Orbital Assembly and Launch for Lunar Operations

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DEVELOPMENT OF AN orbital assembly and launch capacity for the national space program is recognized as the most vital element in the United States' plan for lunar and interplanetary exploration. The capacity for rendezvous, assembly, checkout and launch from orbit provides an immediate and permanent solution to booster payload limitations, broadens the achievable space mission window, and permits the vital utilization of man to the limits of his ability to provide in space the capacity for decision making, the ability to perform secondary (orbital) checkout, the dexterity to yield improved reliability through orbital maintenance, repair and modification and the flexibility to broaden vehicle maneuverability performance limits. The purpose of this report is to discuss some of the general requirements for orbital assembly and launch for lunar missions, to present specific design and performance characteristics for an orbital rendezvous base system, to demonstrate the potential value of rendezvous compatible orbits thus giving improved surface-to-orbit launch logistics and to present a brief appraisal of the Soviet Union's orbital assembly and launch potential.

Best Route to the Moon: Orbital Assembly and Launch

Only a brief period of time has passed since serious announcements were made indicating that first priority was to go for the development of the "rendezvous route to the moon." This decision provided the capability for implementing our "lever into space" as shown in Fig. 1. This "lever into space" concept for orbital assembly and launch operations can be employed to accomplish the goals of manned exploration of the moon and planets beyond, provided we have a strong "fulcrum" from which to act. Effectively, the fulcrum in space is the orbital rendezvous base for assembly, checkout and launch operations for lunar and deep-space missions. When the United States space effort includes this fulcrum in space, we can initiate many new missions with a considerable improvement in launch logistics.

General mission requirements for an earth-orbital assembly and launch system to accomplish manned lunar operations are presented. A concept for development, general system characteristics, and operational use of a proposed orbital launch pad for rendezvous, assembly, check-out and launch of manned lunar flyby, orbiting and landing vehicles are discussed. Particular emphasis is given to utilization of rendezvous compatible orbits and stationkeeping for improved surface-to-orbit launch logistics. The "best route to the moon," employing a proposed Space Canaveral facility as a low-altitude orbital assembly and launch adjunct to Cape Canaveral, will significantly increase the United States' capacity for lunar and interplanetary exploration.

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This writer believes that our conquest of space can more soundly be built through use of an earth-orbital launch base—i.e., a "Space Canaveral" facility as a low-altitude orbital assembly and launch adjunct to Cape Canaveral. Present booster payload limitations are considered inadequate to reach with confidence the moon or planets, land man on their surfaces and return him to earth. We can, however, attain the moon with manned landings, employing the Saturn C-1 or C-3 class boosters, provided these boosters are utilized as surface-to-orbit logistic transports to build and supply a minimum orbital launch base with subsequent assembly, checkout and launch of special lunar craft. The Saturn class boosters using rendezvous techniques envisioned at present will permit assembly in orbit of the required launch base and mission vehicles. Best engineering estimates require about two to ten Saturn shots to build this minimum base. An additional three to ten Saturn vehicles will boost the specially designed spacecraft modules to the orbital base for assembly and launching to the moon. No other mode of transport to the moon can compare favorably, considering reliability, operational simplicity, early operational availability, and in no way can be compared considering growth potential.

Engineering techniques and devices to accomplish orbital rendezvous, coupling, assembly, resupply, and fueling of satellites in space have been studied to a considerable degree. Extensive research and development remains, however, to be accomplished before full utilization of this new dimension for space operations can be made. Potential utility of an orbital launch base is shown on Fig. 2. In addition to the primary objective of providing an assembly point and launch pad for the diverse space missions, possible side advantages include the use of base appendages for experimental research laboratories, and as a continuous launch base for reentry testing.

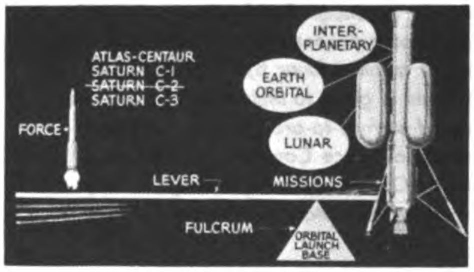


Fig. 1. Lever into space.

The growth of the United States' and Soviet Union's orbital payload capability[1] during the last 4 years is plotted on Fig. 3. A stair-step progression has occurred with a marked difference in capability indicated. Maximum operational orbital payload capability presently for the U.S. is approximately 5,500 lb using the Atlas–Agena, whereas for the U.S.S.R. it is announced as over 14,000 lb. Operational availability of Atlas–Centaur, Titan, and Saturn class boosters will give significant improvements. Saturn C-3/C-4 vehicles are estimated to give payloads of 100,000 lb to 200,000 lb in the 1964–66 time period. This capacity for space payloads (in light of that required for lunar and interplanetary missions) is still markedly insufficient. A significant improvement can result, however, if

Fig. 2. Orbs space missions.

aggressive orbital assembly and launch operations are programmed into our space efforts. As shown on Fig. 3, orbital launch weights for lunar and near-planet missions are approximately 500,000 lb and 5,000,000 lb, respectively. Using orbital assembly and launch, this required capacity can be available at an earlier time period than by direct launch techniques.

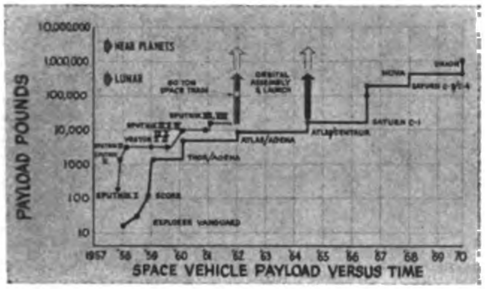


Fig. 3. Vehicle payloads.

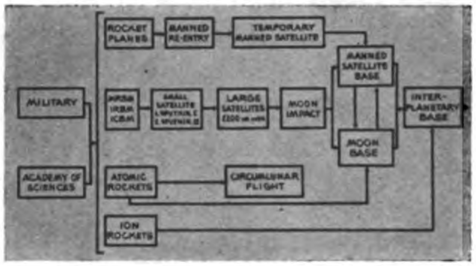


Fig. 4. Soviet rocket missile and space travel program—1958.

In recognizing the potential value of orbital launch operations to our space program, it is of interest to try to determine the Soviet capability to exploit this "springboard to space." Let us first take a look at a published planning chart (1958) of the Soviet rocket, missile and space-travel program[2] as published in a 1960 pamphlet of the Department of the U.S. Army. Fig. 4 illustrates the Soviet Union's planning as of 1958 immediately following launchings of Sputnik III having a payload of 2,925 lb. At the present time, the Soviets have progressed across this chart of space objectives including the temporary manned satellites (Vostok I and II) and the lunar impact probe (Lunik II). Plans for implementation of a manned satellite base and a moon base are shown next on their agenda and closely coupled conceivably employing assembly and launch operations. In February 1960 and again recently, articles in the press have quoted Premier Khrushchev's speeches about the Soviet efforts in development of their so-called "60-ton space train." According to our best estimates, a 60-ton payload is sufficient to perform the lunar flyby and orbital missions but is approximately a factor of 2-4 times

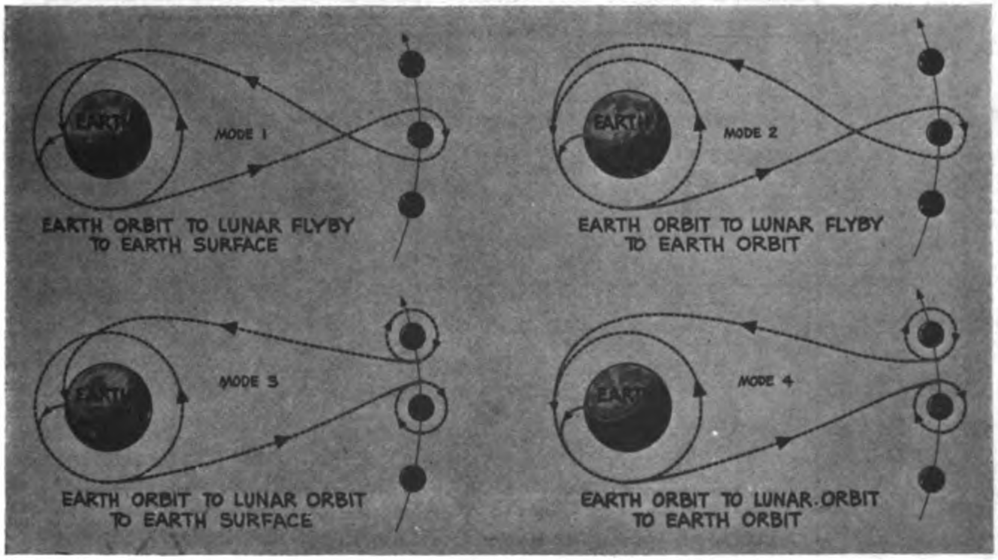


Fig. 5. Earth-lunar trajectory profiles.

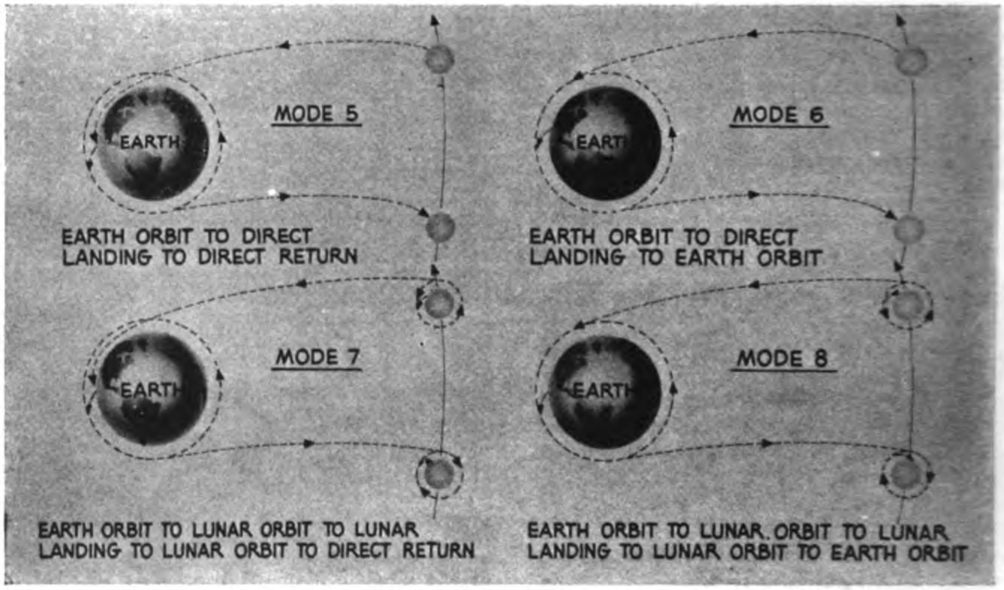


Fig. 6. Lunar landing and return modes.

too low to achieve the lunar landing task. Based on the U.S.S.R.'s announced Venus probe payload capability of 14,000 lb to earth orbit, their 60-ton "space train" would require about nine rendezvous in space to give this assembled payload. Recent booster tests in the Pacific Ocean during September and October of 1961 have had the announced purpose of developing larger boosters. It is surmised that

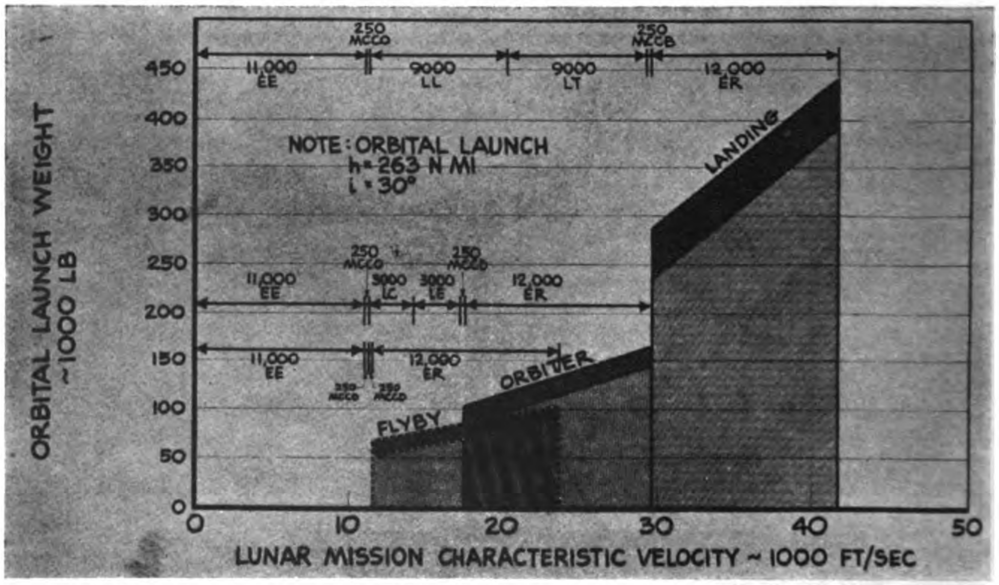


Fig. 7. Lunar mission requirements.

the nine rendezvous may therefore be reduced.

The payload comparison of Fig. 3 shows an approximate 2-yr lag in capability. Recent Soviet booster tests may increase this to 3 years, although NASA's announced plans for Mercury II using Atlas–Agena and Titan may somewhat counter this separation. Production time on available boosters can be far more easily compressed than development time.

In considering the Soviet potential for going in the direction of orbital operations, let us review some of their announced milestones having a direct bearing on requirements to effect rendezvous, assembly and launch in space as shown by Table 1. Additional equipment and operational systems for certain supporting areas that are mandatory in order to provide the Soviets with an orbital operations capability are noted.

Table 1, in summary, suggests that at present a capacity for rendezvous may exist and that manned lunar landings may well occur as early as 1963.

Routes to the Moon

In considering flight to the moon, it is believed that the several earth–moon transport modes may be classified by the following six operational approaches: direct ascent, earth-orbit rendezvous, in-transit rendezvous, lunar-orbit rendezvous, earth-orbit/lunar-orbit rendezvous, and lunar surface rendezvous. Each of these approaches have special merit, although my discussion primarily will concern the second approach—earth-orbit rendezvous. It is believed that this route to the moon has the greatest pay-off for lunar as well as interplanetary missions inasmuch as the total effort of transport to the moon and return is approximately equally divided about the earth-orbit launch base. The total energy, the tasks to be accomplished and the order of complexity for the surface-to-orbit boost phase is reasonably well matched with those occurring during and following orbital launch.

It is recognized, however, that future development of nuclear propulsion will probably encourage the use of special-purpose shuttle vehicles for operation between earth-orbits and lunar-orbits with lower transport costs.

Lunar Mission Energy Requirements

Many factors must be considered in attempting a selection of an optimum approach in developing an orbital assembly and launch base. Principal factors that must be recognized and evaluated include:

(1) Booster payload capacity and launch rate.

(2) Surface-to-orbit booster launch restrictions.

(3) Orbital launch criteria.

(4) Lunar trajectory profiles and energy requirements.

(5) Space environment and hazards.

Table 1. U.S.S.R. Orbital Assembly Potential

Simultaneous launch pad operation	Feb. 1961
Orbital launch from parking orbits	Feb. 1961
14,000-lb payloads	Feb. 1961
Launch on time capability	Sept. 1961
Precision guidance capability	Sept. 1961
?-lb payloads	Sept. 1961
+	
Vostok I-II liquid-fuëled de-orbiting propulsion	?
+	
Rendezvous radar/Guidance/Coupling	
=	
Orbital assembly capability	1961–62
Therefore: Manned lunar landing	1963

(6) Mission vehicle configuration and weight criteria.

(7) Propulsion system and auxiliary power criteria.

(8) Life support and crew requirements.

(9) Orbital checkout requirements and system reliability.

(10) Flight test and evaluation.

(11) Production capacity and cost scheduling.

Synthesis of these primary factors, plus many secondary items, must be achieved in the process of arriving at an optimum orbital assembly and launch logistic system. Only a portion of these system criteria are reviewed in this paper.

In order to design and size an orbital launch system, it is necessary to synthesize a vast number of design equations involving numerous performance variables and constraints in the eleven areas shown. Suffice it to say, a general weight equation must be developed for each vehicle module or element utilized

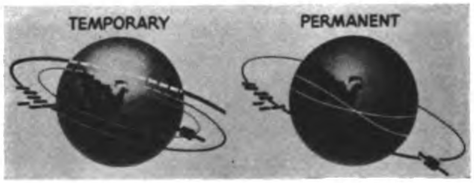


Fig. 8. Orbital assembly and launch systems. *(Left)* Orbital-parking. *(Right)* Rendezvous-compatible.

