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# Operational Problems with Large Space Boosters

O. W. Clark and R. C. Uddenberg



THE LAST TWO YEARS have seen the vigorous inauguration by the United States of an ambitious program for the exploration of space. This multi-pronged effort, under the direction of the National Aeronautics and Space Administration, is critically dependent upon the successful development of a new generation of large boosters, far greater in size than any missile or booster previously developed.

The concept of the NASA Merritt Island launch facilities and the basic principles of the test operations that will be conducted there have been discussed in a number of recent papers but the operational problems that will be encountered in the use of such facilities have had little discussion and indeed it is still too early in the stage design and ground support equipment design of the Saturn V vehicle to define these problems in any detail. Using, however, the known dimensions of the Saturn V vehicle and the published characteristics of the Merritt Island Launch Area as examples, it is possible to make a general study of the nature of the operational problems that will be encountered during the testing, checkout, and launch of such large space vehicles.

The operational problems will be primarily those due to the tremendous size of the vehicle being tested, compared to previous boosters and missiles, and to the intention of testing these vehicles while in the vertical position. The size of the vehicle affects the test operation because of the diameter of the vehicle and its length or, as it is in the vertical position, its height.

In earlier boosters, the diameters have ranged from the three feet for a Bomarc missile to ten feet for an Atlas missile, with the five foot diameter of the Minuteman being a rough average. Compared with these measurements, each of the first two stages of the Saturn V has a diameter of 33 feet; the third stage is 22 feet in diameter. The length of a single S-IC stage may be 140 feet and the overall vehicle may be 350 feet high.

The fact that work areas at the pad and the work platforms in the assembly buildings are at heights up to 400 feet above the surface will make the potential safety hazards, safety design criteria, and safety procedures more significant in the large space booster programs. The physiological human aspects—such as fear of heights, emotional stability of personnel assigned in these areas, design of safety railings, and structure walls to minimize the feeling of insecurity—must be given more emphasis. (The desirability of introducing physiological aptitude tests of certain test operations on an experimental basis should be evaluated.)

NASA PHOTO

Because of the extreme heights, the incorporation of means of emergency egress becomes more difficult and considerably more expensive. As a result, the general trend during more recent missile launch facility designs to eliminate such systems may continue in future programs; if so, emergency situations such as fire or explosion will impose more dangerous conditions for personnel. Therefore, the training of personnel in safety aspects, strict adherence to safety procedures, and development of adequate precautions becomes mandatory to reduce the probability of an emergency.

On the assumption that there will normally not be a service tower (or work platform around the vehicle at any level except the base and possibly the spacecraft), one must consider the possibility that from time to time there will be a requirement to have personnel working several hundred feet above the ground temporarily in a "bosun chair" type of suspension from a crane.

At Cape Canaveral the primary solution to many of these problems will be simply to avoid the problem by sending the vehicle back. The Boeing Company's experience with Minuteman missiles in silos at AMR is that in most cases replacement of components is done by removing the Minuteman from the silo and returning the entire missile to the Assembly Building to make the replacement. In this case, the replacement philosophy has been dictated by the missile design, which in turn was dictated by the Air Force design philosophy for replacement at tactical sites.

In the case of Saturn and other large space vehicles, there is no need to compromise AMR tests by considerations of tactical deployment criteria. Nevertheless, in many cases where access is not convenient at the

pad, it may be desirable to return the vehicle to the Assembly Building for replacement, repair, or modification. For Saturn, in particular, there is a very definite objective to reduce the amount of time spent by the vehicle at the pad and reduce the amount of maintenance work done there.

#### Access to Equipment Inside

In previous missile designs, the circumference of the vehicle was sufficiently small that interior access could be adequately provided through strategically located portholes or access doors through which a hand and arm could be inserted. The size and location of the port was generally determined by the size of a man's hand and the average length of his arm. Occasionally, the ports were larger to allow removal and installation of small hand held components.

In the case of Saturn C-5 stages, with a 33 feet diameter and access restricted during launch pad occupancy to a walkway or crawlway through an umbilical arm, the situation is very different. (See Figure 1) Since access is limited to one vertical plane tangent to the umbilical tower and at four to six horizontal levels specified by umbilical locations, very few access doors can be used.

