November 24, 1986

PROPOSED ARTICLE

TITLE: Quality and Productivity Drive Innovation and Improvement at United Technologies Aerospace Operations, Inc.

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PUBLICATION: Upon clearance, will seek publication in "Industrial Engineering," published monthly by the Institute of Industrial Engineers

May also seek publication in other appropriate periodicals

PHOTOS: Paper copies will be replaced with color photos for publication

COMPANY NAME: The new company name will be used when it has been selected and approved

(NASA-CR-182944) QUALITY AND PRODUCTIVITY DRIVE INNOVATION AND IMPROVEMENT AT UNITED TECHNOLOGIES AEROSPACE OPERATIONS, INC. (United Technologies Corp.) 19 p CSCL 14D

N88-24983

Unclas

G3/38 0146697

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Quality and Productivity Drive Innovation and Improvement at United Technologies Aerospace Operations, Inc.

Quality and innovation have long been hallmarks of this nation's space program. In programs that preceded the Shuttle Program (Space Transportation System) the emphasis has been on meeting the risks and technical challenges of space with safety, quality, reliability, and success. This emphasis has been redoubled in the Shuttle Program with an added emphasis on productivity to respond to the added dimensions of the program. The Shuttle Program is a long term production type program which accommodates payload delivery requirements with a limited quantity of reuseable resources. This dictates that the reuseable Solid Rocket Boosters and Orbiters must be turned around by a relatively small but highly quality and productivity motivated work force.

This is the backdrop against which NASA and their prime contractors for the Shuttle Program must perform as they move into the mainstream of the operations phase of the program. They must have the motivated work force, excellent facilities and equipment, and effective management systems to turn each item of program critical flight hardware around with highest quality, in the required time, and at a competitive cost per flight. With limited quantities of major (and costly) hardware components and a production process constrained at both ends, the challenge quickly becomes a battle to assure the ultimate success of the program.

At United Technologies Aerospace Operations, Inc. (UTAO), the prime contractor for the non-motor parts of the Solid Rocket Boosters, the battle has developed along four primary fronts. These fronts include programs to motivate and reward people, development and construction of new optimized processes and facilities, implementation of specifically tailored management systems, and the application of appropriate measurement and control systems. Each of these initiatives will be described in the following paragraphs. However, to put this quality and productivity program in perspective, UTAO and its role in the Shuttle Program will be described first.

United Technologies Aerospace Operations, Inc.

UTAO is a United Technologies Corporation (UTC) company. Organizationally, it is assigned to Space Transportation Systems under the UTC Defense & Space Systems Group. UTAO's predecessor company, USBI was originally formed in December, 1976 under the Chemical Systems Division specifically to compete for the Solid Rocket Booster contract, a part of NASA's Shuttle Program. Starting with a cadre of seventeen Chemical Systems Division people, the company has developed and grown dramatically. Winning a recent recompetition of the contract, the production company was broken out in January 1985 as USBI-BPC with approximately 1,000 employees at four locations: the Kennedy Space Center in Florida; Huntsville, Alabama; Vandenberg Air Force Base, California; and Slidell, Louisiana. Effective January 1, 1987, USBI-BPC became United Technologies Aerospace Operations, Inc. (UTAO), reflecting the company's broadening role in the aerospace industry.

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UTAO's Role in the Shuttle Program

UTAO is currently under contract with the NASA Marshall Space Flight Center to provide assembly and refurbishment of major solid rocket booster components. Essentially, UTAO operates a doubly constrained recycling production process for NASA to provide solid rocket boosters for shuttle launches. The process is doubly constrained by a firm launch schedule on one end and the recovery of expended boosters on the other end. After retrieval, the expended boosters are refurbished for reuse in follow-on launches. The recycling of the boosters over time produces what can be described as a spiral production process.

Each cycle of the spiral process starts with a building or rebuilding (refurbishing) of the major components of the solid rocket boosters. A set of two boosters is required for each launch. Each booster consists of a nose cap, frustum, forward skirt, four solid rocket motor segments, and an aft skirt. UTAO has primary responsibility for all of these structures except the motor segments. For a new build, there are about 50,000 piece parts that must be assembled into the major structures, not including the motor segments. About 5,000 of the parts are serialized and require careful tracking of very complete histories for the life of the part. The overall system is designed to last for twenty launches, but many sub-components have different lives in terms of time or cycles. Since this is a man-rated and expensive system, strict configuration control is exercised and extensive testing and checkout are required. In addition to the major structures for the two boosters, parts kits are also produced for stacking booster segments, mating the boosters to the mobile launch platform, and mating the Shuttle's external tank to the boosters.

At the completion of the assembly/refurbishment effort, the aft skirts and forward assemblies (nose cone, frustum, and forward skirt), complete with separation and recovery systems, are transferred to NASA and their single processing contractor with the parts kits for stacking. The boosters are then assembled; integrated with the mobile launch platform, external tank and shuttle; thoroughly tested and checked out; transferred to the launch pad where further integration and testing occurs; and launched.

About two minutes after launch, at an altitude of around 30 miles and approximately 130 miles down range, the solid rocket boosters separate from the orbiter and its external tank and begin their descent into the Atlantic Ocean. Once they splash down in the Atlantic, all major booster components are picked up by two USBI-designed and built retrieval ships and brought back to company-operated facilities for refurbishment.

In addition to the challenges inherent in the processes described above, additional challenges are added by exposure of the hardware to salt water during retrieval, handling and integration of ordnance, and the handling of hazardous materials. Each of these, along with the relatively low projected production volume (ultimately 24 flight sets per year), must be considered carefully in designing an effective quality and productivity program. The Solid Rocket Booster program is also part of the larger Shuttle program, and SRB quality enhancement and productivity improvement effort must be integrated with and complement the efforts of other contractors and the customer, NASA.

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The Solid Rocket Booster Quality Enhancement and Productivity Improvement Plan

The company's Quality Enhancement and Productivity Improvement Plan is the primary management tool used to assure appropriate program definition, development, execution, and tracking. It helps to assure that the program is integrated across functional lines and within the NASA and Shuttle contractor community. It also provides the baseline for judging the adequacy of progress and a catalog of past, present, and anticipated efforts.

The plan defines the philosophy behind the company's program and how it will be conducted. It includes sections labeled Forward, Purpose, Objectives, Scope, Organization, and Approach. Programs and Projects are broken down into three main categories: UTAO, Joint UTC/UTAO, and Joint NASA/UTAO. Within these categories, there are further sub-categories (People, Processes, etc.), and each project and program is described on a one-page data sheet. Data sheets name and describe the program/project, identify the organization and person responsible for accomplishment, define the objective, and break out specific time-phased milestones.

Following this section, there is a master schedule which shows the time-phasing of all active projects and sections which define tracking and reporting requirements and describe meetings and dissemination channels related to the program. The final section provides information on completed projects.

The program is tracked at several levels. There are internal management reviews and periodic meetings which address particular programs and projects as the need arises. There are also frequent NASA MSFC project office program reviews and quarterly joint contractor reviews which are hosted by MSFC or a different contractor each time. All of these meetings are used to disseminate and collect information and ideas as well as track progress against the plan.

The Quality Enhancement and Productivity Improvement Plan includes projects and actions which address essentially every facet of Solid Rocket Booster assembly and refurbishment operations: people, organization, equipment, tooling, facilities, documentation, parts, and materials. A sampling of current projects is described in the next three sections.

People and Organization

UTAO has a number of programs which are designed to motivate quality and productivity in activities at all levels of the company. Specific programs address managers, employees, and teams, and the company participates in NASA programs as well as those operated internally or within the United Technologies Corporation family.

