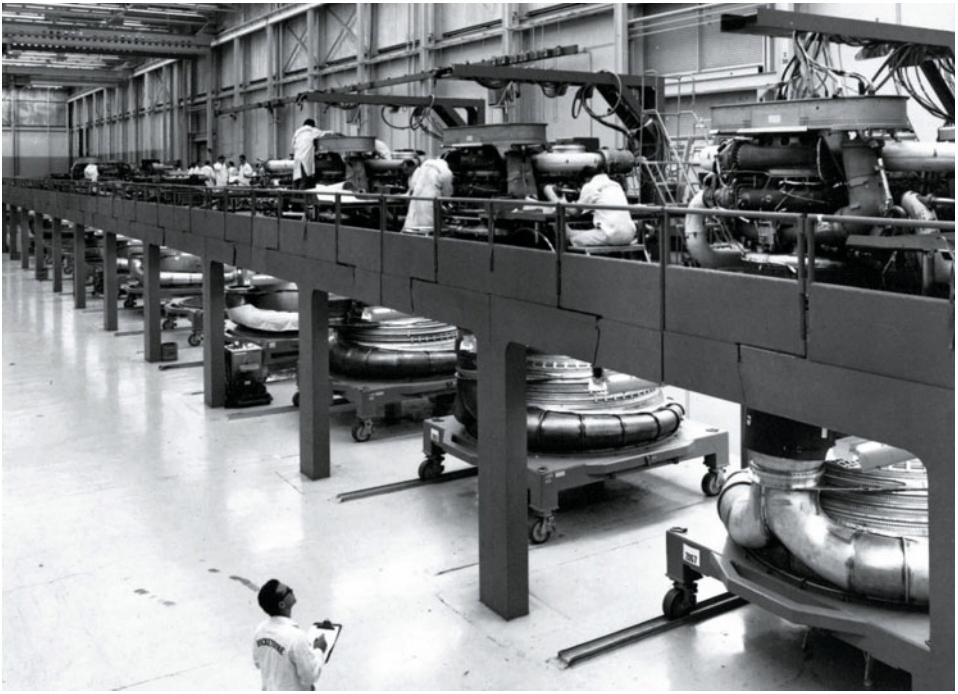
1-177. MANUFACTURING INSTALLATION VERIFICATION. When engine installations and stage assembly are completed, the Stage Contractor performs a manufacturing installation verification. This verification consists of a gaseous nitrogen leak test of the engine interface connections and stage systems.

1-178. INSTALLED-ENGINE INSPECTION BEFORE STAGE SHIPMENT TO MTF.

1-179. The installed-engine inspection before shipment to MTF is made after the stage assembly and verification tests are complete. Each engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits, fluid on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, line markings are correct, the humidity indicator in the thrust chamber throat security closure indicates blue, and there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. The turbopump preservation status is checked in the Engine Log Book, and the turbopump is serviced if required. A final updating of the Engine Log Book is made before engine shipment to MTF. Detailed procedures for inspecting the installed engine before shipment to MTF are in R-3896-11.

1-180. STAGE SHIPMENT TO MTF.

1-181. When installed-engine inspection is complete, the forward stage cover and engine covers are installed, the workstands and platforms are rolled away from the engines, a tractor is connected to the stage transporter, and the stage is pulled to the MAF dock. The stage is loaded onto the barge and secured. The nozzle



5-12 Rocketdyne built new rocket engine assembly buildings in the mid-1960s that included areas for vertically assembling F-1 engines. (Rocketdyne, Harold C. Hall Collection)

extensions are loaded on low-bed trailers, towed to the MAF dock, loaded on the barge using a mobile hoist, and secured. The barge is then moved to MTF by tug.

1-182. STAGE FLOW AT MTF.

1-183. The stage is received at MTF and installed in the test stand. The engine covers are removed, and receiving inspection is performed. The nozzle extensions, slave hardware (normally stored at MTF), and MTF static test instrumentation are installed; then a pre-static checkout is performed. Thermal insulation is not required for static test, therefore it is not installed. Engine maintenance is done and modifications are made as required during engine flow at MTF. Upon completion of pre-firing preparations, the static firing test is performed. After static test, the engines are inspected; the test instrumentation, slave hardware, and nozzle extensions are removed; a pre-shipment inspection is performed; and the stage and nozzle extensions are removed from the test stand and loaded on the barge for return to MAF.

1-184. STAGE INSTALLATION IN TEST STAND.

1-185. When the stage arrives at MTF, the barge is docked next to the test stand. Test stand overhead cranes are attached to the forward and aft ends of the stage;

the stage is lifted clear of the stage transporter and barge, rotated to the vertical position, and positioned into the test stand. During rotation to the vertical position, the thrust chamber and exhaust manifold are monitored for fuel leakage. The stage is secured to the test stand with mechanical holddowns; stage/facility propellant, hydraulic, pneumatic, and electrical connections are secured; and engine covers and engine oxidizer and fuel inlet screens are removed.

1-186. ENGINE RECEIVING INSPECTION.

1-187. After the stage is installed in the test stand, the engines undergo an overall visual receiving inspection. Each engine is inspected for damage, corrosion, and missing equipment and for evidence of fluid in drain line exits. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, the engine soft goods installed life is within specified limits, and there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. Engine orifice sizes and serialized components are checked against those listed in the Engine Log Book. Detailed inspection requirements for installed engines received at MTF are in R-3896-11.

