Manuscript

for ARS Astronautics

ENGINEERING PROBLEMS IN ORBITAL OPERATIONS

February 13, 1962

By

Georg von Tiesenhausen
Future Launch Systems Study Office
Launch Operations Directorate
George C. Marshall Space Flight Center

COVER: Illustration by E. D. Cagle, Launch Operations Directorate, Marshall Space Flight Center, shows an orbiting cryogenic propellant depot consisting of a large liquid hydrogen non-vented tanker and four liquid oxygen non-vented tankers joined together awaiting the orbital launch vehicle for a combined propellant transfer. It is anticipated that this mode of orbital operations will be employed for deep space missions with the NOVA class vehicles.

ENGINEERING PROBLEMS IN ORBITAL OPERATIONS
by Georg von Tiesenhausen

A year ago this author was privileged to report on the major engineering problems associated with developing launch facilities for the first space vehicle, the SATURN C-1.[1] As pointed out in that article, it was necessary to solve these unprecedented problems without benefit of an extensive R&D program. The successful launching of the first SATURN vehicle late last year fulfilled all expectations and proved the soundness of the concept and designs evolved largely from the experience of the planners.

It is in the natural course of evolution of space exploration that launch operations must now be extended from earth to include earth-orbit launch operations and finally to lunar and planetary launch operations. Since earth-orbit operations are the first step in this progression, this article will be limited to a discussion of the problems in this area. Since orbital operations are already an approved part of the NASA's Lunar Program, and there is an abundant supply of literature and reports on the necessity and general character of earth-orbital operations, no justification for the operations will be given here.

The development of a complete orbital launch system for space vehicles is more of an engineering problem than a scientific one.

---

(1) Astronautics, December 1960, p. 30

Therefore, the purpose here is to identify and explain the problem areas and indicate the critical gaps and voids in our experience which must be filled as quickly as possible.

WHAT IS AN EARTH-ORBITAL LAUNCH SYSTEM? The purpose of an earth-orbital launch system is similar to that of the ground launch system, i.e., to prepare, checkout, and launch a space vehicle on a given mission. In a ground launch system, all the required facilities, equipment, and services are located on the ground, whereas, in an orbital launch system, some of the service facilities are located on the ground and others are located in an earth-orbital trajectory.

Like any ground launch system, an orbital launch system must be based on the requirements of a specific vehicle and mission. The peculiar requirements of a vehicle and mission determine the launch operations, which in turn determine the launch facility requirements. Service operations, such as maintenance and repair, will eventually be necessary in orbital operations to support the orbital complex in much the same manner that a ground complex is supported. However, orbital operations will necessarily begin with a minimum of the operations being performed in orbit. This can be accomplished by maximum utilization of the vehicle capacity and ground launch facility capabilities. In initial missions, two ground launches will be used to place the orbital launch vehicle in orbit as two separate payloads.

Fundamentally, the primary concern of the development engineer differs from that of the scientist who usually searches for optimum solutions. The space engineer must seek a workable solution with high reliability in a limited period of time. He prefers to introduce sophisticated refinements after a workable system has been developed. This approach has been employed with success in past rocket development work, and will be adhered to in the development of an earth-orbital launch system.

ORBITAL RENDEZVOUS, THE FUNDAMENTAL ORBITAL OPERATION. The basic concept of any orbital operation system must include the rendezvous technique, i.e., bringing two or more objects together in space. More explicitly, this means that one payload launched into an earth-orbit must approach, communicate with, and finally, mechanically lock on to another payload previously placed in orbit. This marriage may be permanent, as in the case of two stages which are joined together for launching on a lunar mission, or it may be temporary, as in the case of propellant tankers which will separate from the space vehicle after propellant transfer is accomplished. It should be emphasized that the orbital rendezvous is a fundamental and extremely critical requirement for orbital operations, and the technique must be perfected to a high degree of reliability through operational tests before manned missions are attempted. When rendezvous operations become routine and reliable, many of the hazards of orbital launch operations will be eliminated.