Perhaps the most innovative program is the Group Motivational Incentive Program. It provides for 50-50 sharing between the company and employees of specific profits which will be derived from under-running the first block of the Booster Assembly Contract. This program is a first for space programs and within this segment of the industry.

The company's VISIONS program is designed to stimulate and reward the generation of innovative ideas of all kinds, not just those that contribute to quality, efficiency, or dollar targets. It is complemented by a cost reduction program which considers ideas that will reduce costs or increase profits and provides monetary rewards which are proportional to the savings or profits.

UTAO also participates in NASA's motivational programs for individuals and groups. Silver Snoopy awards are presented to individuals by astronauts to recognize their achievements and contributions. Individuals are recognized as Launch Honorees at pre-launch activities participated in by NASA and contractor leadership as well as astronauts. The NASA Center Director also presents team awards periodically for significant team accomplishments. These NASA programs are complemented by internal programs such as employee recognition dinners and other company and corporate awards and recognition.

The company has a well developed and expanding Quality Circles program. This initiative is extended and enhanced by the use of multi-disciplinary Productivity Work Teams or ad hoc teams designed to address specific long-term opportunities or short-term problems.

UTAO also provides a wide variety of skills and management training for people at all levels of the organization. This includes in-house training, seminars by outside professionals, university short courses, corporate-sponsored courses and seminars and, of course, tuition assistance for associates, bachelor's, and advanced degree programs.

At the beginning of 1985, UTAO reorganized into a production-oriented structure, designed to accommodate transition from the development phase of operations into production. It should be remembered that this is the first manned space program to be placed on an extended run, production type footing. Since the program will have the longevity and rate to be considered a production program, appropriate optimization of facilities, processes, and equipment is economically justified.

Facilities, Processes, and Equipment

UTAO has been working with NASA since 1981 to define and build new production facilities optimized for solid rocket booster assembly and refurbishment. The plant resulting from these efforts was completed in August 1986 and is currently being prepared for production at the Kennedy Space Center in Florida. There are a number of interesting features in the plant and process equipment that will give some indication of the innovative thought that went into the development of the facility. In anticipation of the new plant, build-up of large structures (aft skirt, etc.) was moved a couple of years ago from fixed work stands to mobile air bearing work stands, greatly improving flexibility and productivity, and reducing the number of crane lifts by 30 percent. This also allowed the plant to be designed with a nice clean, efficient flow pattern. Flow-through spray and cure cells are included in the thermal protection system application area to avoid back tracking.

Automation and robotics have been applied to enhance quality and save labor as the rate increases and to minimize exposure of employees to less desirable jobs. A gantry robot will be used to sand and solvent clean the exterior

surfaces of major structures in preparation for thermal protection systems application. A new thermal protection system has been developed in conjunction with NASA (Marshall Sprayable Ablator 2). A gantry robot will also be used to spray on ablator and topcoat on the exterior surfaces of the large structures and protective foam on the interior of the Aft Skirt. A vision and smart system will be used to control wet film thickness during robotic spraying operations, and another smart vision system will be used for inspection of prepared and sprayed surfaces.

A new automated checkout system has been developed and is being installed at the new facility. This third generation solid rocket booster checkout system will provide automated post assembly systems tests for all subsystems just prior to transfer for stacking.

An earlier application of automation in the solid rocket booster assembly process is the automated bending of titanium and stainless steel tubes used in Aft Skirt buildup.

Even though initial refurbishment operations will remain in existing facilities on Cape Canaveral Air Force Station, considerable attention has been given to these processes. (It should be remembered that this is the first space launch system where hardware is recovered after launch, refurbished, and reused.) A new gantry robot system has been developed to direct the high pressure water stream used to remove the thermal protection system from flown hardware. It will also allow automated removal of protective foam from the interior of the Aft Skirt. In addition, the entire parts refurbishment operation has been reorganized into a flow line and automated cleaning equipment added to eliminate much of the labor intensive hand cleaning.

All solid rocket booster processes were subjected to considerable analysis as part of the effort to determine the need for, develop, and optimize the new facility. Techniques applied include process flow charting, activity relationship analysis, simulation, and layout comparisons. These analyses produced greatly improved process flows, layouts, tooling, and work paper. This extra attention to processes is expected to yield dividends in quality and productivity.

Management Systems

UTAO began "productionizing" management systems long before the production stage of the program was reached and before improved production facilities were developed. One of the very first systems to be worked was the Integrated Production Control System. This system was built from a modern, closed-loop Manufacturing Requirements Planning (MRP-II) system extensively modified to accommodate the aerospace environment (configuration control, time & cycle tracking, etc.) and interface with other technical management systems then under development (Automated Restriction Tracking, etc.). This system is currently in the final stages of implementation.

Objective "should cost" engineered labor standards have also been developed specifically for solid rocket booster assembly and refurbishment operations. These standards are complemented by a labor collection system which allows performance tracking and assessment of the effectiveness of management adjustments. The standards also provide the basis for routing times for the

Integrated Production Control System and the labor collection system is an integral part of the shop floor control module of the IPCS.

Learning curves are used to set manhours targets for accomplishing the touch labor activities of thermal protection system application, assembly, test, and refurbishment. Variable support activities, such as production engineering, are derived from the touch requirements and are generally driven by the learning curves also.

The "what if" capabilities of the Integrated Production Control System, the automated labor standards system, and other management systems allow simulation of various conditions, scenarios, and decisions to pre-test the effectiveness of management responses before selecting and implementing a particular course of action. We also have a manufacturing simulation software package that allows pre-implementation evaluation of changes in production operations. Impacts on characteristics such as throughput, support equipment requirements, and plant capacity can all be assessed with excellent reliability.

Bar coding is being evaluated for inventory and tool management applications. During tests it helped to improve both the accuracy and efficiency of inventory management, cycle counting, and tool control.

Personal computers which double as main frame computer terminals are helping to improve management and office productivity. This approach places local computing power in the hands of our managers, engineers, and administrative people. At the same time, they have access to the main frame data base and computing power through the terminal capabilities available through these PC's. Word processing and graphics capabilities are also included at appropriate work stations.

Other goal-oriented processes such as Management by Objectives are also integral parts of our management processes. Some of these, like MBO and productivity measures also extend up to corporate levels, assuring that the broadest corporate resources are focused on eliminating impediments and achieving goals.

Our contract also includes a highly motivating feature: a 50/50 share line on under-runs and over-runs. With the goal-oriented management systems described above and a 50/50 share line incentive, there is plenty of motivation to carefully measure and control performance and progress.

Measurement and Control

Measurement and control systems are a well established part of large projects, especially those operating under government auspices. These systems definitely promote good management, and when they are applied with the proper perspective, they can also promote operational excellence and increased productivity. Three systems of this type being applied to the Solid Rocket Booster program include the performance measurement system, productivity measures, and management indicators.

The performance measurement system is a project management cost and scheduled control tool which conforms to NASA and DOD requirements. It budgets and controls dollars and manhours by organizational element and work breakdown structure category. By comparing actual expenditures and work accomplished with budgeted/scheduled quantities, cost and schedule problems can be detected early, isolated to particular organizational elements, and incisively analyzed. This allows early corrective measures to be implemented to assure ultimate achievement of budget and schedule goals. Since manhour budgets have learning curves and other improvement factors built in, the system also provides rough, preliminary measures of organizational productivity.

A productivity measures program similar to one undergoing test and implementation in the Air Force is in the early stages of development and implementation for the Solid Rocket Booster program. In this program, a variant of the nominal group techniques is used to develop and integrate section, branch, and departmental level productivity measures. Since these measures are developed by the people from each of these levels and they are integrated upward, they reflect productivity as viewed from the perspective of the people charged with the job and have better grass roots support.