1-188. INSTALLATION OF NOZZLE EXTENSIONS, SLAVE HARDWARE, AND MTF STATIC TEST INSTRUMENTATION.

1-189. The nozzle extensions, slave hardware, and MTF static test instrumentation are installed on the engines after the stage is installed in the test stand and after receiving inspection. Using Engine Handler Sling G4052 and overhead cranes, the nozzle extension is removed from the barge and from Nozzle Extension Handling Fixture G4080 and Handling Adapter G4081 and placed on Engine Vertical Installer G4049 on the lower stand work platform. The installer, with nozzle extension, is positioned below the engine; then the nozzle extension is installed on the engine, and the installer lowered. The polyethylene bags are removed from the fuel overboard drain system, and the slave fuel, oxidizer, and nitrogen overboard drain lines are installed. The slave igniter harness and MTF static test instrumentation are then installed and connected. Detailed installation requirements are in R-3896-11. Detailed nozzle extension handling requirements are in R-3896-9.

1-190. STAGE PRE-STATIC CHECKOUT.

1-191. The stage pre-static checkout is performed on all engine and stage systems. Immediately preceding pre-static checkout, Thrust Chamber Throat Security Closure G4089 is removed and Thrust Chamber Throat Plug G3136 is installed. The checkout consists of electrical, hydraulic, and pneumatic leak and function tests. A simulated static test, which simulates stage preparation, engine start, ignition, mainstage, and cutoff sequencing, is performed to verify stage acceptability for static test. Detailed pre-static checkout requirements are in R-3896-11.

1-192. STATIC TEST

1-193. When all required checkout procedures, modifications, and maintenance are completed, and the Thrust Chamber Throat Plug G3136 is removed, the hypergol cartridge and pyrotechnic igniters are installed and checked out and the test area is cleared in readiness for static test. A 125-second, uninterrupted-duration stage static test is made to checkout all electrical-electronic, propulsion, mechanical, pressurization, propellant, and control systems that function during actual countdown, launch, and flight. Measurements of the static test are recorded and processed to determine stage acceptability and flight readiness. The engine start for the stage is a 1-2-2 sequence: the center engine starts first, and the remaining outboard engines start in opposed groups of two. The engine cutoff is a 3-2 sequence: the center engine and two opposite outboard engines cut off first; then the remaining two outboard engines cut off.

1-194. ENGINE INSPECTION AFTER STATIC TEST.

1-195. The engine and nozzle extension are inspected visually after static test to verify that damage did not occur during the test. Detailed inspection requirements are in R-3896-11 and include inspecting for exterior damage and missing aluminum tape between thrust chamber exhaust manifold and thrust chamber tubes; inside of thrust chamber for tube and injector damage, injector contamination, and liquid leakage. Other inspections are for tension tie deformation, bent or broken studs, nozzle extension for carbon deposits around flange area, and internal damage and erosion.

1-196. STATIC TEST DATA REVIEW.

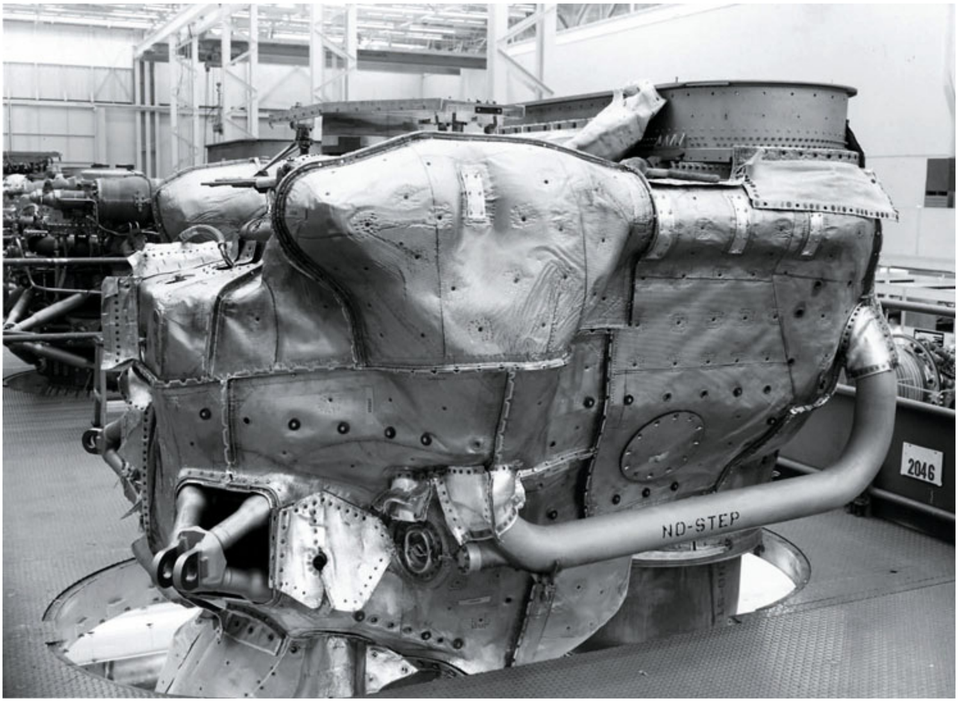
1-197. The static test data is reviewed after static test to determine that the engine is operating within specified limits. Test instrumentation readings are examined to detect abnormalities, sudden shifts, oscillations, or performance near the minimum or maximum limits.