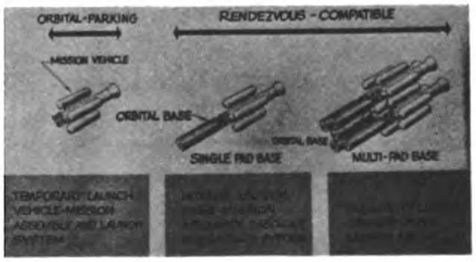


Fig. 9. Orbital assembly and launch concept. Lower inset panels (a) *left,* (b) *center,* and (c) *right.*

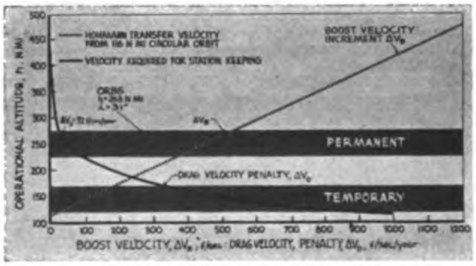


Fig. 10. Operational altitude, air drag, and boost velocity criteria.

in the entire orbital launch system in order to establish the overall system weight and energy requirement. This was performed for a special set of design characteristics for the Northrop engineering study[3] on orbital assembly and launch. Several different earth–lunar flight trajectories were considered; namely, the flyby (Modes 1 and 2), orbiting (Modes 3 and 4), and landing (Modes 5-8) missions with two lunar–earth return approach modes. These are illustrated by Figs. 5 and 6. Fig. 5 shows both lunar flyby as well as lunar orbital trajectories with Modes 1 and 3 depicting direct atmospheric reentry whereas Modes 2 and 4 show return to the orbital launch base. Launch from the orbital base with a coast trajectory to a lunar-orbit followed by descent to the surface as shown by Mode 8 probably is the most versatile approach for earth–lunar operations. Initially, the lunar-orbit phase would be employed only to give improved landing site selection, but eventual availability of nuclear boosters would permit shuttle operations between earth and lunar orbiting bases.

Although the lunar–earth return trajectory direct to the earth-orbit launch base has several significant advantages, time did not permit developing detailed system requirements. Two advantages considered are first the possibility for use of the previously discussed special shuttle vehicles and second that of reducing the return vehicle's atmospheric reentry heat loading since only a ΔV of about 10,000 fps need be considered.

The relationship of orbital launch weight to characteristic velocity for the three lunar missions are presented in Fig. 7. Orbital launch weight is plotted vs the required characteristic velocity. The left-hand side of each mission shows the launch weight for an aerodynamic reentry whereas the right-hand side pertains to a powered reentry. Considering the landing mission, the minimum orbital launch weight is 290,000 lb and requires 30,000 ft per sec characteristic velocity. The velocity increments for the several segments of the mission are earth-orbit escape of 11,000 fps, midcourse-correction-out of 250 fps, lunar-orbit-capture of 3,000 fps, lunar landing of 6,000 fps, lunar-take-off of 9,000 fps, and midcourse-correction-back of 250 fps. The powered reentry mode with 12,000 fps capability increases the orbital launch weight from 290,000 lb to 440,000 lb, an increase of 51 percent. The shaded area illustrates the additional launch weight imposed by radiation shielding. In this

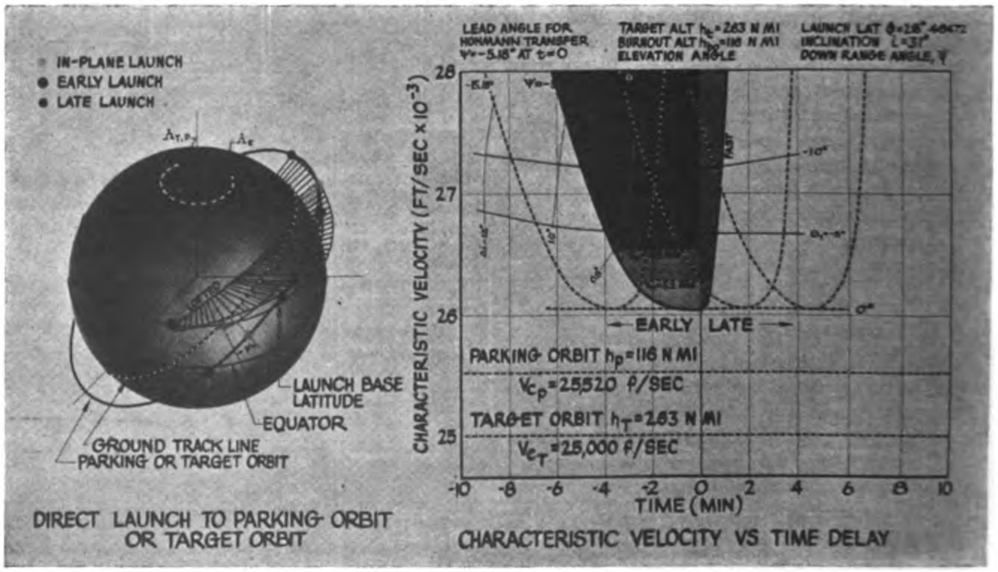


Fig. 11. Direct launch to RCO.

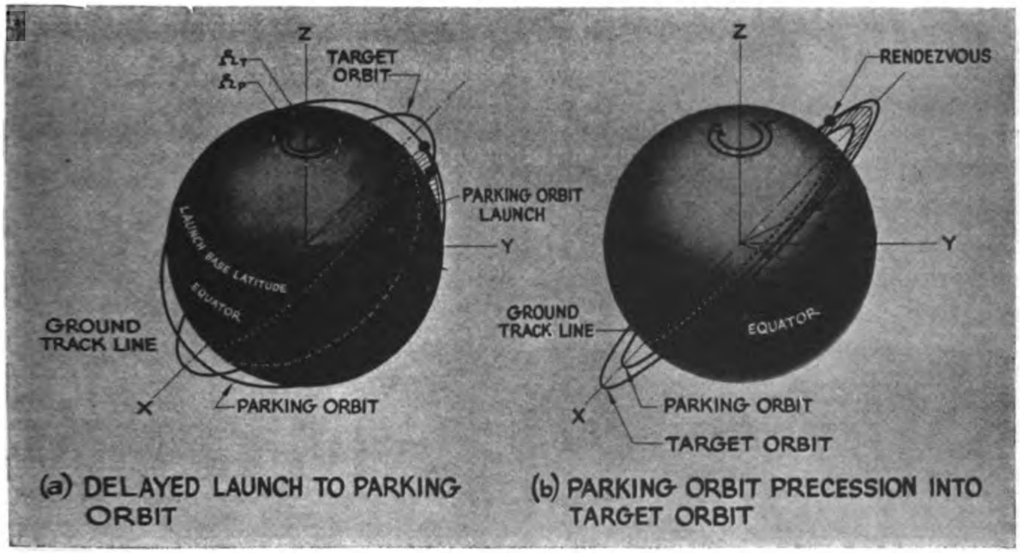


Fig. 12. Delayed launch to RCO.

case, approximately 6,000 lb of water and aluminum shielding serves as a "storm cellar" for Class 3 solar flares, and Van Allen radiation protection. Increasing crew size, mission duration and propulsion performance markedly add to orbital launch weight. However, the use of standardized modules and assembly in space provide the great advantage of flexibility to re-configure the vehicle to provide for changes in crew size and duration. These changes can readily be made through orbital assembly and launch but cannot be made for the direct launch mode to the moon.

Total energy requirements for both orbital launch and direct launch ascents are exactly the same. The basic comparison and determination of performance advantages between orbital launch and direct launch can only be resolved by considering first operational dates, reliability and growth potential. Consideration of these criteria results in a distinct advantage for the orbital launch technique.

Orbital Assembly and Launch Systems

Generally speaking, two basic approaches exist for implementation of an orbital assembly and launch capability. These are defined as either *orbital-parking* or as *rendezvous-compatible* assembly and launch approaches.

Orbital-parking assembly and launch system is an operational procedure that involves placing successive payloads (using direct launches) to the desired orbit, or employing a parking orbit with subsequent injection to the assembly orbit followed by assembly during the natural air-drag decay phase to the orbital launch position.

Rendezvous-compatible assembly and launch system considers similarly a direct launch to a rendezvous compatible orbit (RCO), or use of a parking orbit with subsequent injection to the same RCO, with continuous station keeping of the independent vehicle modules or base on the RCO throughout the life of the base.

Fig. 8 illustrates these two basic operational approaches. Principal advantages and disadvantages are shown in Table 2. Development of a rendezvous-compatible assembly and launch system provides growth potential such as illustrated by Fig. 9. Initial development of an interim launch base comprised of a checkout and life support module employing the rendezvous compatible orbit concept can serve as a single launch pad for mission vehicle assembly, checkout and launch. This approach is recommended in preference to the orbital parking approach. Continuous manned operation by an

Table 2. Significant Features for Orbital-Decay and Rendezvous-Compatible Assembly and Launch Systems

Orbital-Decay	Rendezvous-Compatible
Stationkeeping not required	Rendezvous compatible
Checkout facility replacement	Greater launch opportunities
Fixed assembly time restriction	Permanent facility maintained
Nonconservative initial development	Assembly and checkout time flexibility
Improved booster economics	Launch time selection
	Greater rescue opportunity
	Orbital launch simplification

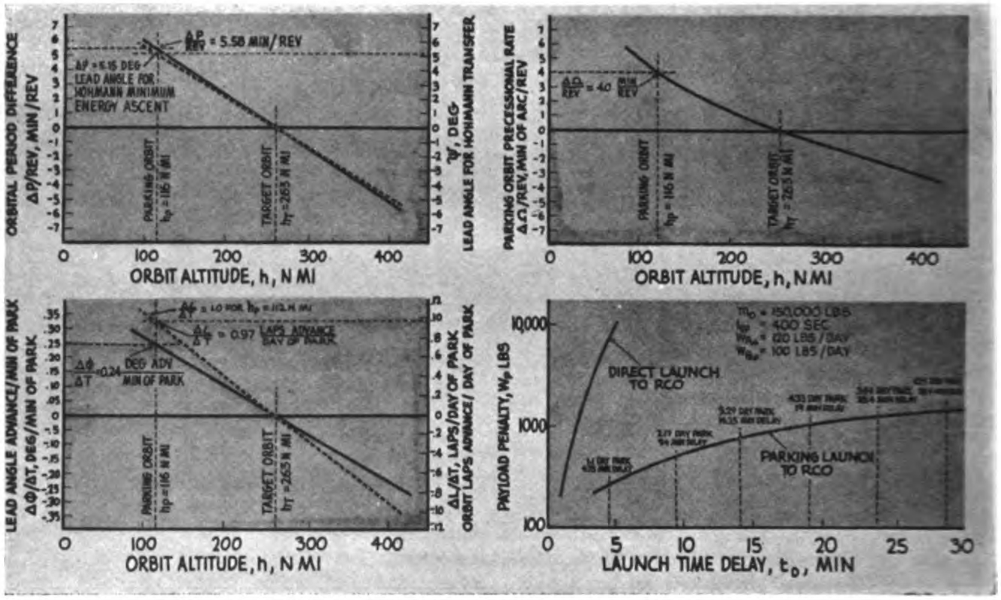


Fig. 13. Parking orbit launch characteristics.

assembly and launch complement is considered desirable. Eventual progression to a permanent launch complex is shown in Fig. 9's inset (c). Multipad as well as orbital tracking facilities may be the course of development.

Launch Restrictions

Surface-to-Orbit Launch Restrictions for Rendezvous

Major launch facilities and tracking ranges now exist at Cape Canaveral (Atlantic Missile Range, AMR) and at Vandenberg Air Force Base (Pacific Missile Range, PMR). These launch ranges, with some restrictions, now provide capacity for easterly as well as westerly launch trajectories. AMR restrictions, because of booster hazards, permit launch azimuths from 46° (Northeast) to 114° (Southeast). Tracking facilities further restrict launch azimuths to about 70° (Northeast) to 110° (Southeast). PMR restrictions allow launch azimuths ranging from about 170° (Southeast) to about 350° (Northeast). In addition to the economic advantage of using low-altitude orbits for assembly, launch azimuths giving as large a component of earth spin (low-orbit plane inclinations) as possible are desirable. However, the orbiting base must not be at too low an altitude so that high drag penalties result. In order further to improve logistics, the booster launch trajectory is programed to result in injection into a rendezvous compatible orbit, thus giving maximum opportunities for launch, rescue, and recovery.

Consideration of such factors as launch azimuth restrictions, rendezvous compatibility, air drag, booster requirements, and radiation shielding penalties results in establishing the best operational altitude and inclination for orbital assembly and launch logistics to the moon. Fig. 10 illustrates only two of these parameters—booster velocity increments for injection to variable altitudes above the 116 nm reference circular orbit, and drag velocity increment for orbit maintenance due to air drag. Here the drag velocity increment is the velocity requirement to maintain a module in orbit having a 100 lb per ft^2 area loading for a period of one yr. Thus, for a 263 nm orbit the interorbital transfer velocity increment ΔV_B is about 520 fps and the drag increment ΔV_D is about 32 fps per year. A further factor is that of determining the best rendezvous compatible orbit, as influenced by the additional constraint of synchronism for earth-orbit launch and lunar-arrival at a specified lunar phase.

Surface-to-Orbit Launch Time Delay Considerations

The most serious problem to development of an orbital assembly and launch capability is recognized as that of "launch-on-time." Delays in launch cause increasingly severe velocity penalties and subsequent payload degradation in accomplishing ascent to, and rendezvous with, the target satellite base. Launch delays cause increasing velocity penalties because of plane angle change that occurs as the launch base passes through and beyond the target launch base orbit plane and as a result of increasingly large injection and adaptation velocity components for ascent and rendezvous with the target satellite on the RCO. The plane change velocity penalty develops for direct ascents to a RCO as well as for the parking orbit (sometimes referred to as orbit phasing) ascent if the parking orbit is established in the plane of the target orbit.

In considering these launch restrictions, the conclusion is drawn that a compromised ascent-to-rendezvous trajectory program is the best solution if launch delays exceed from 3 to 4 min. Direct ascents should be employed if the velocity penalties, or small launch windows can be accepted. However, use of the extended parking orbit technique will give zero payload penalties with considerably larger launch window limits. Other launch techniques for rendezvous operations have been presented by Houbolt,[4] Bird and Thomas,[5] and Straly.[6]

The first two reports demonstrate that, for the condition of small angular differences between launch base latitude and target satellite orbit inclination, the payload penalties for rendezvous will be small. The payload penalty effects associated with launch-pad delays are not as sensitive to delay time, although the practical launch window would be less than 5 min. However, for the condition of a relatively large angular difference between the launch-base latitude and target satellite orbit inclination (Cape Canaveral launch base at 28.5° and an RCO constrained target orbit of about 35° to give multiple recovery opportunities at existing air bases—i.e., Edwards AFB), for example 6.5°, the payload penalty becomes excessively large.

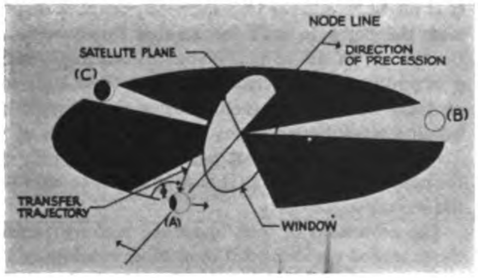


Fig. 14. Escape window display.

The third report effectively extends the technique of Houbolt and Bird by providing booster maneuverability during ascent and the use of parking orbits to minimize payload penalty and increase launch window limits. However, Straly's orbit phasing technique is restricted practically to small angular differences between the launch base and target satellite orbit, and for this condition, launch window limits are of the order of an orbital period.

The extended parking orbit technique outlined in this paper provides a launch procedure having a zero payload penalty and a practical launch window to an RCO constrained target satellite of up to 30 min. The following paragraphs compare payload penalty and window limits of the direct launch technique with the extended parking orbit technique. No attempt is made to compare these two techniques with those of Houbolt, Bird and Straly. It is believed, however, that within the launch window limits of up to 20-30 min that the extended parking orbit approach is superior.