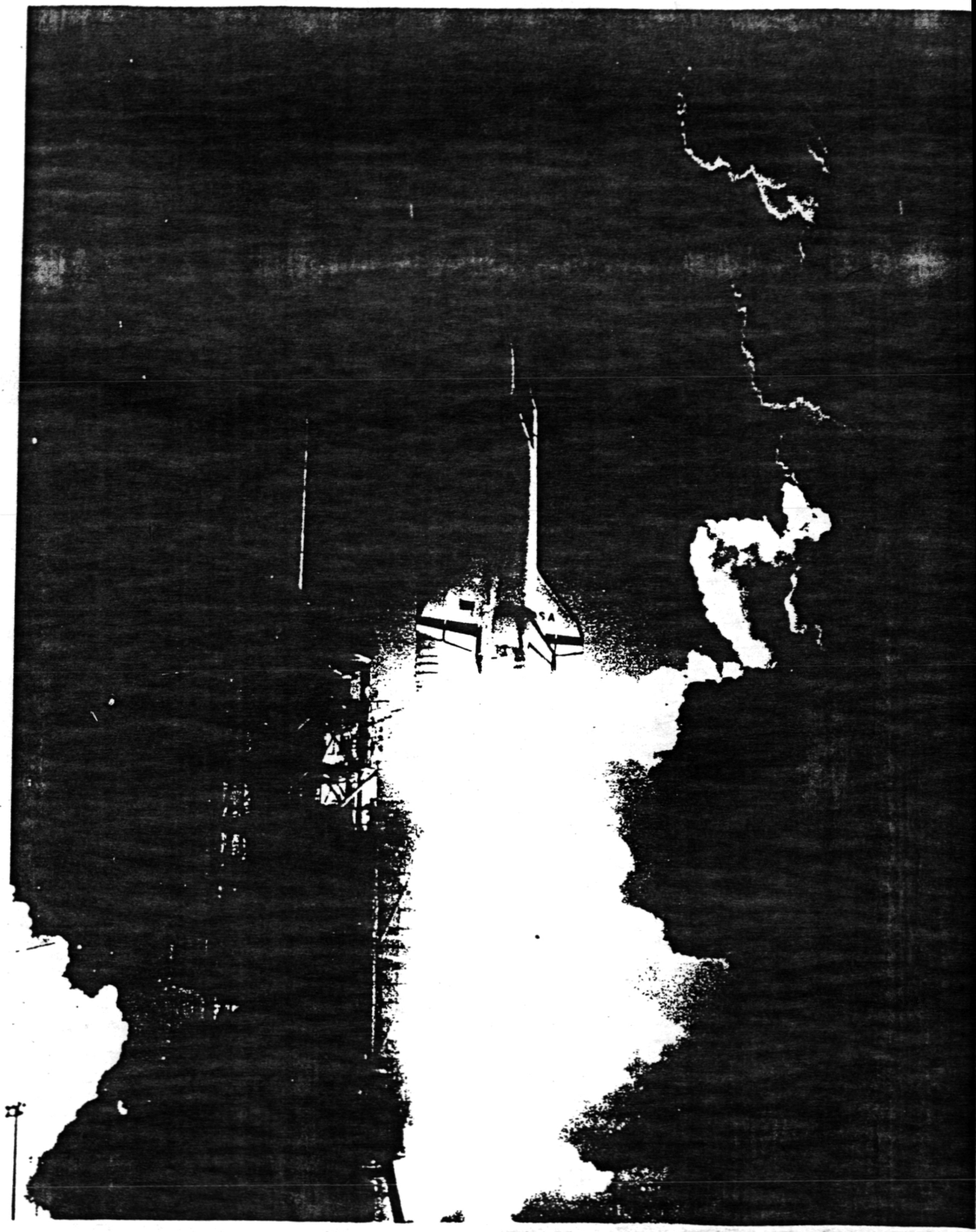
A system of management indicators is also maintained within program management. These include a variety of indicators, including some from the performance measurement system, some from the integrated production control system, progress on key projects, and others. This system focuses on overall company performance, with a strong emphasis on effectiveness (doing the right thing) and secondarily on productivity (only when the proper heading is ascertained).

Going to Work in Space

From the description above, it should be clear that everything possible is being done to produce highest quality Solid Rocket Booster hardware and make the program as technically successful, effective, and efficient as possible. UTAO has some seventy quality and productivity initiatives under way, from the tried and true to the latest technology, in virtually every facet of our operations. These efforts are fully coordinated with and supportive of the NASA program and the efforts of other Shuttle program element contractors. Many of the initiatives in this program are pioneering efforts for the nations' space program.

In recognition of productivity strides made in 1985, particularly in driving touch labor costs down a very rapid learning curve, United Technologies Corporation presented UTAO with the Arther E. Smith Award for excellence in productivity achievements. Previous winners of this annual award were Pratt and Whitney and Sikorsky Aircraft.

The Space Shuttle and Space Station represent man's first enthusiastic steps toward going to work in space. The initiatives described above represent some of the first vigorous efforts to ensure that those steps proceed with quality and productivity.



LAUNCH OF THE SPACE SHUTTLE FROM THE KENNEDY SPACE CENTER IN FLORIDA

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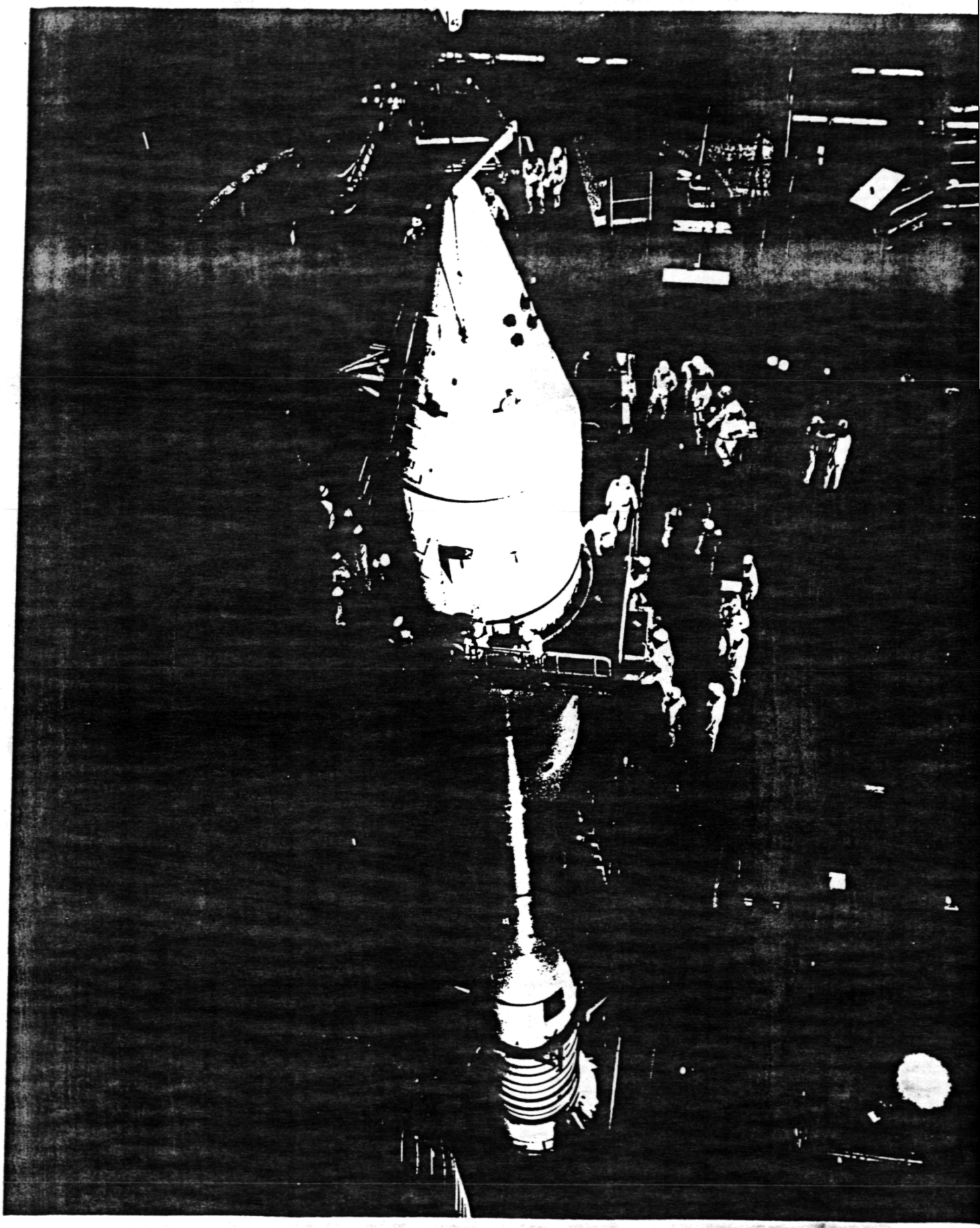