In addition to the guidance, control, and trajectory problems associated with orbital rendezvous, which are discussed elsewhere in this aissue, a host of basic engineering problems must be solved. In the lunar exploration program, orbital rendezvous will require the joining in orbit of masses in the order of 100 tons. These masses, which will be moving at a velocity of about four miles per second with a differential velocity of only a few feet per second, must be brought together softly at the correct spot and in close alignment to permit mechanical engagement. In addition to mechanically locking together of two stages or of a tanker and vehicle, this operation also involves the internal connection of the numerous onboard systems of the two components. These include mechanical systems such as propellant couplings, high-pressure gas lines, etc., and electrical systems. Since it is not yet within the state of the art, even in ground systems, to connect 60 to 100 conductor cables with plug connectors with absolute reliability, the automatic connection of electrical systems in orbital operations is a major problem. Since electrical circuits cannot be omitted from vehicle checkout and control systems, it may become necessary to eliminate hard-wire interstage electrical connections and develop a system using RF links between stages.

It is obvious that the requirements for docking structures, automatic connectors, shock absorbers, indexing and alignment devices, and the unusual forces introduced by the rendezvous docking operation will require new concepts in vehicle stage design.

TANK DESIGN, THE FUNDAMENTAL ENGINEERING PROBLEM. Liquid hydrogen and liquid oxygen must be stored in space vehicle tanks for a much longer time than is provided for in present tank designs. At present, evaporation losses from cryogenic propellant tanks are constantly replenished during ground operations. Since all propellants are consumed in a few minutes of powered flight after lift-off, tanks are currently designed to withstand anticipated static and dynamic loads during pre-launch operations, launching, and flight with minimum attention to the heat transfer characteristics.

This approach is not adequate for space vehicle tankage, since orbital operations and prolonged space flights require propellants to be stored in the stages for long periods. There must be a fundamental change in stage tank design to provide for minimum heat transfer to the propellants. There are several "super-insulations" available which have amazingly low heat transfer coefficients, however, the problem goes beyond the mere application of insulation to the tank walls. The best insulation is useless if the tank structure, supports, and associated plumbing provide a relatively unobstructed heat flow path. For example, a house with several large picture windows will require about the same amount of heating and cooling regardless of the amount of insulation placed in the walls. Present day vehicle stage structures are "picture windows" with respect to heat transfer. This is an area of space vehicle engineering that has been only lightly explored but which requires immediate development effort. The fundamental principle of heat barriers must be applied to the most minute details of the tank designs. A small structural member crossing a heat barrier may leak more heat into a tank than is transferred through the total insulated portion of the surface.

Because of the relative simplicity of an orbital storage tanker, the design requirements are less severe. Figure 3 shows an orbital LOX tanker design which eliminates all structural connections to the tank walls. Tanker design for storage of cryogenic propellants for periods of a month or more are well within the state of the art.

DETERMINATION OF PROPELLANT MASS. When propellant tankers are employed in an orbital operation, the amount of propellant that is transferred to the vehicle stages must be accurately determined (within 0.1%). The total amount of propellant in the tanker prior to transfer is of limited importance, however, it is extremely important that the mass of propellant transferred to each tank of each stage be determined. A method of accomplishing this measurement must be developed. The principle of applying a known force to the vehicle and measuring acceleration cannot be used since this would not differentiate between the various onboard masses in each tank.

MAINTENANCE AND REPAIR EQUIPMENT. Most conventional tools are useless in space where they must be used in a zero-gravity environment. A few special tools which eliminate external reaction forces have been developed, but tests conducted in a simulated zero-g environment with the operator and work area supported on air bearings proved them to be relatively useless also. Since maintenance and repair in space eventually will be a requirement for orbital operations, consideration must be given to these activities in the stage design. This will require a completely new design philosophy for onboard equipment and component arrangement and methods of assembly. Peripheral mounting and high accessibility of parts will be essential. Present thinking is that a free floating man in a space suit should be able to reach and handle any component repair or replacement. Sharp edges and corners must be eliminated to reduce the possibility of damage to the worker's space suit.