1-198. TURBOPUMP PRESERVATION.

1-199. The turbopump is preserved within 72 hours after static test. After removing fluid through the turbopump No. 3 bearing drain line, the turbopump bearings are purged with gaseous nitrogen, and five gallons of preservative oil is supplied to the bearings while the turbopump is slowly rotated. The fluid is then drained through the No. 3 bearing drain line, and the bearings are again purged with gaseous nitrogen. The preservation date is recorded in the Engine Log Book.

1-200. REMOVAL OF NOZZLE EXTENSIONS, SLAVE HARDWARE, AND MTF STATIC TEST INSTRUMENTATION.

1-201. Engine Vertical Installer G4049 is positioned below the nozzle extension and the nozzle extension removed from the engine and lowered onto the installer. Using Engine Handler sling G4052 and overhead cranes, the nozzle extension is removed from the installer, installed on Nozzle Extension Handling Fixture



5-13 The thermal insulation for each F-1 engine was verified in the final stages of assembly, then removed for engine shipment to NASA. This photograph was taken November 4, 1966. (Rocketdyne, Harold C. Hall Collection)

G4080, and the loaded nozzle extension installed on Handling Adapter G4081. The slave hardware, consisting of fuel overboard drain lines and the igniter harness, is removed, cleaned, tested, and repaired or replaced, as required, for reuse during the next static test. The fuel overboard drain system is isolated using clean polyethylene bags. The expended igniters and hypergol cartridge are removed. The MTF static test instrumentation is disconnected and removed and the instrumentation ports plugged immediately by incorporating the applicable retrofit kit specified in Modification Instruction R-5266-391 (ECP F1-391). The Thrust Chamber Throat Security Closure G4089 is installed. Detailed removal requirements are in R-3896-11. Detailed nozzle extension handling requirements are in R-3896-9.

1-202. INSTALLED-ENGINE INSPECTION BEFORE STAGE SHIPMENT TO MAF.

1-203. The engine is inspected before shipment to MAF and after all post-static-test tasks are complete. Each engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits or on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, line markings are correct, the humidity indicator in the thrust chamber throat security closure indicates blue, and there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. All engine protective closures are installed upon completion of visual inspection. It is verified that the humidity indicator in the thrust chamber throat security closure indicates blue at the time of shipment. Detail inspection requirements are in R-3896-11.

1-204. STAGE REMOVAL FROM TEST STAND.

1-205. After engine visual inspection, the engines and stage are prepared for removal from the test stand. The engine and stage covers are installed; stage/facility propellant, hydraulic, pneumatic, and electrical connections are disconnected; and mechanical holddowns are removed. Test stand overhead cranes are attached to the forward and aft ends of the stage; the stage is lifted clear of the test stand, rotated to the horizontal position, and installed on the stage handler on the barge. The oxidizer pump seal is purged during engine rotation to the horizontal position for 30 minutes (minimum) thereafter. The nozzle extensions, installed on Nozzle Extension handling Fixtures G4080 and Handling Adapters G4081, are removed by overhead crane and loaded on the barge. The stage transporter and nozzle extensions are secured on the barge for shipment. A final updating of the Engine Log Book is made before shipment to MAF.

1-206. STAGE SHIPMENT TO MAF.

1-207. The barge, containing the stage and nozzle extensions, is moved from MTF to MAF by tug. Upon arrival at the MAF dock, a tractor is connected to the stage transporter, and the stage is pulled from the barge and towed to the Stage Checkout Building. The nozzle extensions are loaded on low-bed trailers, using a mobile hoist, and towed from the barge to the nozzle extension storage area.

1-208. STAGE FLOW AT MAF.

1-209. The stage is positioned in the Stage Checkout Building at MAF, and workstands and platforms are installed to aid access during inspection and checkout. The engines undergo a receiving inspection, refurbishment, post-static checkout, and pre-shipment inspection. A storage period may be required after refurbishment, if so, the stage is prepared for storage and stored for a specified time before post-static checkout.

1-210. ENGINE RECEIVING INSPECTION.

1-211. After positioning the stage in the Stage Checkout Building, the engines undergo an overall visual receiving inspection. Each engine is inspected for damage, corrosion, and missing equipment and for evidence of fluid in drain line exits. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas and that there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. Engine orifice sizes and serialized components are checked against those listed in the Engine Log Book. It is verified that the humidity in the thrust chamber throat security closure indicates blue. Detailed inspection requirements for installed engines received MAF are in R-3896-11.

1-212. ENGINE REFURBISHMENT.