Fig. 11 illustrates the direct launch case.[7] Here the target satellite is shown on an inclined rendezvous compatible orbit. Analysis was performed to determine the effect of launch time delays[4] for rendezvous with a target satellite. Total characteristic velocity was determined for early, in-plane and late launches to the RCO. The characteristic velocity V_{ch} is plotted on the right-hand figure. Solid lines are for the conditions of varying target positions, or lead angle, with respect to the launch base at time zero. For example, the solid line illustrates the variation of V_{ch} as a function of time for a lead angle of $\psi = -5.18°$ providing a Hohmann transfer at $t = 0$. A 6.2 min early launch to the target on a rendezvous compatible orbit requires about 28,000 fps or about 1,970 fps in excess of a Hohman transfer for the case of a zero time delay. A one-min late launch similarly requires about 1,970 fps excess over a Hohmann transfer. Although the launch base is rotating into and beyond the target orbit plane as a function of time, the actual plane change angles involved are small as shown. The major velocity penalty arises from the large elevation angles at the injection point and at target adaptation. The 3.2 min launch window line illustrates the maximum delay time for a velocity penalty of 260 fps just matching that for the Hohmann adaptation increment at $t = 0$. The 4.2 min launch window requires a characteristic velocity increment twice that for Hohmann adaptation, or 520 fps. Thus, it is concluded that direct launches to either a target satellite on a rendezvous compatible orbit or to a parking orbit in the same plane as the target is a costly oper-

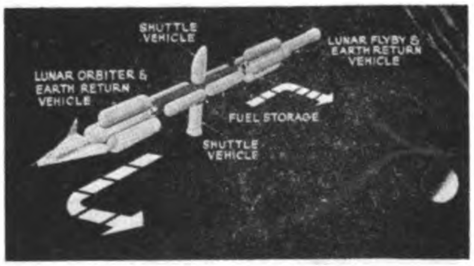


Fig. 15. Orbital rendezvous base system.

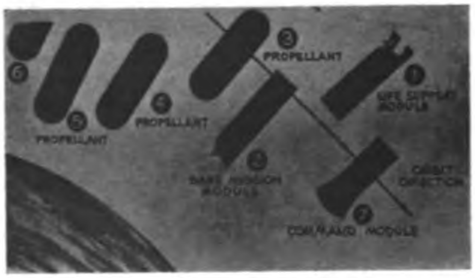


Fig. 16. Launch sequence.

ation with regard to payload penalty and is too restrictive with regard to launch window time.

Shown on Fig. 12 is the approach whereby a parking orbit, having the same inclination as the target, is used to minimize the total characteristic velocity for rendezvous. The target orbit is shown at an altitude of 263 nm with a parking orbit of 116 nm. Because of the difference in precessional rates of the target and parking orbits, an in-plane condition will occur after a given interval as shown on the right-hand side of this figure. The time interval to wipe out the original out-of-plane angle can be related to the delay time occurring at the launch pad. The relationships existing between the target and parking orbits are shown on Fig. 13 normalized with respect to the target orbit. The objective is to synchronize the precessional rate difference with that of the relative target and parking satellite positions.

The upper right-hand graph of Fig. 13 indicates the parking orbit precessional rate increase normalized with respect to the target at an altitude h_t of 263 nm. For a parking orbit altitude h_p 116 nm the precessional rate difference is 4.0 min of arc per revolution, or approximately 1.0° per day. The period difference and lead angle for a Hohmann transfer normalized with respect to the target is shown in the upper left-hand figure. Period difference is about 5.58 min/rev and the required lead angle is 5.15°. The lead angle advance/min of park and laps advance/day of park is shown on the lower left-hand figure. These rates are about 0.24°/min of park or 0.97 laps/day of park.

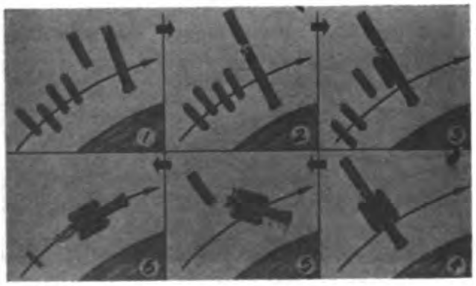


Fig. 17. Assembly sequence.

One can compare the advantages of the extended parking orbit launch to the direct launch by considering the right-hand lower figure. For example, since the precessional rate difference of 4 min of arc/rev is relatively small, it will require about 53.4 revs, or 3.29 days time, to wipe out a 3.56° launch base angle difference corresponding to a 14.25 min launch delay. Thus, as shown on the graph, a 4.75 min delay means a 1.1 day park; a 9.4 min delay, a 2.17 day park; a 14.25 min delay means a 3.29 day park; etc. The author believes that a 5-day park is about the upper limit that might be accepted operationally without scrubbing the flight to wait for another launch opportunity. With use of rendezvous compatible orbits, a second launch opportunity occurs 3.15 hr later for an RCO with N/m (synchronism ratio, number of satellite revolutions per day) of 15 and small n of 2. Thus if the vehicle cannot be launched precisely at the optimum launch time it may be better to hold for the second opportunity.

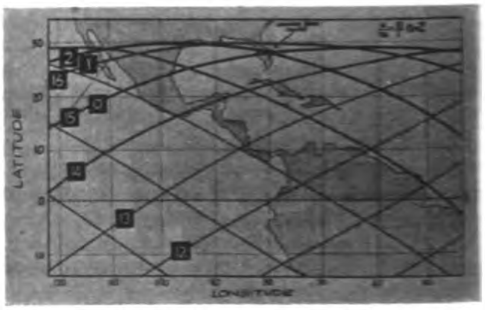


Fig. 18. Rendezvous-compatible orbit (trace on a mercator projection of an RCO).

The advantage of this "overtime parking" using the extended parking orbit launch approach may be compared with that for direct launch as shown on Fig. 13. A 4.75 min delay (1.1 day park) therefore costs about 242 lb in payload penalty whereas this penalty is nearly 10,000 lb for direct launch, a 50-to-1 advantage. A 28.4 min delay, requiring a 6.59 day park, will have a payload penalty of only 1,450 lb. This is far less than for a direct launch and would be considerably smaller than that for the orbit phasing technique.

The small payload penalty and practical launch window limits for the extended parking orbit launch to a rendezvous compatible orbit fullfills the three major criteria for selection of the best launch technique for rendezvous. These are (1) minimum payload penalty for launch delays, (2) practical launch window, and (3) minimum total launch pad time. Although minimum payload penalty is important, the high direct operating costs of launch base crews during unnecessarily long prelaunch delays must be considered. Utilization of RCO's and the extended parking orbit launch concept will give improved surface-to-orbit launch logistics with the following significant results:

(1) Increased number of launch opportunities (maximum of two per day continuously).

(2) Increased number of rescue and recovery opportunities (greater than two per day continuously to selected recovery sites).

(3) Launch and recovery time periods would be fixed and repetitious, thus simplifying scheduling and reducing operational costs of ground handling crews.

(4) Launch time delays up to about 30 min would still permit optimum in-plane transfers from the launch base to the parking orbit and, hence, to the target orbit with nearly zero payload penalty.

Concerning the extended parking time employed in this concept it is this writer's conclusion that "let's accept the time delays that occur and let the flight crew use the park time for indoctrination, or other useful task assignments, and permit the launch crew to initiate assembly and checkout operations for the next shot."

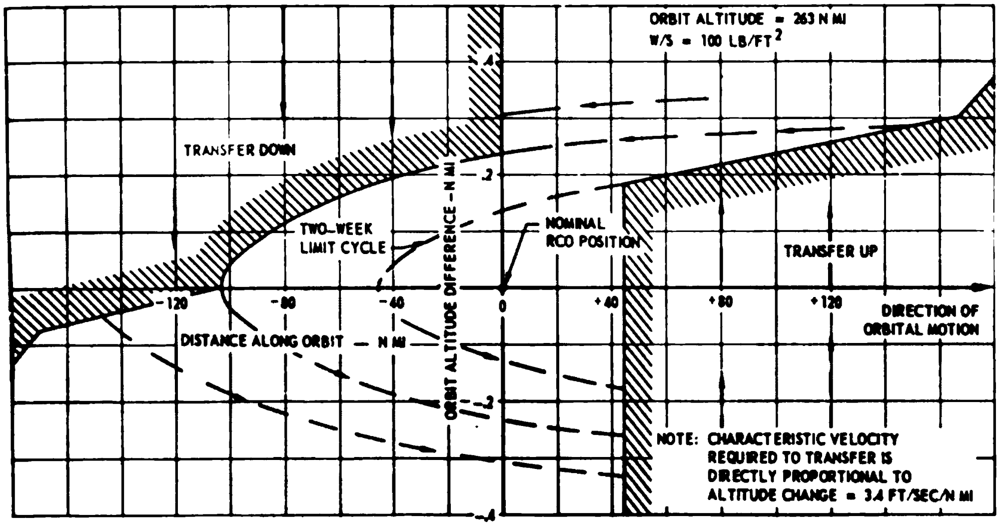
Orbital Launch Criteria

Two additional factors predominate in the choice of an orbit plane for orbital launch operations aside from the restrictions discussed in the preceding section. These are the number of launch-from-orbit opportunities occurring and the Van Allen Belt trajectory transit time. Although polar orbit inclinations yield minimum exposure to Van Allen radiation, the best compromise is to employ the 28.5° to 50° inclination possibilities from Cape Canaveral as depicted by Fig. 14.

Other criteria that must be evaluated are eclipse time or the day-night cycle to which the satellite is subjected. This factor requires serious consideration from two points—the use of the sun as a power source and as an attitude reference.

Launch from orbit is a function of many variables, both geometric and dynamic. A clear understanding of the three-dimensional geometric relationships of the satellite–earth–moon system is necessary to visualize the problem. Geometry for the earth–lunar transfer orbit and lunar arrival window is shown on Fig. 14. Detailed studies have been performed establishing the many orbital launch requirements to effect an optimum earth–lunar transport system and are available in Refs. 8 and 9. Primary objectives of these detailed trajectory studies have been to (1) define the earth-orbit launch criteria for lunar trajectories, (2) establish the departure trajectory sensitivities to orbital parameters, (3) establish mission and vehicle sensitivities to time and energy requirements, and (4) determine analytical techniques for determining optimum launch conditions.

It is essential that launch from orbit should occur when the resulting transfer trajectory will permit a rendezvous, or intercept, with the moon near the line of nodes. An adjustment must be made in the trajectory central angle or the launch plane angle, or both, in event of a nonoptimum launch time, thus



NOTE: CHARACTERISTIC VELOCITY REQUIRED TO TRANSFER IS DIRECTLY PROPORTIONAL TO ALTITUDE CHANGE = 3.4 FT/SEC/N MI

Fig. 19. Limit cycle characteristics for stationkeeping of a rendezvous-compatible orbit.

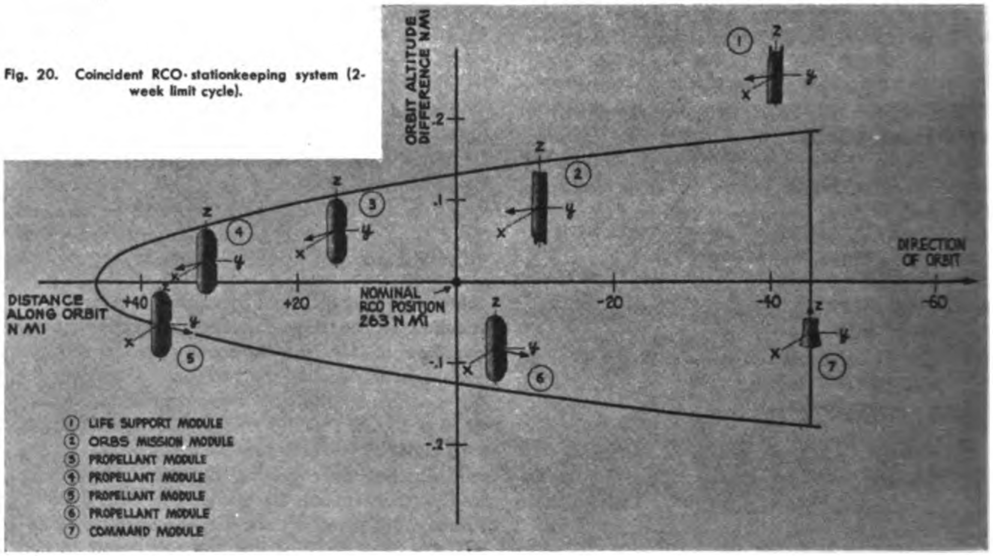


Fig. 20. Coincident RCO-stationkeeping system (2-week limit cycle).

requiring additional energy. The amount of additional propulsion system capability required for the orbit launched vehicles is directly related to the limits established for the "launch or escape window" for the lunar transfer orbit. Because of the precession of the orbital launch base about the earth and the motion of the moon about the earth–moon center of mass, a resulting "launch window" occurs approximately every 10 days. Precise width and frequency of this "launch window" varies markedly with time. Number of launch opportunities (satellite revolutions per launch window) varies accordingly. Practical "launch window" widths or durations of from one to two days, or 15 to 30 Revs will exist with reasonable requirements for additional propulsion energy.

Orbital Rendezvous Base System Concept

Orbital Base Development

The natural course of events in establishing an orbital base for earth–lunar logistics should proceed from an elementary manned space station to the full launch base facility required for sustained orbital launch operations. The elementary manned space station, as the first phase, would serve to develop and demonstrate operational procedures and to establish design requirements for future major subsystems such as rendezvous guidance, control, and computer equipment, mechanical and fluid coupling devices, checkout equipment air locks and extravehicular mobility devices, communication and electronic techniques, etc. At present, first flight tests are planned for this first phase using advanced Mercury multiman maneuverable space capsules. Advanced orbital base development will be constrained to similar vehicle modules anticipated for the Project Apollo program.

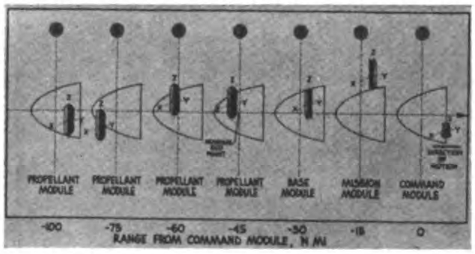


Fig. 21. Offset RCO stationkeeping system (1-week limit cycle).

Key Operational Phases

The principal phases for the operational use of an orbital launch involve rendezvous, assembly, checkout, and launch. Various approaches may be taken, however, in development of the orbital base and mission vehicles. The design of the orbital launch base must be compatible with the operational requirements of the specific missions assigned to the base. It should be recognized that the concept approaches available are very closely coupled to the available booster size and launch rate for surface-to-orbit logistics. Upon first consideration of the problems involved in developing an orbital launch base, one is confronted with a variety of system techniques and operational modes that may be integrated into a working complex.

The objectives of the design study on which this paper is based were to establish the design concepts and characteristics for a disciplined orbital rendezvous, assembly and launch system illustrated by Fig. 15. This design study,[3] referred to as "An Orbital Rendezvous Base System" (ORBS), provides the foundation for development of an economical earth-moon logistics system. The concept is based on employing standardized modules for command and control, life support and propulsion with each placed into orbit by Saturn-class boosters and subsequently assembled to form a launch base for a variety of space missions. Standardized modules have been configured, and are launched from the AMR and injected into a low-altitude rendezvous compatible orbit of about 263 nm with an inclination of 32°. Other specific altitude and inclination combinations uniquely required for orbital rendezvous compatibility and lunar phase synchronism exist and will be discussed in later sections of this paper.

Each of the modules, employed in the ORBS concept for the lunar missions, are injected into orbit and constrained by an on-board guidance system to maintain a precise attitude reference to the orbit plane and local vertical. The five to seven unmanned modules in the proposed concept are constrained to precisely the same orbit but spaced at about 10-mile intervals along the orbit. This technique for injection of the unmanned modules is employed due to a probable maximum booster launch rate schedule for 1965-66 of one shot per week. With this launch rate, it will require 5 weeks to inject the first six manned modules into orbit. Immediately following injection of the last unmanned module and following a brief orbit smoothing phase, the manned command module may be launched. Following injection of the manned command module, assembly of the mission vehicle and base commences. A rendezvous transfer guidance system maneuvers each module from their stationkeeping positions toward the command module. An automatic or manual control system is employed for the terminal maneuvering and coupling to the command module. Upon subsequent checkout of the mission vehicle the base module is uncoupled and the vehicle is maneuvered downrange a safe distance, perhaps a mile, and launched on its trajectory to the moon. Primary consideration was given to crew safety with a 30-day duty cycle established for the crew. Thus, for the assembly period and a 14-day lunar mission (under reasonably optimistic conditions) the crew is in space for a total of about 20–25 days. Total single mission time from first launch to final reentry requires about 60 days.

Some of the specific advantages envisioned for orbital launch operations employing techniques similar to those developed in this paper include:

(1) Increased launch opportunities from orbital base.

(2) Permits assembly of mission scaled vehicles.

(3) Provides configuration flexibility.

(4) Assures early capability for lunar/planetary operations.

(5) Reduces reliability restrictions through mission staging.

