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Facilities Engineering for the National Aeronautics and Space Administration

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The National Aeronautics and Space Administration, like most Government Agencies during these days of the six billion dollar budget cut, is becoming more and more Cost Control conscious. However, even before this, NASA had built many test stands and other test facilities which exemplified the principle of cost control as well as safety. NASA feels that vigorous testing of space vehicles prior to launch is effective cost control.

As most of you know, NASA's mission is the exploration of outer space with the goal set by the late President John F. Kennedy of landing men on the moon within this decade and returning them safely. To accomplish this mission various centers, as shown in Figure 1, have been established throughout the nation. Many of these centers were inherited from previous Government Agencies, such as, National Advisory Committee for Aeronautics, Army Ballistic Missile Agency, etc. Others are entirely new centers, such as Manned Spacecraft Center at Houston, Electronics Research Center at Boston and Goddard Space Flight Center at Greenbelt, Maryland. Some of the centers, such as Goddard, Ames, and Lewis, are concerned with technology development and unmanned space flights. Marshall Space Flight Center, Kennedy Space Center, and Manned Spacecraft Center are concerned primarily with manned space flights. Of these three centers, two are located in our Southeast and I would like to go more deeply into their misssions and their facilities.

Marshall Space Flight Center, the largest NASA Center, with over 6,000 civil service employees, consists of about 1,800 acres within the 40,000 acre Redstone Arsenal located just southwest of Huntsville, Alabama. The Center, valued at more then $300 million, consists of more than 270 structures and buildings with floor space totaling about 4-1/2 million square feet.

Marshall's prime responsibilities are the development of large launch vehicles, such as Saturn I and Saturn V; space crafts for deep space and near earth missions; and studies of future space exploration projects. To accomplish these missions, Marshall is divided into two major organizational elements which are the Research and Development Operations and the Industrial Operations.

It is the responsibility of the Research and Development Operations to insure that the Marshall Center remains expert in the basic aspects of space technology. The Industrial Operations provides the capability of managing the efforts of industry. The Research and Development Operations has eight major laboratories to perform the basic functions of design, development, fabrication, and testing of launch vehicles and payloads. These laboratories and their respective functions are as follows:

Aero-Astrodynamics Laboratory is responsible for the vehicle's shape and design, aerodynamic flow and stability, trajectories, and flight evaluation and performance. To accomplish this, the Aero-Astrodynamics Laboratory has such facilities as a 14 inch Trisonic-Wind Tunnel, High Reynolds Number Test Tunnel and Base Flow Test Sections.

Astrionics Laboratory performs the research and development of components and systems in the area of guidance, control, electrical networks, vehicle borne tracking, measuring telemetry, range safety devices and associated electrical ground support equipment for multi-stage launch of space vehicles. The Astronics Laboratory is housed primarily in a 325,000 square foot electronics research laboratory building.

Computation Laboratory is responsible for conducting high-speed digital computation, simulation and data reduction in the fields of space vehicles research, and for devising improved methods and systems. The laboratory also operates one of the largest concentrations of computation equipment in the world in furnishing a business-type service to the administrative and management segments of the Center. Equipment includes electronic digital computers, analog computers, vibration analysis systems, analog-to digital conversion equipment and other high-speed computers and automation devices.

The Computation Laboratory is now in the process of converting to a 14 million dollar, third-generation, computing systems concept. This concept places the major computer hardware on-line to the user, that is, the computer users have remote operational consoles that communicates directly with the central facility over standard telephone communication lines.

Manufacturing Engineering Laboratory has pioneered in the fabrication and assembly of space boosters from the Redstone to the Saturn S-IC, first stage of the Saturn V, in the facilities shown in Figure 2. These facilities include large hangar-type buildings for the fabrication and assembly of large boosters, a variety of welding equipment, milling machinery, explosive-forming tanks, machine shop for precision machinery, and clean room for assembly of valves and other components.