Special mechanical fasteners must be developed for use throughout the systems. Since tools developed on drawing boards proved so inadequate, both tools and fasteners must be experimentally developed with extensive use of air-bearing tables to simulate weightless conditions. Intelligent location, assembly and fastening methods must be based on a thorough knowledge of statistical evidence on vehicle malfunctions. The present ICBM design philosophy of small compartments with high component density must be revised to provide walk-in compartments with low component density. Fortunately, the physical dimensions of the orbital vehicles will support this philosophy.

GROUND LAUNCH PROBLEMS. To efficiently support orbital rendezvous missions, ground launch and auxiliary facilities must be provided to meet the highest launch density requirements, including service and rescue launches and backup launches. The maximum launch rates that may be required for orbital operations create the major engineering problems in the area of ground facilities. Since it requires about two months to prepare and launch a space vehicle, high launch rates with large space vehicles impose demands which require a high degree of ingenuity for development of efficient ground launch facilities. The magnitude and complexity of these vehicles become apparent when high launch density is considered in relation to the vehicle size, production type assembly and checkout requirements, transfer of erected vehicle and umbilical tower to remote launch pads, long distance data transmission, and high-pressure gas and propellant transfer requirements. Furthermore, when the launch timing (launch window) is critical, the countdown reliability must be high to permit launch within the limits of the "window." Solution of these unprecedented problems requires more than average engineering capabilities. There have been many proposals and suggestions on how to reduce the preparation time in order to secure more efficient use of all launch complex facilities. However, with the present state of the art, it appears that no substantial reduction in checkout time is possible. To many, automatic checkout is the "deus ex Machina" and the answer to all problems. However, experience has shown that automation does not reduce the total countdown time and does not increase reliability. It does reduce the manpower requirements but increases the complexity of ground and airborne systems and requires entry into otherwise closed systems for sensors which creates additional possibilities for failure. Some automation will continue to be used, but only when fully justified.

ORBITAL LAUNCH FACILITY (OLF). The role of the OLF in orbital rendezvous operations is to improve the mission reliability and at the same time reduce the overall mission support effort. Since an OLF can be utilized only after a successful rendezvous with it has been accomplished, it cannot serve to improve mission reliability until orbital rendezvous becomes a routine and highly reliable operation, otherwise, the additional rendezvous would severely reduce the overall mission reliability. Obviously, no reduction in the overall mission support effort can be accomplished with an OLF if the effort required to establish and maintain the OLF is equal to or greater than the effort which would otherwise be expended on the orbital launch vehicle (OLV) system. It is readily apparent that an OLF will not be a simple complex, but must contain the minimum amount of equipment and facilities required to reliably accomplish its mission.

The engineering problems involved here are not so much of the "nut and bolt" variety, but a basic engineering philosophy is involved which is time proven and must be adhered to in OLF planning and design. Briefly stated, this philosophy is as follows:

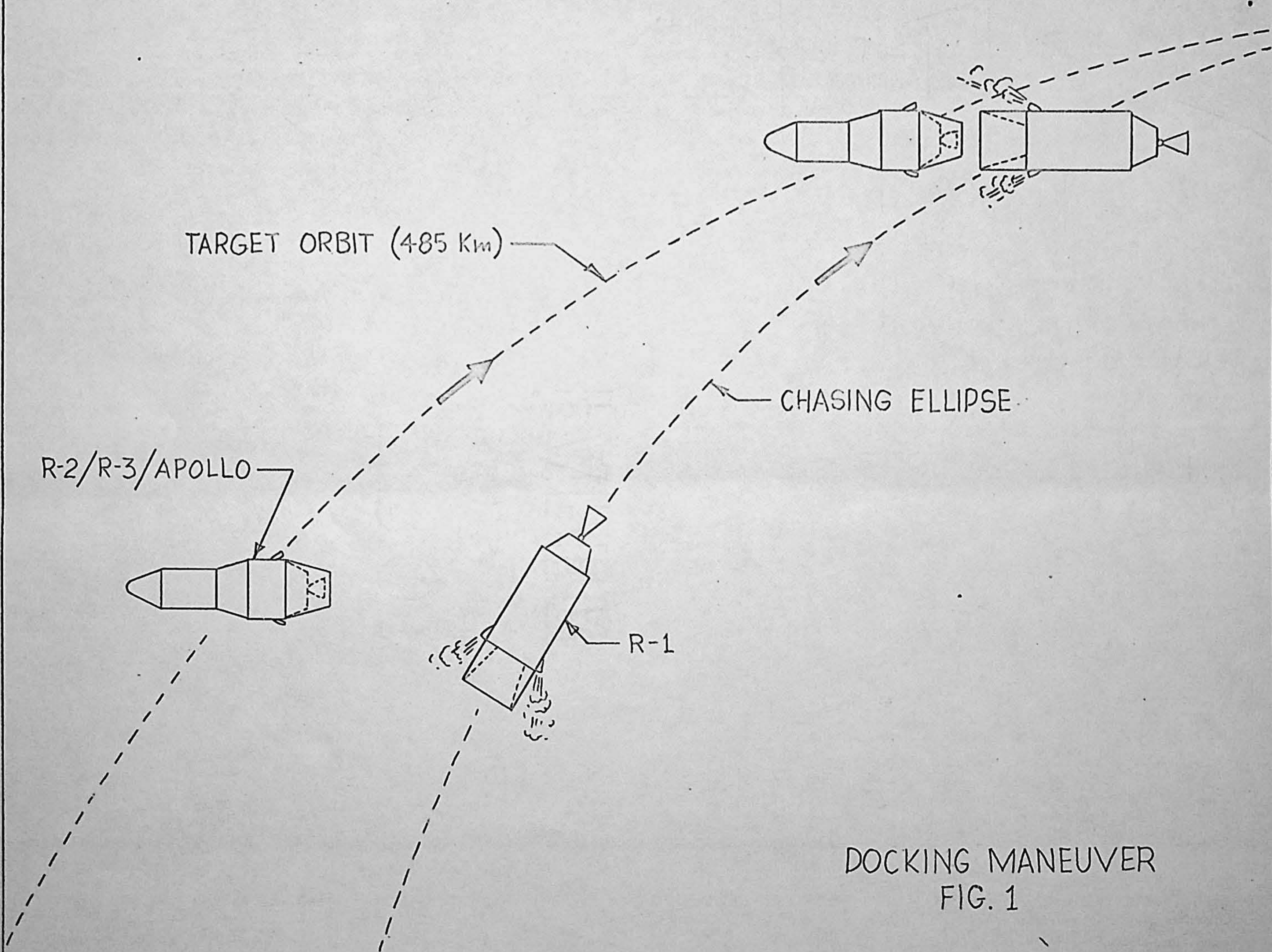
A launch vehicle will always be more advanced than the launch facility and its associated equipment by at least one generation in engineering "state of the art" or one order of magnitude in reliability. In other words, this means that although vehicle designers, by necessity, must utilize the latest technologies, and designs may even advance the state of the art, launch facilities and equipment must stay well within established engineering concepts and must not be advanced into unproven design concepts which could degrade the launch vehicle reliability.

Ground launch facility concepts are just now undergoing the first major change in concepts, i.e., from assembly on-pad to remote vertical assembly and checkout and vertical transfer to the pad. Development engineers must carefully test each step to ensure complete reliability.