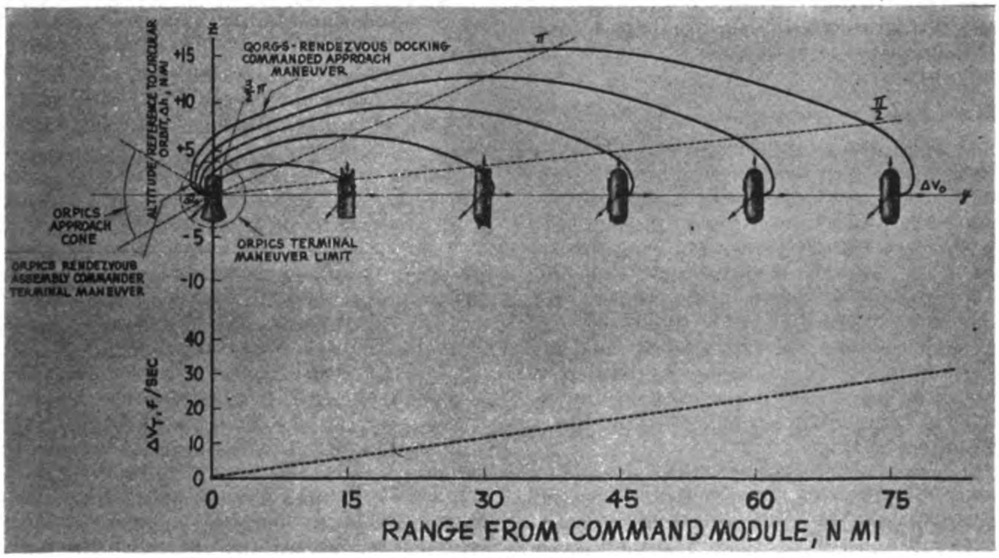


Fig. 22. Relative motion during rendezvous (Offset RCO with Iso-orbital initial condition).

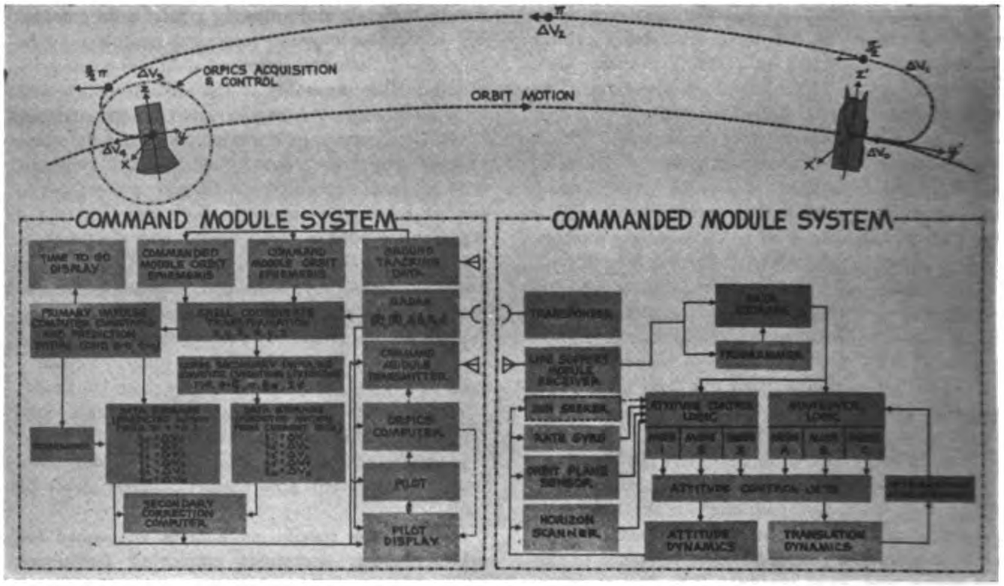


Fig. 23. Rendezvous-transfer maneuver control system, block diagram.

Launch and Assembly Sequence

Launch and assembly sequence is depicted on Figs. 16 and 17. As shown by Fig. 16, the life support module is launched first, base mission module second, the four propellant modules in turn and the manned module last. The assembly sequence is shown on Fig. 17 wherein each module is assembled in turn to the command module, thus minimizing the energy requirements for rendezvous. Inserts 5 and 6 illustrate the decoupling from the launch base and maneuvering of the mission vehicle down range prior to launch.

Orbital Rendezvous Techniques

In order to provide periodic resupply of the orbital launch base and increase the number of launch, deorbiting and rescue opportunities from Cape Canaveral launch pads, we have selected a particular orbit having a special altitude and inclination and termed a "rendezvous compatible orbit" (RCO).[10] This rendezvous compatible orbit provides synchronism of its position-on-orbit and the launch pad at Cape Canaveral. The RCO selected has characteristics of 263 nm in altitude and 32° inclination with the equator. Thus, the orbit ground trace is as shown on Fig. 18 for a synchronous or rendezvous compatible orbit.

Because of the one-week launch rate from Cape Canaveral a "stacking" concept for the unmanned modules is employed until the manned command module is launched. A limit cycle technique, illustrated by Fig. 19, has been proposed as a method for providing continuous maintenance of the assembly and launch base on a rendezvous compatible orbit. Two approaches for this stacking phase are shown in Figs. 20 and 21 and are referred to as coincident and offset stationkeeping systems.[11] Fig. 20 shows the coincident stationkeeping technique with the seven modules constrained to a 2-week limit cycle or period of circulation about the nominal aim point on the orbit. As drag decays the altitude of each over a 2-week period, a small velocity impulse of about one fps elevates the module up to a slightly higher altitude and the limit cycle continues. Here the vertical motion may be extremely small, about ±0.2 nm, whereas the horizontal excursion is ±44 nm.

Although collision probability is small over a 7-week period, a preferred technique may be that shown on Fig. 20. Here each module follows a one-week stationkeeping limit cycle. During these stationkeeping phases, each module is constrained to maintain a particular attitude reference to the local vertical and orbit plane. This is accomplished by a horizon scanner and yaw gyro respectively.

Following injection of the manned command module, the rendezvous transfer maneuver of each module is executed. Relative motion of each module is depicted in Fig. 22. Each module responds to guidance signals or commands from the command module as determined by range, range rate and angular information from the command modules radar, infrared tracker, and computer. The terminal approach to the command module is pricipally along the orbit and may be likened to the landing approach of an airliner to its runway. Although vehicles in orbit have extremely high absolute velocities referenced to the earth's surface—viz., 18,000 mph for low-altitude orbits—it is the relative motion between satellites that concerns us here. If we have two satellites on nearly the same orbit this relative velocity between them will be small. If the satellites are on precisely the same circular orbit, their relative velocity is indeed zero. Satellites placed like a string of beads in space and constrained to nearly identical orbits thus may have maximum relative velocities of about 10 to 20 fps. Subsequent rendezvous maneuvers will increase this relative motion to probably a maximum of 50 to 100 fps. The terminal rendezvous maneuver should be as simple to perform as that of driving and parking a car. Certainly it should be easier to perform than the present rendezvous and coupling of fighter aircraft to a tanker coping with both night time and rough weather conditions. It is believed that manned rendezvous in space can be performed as a matter of routine and with high precision and reliability. Division of equipment responsibility is depicted by Fig. 23. As shown, the command module determines the relative position and motion of the commanded module, computes the command signal, and transmits these to the target module. The responding module receives these signals and activates the appropriate attitude or translational jet to move the module to the command module using a quasi-optimal rendezvous guidance system.[12]

An alternative automatic guidance system has been considered for the terminal phase and is shown in Fig. 24 designated ORPICS[13] (Orbital Rendezvous Positioning, Indexing, and Coupling System). The ORPICS system reduces the terminal approach velocities and positioning displacements of the approaching module to zero. Fig. 25 shows the terminal approach trajectory.

The boost, coast and homing phases for manned ascent to the orbital base is expected to be similar to present Project Mercury flight operations, but modified to include rendezvous maneuvers resulting in docking and coupling to the target base. Ref. 14 presents a detailed system concept for rendezvous and docking.

Vehicle Design

The engineering approach in designing the vehicles employed in this orbital rendezvous base system utilizes the modular concept established for the NASA Apollo manned lunar project. However, the special requirements for orbital assembly necessitated new design techniques. Airlocks provide access between all mission and base modules. Final mechanical, electrical and fuel coupling between modules, following assembly positioning, is performed by the crew from the module interior. Malfunctioned modules may be jettisoned to permit assembly of a replacement module. The base module contains auxiliary power and life support equipment to sustain the entire base and mission vehicle during assembly and checkout. Life sup-

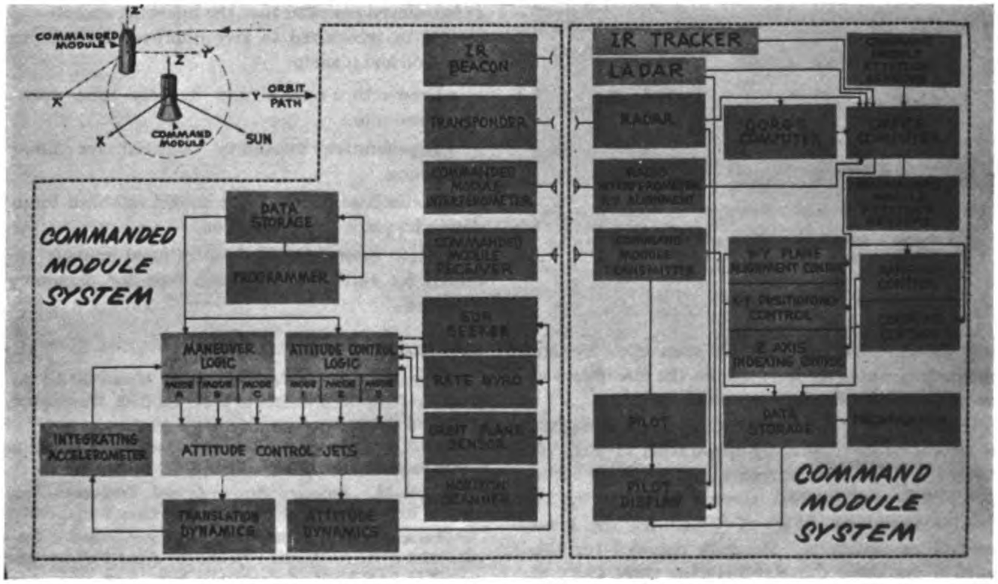


Fig. 24. Rendezvous-docking maneuver control system, block diagram.

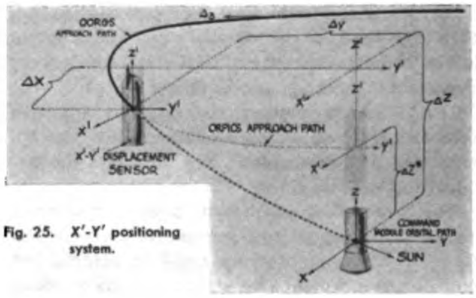


Fig. 25. X′-Y′ positioning system.

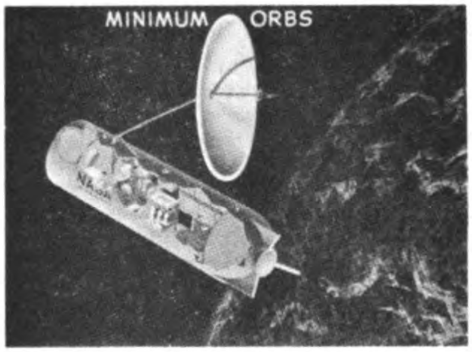


Fig. 26. Base module cutaway.

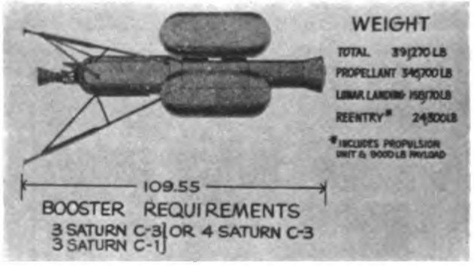


Fig. 27. Lunar landing vehicle, powered re-entry.

port systems are based on an open cycle system eliminating water recovery due to the abundance of water contained within the radiation shield.

Internal arrangements of the ORBS base module is shown by the cut-away illustration of Fig. 26. Auxiliary power is provided by a 15-kw solar dynamic electric system erected in space by inflatable structures. Fig. 27 illustrates the lunar landing configuration. Boosters required for this mission are three C-1 Saturns plus three C-3's or four C-3's. Orbital launch weight ranges up to 440,000 lb. A single propulsion engine of 200,000-lb thrust using liquid oxygen-hydrogen provides orbital boost, lunar landing, and lunar escape thrust. Thrust acceleration ranges from one-half to about four g's.

Concept Summary and Conclusion

Concept advantages for this orbital launch base are briefly summarized as follows:

(1) Economic operation from rendezvous compatible orbits.

(2) Greater launch flexibility from orbital base.

(3) Permits assembly of mission scaled vehicles.

(4) Provides checkout and launch under controlled environment.

(5) Provides configuration flexibility.

(6) Permits shuttle operation between earth-moon.

(7) Assures early capability for lunar/planetary operations.

(8) Provides mission mending capability.

(9) Reduces reliability restrictions through mission staging.

It is the author's conclusion that our decision to go to the moon via the orbital assembly and launch route will greatly influence our capacity to expand our space potential. Orbital assembly and launch will provide greater economy, flexibility, reliability and saving of time than direct ascents to the moon using larger boosters. Consideration should be given to long-range planning concerning integration of lunar operations with development of earth-orbital assembly and launch facilities for planetary missions. It is believed essential that the following operational factors be recognized to give improved logistics to the moon and planets:

- Crew-return-rate should be less than crew-departure-rate.
- Regenerative capability essential for lunar operations.
- Lunar base development should establish foundation for planetary exploration.
- Earth-moon combined operational support required for earth-orbital launch base for planetary missions.

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Mr. PETERSEN. This engineering study illustrates the general mission requirements for an Earth-orbital assembly and launch system to accomplish manned lunar operations based on design information available at the time of the study. A concept for development, general system characteristics, and operational use of a proposed orbital launch pad for rendezvous, assembly, checkout and launch of manned lunar flyby, orbiting and landing vehicles is discussed.

Mr. FULTON of Pennsylvania. You may have advanced your thinking on some of the problems in the interval since you wrote the paper. At any point on which you have changed your mind or brought anything up to date, would you make that interlineation right at that point in the technical report?

Mr. PETERSEN. I have personally been pursuing, with a number of other people at various times, certain elements that were presented in the paper. Since I joined the Air Force I have not been working specifically on the problem. I have not come to any other conclusions than what are presented in the paper.

Mr. FULTON of Pennsylvania. It is up to date, then?

Mr. PETERSEN. I consider it so.

Particular emphasis is given to utilization of rendezvous compatible orbits and stationkeeping for improved surface-to-orbit launch logistics. It was concluded that the best route to the Moon, employing a proposed space Canaveral facility as a low-altitude orbital assembly and launch adjunct to Cape Canaveral, would significantly increase the United States' capacity for Earth-orbital, lunar, and interplanetary exploration.

The referenced report summarizes results of a company-funded study initiated in August 1960. This company-funded study on Earth-orbital rendezvous, assembly, and launch for lunar operations was initiated simultaneously with the August 1960 bidders conference and subsequent award in October 1960 by the NASA of three parallel study contracts to industry to investigate direct launch systems to the Moon. The specific objective of this study was to establish system requirements for an Earth-lunar logistic transport system based on development of an Earth-orbital rendezvous, assembly, and launch system.

The study recognized the several basic modes of transport to the Moon to include the following:

(1) Direct launch (Earth surface launch and direct transit to the Moon);

(2) Earth-orbital rendezvous (Earth-orbital rendezvous, assembly, and launch with direct transit to the Moon or descent from lunar orbit).

Mr. TEAGUE. On each of these, would you talk about the launch vehicle a little? Would No. 1 require the Nova?

Mr. PETERSEN. Well, a larger vehicle, yes, or the present system with some modification——

Mr. TEAGUE. Could No. 2 be done with a number of Atlases?

Mr. PETERSEN. No, not Atlases, but with slightly larger vehicles. The larger the better, the fewer the rendezvous, though I don't think the number of rendezvous is particularly a disadvantage.

(3) Modified direct launch/lunar orbit excursion and return rendezvous (Earth surface launch and direct transit to lunar orbit with descent to lunar surface and subsequent rendezvous to lunar orbit).

(Present NASA concept employs this technique.) This third mode is what I call the modified direct launch (MDL) with lunar orbit excursion and return rendezvous, a combination approach. This third mode should be identified as a modified direct launch to the Moon, and it is, I think, improper to identify it as lunar orbit rendezvous in the same sense as Earth orbit rendezvous.

(4) Lunar orbit rendezvous (direct launch to lunar orbit, rendezvous, assembly, and descent to surface).

This employs earth surface launch of two or more vehicles with direct transit to the lunar surface orbit with subsequent assembly and descent to the lunar surface.

Mr. TEAGUE. What is the difference between No. 3 and No. 4?

Mr. PETERSEN. I would identify lunar orbital rendezvous as the technique employing assembly in a lunar orbit to achieve a mission. The present system to the Moon is effectively a modified direct launch to the Moon and does not employ orbital assembly, and consequently should be properly identified as a modified direct launch, MDL, approach.