Propulsion and Vehicle Engineering Laboratory, as seen in Figure 3, performs aerospace research and development in materials, structures and propulsion systems. The facilities necessary to support these functions range from ceramic laboratories to a four million dollar test stand to perform structural static load testing and verification of full scale vehicle structures. This stand is essentially a 30,000,000 pound capacity compression testing machine. Included also are facilities for non-destructive testing, electron beam welding, salt spray simulation, material fatigue and tensile testing, and environmental test vacuum chambers. The 30,000,000 pound Load Test Annex is used to static load test the full-scale boosters for such critical loading conditions as vehicle lift-off, maximum "Q", rebound, stage separation, etc. (Maximum "Q" is during the flight of the rocket, when maximum dynamic pressure on the structure occurs. Rebound occurs after engine ignition, when the vehicle is being held down by the hold-down arms of the launch pad and the engines for some reason are cut).

The stand is a 140 foot high tower enclosed in a 155 foot high hangar-type building, with instrumentation and computer rooms adjacent in a low bay office area. The cutaway, shown in Figure 4, shows the towers and the seventy foot square by twenty foot deep load platform, or crosshead, which can be positioned from 40 feet above the floor to 115 feet above the floor. This approximately 2,000 ton platform is positioned by four electrically driven linear actuators, called "Roll Ramps", made by the Philadelphia Gear Corporation. These 1-1/2 million pound capacity actuators traveling on four stationary 14 inch diameter, double acme threaded stems, 120 feet long, raise or lower the crosshead at a speed of approximately 2 inches per minute.

After the crosshead has been positioned, it is bolted to the towers. Vertical and horizontal loads to simulate the compression and bending moments that the vehicle will see in flight are applied, as shown in Figure 5, using large hydraulic cylinders. Strain gauges and deflection pods with input directly into the computer provide instantaneous readouts. Facilities, such as this stand, permit verification of vehicle design to minimize safety factors, thereby reducing weight which allows additional payload capabilities.

Quality and Reliability Assurance Laboratory is responsible for the quality and reliability assurance operations that will make certain the successful accomplishment of the flight misssion by the launch vehicle. The vehicle is thoroughly checked out prior to and directly after static test firing, as well as, prior to delivery to Kennedy Space Center for launching.

Space Sciences Laboratory performs scientific research of new concepts in vehicle development and studies of possible future programs. Their facilities resemble typical college and university laboratories with equipment, including medium and small thermal vacuum chambers to simulate outer space conditions.

Test Laboratory is responsible for conducting experimental and developmental testing programs of launch vehicles, components, and other systems. Figure 6 shows the 430 foot Saturn V Dynamic Test Facility which is higher than any building in Alabama. This facility is used to determine the center of gravity and resonant frequency of the Saturn V vehicle and checkout of mechanical mating features. Probably the most dramatic testing is the static test firing of the rocket engines and complete boosters. The importance of ground testing cannot be over emphasized. It is an inherent problem with space launch vehicles that once a flight is started, there is no turning back for repairs. When ignition occurs, and hold-down mechanisms let go, this particular launch vehicle will never be used again. The economics or cost control, if you will, of rocketry require that expensive vehicle's mission success be assured before the countdown. When man is a passenger, this factor becomes doubly significant. Although at first glance, the hugh ground facilities necessary for testing may seem expensive, the test capability allows complete testing without the loss of the rocket stage. Held captive by the hugh test stands, as seen in Figure 7, the stages are run through full strength, and full duration "hot" firings. Through ground testing, engineers reduce to a minimum the number of expensive live research and development rocket launches.

When a scientific satellite, which may have been years in the making, or a spacecraft, which has a human cargo, is mated to a launch vehicle, the engineers know that every human and technical precaution has been taken on the ground to assure success in space. The rocket stages, carrying the precious payloads, have already proved that they can perform.

The plant engineering functions for Marshall are handled by the Facilities and Design Office and the Technical Service Office. The Facilities and Design Office is responsible for facility planning, design and construction; as well as design and coordination necessary to keep the plant functioning. Technical Services Office performs the maintenance, repairs, and minor modifications to the facilities and their systems. Their facilities, slightly over 75,000 square feet, consist of the normal shops, equipment and supply storage areas and offices.

Industrial Operations has offices which serve as management centers to administer contracts to private industrial firms who assist with Marshall Center missions. These offices must see that all the various components and stages are built to specifications and will work together when assembled into a complete vehicle.