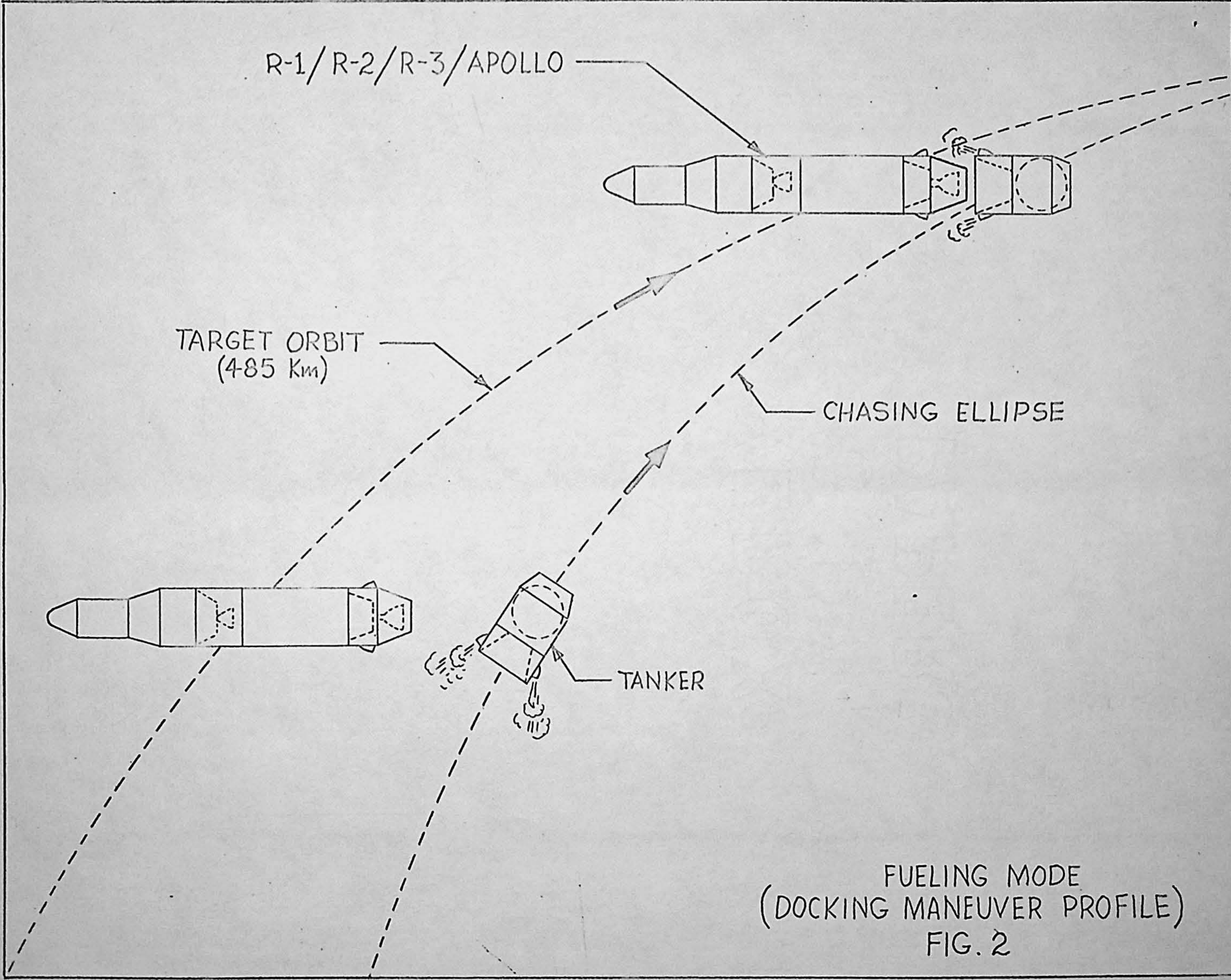
It is much like soldiers checking an unknown mine field where the mines are the hidden problems which could explode quite unexpectedly.

To apply this philosophy to orbital rendezvous and launch operations, it is obvious that the first generation of OLV's must be launched without the use of an OLF. In the meantime, the OLF must be developed on a conservative basis to include the solution of all known problems and those developed by the first OLV flights. The OLF development must proceed carefully through various phases, perhaps first as a space laboratory in connection with ground support development until it emerges as a reliable entity for operations in an actual space environment. Only when this is achieved can a space transportation system rely on the OLF as an "old reliable" station in space. In its ultimate concept the OLF should provide space crews with checkout facilities, life support, radiation protection, at least a one-time solar flare protection, emergency propellant depot, spare parts and tool depot, and a maintenance and repair hangar.