STACKING THE SOLID ROCKET BOOSTERS ON THE MOBILE LAUNCH PLATFORM

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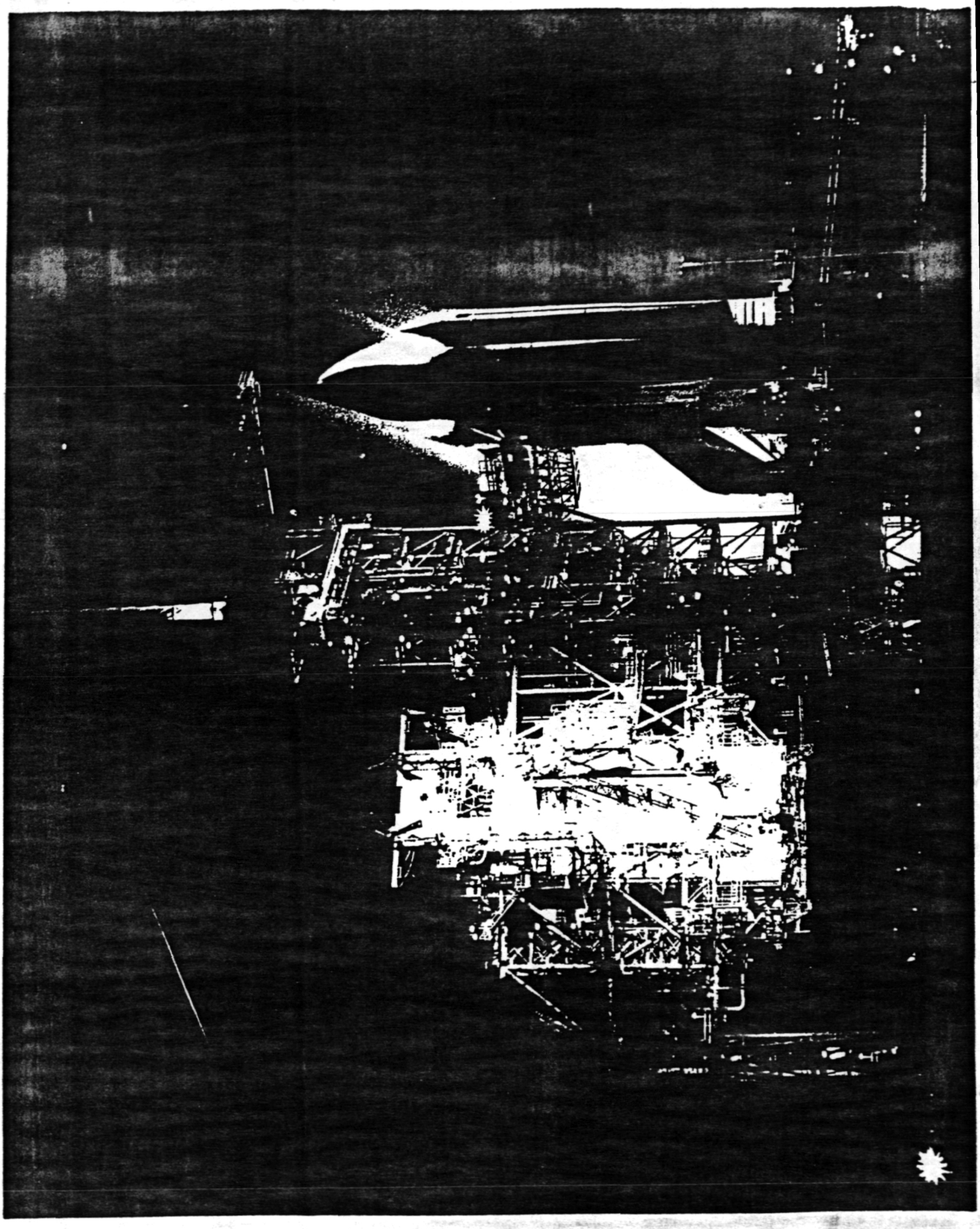

THE SPACE SHUTTLE BEING PREPARED FOR LAUNCH AT PAD 39A AT THE KENNEDY SPACE CENTER

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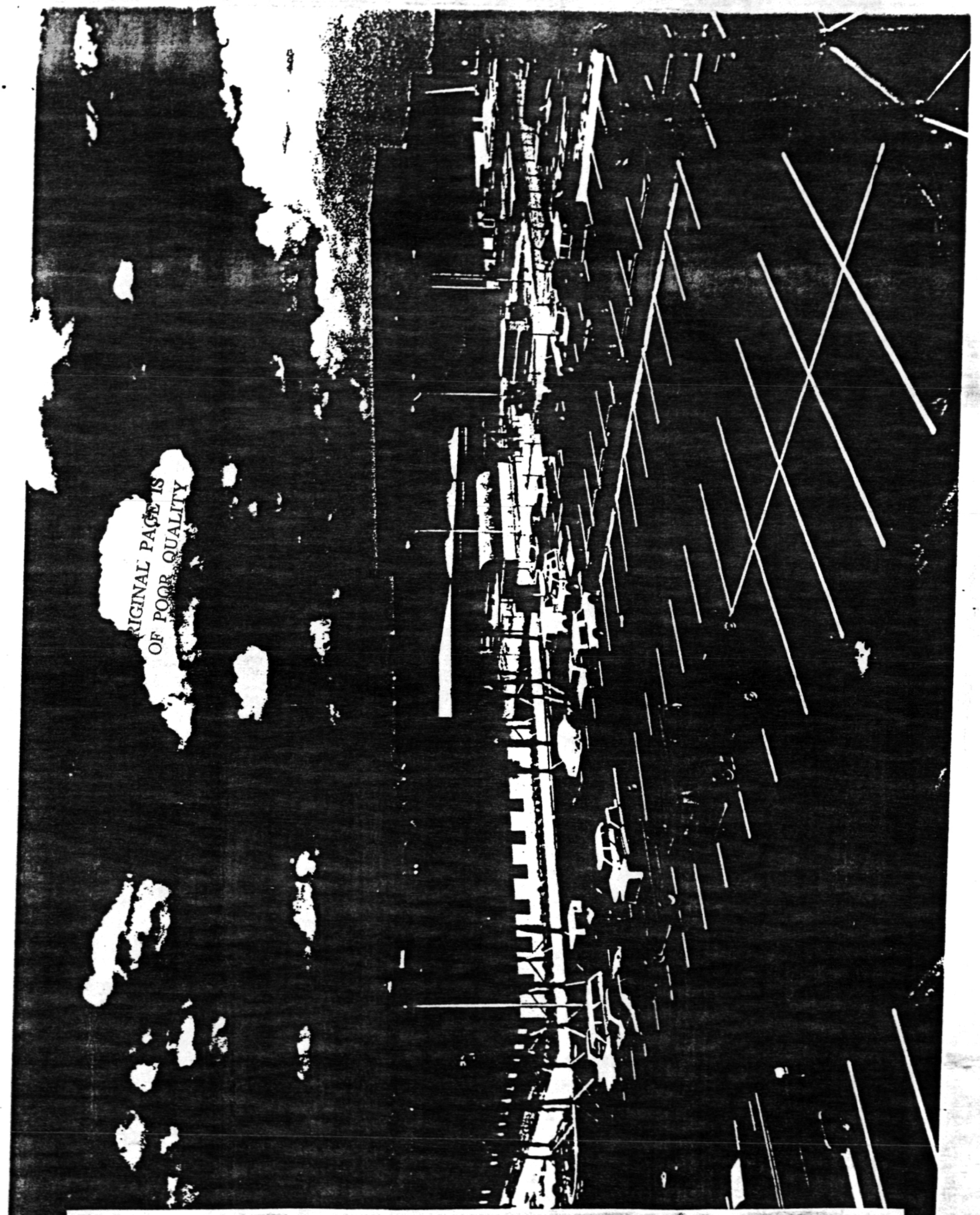