Industrial Operations also directs two government-owned facilities that extend the manufacturing and testing capability of the Marshall Center. These are the Michoud Assembly Facility in New Orleans, Louisiana, and Mississippi Test Facility located in Hancock County, Mississippi. Although located in separate states, the two installations are only about 45 water miles apart.

Michoud, as seen in Figure 8, is the production site for the first stage booster for the Saturn IB and the Saturn V. Michoud's manufacturing building is one of the largest single-floor, air conditioned buildings in the country, covering almost 43 acres. The plant was originally conceived as a shipyard during World War II. It was used briefly for the manufacture of cargo planes and later, during the Korean conflict, a small portion of the plant was used for the building of tank engines. The primary factors that influenced the selection of Michoud were: it offered several existing buildings, including the large manufacturing building; it was accessible by water, necessary in transporting large rocket stages; and sparsely inhabited land was available nearby for a static testing site.

Mississippi Test Facility (MTF), the central testing site for large rocket stages, shown in Figure 9, is located in southern Mississippi. The present mission at MTF includes acceptance testing of the first and second stages of the Saturn V. MTF became operational in April 1966, with the static firing of the Saturn V second stage. The complete test site includes three huge test stands to test the first and second stages, linked by a seven and one-half mile canal system for transporting the stages and fuels. It is supported by control centers and data acquisition facilities.

Like Marshall Space Flight Center, Kennedy Space Center (KSC) plays a key role in manned space flights. Kennedy Center is NASA's center for the development of launch philosophy, procedures, technology and launch facilities. KSC plans and directs pre-flight preparations, vehicle integration, test and checkout of launch vehicles, spacecrafts and facilities, coordination of range requirements, and countdown and launch operations.

Involved in this primary mission are a host of technical and administrative facilities. The facilities necessary for the Apollo program are located in two basic areas: Launch Complex 39, shown in Figure 10, where facilities have been constructed to implement the assembly, checkout, and launch; and the Industrial Area, approximately 5 miles south of Complex 39, which houses administrative and engineering personnel, and provides test facilities for the Apollo spacecraft.

The hub of operations at Launch Complex 39 is the Vehicle Assembly Building (VAB), as shown in Figure 11. This 52 story high building contains approximately 130, 000, 000 cubic feet of interior space. The building contains two operational areas: a low bay area 210 feet high and a high bay area 525 feet high. The low bay houses eight preparation and checkout cells for the second and third stages of the rocket. The high bay contains four vertical bays for the assembly, integration and checkout of the launch vehicle and spacecraft. Adjacant to the VAB is the Launch Control Center, a four story structure, which is the electronic brain of Complex 39. It contains four control and firing rooms, one for each high bay in the VAB, to checkout and launch a space vehicle.

Major facilities, such as some of these we have just seen, require several years from original concepts to operational facilities. In the Government we may get a large amount of funds earmarked for Research and Development (R&D) for a particular program. However, the facility funding for this program remains a separate package from the R&D funding. For example, the Apollo Program is an approximately 10 year program, costing more than twenty billion dollars. The major facilities for this program are funded each year from different funds after authorization from Congress.

We, in facility management, often find it difficult to provide certain types of facilities in time to be completely responsive to program needs. Expediting facilities often tends to greatly reduce Cost Control. It is most important that potential facility-program interface problems be recognized during the early planning phase. This is true for space programs, or manufacture of automobiles, or paper bags.

For the purpose of this discussion, I would like to break the facility evolution into four different stages:

1. Function Requirements and Concept Phase
2. Budgeting, Funding and Design Phase
3. Construction and Shakedown Phase
4. Operational Phase

Function Requirements and Concept Phase

During this phase, it is first recognized that there is a requirement for a facility, or modifications to an existing facility, to accomplish the program or a function of the program. The first step involved is the definition and justification of a program oriented facility. In the Government, many echelons must review and approve for futher study (known as a Preliminary Engineering Report) this facility requirement. Once the need is recognized and justified, many variables must be considered, such as, when, where, how, how much, etc. This is the ideal time to start Cost Control and I don't mean by omitting the cost of planning. Planning of facilities should be done by professionals and not laymen. Proper planning by means of conceptual design or preliminary engineering report, will help to insure the owner, whether it is the Government or private industry, that he is getting the most useful facility for his money. It gives him better insight into what the facility will accomplish for him, as well as, what it is expected to cost him. The PER, which normally cost from one to three per cent of the construction cost, depending on the complexity of the project, is the phase of a project where changes cost the least. This is where Cost Control could and should have its "Finest Hour." This is the best time during the life of a project to determine if it is best to provide centralize moritoring of operations and maintenance; centralize air conditioning systems; use of concrete or steel; and other cost controling techniques. The PER could be worked up using two or three approaches to the project solution with the advantages, disadvantages and cost of each solution. This would allow management to decide if it is worth the money to go First Class, as well as, produces creative thinking for a cost conscious solution. To be a successful study, there must be much iteration and feedback during this phase of a program.