In places where they are located, the doors will be enlarged so that a man can crawl into the interior of the vehicle. Interior walks or work platforms will be required to reach equipment that is installed anywhere from several feet up to 30 feet from the doorway. Since weight is always a consideration, and is likely to be appreciable here because of the required catwalk span, permanent flyaway provisions are impractical. Some capability of disassembly and removal of the platforms through the access door must then be provided.

This brief analysis leads to a series of access problems which combine de-

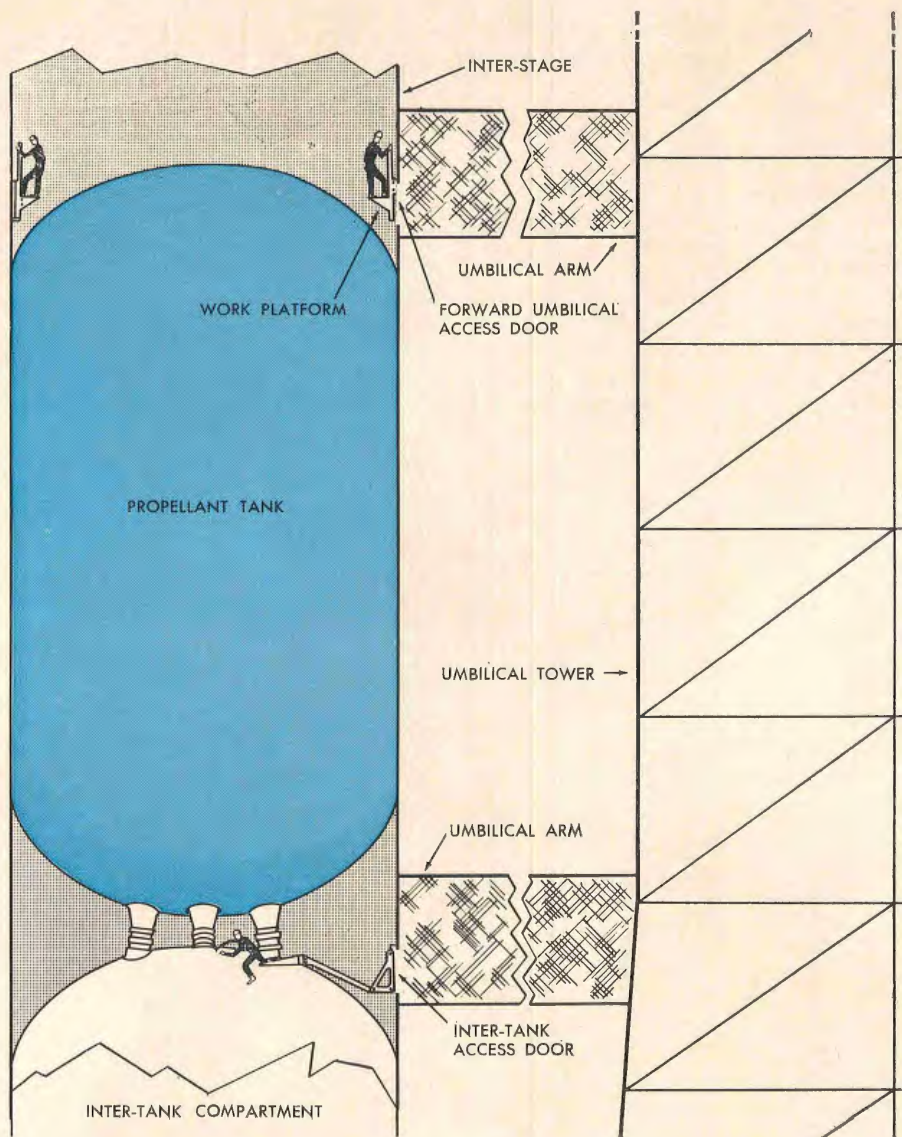
sign and operational considerations.

If the internal platforms are of the non-fly-away type (that is, they must be removed before launch) they probably will be removed at some late point in the countdown, probably within the last two hours. This means that the installation and removal provisions must be performed in only a few minutes to conserve valuable countdown time or to achieve a restrictive launch window.

No matter how late in the countdown these platforms are removed, it is conceivable that they may again need to be replaced in the vehicle. Some malfunction, minor in terms of time required to correct by component replacement, but mandatory for the flight, will require the replacement of the platform after removal and after propellant servicing. A platform to be replaced in the vehicle by a single man kneeling on the umbilical arm and working through a small access door will require that the platform, or at least the first section of the platform to go in and the last section to come out, must be light in weight, not overly cumbersome, and easy to align and secure on whatever support structure is provided. The platform must also be designed to minimize the possibilities of being dropped during installation or removal and to minimize any possible damage that might be caused if it were dropped.