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NASA's NEW SOLID ROCKET BOOSTER ASSEMBLY AND REFURBISHMENT FACILITY AT THE KENNEDY SPACE CENTER. THIS NEW FACILITY WAS DESIGNED AND DEVELOPED AND IS OPERATED BY UNITED TECHNOLOGIES AEROSPACE OPERATIONS, INC.

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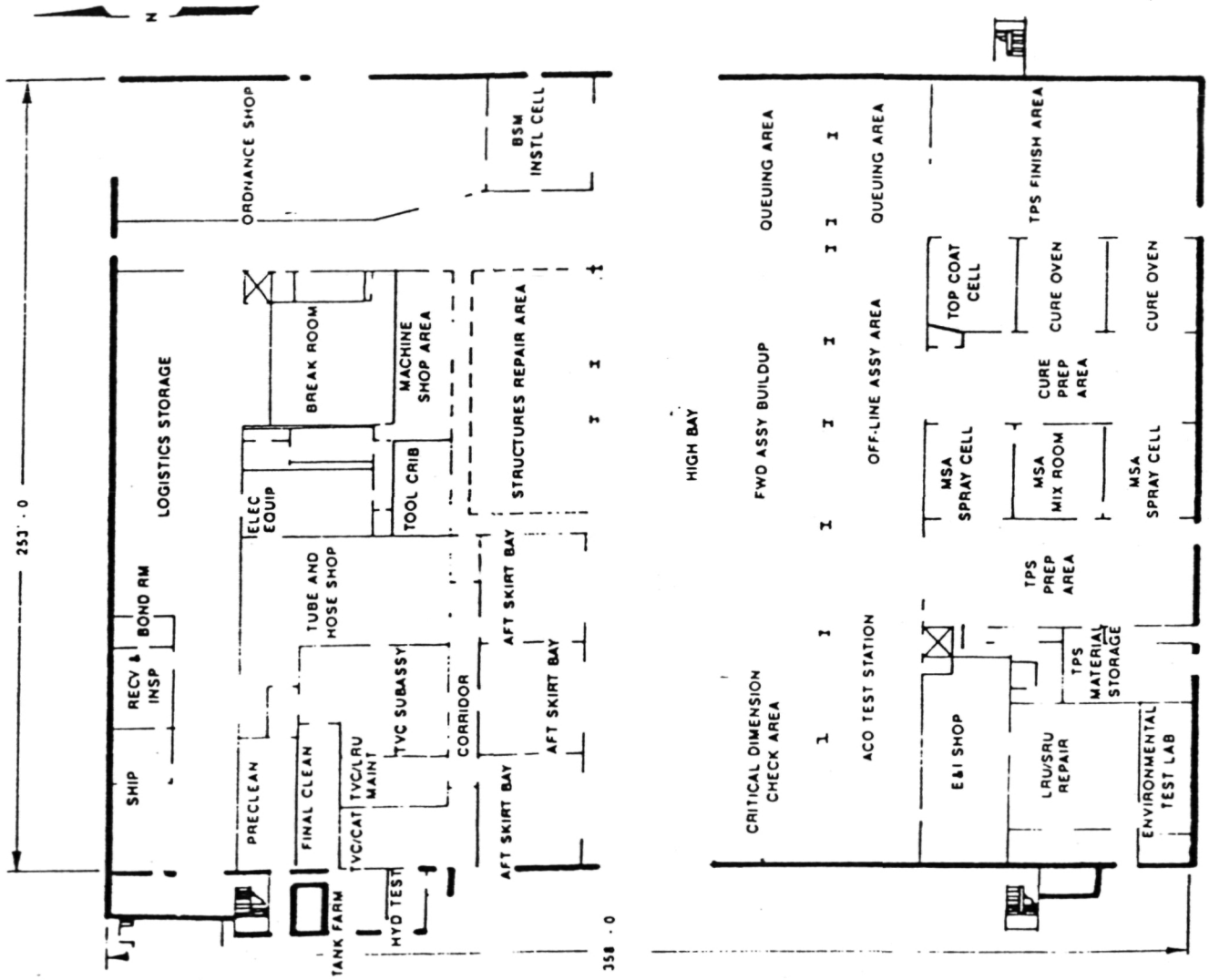
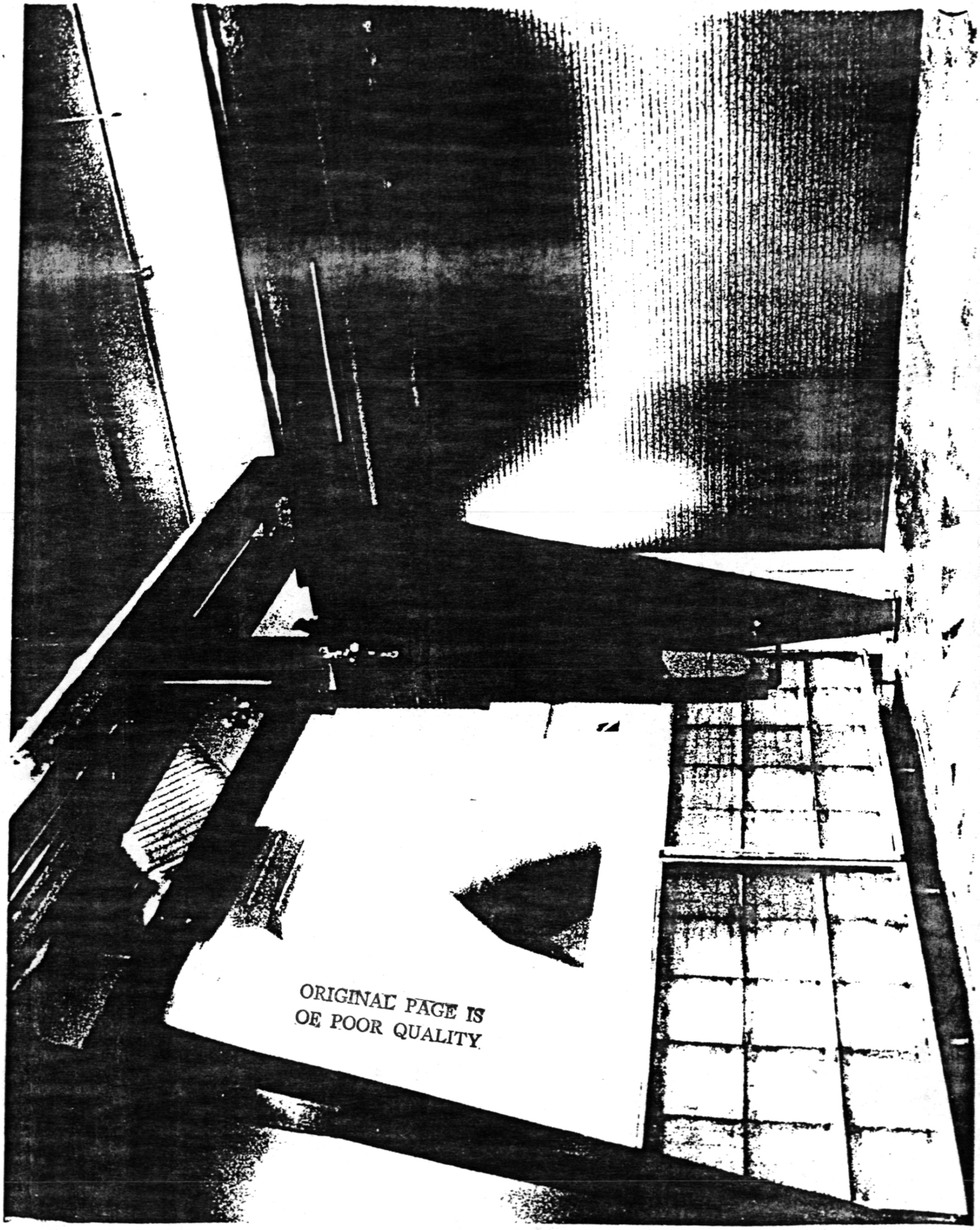
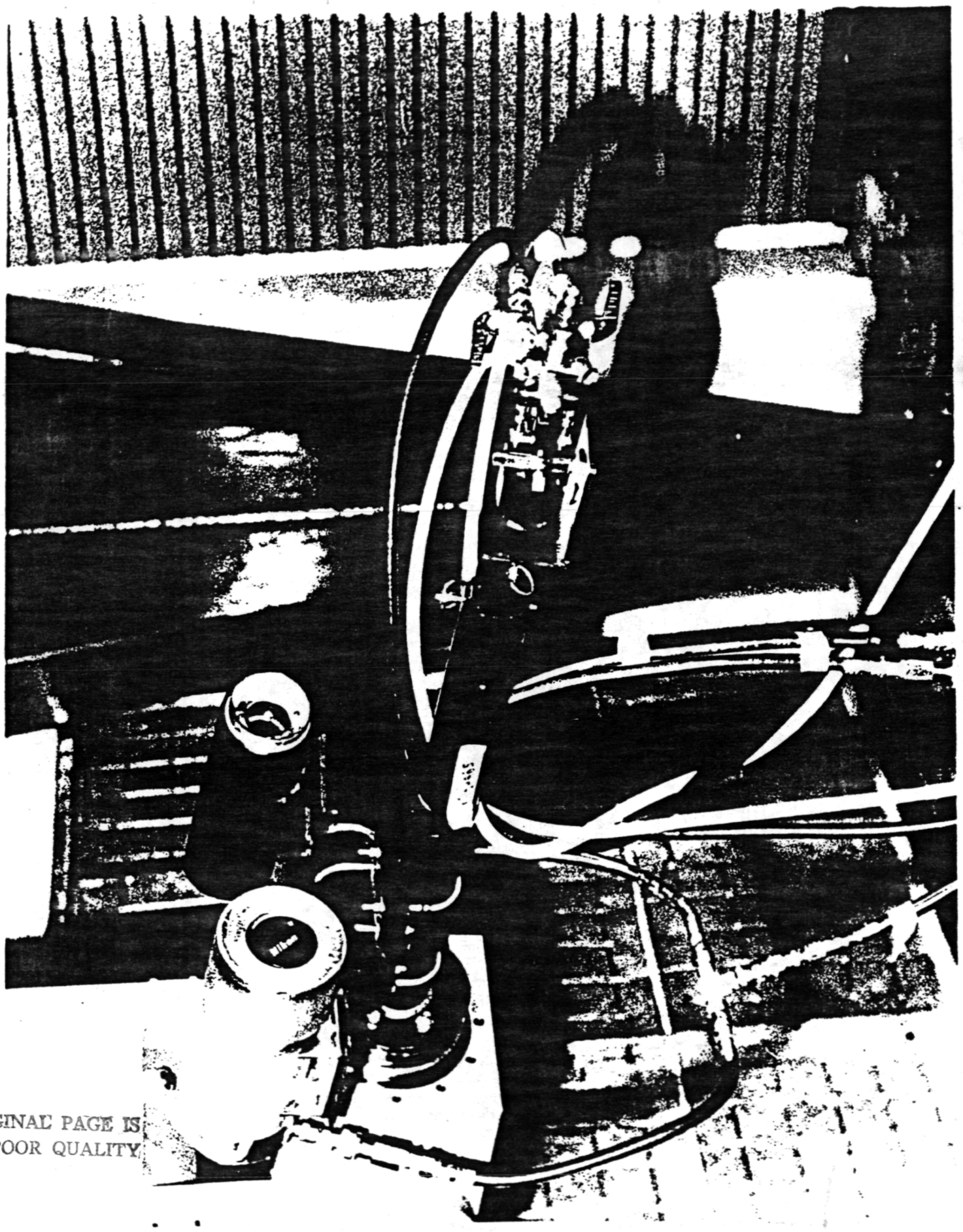