Budgeting, Funding and Design Phase

In the Government, the facility budgeting, funding and design phase takes approximately two years for a complex project. The PER serves to justify the budget request. In an R&D type facility, it is almost impossible to present as accurate budget request without a PER. The budget for NASA and other governmental agencies is submitted by the Administration to Congress in January for the next fiscal year which begins July 1. If the budget request for a facility is not submitted to the agency headquarters by mid October, it is almost impossible to have it considered for another full year. This is possibly a constraint that private industry would not encounter to this extent. This constraint tends to make the facility functional requirements needed up to a year sooner.

After our proposed project has been submitted through agency headquarters to Congress and authorized, this authorization still does not fund the project. Funds must be received through the Bureau of Budget, for the President may choose not to proceed with all projects authorized by the Congress. As in FY 1969 (which commenced last July), the Congress authorized 4.1 billion dollars for NASA, but this does not include our share of the 6 billion dollar cut from the President's budget recently imposed by the tax surcharge bill which was signed by the President last summer. NASA's portion of this cut reduced our budget below 4 billion dollars. On large multi-million dollar projects, funds for design are normally funded from prior fiscal year funds from those funds for construction.

While funds were being requested and received, design criteria based on the PER have been developed and an Architect-Engineer (A-E) has been selected. The A-E should not necessarily be the same that developed the PER for some are better planners than designers and vice versa.

Selecting the right A-E could well affect cost control. Given the criteria, several A-E could be requested to submit technical presentations without submitting the cost to do the design. This presentation should include such items as how they plan to accomplish the task, how long it will take them to accomplish, who they plan to put on the job, why they feel they are qualified for this job, what similar jobs have they accomplished, what were the percentage of contingencies required on previous jobs, etc.

After the presentation (which can be formal or informal, such as submitting a resume of past performance and plans to accomplish the proposed work) the firms can be rated in relative order on data submitted, past performances the owner might have had with the A-E, location of the A-E's Office in relationship to the owner's and other items which might be pertinent.

Once an A-E has been selected, then negotiation of a design contract can commence. The place to economize is not on the selection of an A-E, for his cost for design will only be approximately six percent (6%) of the project cost.

Picking a thorough, well qualified A-E is one of the best cost control factors available to an owner. Close coordination between the client and A-E during design will tend to assure that the intent of the criteria is met prior to costly field changes during and after construction.

<u>Construction and Shakedown Phase</u>

Once the design is completed, the construction phase is ready to commence. The Government, unlike most private industries, must advertise and award to the low responsive bidder. Since most all construction contractors pay taxes to support the Government, this is the only fair way. However, there are times we wish we could award construction contracts on some other basis. We have found in the Government that it is to the Contractor and Government's advantage that the Contractor be required to run his job using PERT or Critical Path Method (CPM). In this manner, it is easier to determine if the Contractor is on schedule. If not, where he needs to concentrate his efforts to get back on schedule. The length of the construction phase naturally depends on the type and complexity of construction as well as any possible long lead time equipment. However, generally speaking, we plan on approximately 8 months construction time for a quarter million dollar job and as the construction dollar value doubles the construction time would increase in increment of 3 months (i. e., a half million dollar job would take 11 months; a million dollar job would take 14 months, etc.). Added to this time would be time to check out or shakedown the facility. Likewise, this would depend on the particular facility, but we normally plan for a check-out time of 10% to 15% of the construction time. This might seem a little high, but we are speaking about a R&D type facility and not office buildings or maintenance shops.