Mr. FULTON of Pennsylvania. Why do you use a smaller vehicle if it is really a modified direct ascent to the Moon?

Mr. PETERSON. I have a few comments that will bear on this later on. Primarily, the vehicle may be smaller for the modified direct launch only if the excursion module descending to the lunar surface encompasses less payload and backup systems than those selected for Earth orbit rendezvous.

Mr. TEAGUE. If we ask questions that you are going to cover later on, just say so.

Mr. PETERSON. All right.

(5) Lunar surface rendezvous (direct launch to lunar surface with lunar surface assembly and launch).

(6) Earth-orbital rendezvous/lunar-orbital rendezvous (general concept employing rendezvous, assembly, and launch operations in both Earth orbit and lunar orbit).

Each of these primary modes of Earth-lunar transport have special merit though primary emphasis was given to the Earth-orbital rendezvous mode. It was believed that this route to the Moon had the greatest payoff for lunar as well as interplanetary missions, but further would provide a useful foundation for expanded Earth-orbital civil and military space programs. Completion of any single program or mission, lunar or interplanetary, using the Earth-orbital assembly and launch base as a "fulcrum" or "springboard," would accrue a stronger space foundation or capacity in the form of technology, orbital operations experience, as well as facilities in space to serve as an operational catalyst for future programs.

Mr. TEAGUE. Are you saying that EOR has a much greater growth potential than LOR?

Mr. PETERSEN. Yes; I think it has a strong bearing on all our programs in space. Many of these will rely on Earth-orbital operations; we have plans to build navigational satellites, weather satellites, and many other scientific laboratories that will require a considerable amount of manned operation in space, and I think an adequate orbital launch facility could best serve this operational purpose in space.

It was recognized that the total effort of transport to the Moon and return is approximately equally divided about the earth orbit launch base. The total energy, the tasks to be accomplished, and the order of complexity for the surface-to-orbit boost phase is reasonably well matched with those occurring following orbital assembly and launch. It was further recognized that the development of specialized modules for propulsion, command or flight control, life support and auxiliary equipment, as building blocks for assembly in space, provided the desired qualities of flexibility and growth potential. It is these two areas that are considered the key criteria in identifying the advantages of Earth-orbital rendezvous. Earth-orbital rendezvous is considered to have far more growth potential and flexibility than can be achieved by any launch system. The ability to significantly increase production capacity in a far shorter time period rather than the continual initiation of new R. & D. programs for larger boosters was accepted as a necessary objective. It was further recognized that future development of nuclear propulsion would encourage the use of special-purpose shuttle vehicles for operation between both Earth- and lunar-orbital assembly and launch bases with lower transport costs.

Generally, the concept of orbital rendezvous operations considers the sequential rendezvous of multiple satellite vehicles and is construed to include succeeding phases of docking, coupling, assembly, checkout, and launch toward completion of more complex, specialized missions. The utilization of these orbital operations permits the full benefit of rendezvous to be attained in execution of larger space missions by assembly techniques in space. Considering these six modes of transport, only modes (2), (4), (5), and (6) employ multiple launches and subsequent rendezvous and assembly for execution of larger missions in space.

General conclusions established by the referenced engineering study were as follows:

(1) The capacity for rendezvous, assembly, checkout, and launch from Earth orbit provides an immediate and permanent solution to booster payload limitations;

(2) Broadens the achievable space mission window; and

(3) Permits the vital utilization of man to the limits of his ability to provide in space the capacity for decisionmaking, the ability to perform secondary (orbital) checkout, the dexterity to yield improved reliability through orbital maintenance, repair, and modification, and the flexibility to broaden vehicle maneuverability performance limits.

Specific advantages to be gained through development of a capability for rendezvous and assembly and the implementation of an orbital launch base were identified as follows:

(1) Permits assembly of mission-scaled vehicles (negates booster payload limitations by assembly in space of appropriately sized vehicle to match mission requirements; provides mission flexibility and growth potential; provides positive means to offset payload growth during development rather than through elimination of redundancies and backup equipment as occurs for direct launch systems); in addition to what I have here, I wish to emphasize that we can build mission-scaled vehicles. For example 2 years down a program or project route, if someone concludes that he would like to have a four- or five- or six-man crew we can add on propulsion modules to provide this flexibility. In the present system the only way you can go—the only direction you can go is to back off from a three-man

crew to a two-man crew and throw overboard redundancies and backups.

(2) Provides configuration flexibility (offsets launch and aerodynamic drag restrictions and provides improved configurations for auxiliary power and nuclear propulsion systems).

You don't have to live with the specific articulated arms that can be folded inside the nose cone. One can refigure the system, employ certain APU panels or structure after you have exited from the atmosphere and therefore avoid the confinement of the aerodynamic shroud on the vehicle.

(3) Provides secondary (orbital) checkout and launch (reduces reliability restrictions through mission staging; provides stabilized or controlled environment for checkout and launch);

(4) Provides mission-mending capability (permits possible return to orbit and subsequent rendezvous for certain abort conditions of lunar and interplanetary vehicles exhibiting malfunctions during escape maneuvers, thus salvaging key elements of large mission vehicles);

(5) Provides improved launch logistics through use of rendezvous compatible orbits (RCO's)—I may refer to these by the abbreviation "RCO's" a time or two—and station keeping (the operational procedure of employing rendezvous compatible orbits, RCO's, to provide a "milk run" synchronism of the orbiting assembly and launch base yields two optimum, in-plane, launch opportunities per day, for rendezvous with zero-payload penalty; the RCO synchronous orbit simultaneously yields two optimum, in-plane, recovery opportunities per day from orbit to a preselected landing site; the RCO synchronous orbit further provides two optimum, in-plane opportunities per day for both rendezvous or recovery-type rescue or retrieve missions; offsets payload penalties associated with launch operations to randomly orbited target satellite stations).

Mr. Riehlman. Would you just explain that a little more?

Mr. Teague. Why don't you go a little slower?

Mr. Petersen. A rendezvous compatible orbit is just a class of orbit that can be employed in space to give milk run synchronization with the launch station. There are many problems, associated with improved logistics, to Earth orbit, such as delays on the launch pad, so on, since we have a vehicle in orbit around the Earth, and the Earth spinning beneath it. We can by using stationkeeping capability on board the vehicle in orbit constrain it to a fixed orbit so that the ground track line over the surface of the Earth repeats itself. If we select the altitude and inclination just right and have stationkeeping on board the station in space we can drive it or constrain it, at very low cost, to repeat its ground track line over the face of the Earth. Stationkeeping is the ability to make minute maneuvers in space, to restrict a satellite to a fixed selected orbit. We can maintain or constrain the vehicle to follow the same orbital path in space so that twice a day there is an optimum in-plane launch opportunity. We can constrain the vehicle in space by stationkeeping, by using small rockets on board, fired periodically on perhaps a 2-week limit cycle, and drive the satellite into the desired orbit so that once a day it will have a north going path right over the cape and two revs or three revs later it will have a southgoing path over the launch base. Thus, we can improve our launching capability, so that our logistics to space can be obtained at a very low cost per pound of payload in orbit. To constrain a vehicle on the order of, say, the Apollo command module, support module, and other modules that might be attached to it, it would cost about 30 feet per second per year in characteristic velocity to provide this stationkeeping capability.

We all know it takes about 25,000 feet per second to constrain a vehicle in an orbit around the earth. We have need for only 30 feet per second, roughly a thousandth of that, to periodically adjust the orbit to give this rendezvous compatibility with the launch base resulting in two optimum inplane launch opportunities per day. Twice a day we can expect to have milk run synchronism of the base in space with the Cape Canaveral launch base. It is essential to have the target space station at some desired central angle position with respect to the center of the Earth and the Earth-surface launch base, so that when you launch from the launch pad the ascending vehicle will arrive in space together with the target space station.

If you use stationkeeping you can drive or constrain the station in space to follow this rendezvous compatible orbit trace. Primarily the successive velocity impulses employed on a 2-week limit cycle are simply used to offset the aerodynamic drag occurring on the target station and to reelevate the station to its original altitude. Say we select an inclination of 35° and altitude of 264 nautical miles. We would use little impulses every 2 or 3 weeks to elevate or reelevate the station a mile or two in orbit to offset the altitude dissipated by air drag. Thus we can constrain it month after month to give this repeatability, repeating the ground track line over the surface of the Earth day after day, to give us this rendezvous and recovery compatibility with the launch and recovery sites.

If we don't use this technique we have random orbits. All the 100 satellites we have placed in space now are on random orbits and to achieve rendezvous with these vehicles may pose severe payload penalties. It is very rare they ever pass through the original injection point, which is necessary in order to give a new minimum energy path to effect rendezvous with them. The use of random orbits generally may result in a high payload penalty associated with the rendezvousing vehicles. Alternatively you may have to wait perhaps 3 weeks or 6 months; or perhaps never would you have a truly optimum access to the target satellite. The stationkeeping system required can be provided at low cost to the vehicle system and it is essential to providing a low-cost logistics system to low-altitude orbits.

Mr. TEAGUE. Mr. Roudebush.

Mr. ROUDEBUSH. Wouldn't this require a technical knowledge and excellence that we have not presently attained?

Mr. PETERSEN. We have not demonstrated stationkeeping to date. But we are building stationkeeping techniques into the 24-hour satellites. I believe we presently have all the information, guidance equipment, and propulsion capability to do this now.

Mr. ROUDEBUSH. This would require repeated starting and stopping by radio direction?

Mr. PETERSEN. Yes, if the station were unmanned, though generally I am referring to a manned station.

Mr. ROUDEBUSH. Do we have that technical knowledge?

Mr. PETERSEN. Yes.

Mr. ROUDEBUSH. We can bring satellites into the precise orbit we want now?

Mr. PETERSEN. Very nearly for unmanned systems—yes. Manned systems could more easily be adjusted very precisely to the desired orbit.

Mr. BELL. Do you mean the second vehicle can be launched at exactly the precise time desired?

Mr. PETERSEN. There is no assurance that one can do this but there are several solutions in event you cannot. Certainly the launch time delays on the launch pad greatly influence the payload penalties. Even a minute's delay on the launch pad increases the payload penalty severely.

Mr. BELL. Even when we launch one today we have the long countdowns, and there is also a question of whether the launch will be at the precise time or not.

Mr. PETERSEN. That is very true.

Mr. BELL. Until we conquer that, aren't we in trouble on the exact meeting in orbit?

Mr. PETERSEN. Yes, sir. This can only be solved by experience, more launches and improved reliability, and the use of perhaps the best solution, that of a backup vehicle. It might even take two backup vehicles to provide this launch window capability.

Mr. FULTON of Pennsylvania. Could I give you a glowing example of almost rendezvous in space. The Soviets had a perigee of 111 miles on one vehicle and 112 on the other, and apogees of 163 to 166 miles, within 2 or 3 miles of each other. So the Russians were able to do it a day or so later.

Mr. BELL. But they had a precise time when that second vehicle was going to be launched, apparently.

Mr. FULTON of Pennsylvania. We are talking about whether such a system is possible.

Mr. BELL. It is possible, but we have not achieved it yet.

Mr. FULTON of Pennsylvania. To be able to come within 1 mile in height and 2 miles in orbital path on an orbital plane similar to another satellite is a tremendous accomplishment. Don't you think so?

Mr. PETERSEN. I agree. Vostok 3 and 4, apparently from what I have seen in the press, came very close to achieving rendezvous. They may have, as far as I know, even completed rendezvous, docking, coupling, and uncoupling, on the unobservable side of their orbit, then establishing a drift rate of about 24 miles per hour, as was reported, I believe.

Mr. TEAGUE. Mr. Daddario.

Mr. DADDARIO. This ability you say we are developing to have a fixed orbit, of which we can keep track and take a sight on, and then to be able to launch another vehicle for a rendezvous, seems to me the one way of doing it. But isn't NASA doing anything else to launch a vehicle, track it, in even random orbit, and then adjust the orbit of the rendezvous vehicle to catch up?

Mr. PETERSON. Sure.

Mr. DADDARIO. What are the problems attendant to that?

Mr. PETERSEN. Minimum payload penalties result if the target vehicle in space is at a specific position on its orbit relative to the launch base. The only way one can obtain this is to use this stationkeeping capability to drive it in to this constraint. If you don't have this compatibility with the launch base you can certainly back off and accept whatever out-of-plane angles occur, whatever noncorrect central angle exists. You might have to sit on a parking orbit half a day, a day, or a longer time, to improve the conditions for subsequent injection to the target station. But it is not a complex system to provide this station keeping. We can't get to the Moon and impact on a certain spot without a similar very precise propulsion capability and guidance system. It doesn't require anything new to be added to the system.

Mr. DADDARIO. One of the elements I read in your report is that through the Earth-orbital capability we would develop a wider space program. It seems to me, it would have military implications to be able to go and inspect a satellite in space which could be put up by another country and would not be put into this same kind of fixed orbital station-keeping capacity. A part of our effort ought to be directed toward the ability to send a satellite into space to have this rendezvous capacity to catch up with a vehicle, rendezvous in orbit, inspect it, and neutralize it, if it becomes necessary. This would seem to be a proper objective within the limitations of our capability to widen our program for security purposes.

Mr. PETERSEN. I agree military applications, certain of them, such as inspection of satellites, demand and require a higher degree of maneuverability to cope with non-coplaner or uncooperative targets than we need for civil or military R. & D. programs aimed at just developing an Earth-orbital capability.

Our civil program and most of our military research and development programs in space, the logistics ought to employ the most efficient launch procedures possible—there is no point in thinking we can hide, nor should we try to hide, these R. & D. vehicles in space. Certainly for the research and development military programs that have been proposed, there is little point in hiding these in space. In fact, I don't think you can, certainly not on low-altitude orbits. And on the civil side we ought to develop a minimum low-cost operation technique to permit the subsequent rendezvous of these vehicles, and it should be done on the minimum cost basis.

I think it can only be done by having a rendezvous and recovery compatible orbit operation. The launching of vehicles on random orbits is appropriate for single missions by themselves. You do not need station keeping for single orbit missions. But for repeated rendezvous with space laboratories in space, or assembly of launch pads in space for other missions, that requires mutliple rendezvous, we should use the lowest cost system, with the lowest payload penalties, to do it. Certainly there are military missions where you would never use rendezvous or recovery compatible orbits, at all.

Mr. TEAGUE. Mr. Bell.

Mr. BELL. Mr. Petersen, is the general principle involved in rendezvous that after you get the first vehicle in orbit to keep it on a fairly constant orbit, and when the second vehicle is launched, to have it catch up by a continuing widening of orbit to the point where the vehicles come together? Is that the general principle?

Mr. PETERSEN. You are getting at the use of parking orbits for the subsequent injection of a vehicle to a target satellite. Because of launch time delays there is a need to place the ascending vehicle on a parking orbit to relieve the payload penalties of final rendezvous with the vehicle. Because of launch time delays you go to a parking orbit and wait there because of the period difference between the two, to permit a lower energy ascent to the target, in the same orbit; thus the parking orbit is really used only to provide a favorable angular relationship with the target, and this could vary in time depending on the launch time delay. A parking orbit may be used for launch to a target satellite on a random orbit as well as those employing station keeping to provide rendezvous compatible orbits.

Mr. FULTON of Pennsylvania. Do you recommend the immediate planning and construction of a space platform by the United States so that we can have in orbit a permanent installation, or permanent installations, which might be space laboratories, space viewing depots, and even give space mechanical assistance on mating capsules, repairing, and even recovering capsules that go into random orbit?

Mr. PETERSEN. Right. I feel strongly that a good Earth orbital capability for manned operation, of 260 nautical miles or in that general area, is very vital to all of our programs involving man in space, whether to provide operational support to him for our civil programs as well as military——

Mr. FULTON of Pennsylvania. We have no recommendation in the authorization, as you know, for such a platform. But you would recommend it?

Mr. PETERSEN. I do, strongly.

Mr. TEAGUE. I think we ought to continue your statement, Mr. Petersen, and please go slowly through those sentences and make it as clear as you can.

Mr. PETERSEN. I will try to.

Mr. TEAGUE. They are rather complicated.

Mr. PETERSEN. Well, the sixth item encourages development of the "building block," or vehicle module, approach for design of large space mission systems. Orbital rendezvous concept thus yields lower production costs, higher reliability, and greater payload delivered to orbit for mission application at any given instant of time; significant consequence afforded by the orbital rendezvous or "building block" approach is the more rapid transition of technical personnel to the application and use of the payloads delivered to space—it is the application and use of the manned and unmanned payloads delivered to space that provides the greater payoffs of space technology and science; launch boosters serve primarily as a means to an end, that of transport of valuable payloads for its specific mission.