MANUFACTURING BUILDING
FIRST FLOOR PLAN

LAYOUT OF THE NEW ASSEMBLY AND REFURBISHMENT FACILITY



THIS LARGE GANTRY ROBOT SANDS, CLEANS, APPLIES THE THERMAL PROTECTION SYSTEM TO AND INSPECTS THE SURFACE OF THE MAIN SOLID ROCKET BOOSTER STRUCTURES.



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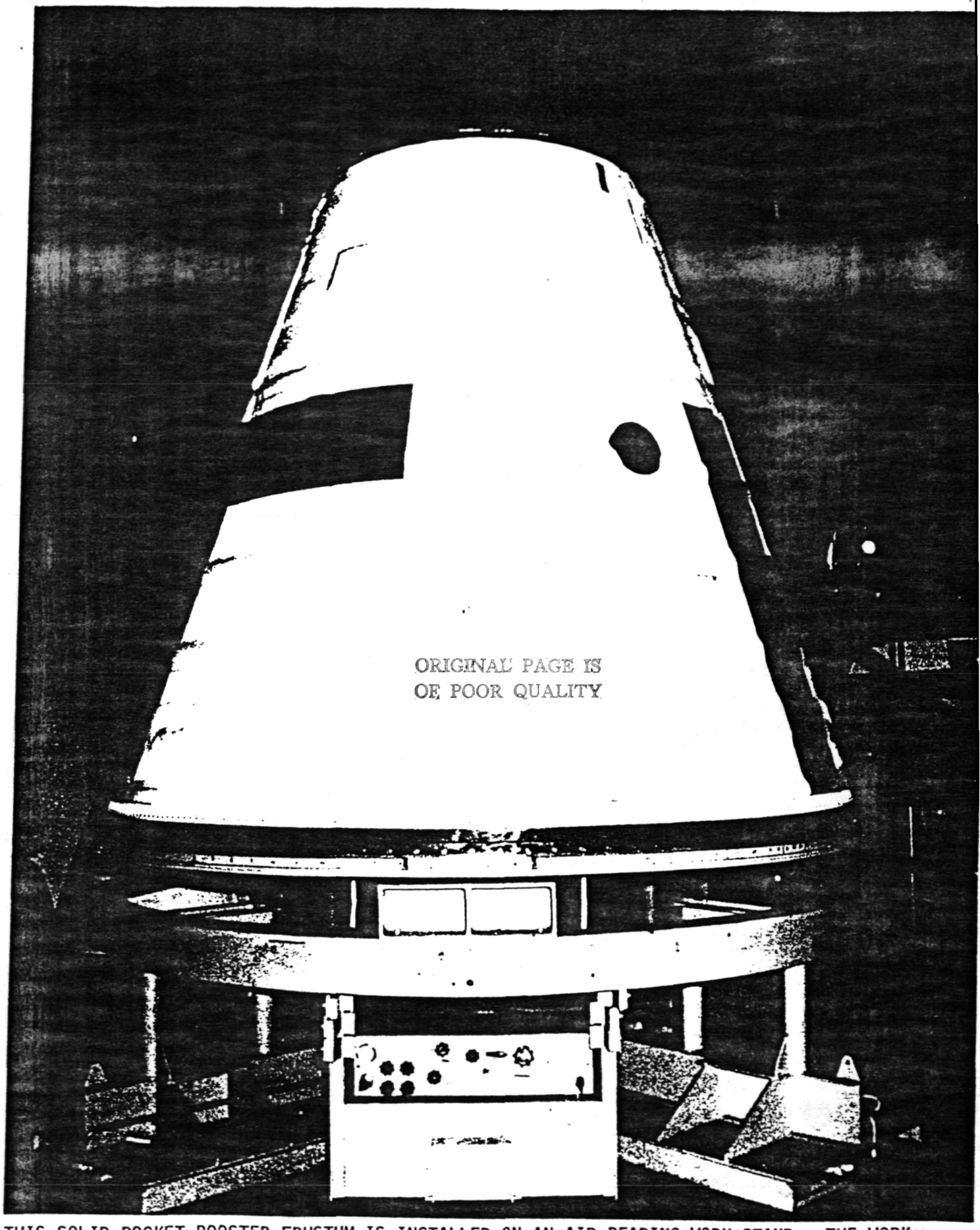
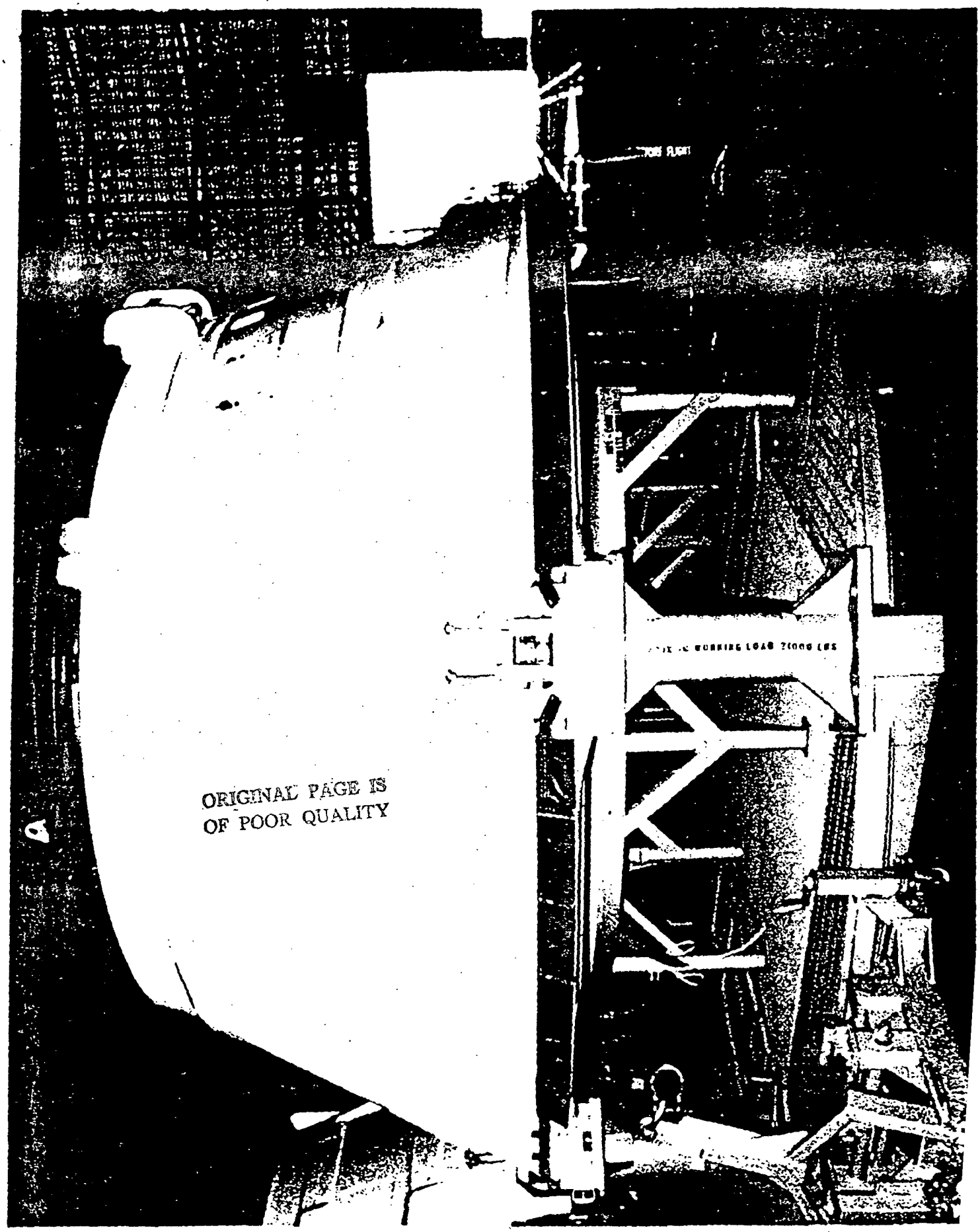
THIS ROBOT END EFFECTOR INCLUDES A SPRAY NOZZLE, LIGHT SOURCE, AND A CLOSED CIRCUIT VIDEO CAMERA. IT IS USED TO SPRAY PROTECTIVE FOAM IN THE AFT SKIRT AND FRUSTUM STRUCTURES FOR THE SOLID ROCKET BOOSTERS.



THIS SOLID ROCKET BOOSTER FRUSTUM IS INSTALLED ON AN AIR BEARING WORK STAND. THE WORK STAND ELIMINATED 30% OF THE REQUIRED CRANE LIFTS, ALLOWS EASY MOVEMENT DURING PROCESSING, AND WAS THE KEY FACTOR IN THE DEVELOPMENT OF AN EFFICIENT, PRODUCTIONIZED FLOW SHOP PROCESS.