Because of the awkward space arrangements on the interior of the vehicle, any component weighing over 60 pounds will probably require two men for its handling, which means that the platform must support two men and the component.

During all of these situations there must be no deterioration of vehicle reliability; that is, there should be no appreciable danger of damage by dropping or by bumping of the tanks or shells by components or platforms.



*Work Access-Vertical; Forward and Intertank Compartment.*

In addition, if there is any possibility that a man might step on a tank head, the head must be capable of withstanding the load, or there must be temporary mattress pads, or the test engineer must wear special shoe packs. Similarly, with respect to dropping of tools, there must be individual attachments to each tool, or pads or close mesh nets temporarily suspended below the work area, or screens on the side of the platforms. Vehicle reliability must be maintained despite adverse working conditions.

#### Environmental Control

Because of the large size of the vehicles, environmental control of complete components in areas adjacent to cryogenic tanks (such as LOX and LH<sub>2</sub>) will probably be im-

practical. This leads to several problems.

Temperature sensitive electronic equipment, such as telemeter, signal conditioners, tracking, and ordnance rf systems, that is installed in these areas will probably be installed in environmentally controlled cannisters. The maintenance philosophy could either be removal and replacement of the entire cannister or removal and replacement of a component within it. Either approach could create special problems, such as lifting and moving the entire cannister, or opening the cannister and making critical emplacements, connections, or adjustments inside the cannister under adverse visibility and access conditions.

When tanks are serviced there could be safety hazards because of

inflammable or explosive vapors. This will require special consideration of personnel-to-vehicle grounding and non-sparking equipment and clothing, particularly during removal of work platforms.

It is apparent that the times during launch operations in which access is required is significant. If access is required after the tanks are filled, the temperature in these areas may range as low as  $-100^{\circ}\text{F}$ . Thus, protective clothing would be required.

Undesirable as it might be to enter the vehicle after it is loaded, there is always the possibility that making minor repairs or replacements under difficult conditions is more desirable, and will cause less launch delays, than draining propellants and returning the vehicle to the Assembly Building. This does involve, however, certain additional design considerations. If the test engineers are to wear protective clothing during certain periods of time in these areas, then all fasteners, methods of attachment, and trouble shooting test points must be functionally capable of operation by personnel attired in clothing that is bulky or restrictive in movement.

#### Access to Equipment Outside

A prime problem concerning access to equipment outside the vehicle is the use of antenna hoods for complete testing of the RF link through antenna systems. If large vehicle launch facilities have no routine service structure at the pad, and external access is restricted to the plane adjacent to the umbilical towers, there would be appreciable effect on the concept of the utilization of such hoods. For if the hoods cannot be removed easily when the tests on the pad are completed, there must be other provisions for limiting radiation. These might be coaxial switches in temporary hardline cable connections ahead of the radiating elements. Such provisions would necessarily have to remain in the system until relatively late in the launch preparation phase. The changing of such connections then inherently provides a potential effect on the overall system reliability and must be evaluated accordingly. In any case, the problem is another typical example of the relationship between operational problems with these large space boosters and the stage design itself.

#### Size of Components

The large size of the advanced vehicles will create new problems with respect to the size of compon-

ents normally subject to field replacement. For example, valve assemblies in 20 inch LOX lines and 12 inch RP-1 fuel lines and TCV activators are approaching the size of a small man. The removal and replacement of these components will demand design emphasis on access requirements to interior areas to the same or to a greater extent than is required in small vehicles such as Minuteman.

In many cases, at various levels of the vehicle the size of the components will require special slings or mechanical devices for handling the components. Access provisions for the handling equipment in close proximity to the vehicle or under the vehicle in the first stage engine area will create special design considerations.

Moving flight batteries weighing 80 to 100 pounds through an umbilical arm and through a crawl-in access door inside the vehicle is a task that will tax the capabilities of two men under restricted physical movement conditions unless special handling provisions are incorporated. This is an operation that under some conditions might be performed within one day of scheduled launch and it is very probable that the batteries will have to be replaced at the pad several times during the course of the test.