We are still pursuing the approach of building a new booster vehicle, including the extensive research and development efforts for every new mission that is coming along. We are not building, at all, "propulsion system building blocks" that can be used across the board—well, there are a few exceptions. But on the propulsive side we are not developing propulsive system building blocks in the form of engine modules or fuel modules that can be assembled in orbit and operated to give us a booster amplifier, in essence, to perform bigger missions.

Mr. TEAGUE. Are you saying we are building the house from the top?

Mr. PETERSEN. Well, we are not obtaining or including the growth potential and flexibility in our space program that you can obtain from the "building block" approach as far as propulsion systems or life support modules, and so forth, are concerned.

Mr. ROUDEBUSH. Would you say our program is overly specialized? We are building, in other words, special vehicles for a special purpose without a broad base?

Mr. PETERSEN. All of them so far are with that in mind. We have very fine objectives and in may ways, I think, an extremely good space program. But we are not including the two characteristics, growth potential and flexibility, on the design end of these systems as strongly as we ought to. We are not getting the growth potential and flexibility that we can accrue from Earth-orbital operations.

Without these "propulsive system building blocks" and other building block modules, I think in a way we may well get beat at the game we are supposed to play the best, that of large production runs. The sooner we fix on a given booster with a larger production run, improved reliability and lower cost will result. Faster transition of engineering and technical talent to the payloads will result and this is where the real value or payoff from our space program will come, not booster technology. Certainly some comes from that, but the ability to apply the greater effort of the Nation to the payloads, where the real scientific benefits will come from—and not from the booster end. The sooner we go into a larger production run on boosters the greater the reliability and lower cost. We ought to improve our boosters, certainly, but we should fix and obtain higher production runs on perhaps standardized boosters.

Mr. TEAGUE. Mr. Daddario.

Mr. DADDARIO. I read testimony that Secretary McNamara gave to one of the appropriations subcommittees the other day, in which he referred to the Titan III as this kind of booster, that it would be the "building block" on which the future payloads would be delivered. Is this what you are talking about, too?

Mr. PETERSEN. I am not referring to a given specific booster, though it is identified as a standard launch booster, but that is not the specific point I have in mind.

Mr. DADDARIO. That is just the point. How does your statement either agree with or differ from Secretary McNamara's presentation on the use of the Titan III as a potential standardized booster?

Mr. PETERSEN. Well, I am sure the Titan III can be used as a standard booster; every one of our boosters can be used as standard boosters. I don't know what I can add to this, except that I would recognize the Titan III as a standard booster and it could be used and exploited right now.

Mr. DADDARIO. I don't say you might agree that the Titan III would be the standardized booster, but is that what you are talking about, getting a booster manufactured in such a way as to take advantage of our productive capacities and getting a standardized vehicle to develop our space system?

Mr. PETERSEN. Sure. Either the Saturn or Titan III could be used as standard launch boosters. Maybe I am not understanding you.

Mr. DADDARIO. I am trying to find out from you if, in this particular instance, when we are talking of "building blocks," you and Secretary McNamara are talking of the same thing, or if you are referring to "building blocks" actually in the payload?

Mr. PETERSEN. I am talking of "building blocks" on the propulsion end, that will serve the ends of assembly in space. I think perhaps maybe the term "standard launch booster" generally is used in the military and civil programs, standard launch boosters with many applications, that can be launched for high-altitude probes generally, or single-mission objectives, and as such have a variety of payloads and so forth. But I am talking here of use for assembly in space, and going from there. Neither the Titan III or Saturn C–1 are being designed in this light. They are not building blocks in this light.

Mr. DADDARIO. That is the answer to my question.

Mr. PETERSEN. It is not considered practical to summarize the specific design details of the referenced orbital rendezvous study. Certain conclusions of the study could, at the time it was prepared, only be identified in a qualitative sense. However, the above-listed specific conclusions or advantages identify key operational procedures essential to the development of an economic space logistics system.

Major factors, or system requirements, that seriously affect development of an orbital launch base, as well as other space vehicle systems involving rendezvous and lunar or interplanetary landings, are not to be discounted as simple problems to be solved though techniques exist to counter or offset all of these factors. These major factors that must be considered are those of launch time delays and the related payload penalties; rendezvous, docking, and coupling with the target station or soft landing at a preselected point in space; propellant handling and storage in space and related propulsion system checkout; mechanical and electrical assembly and associated checkout and maintenance; factors of attitude control, long-term guidance and navigation and need for onboard computing and data processing; and long-term radiation protection.

Launch time delays and the serious effect of payload penalties can be solved by improved reliability; may be offset by multiple launch pads and the necessary backup vehicles to meet launch window limits; or may be relieved by use of rendezvous compatible orbits due to the increased number of optimum launch opportunities, as many as two per day, the use of maneuverable ascent launch vehicles, and the use of parking orbits.

Terminal rendezvous, docking, and coupling in space will be practically resolved by increased reliance on the pilot-in-the-loop, coupled with redundant automatic guidance systems, and simplified through use of stationkeeping constraints on the target satellite station.

Pilot-in-the-loop is the integration of the pilot into the command of the vehicle to literally drive it as we maneuver any vehicle. Generally the pilots in the vehicles so far, either the civil or military, do not have the pilot tied into the loop from liftoff at the launch pad.

Mr. FULTON of Pennsylvania. Do you orbit by pilot-in-the-loop?

Mr. PETERSEN. No, by the guidance system, and control circuitry. The vehicles so far, the Mercury vehicles and even the Dyna-Soar X–20, have the pilot-in-the-loop only to a degree. In the automatic guidance system of Mercury for example, the pilot does not have primary guidance responsibility. Presently he is in during the ascent phase only in the abort side, has the prerogative of pushing an abort button, but doesn't steer the vehicle all the way. Many people working on the X–20 have concluded the pilot can provide considerable safety and perform better if placed fully in the guidance loop all the way from liftoff into orbit.

Mr. TEAGUE. Mr. Bell.

Mr. BELL. Concerning this checkout system, and the necessity for precise timing in the launch of the second vehicle, Dr. Seamans indicated that the Saturn V would be checked out in a seperate enclosure 2 or 3 miles from the launch pad and that after checked, it would be brought to the launch pad in an upright position for final checkout and firing.

Would this improve the accuracy and preciseness of the timing?

Mr. PETERSEN. Surely, these would be essential in using—in enclosures such as are in the plan at the cape, to provide initial checkout in the vertical attitude, then moving these out for final checkout at the launch pad.

Mr. BELL. NASA has only one vertical enclosure for a checkout; doesn't it?

Mr. PETERSEN. There is room for a number of vehicles, as I recall it.

Mr. BELL. It is my understanding that the Russians move their vehicles directly to the pad for launching. The checkout is made inside an enclosure ahead of time, and, strangely enough, I understand they lay it down and check it out. Is that correct?

Mr. PETERSEN. I have heard some of the same information——

Mr. BELL. In other words, the launch vehicle doesn't have to be in a vertical position?

Mr. PETERSEN. They don't have to be. Certainly big vehicle systems and the Saturn C–1, C–5, will be much taller than any that the Russians apparently may have checked out to date and perhaps it wouldn't be very practical to do it horizontally. You could do it, but I don't think there would be many advantages. The larger the vehicles become the advantage would be to use the system that is being followed by NASA presently. It certainly gets complicated when you have as many as nearly 10 stages to check out, whether horizontal or vertical. The present Apollo system employes 10 major operational phases to perform its mission.

Mr. BELL. I understand that in Gemini, NASA will have to do a lot of checkout outside of the vehicle. Is that correct?

Mr. PETERSEN. There would be a need for doing this, certainly. If there are access ports on the launch pad—on the Gemini they don't have this enclosure, so the vehicle is effectively assembled on the pad and fired from there.

Mr. BELL. I see.

Mr. PETERSEN. Propellant handling in space may initially be simplified to only involve individual propellant modules wherein each module serves as a separate propellant "building block" element of the required vehicle propulsion system. Use of propellant modules eliminates the problems of direct pumping, or propellant transfer, under the zero gravity environment. The propulsion system building blocks would normally consist of a liquid rocket engine plus the associated fuel and oxidizer tanks with means to attach or assemble these modules into the required cluster size.

Onboard, self-contained guidance and control system requirements for Earth-orbital rendezvous are essentially identical to those established for soft lunar landing at a preselected site, thus no new technical problems arise. Similarly, other factors, those of assembly in space and radiation effects, are not unique to Earth-orbital rendezvous or in operational use of an orbital launch base.

An important consideration to be recognized in employing the orbital rendezvous and assembly concept is the opportunity to gain the significant economic benefits accruing from reliability improvements as reflected by larger production runs of a given booster system.

It is believed important that the orbital launch base be established with a practical orbital inclination of at least 35° to provide adequate land recovery opportunities from space to existing and available recovery areas within the United States. Further, that the orbital altitude be selected appropriately in relation to the inclination, namely, about 264 nautical miles to assure maintenance of the rendezvous and recovery compatible orbit concept.

Going back a little more to the concept of rendezvous compatible orbits, we could identify these in a way more broadly as rendezvous, rescue and recovery compatible orbits. Having this constraint of the station in space we can select the altitude and inclination also to provide two optimum in-plane recovery opportunities to a landing site. One obtains an increased number of inplane launch opportunities to rendezvous, an increased number of inplane recovery opportunities, plus additional optimum inplane opportunities for rendezvous and recovery because of rescue and retrieve requirements. You cannot have these additional rendezvous, rescue or recovery opportunities with a random constraint, or random launching of vehicles.

The importance of implementing an Earth-orbital rendezvous, assembly, and launch system is very evident by observing the historical plot of proven booster payload capability as a function of time. A stair step progression has occurred for both the United States and for the U.S.S.R. since 1957. Our maximum payload capability of about 5,500 pounds was established in 1960 by the Atlas-Agena and remains to this date. A further improvement in this stair step advance will not be available to the United States until 1964–65, at which time the Saturn I and Titan III will provide between 20,000 and 30,000 pounds to Earth orbit. The U.S.S.R. payload capability, as announced by the U.S.S.R., jumped to 14,000 pounds in 1961 and subsequent estimates have ranged as high as about 17,000 pounds in 1962. Considering the orbital launch weight required for manned lunar landings, which are estimated to range from 250,000 pounds to about 450,000 pounds, depending on crew size, and so forth, the U.S.S.R. would require about 10 to 15 rendezvous operations. It is quite probable that the required number of rendezvous operations will decrease as newer booster systems are established by the U.S.S.R.

Very nearly the required tonnage for a single manned lunar flyby mission was evidently launched successfully to Earth orbit, or space, during the past year when 12 Cosmos satellites, 2 Vostoks vehicles and 1 Mars probe were launched. The recent near-rendezvous of the Vostok III and IV vehicles, in August 1962, demonstrated many of the essential capabilities necessary to the development of an Earth-orbital launch base. Though apparently failing to attempt or effect the final closure, or docking and coupling, with the Vostok III vehicle, the launch of the Vostok IV illustrated at least three key aspects essential to Earth-orbital operations. These are a reasonably small launch time delay, either rapid erection and checkout of subsequent vehicle on single launch pad or availability of auxiliary launch pad, and sufficient onboard guidance and maneuver capability for terminal adaptation or injection near a target satellite. The initial orbital characteristics of Vostok III and IV, with an announced separation of about 3 or 4 miles and only a small variation in inclination and orbital velocity, would have required but small velocity increments to effect the docking or closure maneuver. Therefore, it may be concluded that if major emphasis were given by the Russians to a single lunar mission, using Earth-orbital rendezvous, they would have the ability to accomplish this at the present time.

Our ability to close the gap in capability for accomplishing large space missions is believed to rest primarily upon the implementation of an orbital assembly and launch base. Earth-orbital, manned, scientific laboratories in space are important; however, the development of an orbital assembly and launch base in space is at least as vital to our space program. In order of necessity, I believe the orbital assembly and launch base is of prime importance because of its inherent value to all of our space operations, whether it is scientific laboratories, other civil or military Earth-orbital missions or support operations, or lunar or interplanetary programs.

An important parallelism may be drawn concerning our need for an orbital assembly and launch base and the parallel need for our large seaports in support of oceangoing traffic. As our seaports serve to integrate the small cargoes of trains, trucks, buses, cars, and coastal ships, so also will our spaceports serve to promote space traffic by integration or assembly of individually launched payloads.

I have recently compiled a bibliography of the scientific and engineering contributions to the open literature, as well as company or governmental agency sponsored reports, specifically dealing with the subject of rendezvous and Earth-orbital operations. This bibliography consists of nearly 1,000 technical papers with approximately 2,000 individual authors with pertinent contributions made by an estimated additional 5,000 or more supporting personnel. So considerable effort has been and is devoted to the area of orbital operations. That is, rendezvous and Earth-orbital operations.

The present status of engineering projects and technologies directly related to an Earth-orbital operational assembly and launch base is sufficiently well founded to justify initiation of a major U.S. space program for its development. Perhaps a solution, as illustrated by the newly formed U.S. Satellite Communications Corp., is to establish a new U.S. Space Port Corp., supported by the U.S. Government in part and by private industry and the U.S. public. This orbital facility would serve to promote space research and space operations by industry, other agencies of the Government and provide an orbital launch service to the free world countries desiring an active participation in space development.

Mr. TEAGUE. Are there any further questions?

Mr. FULTON of Pennsylvania. Would this U.S. space port be in addition to the present Apollo program, or could it be made part of that program?

Mr. PETERSEN. I think it ought to be part of an overlying structure to support our whole space operation, military and civilian.

Mr. FULTON of Pennsylvania. Looking at the cost of it, would it be an entirely new cost, or could part of the cost be paid by what NASA is presently doing on the Apollo program?

Mr. PETERSEN. I presume that with the present fixed program or direction of effort underway that there would certainly be required modification to achieve a good assembly capability in space.

Mr. FULTON of Pennsylvania. How much extra would this cost be if it were added to the Apollo program?

Mr. PETERSEN. I could not come up with a figure now.

Mr. FULTON of Pennsylvania. How much time would it take to get this kind of a space platform?

Mr. PETERSEN. I think we could begin to do this on a more rigorous basis with the present system. But to truly exploit and provide an orbital launch capability you have to provide building block support systems and building blocks to go along with this, to have total system capability.

Mr. FULTON of Pennsylvania. NASA could do the space platform program, though, with the present booster equipment, without going to the Apollo-type C-5 Saturns, couldn't it?

Mr. PETERSEN. Well, sure, the Gemini system with Titan II and Titan III could provide a pretty good start with the Earth orbital operation. The Saturn C-1 and Titan III, certainly, would provide a pretty good initiation point to develop an Earth orbital operation.

Mr. FULTON of Pennsylvania. Were you consulted on the decision to use the Earth orbital or lunar orbital approach on the Apollo program?

Mr. PETERSEN. I wasn't consulted directly. While I was with the Northrop Corp. we pursued this study and had contact with many of the technical groups in NASA, certainly.

Mr. WAGGONNER. Would the gentlemen yield?

Mr. FULTON of Pennsylvania. Certainly.

Mr. WAGGONNER. To your knowledge, was the Air Force consulted as to the relative merits of lunar orbit versus Earth orbit with respect to which would give the military the greatest advantage?

Mr. PETERSEN. I suppose it was, but I am not aware of it. I only joined the Air Force as a civilian less than a year ago. I can't answer that directly.

Mr. TEAGUE. Mr. Petersen, it is true that NASA gave out study contracts, including yours, to study the various approaches to accomplishing the manned lunar landing. After those studies were completed, NASA consulted with DOD, the Space Council, and with the President's Advisory Committee. So through DOD, the needs of the Air Force were considered; however, perhaps they were not consulted directly, I don't know. In any case, Mr. Petersen was not with the Air Force at that time.

Mr. PETERSEN. The study we performed was relatively small, supported only by company funds, and it was not one of the three winning contractors that performed those three direct studies to the Moon in 1960 and 1961.

Mr. TEAGUE. I might say that we have in the record of March 19, 1963, the statement submitted by Dr. Welsh, the Executive Secretary of the Space Council, who said that in his opinion "LOR" was a proper decision. I think you were at Houston, Mr. Waggonner, when the astronauts said they voted for LOR.

Mr. FULTON of Pennsylvania. Could we have your comment on the relative merits of Earth orbital rendezvous and lunar orbital rendezvous insofar as it applies to the Apollo program? Could you evaluate that?

Mr. PETERSEN. First, we should identify the two as Earth orbital rendezvous and modified direct launch to the Moon, parenthetically with lunar rendezvous, if you like.

Mr. FULTON of Pennsylvania. But you mean the same as the customarily used "LOR"?

Mr. PETERSEN. Yes. I think all of our future programs, whether they are communications satellites or other low altitude satellites, can benefit by a manned, low altitude assembly base in orbit and can be used to perform maintenance, repair, and modification of them, support laboratories in space, and assemble vehicles for interplanetary missions. All these can benefit by having a low altitude logistics system, or assembly base, for support.