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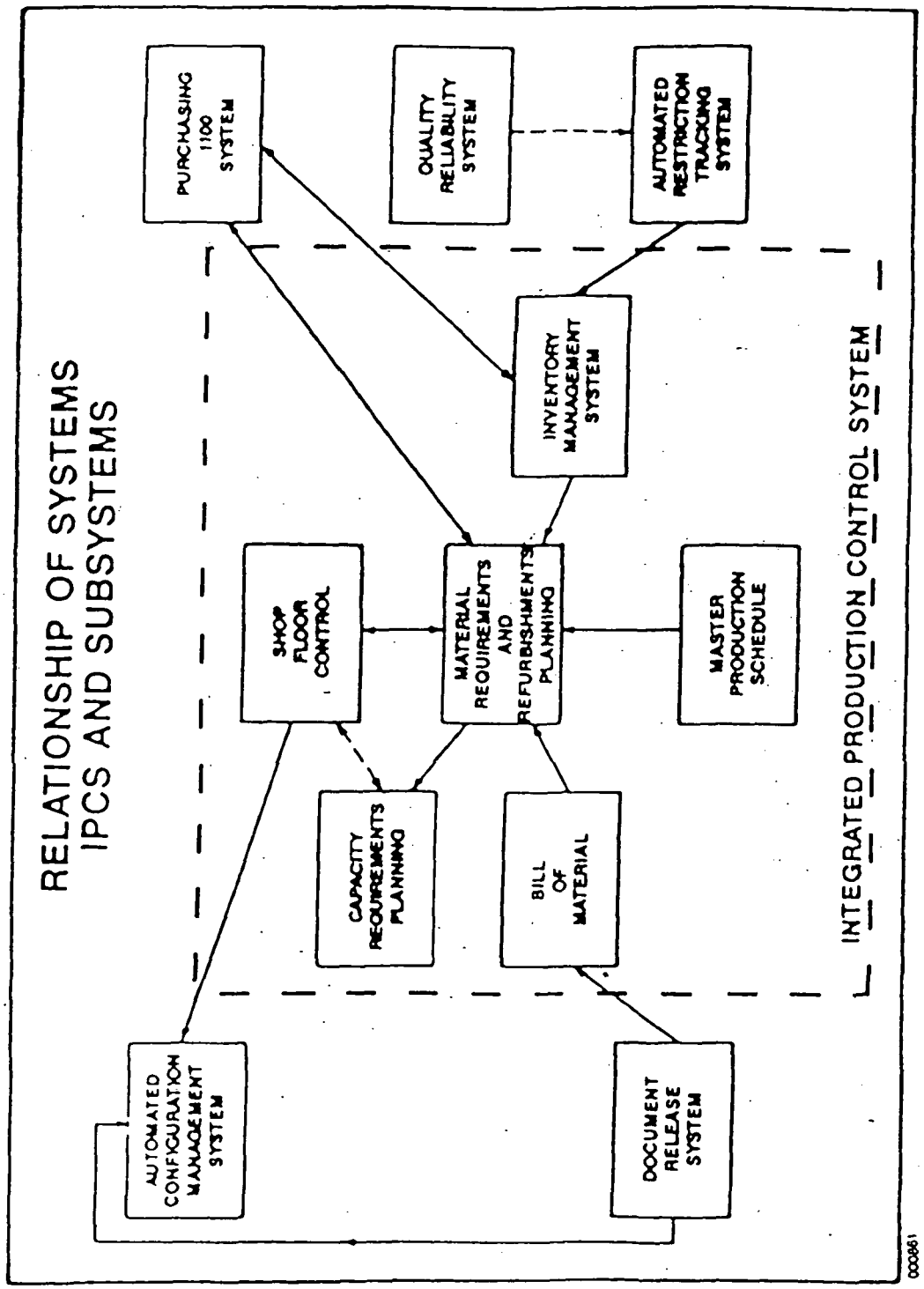
A SOLID ROCKET BOOSTER AFT SKIRT INSTALLED ON AN AIR BEARING WORK STAND.



THIS CLOSED LOOP AEROSPACE MATERIAL REQUIREMENTS PLANNING PRODUCTION CONTROL SYSTEM IS THE HEART OF UNITED TECHNOLOGIES AEROSPACE OPERATIONS' PRODUCTION MANAGEMENT APPROACH.

USBI Booster Production Company, Inc.

UNITED TECHNOLOGIES

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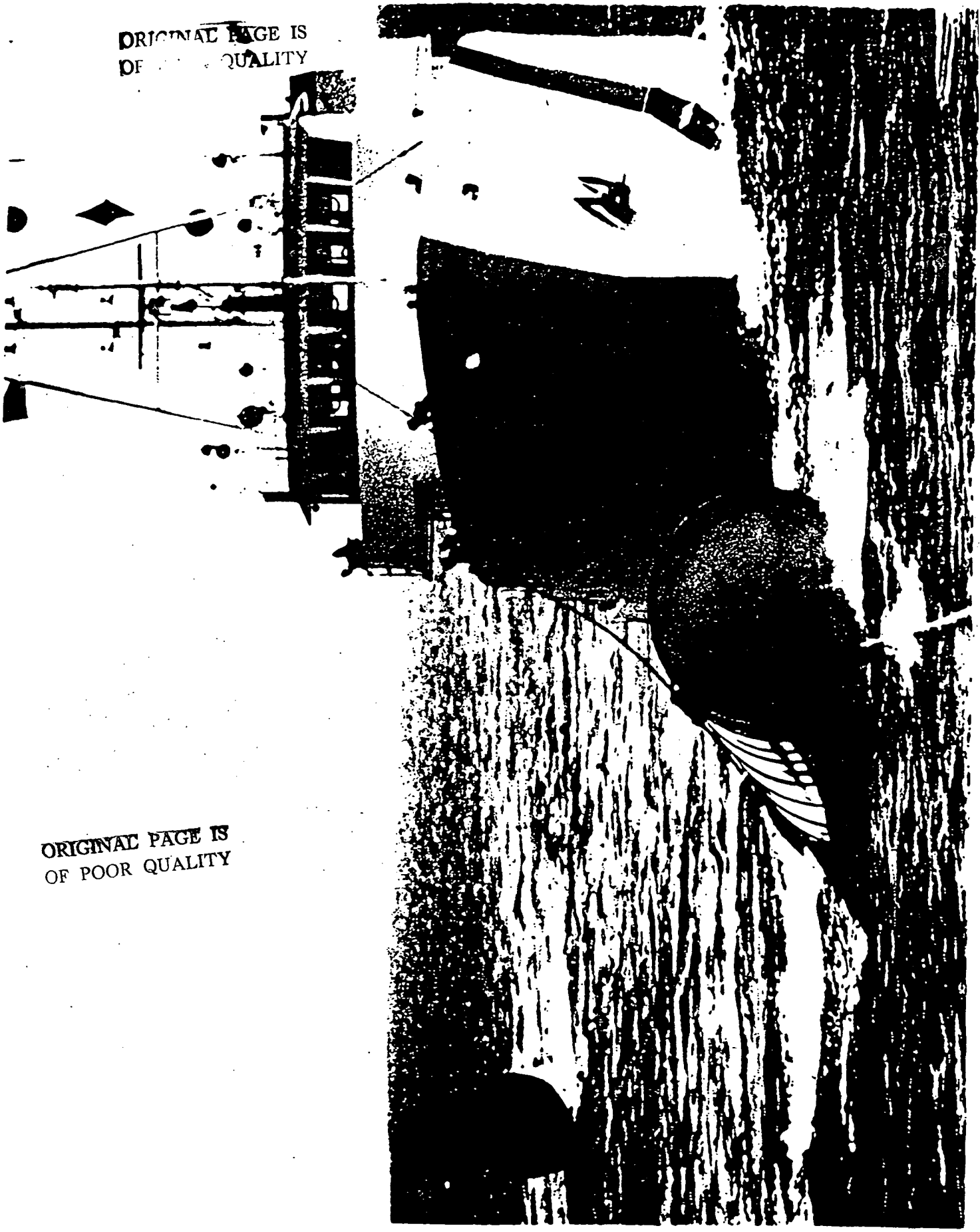

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THE SPACE SHUTTLE IS THE FIRST PROGRAM OF ITS KIND TO USE FLIGHT HARDWARE THAT HAS BEEN RECOVERED AFTER LAUNCH AND REFURBISHED FOR USE IN SUBSEQUENT FLIGHTS.