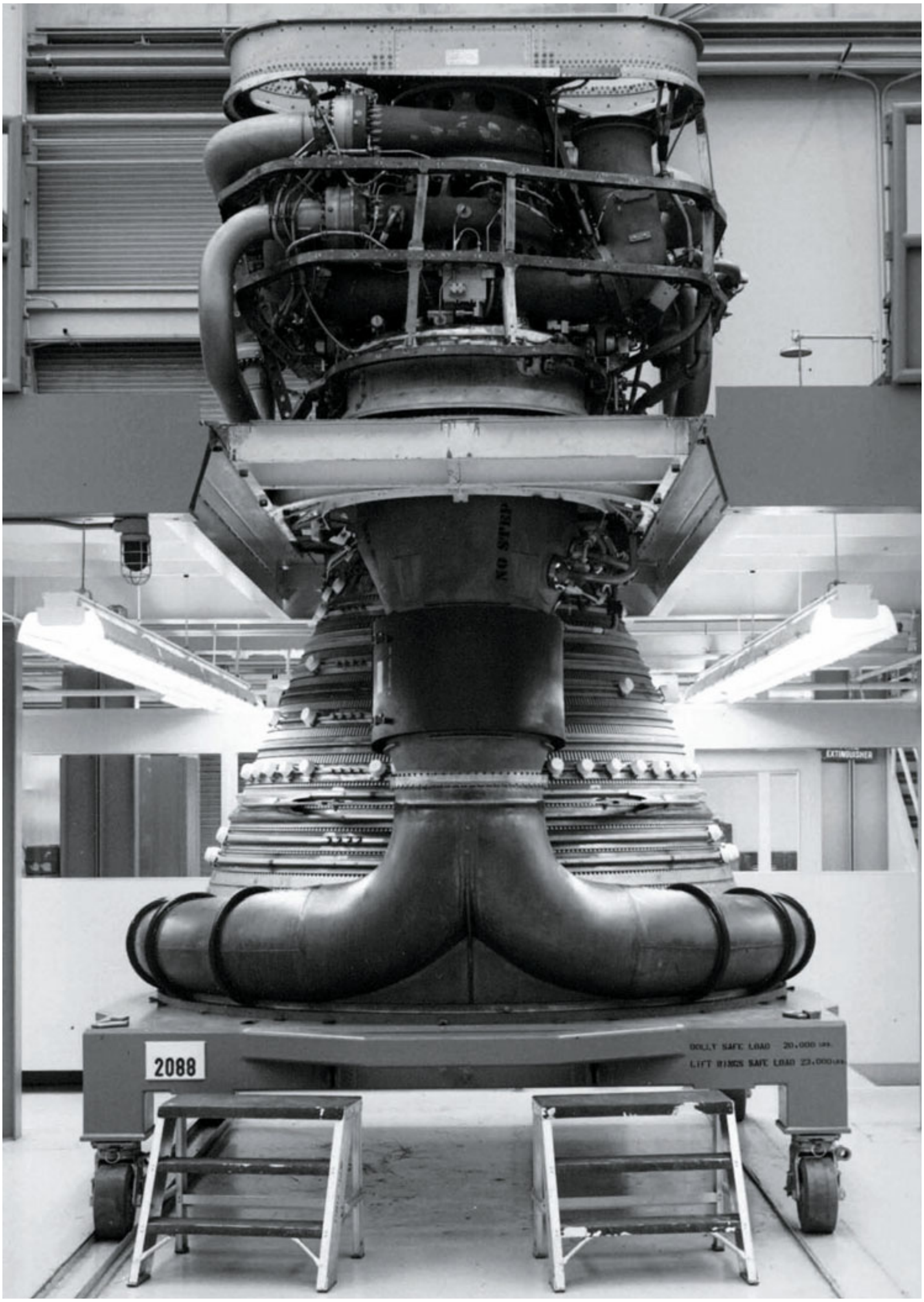
1-213. The engine is refurbished after receiving inspection. The engines are first cleaned of any foreign matter and corrosion that may have resulted from exposure to rain, humidity, sand, or dust. The oxidizer dome insulator is installed in accordance with requirements specified in R-3896-6. The flight igniter harness is installed, tested and connected in accordance with requirements specified in R-3896-11. Outstanding maintenance or modification, as required by ECPs and EFIRs, is done during the refurbishment period.

1-214. STAGE STORAGE.

1-215. Storage of installed engines is scheduled following completion of refurbishment. The amount of time the stage remains in storage is determined by the Saturn V vehicle launch schedule. Stage storage, in excess of six months, requires that engine post-static checkout be performed when the stage is removed from storage. Installed engines are visually inspected for damage, corrosion, and missing equipment, and for evidence of fluid in oxidizer and nitrogen purge overboard drain lines. It is also verified that corrosion preventive and aluminum-foil tape is present in specified areas, the gimbal boot is installed, there are no voids in the turbopump housing cavity filler material, and that fuel overboard drain system isolation polyethylene bags do not contain fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. The turbopump preservation status is checked in the Engine Log Book and the turbopump is serviced if required; desiccants are installed in the thrust chamber throat security closure and the closure is installed; and humidity indicators are checked for a blue indication. The engine-to-stage gimbal actuators are locked to prevent engine movement, and the stage is stored in an environmentally controlled area. The engines are inspected periodically during storage. Detailed inspection requirements for installed engines in storage are in R-3896-11.

1-216. POST-STATIC CHECKOUT.