Operational Phase

The operational phase is based on the mission date which this facility is to support. This particular facility might be one of many and we might need it 5 years before actual mission completion date, such as, we would need R&D testing facilities and manufacturing facilities much sooner than launch facilities. Therefore, the operational phase is that time from shakedown or check-out until actual mission operational date.

We have discussed the NASA facilities in the Southeast and the mechanics for obtaining these facilities. A facility must have cost control considerations throughout to be a well planned facility. Cost Control is a factor of economics which can reduce maintenance, operational or construction cost. At Marshall, cost control has been a determining factor in such decisions as location of the assembly plant, shown in Figure 12, for the Saturn I and Saturn V in New Orleans. Not only was this renovated plant considerably cheaper, but available many months ahead of a new facility. Also, at Michoud, there was a problem in disposal of 400,000 gallons per day of chemical wastes used in the fabrication and cleaning of these boosters. Samples of the wastes showed a highly complex composition of various alkalies, acids, oxidizing agents, solvents, etc., used in the manufacturing process. Although the pH of incoming wastes varied extremely from slightly more than one to more than eleven, the pH leveled out to a predominately strong acid in the holding pond. Possible solutions to this waste disposal that were considered were discharge to municipal sewers, dilution and discharge to the canal, barging to sea, treatment by ion exchange process, chromium reduction and precipitation, and deep well injection.

With discharge into municipal sewers and navigational canals not acceptable to local authorities and barging to sea proved to be too costly due to labor and tug rental, three solutions did warrant serious consideration. Ion exchange, chromium reduction and deep well injection were considered against such criteria as initial construction cost, power and chemical required, maintenance and repair and labor.

After an exhausted study, it was decided that the most economical and best solution was to use deep well injection after some treatment and neutralization.

Cost control, likewise, played a major part in the location of the Mississippi Test Facility on near-by sparsely inhabited land. After fabrication and check-out of the S-IC stages, they are barged from Michoud some 45 miles to MTF, fired and returned to Michoud for post firing check-out and preparing for launch.

I am sure that in your plants as well as ours, reducing high, ever rising, labor cost is of paramount importance to you and your plant manager. (If they ever get a machine to look after the machines, we too may be looking for another job.) NASA has implemented or planned such labor saving items as centralization of air conditioning controls for monitoring large buildings and complex of buildings; installation of utilities monitoring systems; and fire surveillance systems so that all building can be monitored at the fire station.

Cost Control has been a determining factor in such operations as the use of diesel powered instead of gas or electic powered pumps for the high pressure water systems used in protecting the deflector plate or bucket on our large static-firing test stands.

We have been able to use facilities such as test stands, fabrication and check-out buildings originally constructed for Redstone program on the

Saturn I program and to some extent on the Saturn V program. Figure 13 shows a test stand designed for the Redstone program and was later modified for the Jupiter and Juno programs. Figure 14 shows how the same stand was later modified for the Saturn I and Saturn V programs. The 1.6 million pound thrust Saturn IB is shown on the left and the right side has been modified so that a single 1.5 million pound thrust F-1 engine can be static fired.

We have taken large warehouse buildings inherited from the Army and converted them into space science laboratories and office buildings. Many of our buildings still in use were built during World War II for the manufacture of poison gases. We are now in the process of converting a stand designed to test and check-out the hold-down arms and mechanisms used to secure the Saturn V during static firing to a platform for an observatory telescope. The stand is approximately 25 feet high made of heavy braced wide flange columns joined at the top by deep plate girders. Use of this obsolete stand will save the Government approximately $100,000.

The Load Test Annex, the 30 million pound structural static load test stand, had many major features influenced by cost control factors. Some of these were enclosing the stand in a building shell so that testing, including preparation and removal, could be accomplished without stopping work due to inclement weather or high winds affecting stress readings; and providing a linear actuator system to raise or lower the approximately 2,000 ton crosshead the 75 feet in one day with a crew of 2 or 3 men instead of the "conventional" hydraulic jacking system requiring one week with 8 to 10 men.

I have tried to show this morning some of NASA's facilities located in our Southeast and how these facilities evolve from concept phase to operational phase, as well as, some examples of the cost control that went into these facilities. I would like to complete by talk with a film showing the evolution of perhaps the largest complex built here in the Southeast, the Vertical Assembly Building and Launch Complex 39 at John F. Kennedy Space Center, Florida.