It should be noted that ground equipment, such as slings and hoisting provisions, does not constitute the total problem; there must be included in the design of the stage components themselves adequate, readily accessible field handling provisions such as lugs, brackets, or support points. One of the principal factors here is a common overemphasis by design engineers that either the part will never need replacing, or that if it does need replacing, this is best done at the factory.

There is no question that the factory replacement of large and heavy components is desirable. But, the tremendous size and weight of the assembled vehicles of the type under discussion leads to problems in transportation and timing that preclude such procedures, and obviously preclude the provisioning of spare, or alternate, vehicles.

For these reasons, there must be continuing emphasis on provisioning for field handling and field replacement of even large components.

#### Vehicle Interior Lighting

Operations personnel will be working inside a large diameter vehicle under quite variable conditions from the

factory to the launch pad. The requirements for interior lighting in support of these activities must be evaluated at an early stage and provisions incorporated during the design of the ground or flight hardware. General factors to be considered are the duration of the work period, the functions to be performed, and the processing phase during which the function is performed (such as factory versus launch pad). The maintenance philosophy will have a heavy influence on the requirements.

The means of providing interior lighting may take several forms, depending upon the evaluation of requirements and the determination of most practical methods. In general, each method may affect the configuration of the ground equipment or flight hardware.

A battery powered portable head mounted light or a temporary extension cord arrangement plugged into a receptacle mounted on the umbilical arm or work platform adjacent to the vehicle could be used. The extension cord would allow the light to be suspended by a temporary attachment in the work area, such as a hook arrangement, magnetic clamps (depending on structure materials), suction cups, or slide-in/out brackets mounted permanently in strategic locations.

Permanently installed fly-away wiring and lights in the vehicle could also be used. These lights would obtain power through the umbilicals or via short connector cables through an access door to a receptacle on the umbilical arm or work platform.

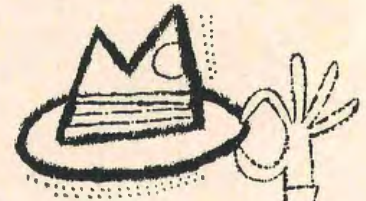
#### Communications

As launch vehicles grow larger, the requirements for communications between test personnel become more acute. The requirement for a Bomarc type vehicle, for example, was for a crew of about 5 people at one time, working on a vehicle only 40 feet long. The requirement for a Saturn type vehicle will be for about 60 people operating on a vehicle 400 feet high.

The problem becomes still more acute when facilities are separated so that the entire control of the test operation is from a different area than the one in which the operations are performed.

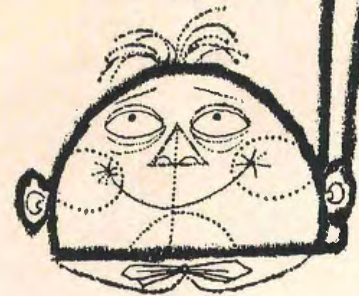
As shown in Figure 2, the distance between the flight hardware and the individual system test sets may vary from 50 feet to several hundred feet. The normal mode of operation during vehicle test operations will require several subgroups of stage people