1-217. The post-static checkout is done after refurbishment tasks are completed, after a stage is removed from storage on which a post-static checkout had not been previously accomplished, or after stage storage has exceeded six months. The post-static checkout consists of complete electrical, hydraulic, and pneumatic leak and functional tests of the installed engines and stage systems. The post-static checkout is completed with a simulated launch test that consists of stage preparations, engine start, ignition, mainstage, liftoff, flight, and engine cutoff in the prescribed sequence to assure flight readiness of the engines and stage. Post-static



5-14 F-1 engine No. 2088 prior to mechanical and electrical checkout in December 1968. (Rocketdyne, Harold C. Hall Collection) checkout includes a flight instrumentation function test, turbopump torque test and heater function test, lead and function test of the bearing coolant control valve, hypergol manifold, thrust-OK pressure switches, thrust chamber prefill line, ignition monitor valve, oxidizer dome and gas generator oxidizer injector purge system, cocoon purge system, and hydraulic system. Leak test of the thrust chamber, heat exchanger helium and oxidizer systems, propellant fuel and oxidizer systems, exhaust system, and valve timing function tests are also accomplished. Installed engine tests are conducted in accordance with requirements specified in R-3896-11.

1-218. INSTALLED-ENGINE INSPECTION BEFORE STAGE SHIPMENT TO KSC.

1-219. The installed engine is inspected before shipment to KSC and the Engine Log book is reviewed after post-static checkout tasks are completed. Each engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits, fluid on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, that line markings are correct, that the humidity indicator in the thrust chamber throat security closure indicates blue, and that turbopump housing cavity filler material does not contain voids. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. The turbopump preservation status is checked in the Engine Log Book, and the turbopump is serviced if required. A final updating of the Engine Log book is made before engine shipment to KSC. Detailed procedures for inspecting the installed engine before shipment to KSC are in R-3986-11.

1-220. STAGE SHIPMENT TO KSC.

1-221. After the engine pre-shipment visual inspection is completed, the forward and aft stage covers are installed, workstands and platforms removed, and the stage pulled from the Stage Checkout Building to the MAF dock for transport to KSC by barge. The nozzle extensions, engine loose equipment, and the thermal insulation are loaded on low-bed trailers and transported to the MAF dock where they are removed from the trailers and loaded on the barge and secured for shipment. Handling requirements for nozzle extensions and loose equipment are in R-3896-9. After the nozzle extensions, loose equipment, and thermal insulation boxes are loaded and secured, the stage is loaded onto the barge and secured. The barge is then moved to KSC by tug.

1-222. STAGE FLOW AT KSC.

1-223. The barge arrives at KSC dock where the stage, nozzle extensions, loose equipment, and thermal insulation boxes are off-loaded. The stage is towed from the dock to the Vertical Assembly Building (VAB). The nozzle extensions, loose equipment, and thermal insulation boxes are loaded on low-bed trailers and transported to the VAB. The stage is removed from the stage transporter and erected onto the Launch Umbilical Tower (LUT) where the engine visual receiving inspection, loose equipment installation, modification and maintenance, stage and engine leak and functional tests, and thermal insulation installations are accomplished. These tasks are conducted concurrently with the Saturn V vehicle assembly and testing. A final updating of the Engine Log Book is made after engine activities during stage flow are complete.

1-224. STAGE INSTALLATION ONTO LAUNCH UMBILICAL TOWER (LUT).

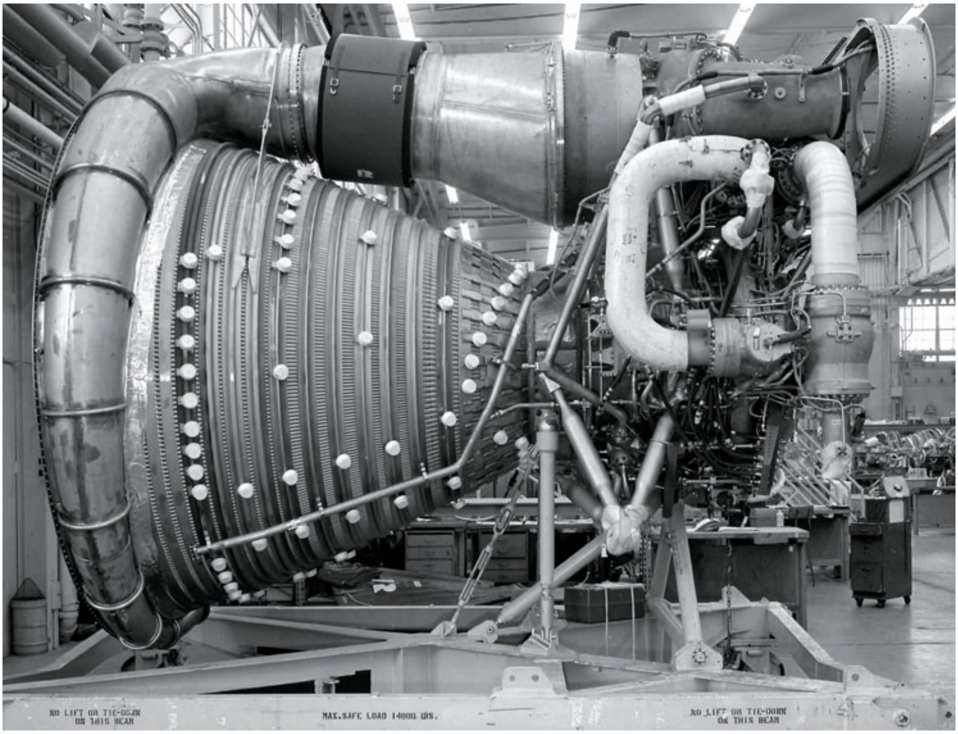
1-225. The stage is received in the low bay of the VAB. The forward and aft stage covers are removed and the stage and engines prepared for rotation and installation onto the LUT. The Engine Service Platform (ESP) and the LUT are moved into the high bay. The stage, on the transporter, is moved from the transfer aisle to the erection bay where the stage is removed from the transporter and rotated to the vertical position by overhead cranes. The stage is then moved by high bay crane and erected on the LUT and secured with four mechanical holddowns. The ESP and LUT level platforms are positioned around the engines for receiving inspection.