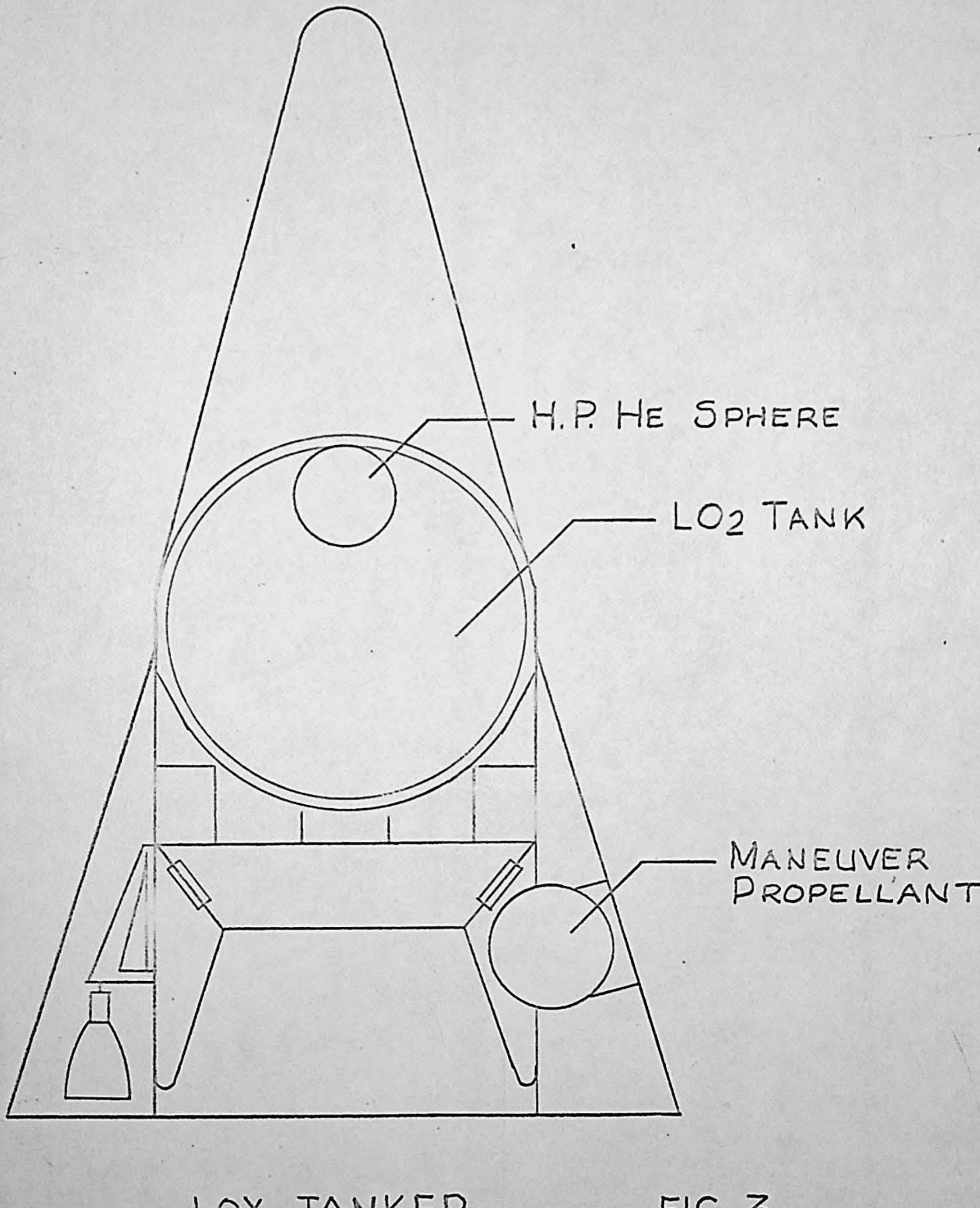
From the above discussion it is apparent that orbital operations are the key to all major lunar exploration and deep space missions. Therefore, it is imperative that a major engineering effort be made in this area immediately and that the effort be continued throughout the development phase of the Orbital Operations program.