Mr. FULTON of Pennsylvania. You spoke of the three major methods: direct ascent, Earth orbital rendezvous, and lunar orbital rendezvous, or modified direct ascent, as you call it. Would you comment on the decision whereby the United States had tentatively set its course on Earth orbital rendezvous, then in midpassage, around the latter part of last summer, changed its direction, and adopted the policy of lunar orbital rendezvous for the lunar landing program?

Mr. TEAGUE. Mr. Fulton, I read the technical paper by Mr. Petersen, and he was the only person that I could find who has really written the story of rendezvous. I don't think he should be asked to comment on a decision made by people who are now above him. He came here to discuss rendezvous, and I would hope we will not put him in the position of approving or disapproving what a superior command has done. I think to put him in that position is unfair to him.

Mr. FULTON of Pennsylvania. I would accept that.

But I would say: Would you then comment on your recommendations, on which is the best mode, leaving out what the decision was. What is your final recommendation on the mode most likely to succeed, and the mode most likely to get a return on abort; and the cheapest mode; and the shortest time mode as well as the most efficient?

Mr. TEAGUE. Mr. Fulton, I think you are asking the same question. I think Mr. Petersen's presentation speaks for itself.

Mr. FULTON of Pennsylvania. Well, the presentation has various aspects that lean toward a decision. When you get recommendations that point in one direction, you would like to know what his conclusion is.

Mr. PETERSEN. Let me make just a comment.

Mr. FULTON of Pennsylvania. I don't want to put you on the spot.

Mr. PETERSEN. I appreciate that. I have many friends on both sides of this argument. Some things have no concrete, absolute answer, they depend on many attenuating or related circumstances.

I think in the long run we are not interested in just landing a single crew on the Moon, but really interested in a reasonably necessarily long-term study of the Moon scientifically to consider its applications and unique characteristics as applied to what we are involved in here on the Earth. And we cannot achieve this by a single landing on the Moon. In the long run I am sure we are interested in a sustained program until we finally conclude that we have milked the Moon of all its scientific value and applications and don't want to pursue it further. A sustained activity lasting 15 to 30 years should be planned as a minimal lunar program.

Mr. FULTON of Pennsylvania. I look at your position as a change in emphasis, rather than one which calls a decision right or wrong. So in that area of reference I think you could comment.

The second point is: In looking at the Moon flight, you are really saying that you want it to have a constructive effect on later space exploration programs by the United States, rather than as a single flight, which, when it is over, ends the Moon program without maximum lasting benefits.

Mr. PETERSEN. I think our approach should be on the side of growth potential and flexibility and that those two parameters shoud be the strongest or heaviest-weighted in making a decision.

Mr. FULTON of Pennsylvania. In that context, you then recommend Earth orbital rendezvous for future space programs so that we can use not only the gain from a particular program but also a space platform or space port for future launches?

Mr. PETERSEN. That is right. Yes.

Mr. TEAGUE. Any other questions?

Mr. Bell.

Mr. BELL. Mr. Daddario, do you want to go first?

Mr. DADDARIO. Go ahead, Mr. Bell.

Mr. BELL. Mr. Petersen, I note that you have built up a considerable scientific bibliography to which you refer in your statement. Where is this material? Is it all in one place, or has it been printed?

Mr. PETERSEN. I have been assembling this for sometime. It is not in a published form yet. But I anticipate having it in a form which would be printed, just to give a complete listing or nearly complete listing of the effort supporting the general subject area.

Mr. BELL. When you have completed this what are you going to do with it?

Mr. PETERSEN. Well, it would only be made available to anyone technically interested, or who wants to use it for the pertinent references in the various subject areas. I have only done it to kind of maintain an inventory of effort along these directions. Many other people do it also.

Mr. BELL. It is certainly going to be a wonderful thing for people to refer to. I would think possibly the most logical filing spot might be the ASTIA area?

Mr. PETERSEN. That is correct.

Mr. FULTON of Pennsylvania. Mr. Chairman.

Mr. TEAGUE. Mr. Fulton.

Mr. FULTON of Pennsylvania. Mr. Petersen, could you supply us with your bibliography of the technical papers you have prepared or had published in this field, both your own as well as in conjunction with someone else as coauthor, so we could add that to your biography?

Mr. PETERSEN. Yes, I will forward this list. I won't have the special bibliography availably for just a little while. It includes a number of in-house reports by various companies, and I have to clear it with these to make sure they are in agreement to including a listing of some of these internal reports I have had access to.

Mr. FULTON of Pennsylvania. I think it would be well worth while to have it collected for students and research people.

(The information requested is as follows:)

TECHNICAL PUBLICATIONS AUTHORED BY NORMAN V. PETERSEN

"Lifetimes of Earth Satellites From New Circularity," presented to Fifth International Astronautical Federation Congress, Copenhagen, Denmark, August 1955.

"General Characteristics of Satellite Vehicles," Journal of Astronautics, volume 2, Nos. 2 and 3, 1955.

"Conquest of Space," Sperryscope, No. 3, 1955, Iowa Transit, volume 60, No. 4, 1956.

"Earth Satellites—Some Characteristics and Problems," Sperry Engineering Review, volume 9, No. 2, 1956.

"Lifetimes of Earth Satellites in Near-Circular and Elliptic Orbits," Jet Propulsion, volume 26, No. 5, 1956.

"Factors Affecting the Lifetime of Earth Satellites," Aero Digest, volume 73, No. 1, 1956.

"Summary of Proposed Methods for Determining Satellite Lifetimes," proceedings of the Seventh International Astronautical Congress, Rome Italy, September 1956.

"Project Skyball—A Proposed Primary Satellite Trainer for Space Flight Operations," proceedings of the American Astronautical Society, fourth annual meeting, January 1958.

"Rescue and Retrieve Space Missions," proceedings of the Second International Symposium on the Physics and Medicine of the Atmosphere and Space, November 1958, School of Aviation Medicine, USAF Air University, Randolph Field, Tex.

"Satellite Rendezvous Operations," proceedings of the American Astronautical Society, fifth annual meeting, December 1958.

"Rendezvous in Space—Effects of Launch Conditions," Aero/Space Engineering, (summary article), May 1960, volume 19, No. 5, N. V. Petersen and R. S. Swanson.

"Rendezvous in Space—Effects of Launch Conditions," IAS Proceedings, Manned Space Stations, May 1960, N. V. Petersen and R. S. Swanson.

"Satellite Rendezvous Navigational Requirements," Journal of the Institute of Navigation, autumn 1959, volume 6, No. 7, N. V. Petersen, L. Pode, and L. Hoover.

"Rendezvous Compatible Orbits," Astronautical Science Review, October–December 1959, N. V. Petersen and R. S. Swanson.

"The Influence of Launch Conditions on the Friendly Rendezvous of Astrovehicles," proceedings of the American Astronautical Society—Second western national meeting, August 1959.

"Satellite Rendezvous Guidance Concept," proceedings of the American Astronautical Society—Sixth annual meeting, January 1960, N. V. Petersen, R. S. Swanson, and L. Hoover, Western Aviation, April 1960.

"Lunar Landing Simulator," presented, Institute of Aeronautical Sciences, national summer meeting, Los Angeles, June 1959.

"Stationkeeping of Satellites in Rendezvous Compatible Orbits," August 1961, American Rocket Society Preprint 1954–61, N. V. Petersen, R. S. Swanson, and P. W. Soule; Progress in Astronautics and Rocketry, volume 8, 1962, Academis Press.

"Earth-Lunar Logistics Employing Orbital Assembly and Launch," Space Logistics, John Wiley & Sons, Inc., 1961, N. V. Petersen, H. Reich, and R. S. Swanson.

"Orbital Assembly and Launch for Lunar Operations," Institute of the Aerospace Sciences, annual meeting, New York, N.Y., January 22–24, 1962, IAS paper No. 62–81; Aerospace Engineering, volume 21, No. 8, August 1962.

"Rendezvous, Docking and Transfer," lectures in Aerospace Medicine, School of Aerospace Medicine, Brooks Air Force Base, Tex., February 6, 1963; Proceedings of the Lectures in Aerospace Medicine (to be published).

Mr. TEAGUE. Mr. Daddario?

Mr. DADDARIO. Could you give us a job description of your position as technical director, Mr. Petersen?

Mr. TEAGUE. What we are interested in are the technical programs you are working on now for the Air Force.

Mr. PETERSEN. I report to Gen. Irving L. Branch, Commander of the Air Force Flight Test Center, which operates as 1 of the major 14 elements of General Schriever's Air Force Systems Command, having 7 divisions and 7 centers. We have the task of performing the aircraft as well as space flight testing, where this is primarily to do what is called category 2 flight testing of these vehicles, which includes the whole spectrum of aircraft vehicles, a few of the Army and Navy programs that the Air Force works with. This is to obtain the performance characteristics, stability, and control characteristics of these vehicles and assist in obtaining a better production vehicle for use by the military.

I assist in a general technical way. I am, in effect, staffed to General Branch, and as such, aid him in a technical way across all the programs that we have. I don't become directly involved with many of them.

We have some 176 projects presently going on at the Flight Test Center, and, actually, even though—I am not trying to imply anything, but actually the workload at the Flight Test Center is even larger now than it has been for the past few years, and this primarily stems from a few new aircraft that are coming, a great many iterations of the same vehicle, like the B-52-H is from a long family of B-52's, and the last test program on the B-52 is about completed.

Col. Harold Norton is in charge of the rocket research laboratories and reports directly to General Demler at Bolling. Colonel Norton's rocket research laboratory is 1 of some 20 tenants on the Test Center and the Air Force Flight Test Center is the host organization. Our procurement people at the Flight Test Center provide a supporting service to the rocket research laboratories in the award of their research contracts, and so forth.

Mr. DADDARIO. Does Dyna-Soar fit in there?

Mr. PETERSEN. Right; the planned flight test program for the X-20 will be somewhat similar to that for the X-15. The X-20 will be carried aloft on a B-52, which is presently at Wichita being modified to carry the Dyna-Soar. The airdrop flight test program will be performed at Edwards, in about 1965.

Mr. DADDARIO. To get into a somewhat different area for a moment, last year Dr. Baker, of Bell Telephone Laboratory, testified before our committee that there was a split in the Technical and Scientific Committee concerning how we should be developing our space program to get more out of it. There was some question as to whether or not we were doing enough in order to protect and maintain the security of this Nation. Do I read a similar fear in your mind about this program? You state that we can get to the Moon either by the method chosen or by some of these other methods, but that you say that we ought to be doing more. Is your desire to do more motivated by the idea that we should do more for security purposes?

Mr. PETERSEN. I think both on the civil side as well as the military side that at any instance of time we would have the stronger foundation for space programing if we had a good Earth-orbital operational capability, and this certainly will provide a much stronger support to the military.

If the decision is that we pursue this military space role or direction then a good Earth-orbital capability will support that most effectively.

Mr. DADDARIO. Will we not have this capability as a result of the decision to go to the Moon through the modified lunar orbital techniques?

Mr. PETERSEN. There are many payoffs for many programs that we initiate. Every program has some payoff. There will be many technological benefits derived from the current program, across the board. But just having technology and knowledge is not enough, there is a long time in implementing these. Pursuing space research and technology is important. You can't expect to have an off-the-shelf systems capability available at any instant of time. It takes at least 5 years or more to develop any practical vehicle. Just developing technology is only part of it.

Mr. DADDARIO. That is because it is not being developed specifically to perform definite missions? Is that a proper conclusion?

Mr. PETERSEN. Militarywise we are not in a position to do much operationally in space at the present time. Before we can, I think, even do very much on the civil side, and certainly on the military side, we need a good applied R. & D. program using manned laboratories in space; and these are going to have to be operated for a considerable length of time before you can truly develop good operational capabilities in space. Most operational military space systems certainly will generally be constrained to random orbits, and possess an excess maneuverability, and so on. But for some time, we need a good R. & D. capability in space if we are going to get around to doing anything operationally. This R. & D. phase by the military can best be performed by employing a low-altitude complex of orbital laboratories using rendezvous compatible orbits for better logistics.

Mr. DADDARIO. It will have a great deal of technical fallout, then, but may not necessarily fit some of the programs which the military feel may be necessary. Is that what you are driving at?

Mr. PETERSEN. I assume you are speaking in reference to our lunar program, yes.

Mr. TEAGUE. Mr. Petersen, is this a fair question: If we had not set the manned lunar landing as a national objective, do you believe, looking at an orderly way of developing our space program, that our emphasis would now be on EOR or LOR?

Mr. PETERSEN. If we didn't have a specific mission to go to the Moon, a hoped-for target date, we probably wouldn't have any orbital assembly and launch system under development; we would probably be pursuing the scientific satellite area, perhaps still not with emphasis on the launch capability.

The desire for an orbital launch capability stems only from wanting to do other Earth-orbital missions or lunar or interplanetary missions or laboratory missions. I think the first step is to have an orbital assembly and launch capacity. The launch capacity can be used for other Earth-orbital missions as well.

Mr. WAGGONNER. Mr. Petersen, I think what the chairman really meant was that if we didn't attach time as a significant factor to the lunar landing program, would we pursue it from the Earth-orbital rendezvous method, or the lunar orbit rendezvous method?

Mr. TEAGUE. Yes. In other words, is EOR going to be the workhorse of the space program in the future?

Mr. PETERSEN. I feel it is an essential part of the program. We are always booster limited.

I think the objective of going to the Moon is a real fine one. We also have an objective of going for manned missions to Mars and Venus, and we are forever limited with—faced with booster limitations.

Mr. WAGGONNER. Do you feel from a purely military standpoint, there is much more that could be done a lot quicker with EOR than with LOR?

Mr. PETERSEN. Sure. Yes.

Mr. TEAGUE. Any other questions?

Mr. RIEHLMAN. Mr. Chairman.

Mr. TEAGUE. Mr. Riehlman.

Mr. RIEHLMAN. It would be fair to deduce from what you said that had NASA chosen EOR as the method of getting to the Moon, that NASA would have had greater cooperation and interest from the military. As you said today, military application, in the future, at least as you see it, is going to be attached to the EOR program?

Mr. PETERSEN. I think it is a fine and wonderful thing that we have a civil program distinct from the military. I think there are certainly areas in which the two can cooperate in many ways. Some of this cooperation already exists, but not to a very strong degree. It is not that they don't want to, it is just that the mechanism is not set up. We have a good civil program, generally.

Mr. RIEHLMAN. I agree with you on that. But I am also looking to the future with respect to the cooperation NASA is going to get from the military and the interest it is going to get from the military on the elimination of overlapping or duplicative activities in these fields.

Mr. PETERSEN. I don't think in the military we have a mission as far as the Moon is concerned. I think we might keep an eye peeled to the Moon militarily. But I think there is such a giant frontier in Earth-orbital space, for the military, to consume all the energy that the military could put in this direction if this were the decision.

Mr. RIEHLMAN. What I am trying to say is, this is where the concentration of interest is going to be on the part of the military.

Mr. PETERSEN. Right.

Mr. RIEHLMAN. Had it chosen EOR, NASA would have not only had the support of the military in connection with the military's interest in the EOR program, but could have also advanced its program to go to the Moon.

Mr. PETERSEN. Right. Personally, I would much rather pursue peaceful pursuits. If we elect to have a military space capability I think the Earth-orbital mode of mission operation is the first one we should be concerned about.

Mr. RIEHLMAN. I agree with you 100 percent. We are all concerned about the peaceful applications of space. But we just cannot forget the fact that there is certainly a great possibility that the military is going to be just as vitally interested in this program as NASA is. If for nothing else, than just for the psychological advantage of putting a man on the Moon, without knowing exactly what the advantages will be, or what we are going to gain from that type of venture.

Mr. FULTON of Pennsylvania. Would you yield?

Mr. RIEHLMAN. Yes, sir.

Mr. FULTON of Pennsylvania. One comment which you made has always concerned me, particularly when I have heard it from witness after witness from the DOD. That is your statement that "If we"—meaning the United States—"elect to have a military space capability." That kind of comment always leaves me up in the air, up in space. The reason is that you don't say you bave decided one way or the other, but that you are uncertain.

Now, at some point in time, or some point in space, or atmosphere, the DOD and the Air Force must come up with a decision as to whether they have a military defense or security function in the strategic area of space. In my opinion that decision should have been made many years ago, back in 1954 or 1955.

Mr. TEAGUE. I would say to you gentlemen, that you are going to get a good chance to ask questions on that, soon. But Mr. Petersen is not the man to answer it.

Mr. FULTON of Pennsylvania. But did Mr. Petersen actually mean it when he said, "If we elect to have a military mission in space?"

Mr. PETERSEN. First off, you have to try to identify the military threats that exist, then try to mechanize the weapons systems to cope with these. And I don't feel one can identify the threat very clearly or precisely, or even mechanize the system precisely to cope with that threat.