1-226. ENGINE RECEIVING INSPECTION.

1-227. After the stage is installed onto the LUT, protective closures are removed and the engines undergo an overall visual receiving inspection. The engines are inspected to verify that damage did not occur during shipping and that all equipment listed on shipping documentation was received. Each engine is inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits, fluid on the engine exterior, and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum foil tape is present in specified areas, the engine soft goods installed life is within specified limits, there are no voids in the turbopump housing cavity filler material, and that turbopump and outrigger arm surfaces do not contain scratches through paint. The fuel overboard drain system insulation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. Engine orifice sizes and serialized components are checked against those listed in the Engine Log Book. Oxidizer and fuel high-pressure duct covers and thrust chamber covers are installed after visual inspection completion. Detailed inspection requirements for installed engines received at KSC are in R-3896-11.

1-228. LOOSE EQUIPMENT INSTALLATION.

1-229. The engine loose equipment is installed after engine receiving inspection is completed. The loose equipment consists of the nozzle extension, oxidizer overboard drain line, fuel overboard drain line, nitrogen purge overboard drain line, and fuel inlet elbow-to-interface boots. Using Engine Handler Sling G4052 and overhead cranes, the nozzle extension is removed from Nozzle Extension Handling Fixture G4080 and Handling Adapter G4081 and placed on the Nozzle



5-15 Protective covers were placed over the threaded attachments used to secure the thermal insulation. (Rocketdyne, NASA)

Extension Installer. The five nozzle extensions and Nozzle Extension Installers are placed on the Engine Service Platform in their respective engine positions. The Engine Service Platform is then raised from ground level up through the opening in the LUT until the nozzle extension flanges are approximately 5 inches below the thrust chamber exit flanges. Final adjustments are made and the mating of the extension flanges to the thrust chamber exit flanges is done with the individual Nozzle Extension Installers. After the nozzle extensions are secured to the engines, the overboard drain lines are attached and secured. Loose equipment is installed in accordance with requirements specified in R-3896-11. Detailed nozzle extension handling requirements are in R-3896-9. The stage fins and engine shrouds are installed in accordance with stage contractor requirements.

1-230. MODIFICATION AND MAINTENANCE.

1-231. The engine modifications and special inspections may be made and maintenance tasks may be performed, if required, throughout the stage flow at KSC. Modifications and special inspections are made as a result of approved ECP or EFIR action, and scheduled through joint agreement between the customer, stage contractor, and engine contractor. The engine maintenance is performed, if required, as a result of discrepant hardware noted during receiving inspection or engine lead and functional testing.

1-232. STAGE FUNCTIONAL TEST.

1-233. The stage functional testing is started after stage installation onto the LUT. The electrical, hydraulic, and pneumatic lead and functional tests are made in conjunction with vehicle assembly. The stage functional test consists of a flight instrumentation function test, turbopump torque test and heater function test, engine sequence verification test, leak and function test of the bearing coolant system, hypergol manifold, thrust-OK pressure switches, thrust chamber prefill line, ignition monitor valve, oxidizer dome and gas generator oxidizer injector purge system, oxidizer pump seal purge system, cocoon purge system, and hydraulic system. A leak test of the thrust chamber, heat exchanger helium and oxidizer systems, propellant fuel and oxidizer systems, exhaust system, and valve timing function tests is also performed. Installed engine tests are performed in accordance with requirements specified in R-3896-11.

1-234. THERMAL INSULATION INSTALLATION.

1-235. The thermal insulation (TIS) is installed after engine leak and functional testing is complete. The TIS is installed to completely envelop the engine and provide protection from extreme temperatures created by plume radiation and backflow during cluster engine flight. To allow access for verifying the integrity of engine components and systems and to prevent possible insulator damage from fluid spillage, the TIS is not installed until engine testing is complete. The required sequence and methods for TIS installation is in R-3896-6. After the thermal insulation is installed and before moving the Saturn V vehicle from the VAB, an engine environmental cover is installed on each S-IC engine, from the thrust chamber throat area to the exit end of the nozzle extension, to protect the thermal insulation from inclement weather. The cover is wrapped around the thrust chamber and nozzle extension and placed so that engine overboard drain lines are exposed through holes provided in the cover, and access flaps, four places, are located to provide access to drain ports and igniters. Overlapping edges of the cover are laced together, excess material is gathered around the thrust chamber throat and folds tied, and the cover drawn tight under exit end of nozzle extension. Detailed requirements for installation of the cover are in R-3896-11.

1-236. SATURN V VEHICLE FLOW AT KSC.