DOCKING MANEUVER
FIG. 1



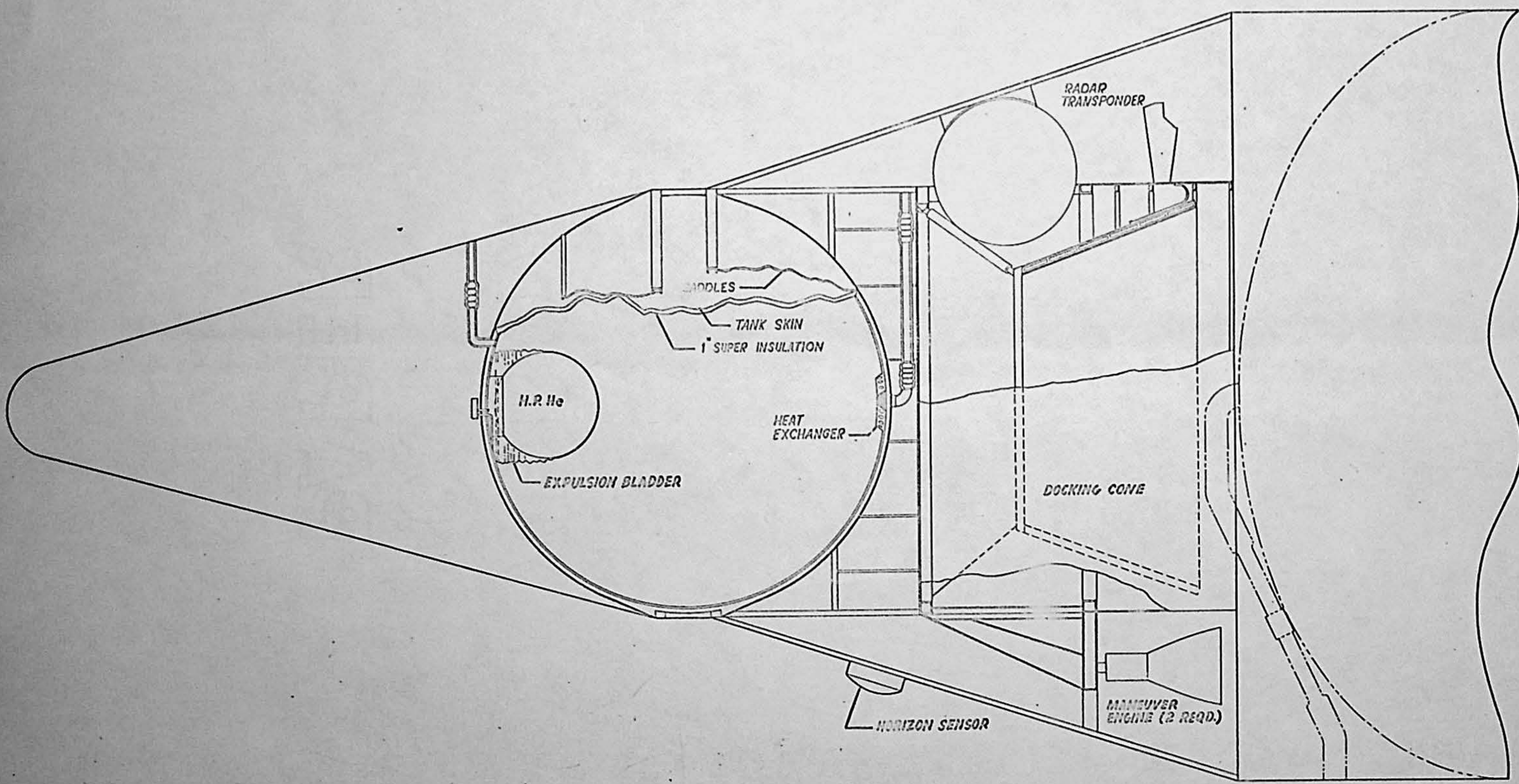
FUELING MODE
(DOCKING MANEUVER PROFILE)
FIG. 2



LOX TANKER FIG. 3

TANKER

FIG. 3



RADAR TRANSPONDER
SADDLES
TANK SKIN
1" SUPER INSULATION
H.P. He
HEAT EXCHANGER
EXPULSION BLADDER
DOCKING CONE
HORIZON SENSOR
MANEUVER ENGINE (2 REQD.)