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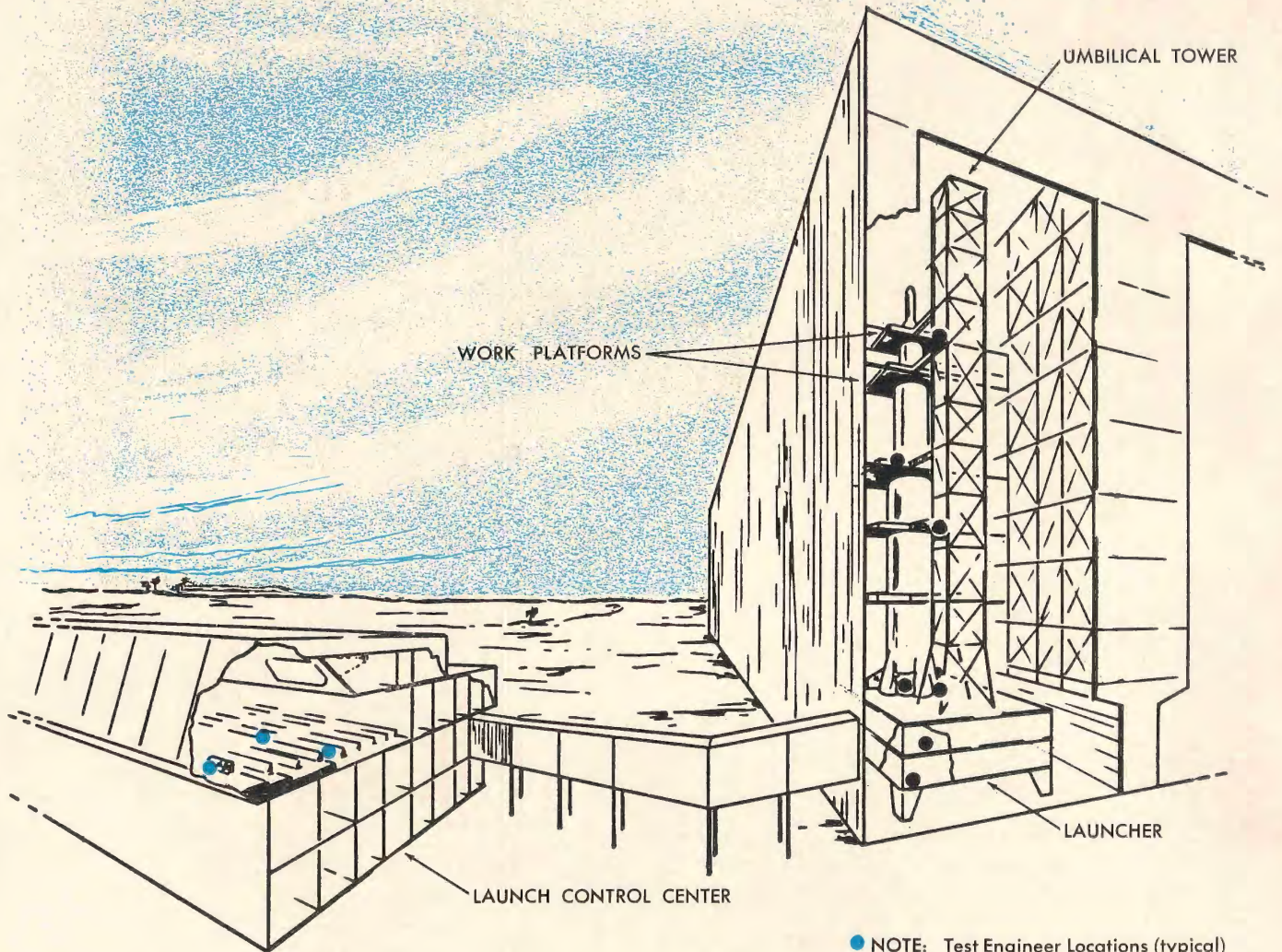
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● NOTE: Test Engineer Locations (typical)

*Conduct of Test Operations.*

working concurrently in parallel with similar groups of three to four other major stages, each checking out their individual systems. Most of these people will be out of sight and hearing with respect to each other (even when working on a single subsystem). They will be working under remote test conduct control (automatic or manual modes) from a building as much as three miles away and getting real time data processing and feedback to displays at test sets near the vehicle or to the test control room. The widely spread and multipath nature of the system makes a tightly controlled and widely distributed communications net mandatory. In general, these requirements can probably be best fulfilled by a hardwire system with strategically located outlets for plugging in and longer coilwire stretch connections to headsets. These would be similar to

systems presently in use, such as MOPS, MITOC, and Norcom. The locations of outlets, however, will be somewhat unusual with respect to previous programs. Since personnel will be working inside the vehicle at distances up to 30 feet from an access door, it may be desirable and practical to extend the communications net into the vehicle itself through permanently installed fly-away wiring and strategically located outlets in work areas of heavy usage and long duration. The connection between the vehicle and the work platforms or launcher umbilical arms could be one that is broken when convenient at the time of final prelaunch preparation of the vehicle.

This mode of operation is basically an extension of the large aircraft ground communications principle where ground crews are plugged into the aircraft radio system intercom

for communications with the personnel on board the aircraft during ground tests and preflight readiness checks.

**Conclusions**

A great deal of thought is required in the design stage for the requirements of checkout of large space vehicles. Adequate consideration must be given to the operational and servicing problems that will be encountered during preflight checkout. If these problems have been difficult in the past, they are going to be more so with the large space boosters of the future. It is necessary, then, to begin an analysis before the design is complete and the operations are being conducted. This approach will allow adequate time to alleviate many of the operational problems that are certain to be encountered.