1-237. While the S-IC Stage is being received and erected in the VAB, the S-II Stage, S-IVB Stage and Instrument Unit are received in the VAB and placed in the checkout bays where they undergo a complete pre-erection checkout. Upon completion of S-IC erection, the Saturn V vehicle assembly is started, concurrently with S-IC Stage testing. When the fins, fairings engine shrouds and nozzle extensions are installed, the S-IC Stage assembly is complete. The Instrumentation Unit is moved into the high bay, placed on a platform near the S-IC Stage, and an S-IC Stage-Instrumentation Unit-checkout is performed.

Upon completion of pre-erection checkout, the S-II Stage is moved from the checkout bay to the high bay and mated with the S-IC Stage. The S-IVB Stage is moved from the checkout bay and mated with the S-II Stage, and the Instrument Unit is removed from the platform and mated with the S-IVB Stage, completing the assembly of the Launch Vehicle (LV). After individual modules are checked out at the Manned Spacecraft Operations Building (MSOB), the Apollo spacecraft, consisting of the mated lunar excursion, and service and command modules, is moved into the VAB and mated mechanically (lunar excursion module-adapter to forward mating flange of the instrument unit).

1-238. VEHICLE TESTING.

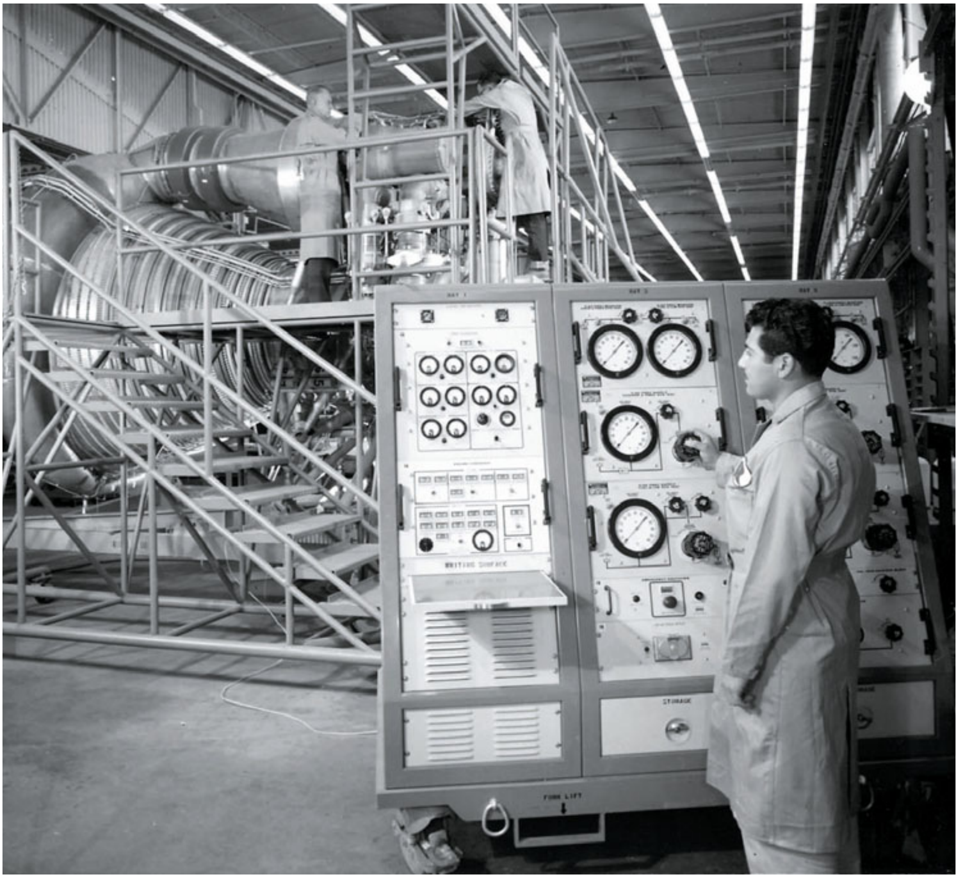
1-239. After the Apollo spacecraft and launch vehicle are mechanically mated, spacecraft modules are connected to their umbilicals from the umbilical tower of the mobile launcher and pre-power-on tests are made. When it has been determined that all flight and ground systems are satisfactory, full power is applied to the spacecraft. The spacecraft is then mated electrically to the launch vehicle and combined system tests, consisting of simulated countdowns and flights that exercise both flight and ground systems, are made. During the final combined system testing phase, the spacecraft and launch vehicle ordnance, minus pyrotechnics, are installed including the launch escape system. When the combined system testing is complete, the test data is reviewed, and if acceptable, the Saturn V vehicle is ready to be moved to the launch pad.

1-240. TRANSFERRING VEHICLE TO LAUNCH PAD.

1-241. The Apollo/Saturn V is transported from the VAB to the launch pad by the crawler transporter. The extendable platforms that enclosed the vehicle in the VAB are retracted, connections between the mobile launcher terminals and the terminals in the high bay are disconnected, the doors of the high bay are opened, and the transporter brought in and positioned beneath the platform section of the launcher. Hydraulic jacks are extended from the transporter to lift the launcher clear of its pedestals. Then, at a speed of approximately 1 mph, the transporter carries the launcher and the fully assembled Apollo/Saturn V to the launch pad for positioning.

1-242. LAUNCH PREPARATIONS AND TESTING.

1-243. After all electrical and pneumatic lines to the Apollo/Saturn V are reconnected through terminals at the base of the mobile launcher, and propellant lines, also connected through the launcher, are verified as correct, and it has been ascertained that no changes have occurred in the vehicle since it left the VAB, tests are made on the communication links to the vehicle. Measurements are also taken on systems such as the cutoff abort unit, radio-frequency, tank pressurization, and launch vehicle stage propellant utilization system. A Flight Readiness Test (FRT), backup guidance system test, and S-IC fuel jacket/oxidizer dome flush and purge are performed. Hypergolic propellants are loaded in the spacecraft tanks, RP-1 fuel is loaded in the launch vehicle tanks, and Countdown



5-16 F-1 engine No. 007 during a leak and functional checkout on May 3, 1962. Note the configuration of the turbine exhaust manifold. (Rocketdyne, Frank Stewart Collection).

Demonstration Tests (CDDT) are performed. Liquid oxygen and liquid hydrogen are loaded into the launch vehicle during the last few hours of the countdown.

1-244. SATURN V VEHICLE LAUNCH.

1-245. The data in this paragraph is only used to describe a typical vehicle launch and is not intended to represent actual launch data. With S-IC stage engines and launch vehicle preparations complete, the S-IC engines are fired, all holddown arms are released, and the vehicle committed for liftoff. The vehicle rises nearly vertically from the launch pad, for approximately 450 feet, to clear the launch umbilical tower. During liftoff, a yaw maneuver is executed to provide tower clearance in the event of adverse wind conditions or deviations from nominal flight. After clearing the tower, a tilt and roll maneuver is initiated to achieve the flight attitude and proper orientation from the selected flight azimuth. The S-IC center engine cutoff occurs at 2 minutes 5.6 seconds after first vehicle motion to limit the vehicle acceleration to a nominal 3.98 G-load. The S-IC outboard engines are cutoff at 2 minutes 31 seconds after first vehicle motion. Following S-IC engines cutoff, ullage rockets are fired to seat S-II stage propellants, the S-IC/S-II stages separate, and retrorockets back the S-IC stage away from the flight vehicle. A time interval of 4.4 seconds elapses between S-IC engines cutoff and the time the S-II engines reach 90 percent operating thrust level. Following the programmed burn of S-II engines, the S-II/S-IVB stages separate and the S-IVB engine places the flight vehicle in an earth parking orbit.

1-246. POST-FLIGHT DATA EVALUATION.

1-247. The post-flight data is evaluated to determine that the S-IC stage engines operated within the specified values during vehicle launch. The engine parameters are reviewed for abnormalities, sudden shifts, oscillations, or performance near the minimum or maximum limits. The engine performance values are then reviewed and compared to the predicted engine values to determine that all engine objectives were satisfactorily met.

1-248. UNSCHEDULED MAINTENANCE FLOW.

1-249. Unscheduled maintenance consists of those operations required in addition to normal engine and hardware processing, to repair damage, replace discrepant components or hardware, perform modifications and EFIRs, decontaminate, re-preserve, repair thermal insulation, or rectify any unsatisfactory condition. The unscheduled maintenance tasks are done at a specified time and at the location designated, during the normal engine flow process. The locations where unscheduled maintenance can be done are Rocketdyne, MAF, MTF, or KSC; depending on the extent of the task, urgency, capabilities of the location, and how schedules are affected. The location established for complete component maintenance, repair, and testing is the CM&R room at MAF. This facility provides component maintenance support for MAF, MTF and KSC. Limited repairs on components can be made in-place on the engine at MAF, MTF or KSC as directed by the customer. The necessary hardware required for supporting engine and component repairs at field locations is stored and maintained at MAF.

2-250. UNSCHEDULED ENGINE REPAIR SERVICING.

2-251. Unscheduled engine repair and servicing consists of various types of repairs and servicing tasks that are done whenever practical to correct any discrepancies that may exist, perform special inspections, and to update the engine configuration. The various repairs and servicing tasks may include such items as: braze and weld repair thrust chamber tubes, remove and replace components, clean contaminated areas, remove corrosion, touch-up of damaged surface finishes, modifications, EFIRs, post-maintenance tests, lubricate, preserve, and replace desiccants.

1-252. COMPONENT REPAIR.

1-253. Uninstalled engine components from MAF, MTF, or KSC that require repair, modification, analysis or testing are processed in the environmentally controlled CM&R room at MAF. Processing engine components in the CM&R room is required to repair a discrepant component from an engine, perform modifications, failure analysis, inspections, recycle testing, or pre-installation testing. After processing in the CM&R room, the components are designated to be installed on an engine, returned to the engine support hardware center as a spare, returned to the manufacturer, or considered as surplus or scrap. Detailed procedures for component maintenance and repair are in R-3896-3.

1-254. SUPPORT HARDWARE.

1-255. Engine hardware required for supporting the activities at MAF, MTF, and KSC is maintained in the Engine Support Hardware Center at MAF. The Michoud facility is the primary hardware supply center, since the majority of engine and component activity takes place at his location. At MTF and KSC a limited inventory of hardware is maintained to make sure of immediate availability of those items frequently used at these locations. Whenever an urgent need arises at either MTF or KSC, and the hardware required is not locally available, the item is expedited to that location directly from MAF or Rocketdyne.