Mr. FULTON of Pennsylvania. At this point in time, then, there is both National Aeronautics and Space Administration's interest in Earth-orbital rendezvous, as well as a military Air Force's interest in Earth-orbital rendezvous procedures?

Mr. TEAGUE. The military would be lacking in their responsibility if they didn't look at everything happening in this world as far as the defense of this country is concerned.

Mr. PETERSEN. Certainly the military is given the mission of providing defensive, and in some ways offensive, capabilities, and space is just one more place of doing things. One can develop backup retaliatory capabilities to provide a certain potential deterrent. Space is just another area for developing systems and defenses.

Mr. FULTON of Pennsylvania. I will ask the reporter to read my question.

Mr. TEAGUE. The Chair will rule that the question will be left as it is, and we will hear Mr. Fuqua's question.

Mr. FUQUA. I may fall on the same ruling.

You mentioned the "building block" approach of our space system. Then, in probable future exploratory trips to Mars, say, or some of the other planets, the lunar-orbital rendezvous will have no practical effect and we may have to then go back to Earth-orbital rendezvous for a trip to something like Mars?

Mr. PETERSEN. I would think so, though certainly a C–5 vehicle is only 3,000 tons and only about the size of a small destroyer. It is still not very big as far as ocean vessels we build. We could build 10,000 tonners, perhaps big enough vehicles to do the single mission to Mars in one vehicle. But I think we can easier capitalize on having more tonnage delivered to Earth-orbital space faster by going to the assembly route, and far quicker and cheaper.

Mr. FUQUA. And this would have more long-range effects, for example, to Mars and Venus?

Mr. PETERSEN. It is a booster or payload amplifier, assembly in space is, and we can use at any instant in time available techniques, available systems, and if properly configured and designed these can give you flexibility and growth potential that you cannot attain any other way. It is a launch system amplifier, literally, in letting you do missions that weren't on the books originally.

Mr. TEAGUE. Mr. Roudebush.

Mr. ROUDEBUSH. Mr. Petersen, you made certain observations on the dual launchings recently performed by the Russians, and mentioned their capability of putting a 17,000-pound vehicle in orbit. Approximately what thrust would that require?

Mr. PETERSEN. It would depend on the efficiency of the propulsion system.

Mr. ROUDEBUSH. Well, approximately.

Mr. PETERSEN. Well, C–I Saturn is going to deliver somewhere between 20,000 and 30,000 pounds, and it will have 1,500,000 pounds, so you would have—well, on the assumption that it has the same propulsive efficiency, same propellant system as the C–I, it would be perhaps on the order of 1 million pounds.

Mr. ROUDEBUSH. One other question. Concerning station keeping or controlling the orbits, would you say that on the basis of the experiments performed by the Russians, that they are developing an excellence on this stationkeeping technique? Would you say they are ahead of us on that capability at the present time?

Mr. PETERSEN. So far I have seen no definite statements that subsequent maneuvering in space was performed to make it clear to us in the United States, the free world, that they actually rendezvoused and docked and coupled the two Vostok vehicles. On the basis that they did not, on the basis of what I have seen to date, there were no subsequent maneuvers performed other than perhaps of an attitude nature, no translational maneuvering to change the separation rate or drifting rate, which continued at perhaps 25 miles an hour. There was some position difference between them, shortly after but apparently not very much. Apparently this remained about constant. I have no direct information other than what I have read in the open literature.

Mr. ROUDEBUSH. The reason I ask this series of questions I think is obvious. If the Russians are directing their efforts toward developing the Earth-orbital rendezvous technique rather than perhaps a direct ascent or lunar orbit rendezvous technique, this may imply something.

Mr. PETERSEN. I think their total space program, what we have seen to date, is much narrower than ours. On booster capability they are ahead of us. As far as demonstrating three of the vital characteristics to providing assembly capability in space, of having a reasonably short time delay, and ability to get the second vehicle off at the right time, the ability to guide it approximately into the vicinity of the target, and the ability to check out, erect, and check out a second vehicle quickly, these are essential ingredients of having an assembly capability. If we use rendezvous compatible orbits you can identify the launch time very precisely, establish a precise schedule for the launch crews, and in addition you can have the two launch opportunities per day. One or two backup vehicles can assure a vehicle ready at the right time.

If the station is on random orbits you can have certain window limitations, rather broad; if you use parking orbits you can even expand it, provided—and the payload penalties are not particularly large—providing the inclination of the target station is about the same as the launch space. If you steepen up the inclination the payload penalties increase.

Mr. ROUDEBUSH. The evidence of the Soviet experiments then more or less tends to point toward Earth-orbital rendezvous, rather than lunar, is that correct?

Mr. PETERSEN. I would certainly concur with that, that everything they have done to date supports a capacity for orbital assembly in space, and I am just hazarding a guess that this is perhaps the route they may take.

Mr. ROUDEBUSH. We are all guessing, of course but going on the evidence, I would certainly agree that it indicates they are thinking about assembly in low Earth orbit and rendezvous.

Mr. PETERSEN. Having multiple launch pads, quick erection and checkout, short launch time delays, are vital to an orbital assembly capability.

Mr. DADDARIO. Then you wouldn't be surprised, from what you say, if the Russians were to go to the Moon tomorrow?

Mr. PETERSEN. No, I think we can anticipate seeing a string of payloads in space that will be tied together, rendezvoused, coupled; maybe the first attempts will be just a flyby, lunar excursion, but——

Mr. BELL. Would the gentleman yield on this point?

Mr. DADDARIO. Yes.

Mr. BELL. If the Russians have been only able to get 17,000 pounds into space as far as their booster capability is concerned, they will have had to have considerably stepped up their booster capability to go to the Moon tomorrow, wouldn't they?

Mr. PETERSEN. I don't know. They launched 12 Cosmos series satellites and 2 Vostoks and a Mars vehicle in 1962. The total tonnage of this delivered to Earth orbit is on the order of about between 150,000 and 200,000 pounds.

Mr. BELL. Oh, is that right? I thought their Vostoks were in the neighborhood of 20,000 pounds.

Mr. PETERSEN. 10,000-something, I believe, sir.

Mr. TEAGUE. He is talking about total tonnage.

Mr. PETERSEN. Total tonnage.

Mr. BELL. In other words, you have to be able to boost 250,000 to 400,000 pounds, as you are saying?

Mr. PETERSEN. That is right, 250,000 to 400,000 pounds from Earth orbit depending on the crew size, flight path, duration time, stay time, backups, redundancies, whatever you want to design into it. If you want a minimal system, then it is on the lower side.

Mr. BELL. But at any one single time they have not come close to it, have they?

Mr. PETERSEN. Oh, no, no.

Mr. BELL. That is what would have to be done, isn't it?

Mr. DADDARIO. As I understand it, you are talking about putting up these payloads and putting them together——

Mr. PETERSEN. On a daily basis, launching of 10 or 15 satellites, or on a weekly basis, depending on the environmental system on board, does not appear unreasonable. They have already demonstrated ability to fire two vehicles from the same launch pad in 24 hours, apparently, and conceivably they could do this 10 days in a row.

Mr. DADDARIO. And that would do the trick?

Mr. PETERSEN. At least for a flyby mission, it would be ample.

Mr. FULTON of Pennsylvania. If the Russians put this "Toonerville Trolley" train together in Earth rendezvous in the near future, the U.S. space program might be sitting on the launch pad with a Pullman or Cadillac type assembly, and the Soviets would be 6 years ahead.

Mr. PETERSEN. Possibly.

Mr. Teague. Any further questions? Mr. Yeager?

Mr. Yeager. Mr. Chairman, I have a number of questions which I would like to submit for the record for Mr. Petersen to answer, if I may.

Mr. Teague. Without objection, it is so ordered. Mr. Petersen, would you please answer these questions for the record?

Mr. Petersen. Yes, sir; I will be glad to.

(The information requested is as follows:)

Earth and Lunar Rendezvous Techniques

1(*a*). Question. What are the unique characteristics of the direct flight mode?

Answer. The direct flight mode defines the operational approach for ascent to the Moon using a single vehicle to accomplish the entire mission from the Earth-surface launch pad to final touchdown on the lunar surface. Generally, the direct flight mode also implies the further restriction that the payload landed on the Moon is of sufficient size, permitting launching, and followed by a direct return flight to the Earth.

1(*b*). Question. What are the advantages of the direct flight mode?

Answer. Perhaps the primary advantage for the direct flight mode is that this approach may provide the minimum total flight time or travel time from Earth-surface launch to touchdown on the Moon.

1(*c*). Question. What are the disadvantages of the direct flight mode?

Answer. Primary disadvantages are (1) the initial gross weight on the Earth-surface launch pad is a maximum for a given delivered payload; (2) the system lacks growth potential and flexibility in that once the first, second, and subsequent booster-stage sizes are fixed and development initiated, the payload size is similarly restricted and cannot be increased if desired at a later date; (3) all stages must be checked out on the launch pad for the full mission; (4) maximum reliability probably would be attained only after an extended time period, since total number of vehicles per unit payload delivered to the Moon would be smaller than if the Earth-orbital rendezvous approach were followed since this may be accomplished with somewhat smaller surface-to-orbit boosters having a larger total production.

2(*a*). Question. What are the unique characteristics of the EOR mode?

Answer. The principal unique characteristics include the following: (1) booster limitations are negated by employing rendezvous and assembly in Earth orbit; (2) maximum growth potential exists since mission-scaled vehicles can be assembled in orbit to match any desired current or future mission objective; (3) provides configuration flexibility since the assembled modules in space can be reconfigured as desired since aerodynamic forces need not be considered; (4) provides opportunity for secondary (orbital) checkout and launch, thus reducing reliability restrictions through mission staging; (5) provides mission-mending capability (permits possible return to orbit and subsequent rendezvous for certain abort conditions of lunar and interplanetary vehicles exhibiting malfunctions during escape maneuvers, thus salvaging key elements of large mission vehicles); (6) provides improved launch logistics through use of rendezvous compatible orbits, RCO's, and station keeping (this is an operational procedure of employing a special class of orbits termed "rendezvous compatible orbits," RCO's, to provide a "milk run" synchronism of the orbiting assembly and launch base yielding two optimum, in-plane, launch opportunities per day, for rendezvous with zero-payload penalty; the RCO synchronous orbit simultaneously yields two optimum, in-plane, recovery opportunities per day from orbit to a preselected landing site; the RCO synchronous orbit further provides two optimum, in-plane opportunities per day for both rendezvous or recovery-type rescue or retrieve missions; and, offsets payload penalties associated with launch operations to randomly orbited target satellite stations; and (7) encourages development of the "building block," or vehicle module approach for design of large space mission systems (orbital rendezvous concept thus yields lower production costs, higher reliability and greater payload delivered to orbit for mission application at any given instant of time; significant consequence afforded by the orbital rendezvous or "building block" approach is the more rapid transition of technical personnel to the application and use of the manned and unmanned payloads delivered to space that will provide the greater payoff of space technology and science; launch boosters serve primarily as a means to an end, that of transport of the valuable payloads for its specific mission).

2(*b*). Question. What are the major advantages of the EOR mode?

Answer. Major advantages for the EOR mode are generally summarized in part 2(a) of this question.

2(*c*). Question. What are the significant disadvantages?

Answer. No major disadvantages can be identified, **with the exception that a reasonable booster capability for delivery of payloads to Earth orbit should exist** so as not to require an excessive number of rendezvous.

3(*a*). Question. What are the unique characteristics of the LOR[1] mode?

Answer. The unique characteristics of the LOR (MDL) mode are as follows: (1) A direct ascent is made by a single vehicle from the Earth-surface launch base with a direct transit to the Moon, or via a brief parking phase on a parking orbit to adjust for launch delays; (2) lunar orbit capture occurs with the vehicle constrained to a low-altitude orbit followed by descent to the surface by an onboard lunar excursion module. Subsequent launch occurs with the excursion module and escape propulsion stage in lunar orbit; (3) after rendezvous and coupling is accomplished, crew transfer completed, excursion module is hence jettisoned and an escape maneuver from lunar orbit is executed; Earth return transit occurs with necessary midcourse corrections followed by reentry and recovery of crew on board the command module; (4) this mode of transport to the Moon is best identified as a "modified direct launch" since a single vehicle is employed for complete mission with only an excursion away from and return to the basic vehicle in a lunar orbit.

3(*b*). Question. What the the **major advantages of LOR as compared to EOR?**

Answer. No major advantages of the LOR (MDL) mode over EOR **are anticipated.**

3(*c*). Question. What are the significant disadvantages of LOR?

Answer. Primary disadvantages of the LOR mode are as follows: (1) Payload limitation of present Saturn V vehicle restricts redundancies and backup systems with attendant higher risks involved; (2) lacks growth potential available through assembly in Earth orbit, lunar orbit or at lunar surface; (3) possibility of abort action such as to result in subsequent adaptation into Earth orbit and salvage of major "building blocks" for reuse on later flight not realizable since Apollo vehicle not designed for assembly in orbit; (4) growth potential and flexibility of LOR (MDC) not available since single vehicle employed throughout major portion of flight.

4(*a*). Question. What should be the mode selection criteria?

Answer. I believe the two primary criteria which should be considered are growth potential and flexibility. Here, I define growth potential as that quality about our space logistics system which will provide a capability for negating the problem of booster payload limitation. Use of the first available practical booster systems, for example the Saturn C–1 and Titan III and initiating a large production capacity for these boosters, will lead to improvements in reliability together with reduced costs. Further, development of "propulsion system modules or building blocks," plus other "life support" or equipment modules as "building blocks" for assembly in space following rendezvous, will lead to similar gains in reliability and lowered production costs. The inherent quality of flexibility as a significant selection criteria for determining best logistic system to employ should be recognized. Consideration of these two selection criteria should be heavily weighted because of the overall effect on nearly all of our space programs, including Earth orbital operations as well as lunar and interplanetary missions. Further, recognition of the value of these two criteria is further identified when evaluating or comparing the possible potential value of the EOR mode and the LOR (MDL) mode to the U.S. military organization.

5(*a*). Question. Which mode is the **most attractive from a mission success and safety** standpoint?

Answer. The EOR mode is the most attractive in considering the aspects of mission success and safety. This is true for two major reasons: (1) a positive growth potential provides the opportunity to increase booster capacity, or size in orbit, by assembly of additional propulsion modules to account for gradual growth of the payload during development (both the direct flight mode and modified direct flight mode lack this potential of compensating for payload growth—only alternative with these two modes is to reduce mission duration, reduce redundancies or backup subsystems or to reduce crew size, etc.); (2) the EOR mode pro-

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[1] LOR (lunar orbit rendezvous) is recognized as the designation for the present NASA Apollo flight mode to the Moon; however, since the present mode effectively employs a single vehicle for the lunar mission with an excursion to the lunar surface followed by launch and rendezvous with the initial vehicle in lunar orbit, and further does not employ assembly in space, is identified as a modified direct launch (MDL) mode. Reference, therefore, will be made throughout these comments to the LOR (MDL) mode.

vides additional safety procedures over and above those provided by the modified direct launch mode or any other mode (these include (i) a mission-mending capability by permitting a possible return to orbit and subsequent rendezvous for certain abort conditions, (ii) provides secondary, or orbital, checkout following boost to orbit and prior to launch from orbit).

6(*a*). Question. What operations in LOR and EOR mission profiles are the most critical from a mission success/safety standpoint?

Answer. It is difficult to identify specific operations for either LOR (MDL) or EOR which are the most critical from a mission success/safety standpoint. Perhaps primary propulsion for descent to the lunar surfaces, as well as the subsequent launch for both EOR and LOR (MDL) may actually be the most critical. Abort modes for Earth escape and possible rescue from the lunar orbit phase, in event of malfunction, provide some attenuation of risk. Resupply of standard Apollo crews on the lunar surface due to malfunctions developing following landing may readily be handled by subsequent supply craft or cached prior to the manned flight.

7(*a*). Question. What should be done to minimize the potential hazard problems of LOR?

Answer. A considerable number of approaches may be pursued to minimize potential hazard problems of LOR (MDL). Improvements in reliability, reduction of equipment weight where possible, and improvements in propulsion performance are, of course, important. Use of logistic vehicles to land supplies at the lunar site prior to and following the manned landing; use of a backup landing craft placed on the surface of the Moon prior to the manned flight; use of a backup command module placed in orbit about the Moon prior to the manned flight; and, the use of three backup Apollo vehicles complete with the exception of employing only two-man crews to permit subsequent rescue of the stranded Apollo crews in lunar orbit or on the lunar surface. Consideration of these solutions illustrates the value of employing EOR to provide initially larger lunar vehicle systems incorporating the necessary redundancies and backup equipment to minimize potential risks for the first lunar mission. Perhaps the best solution would be to combine the best parts of the LOR (MDL) mode with the growth potential and flexibility of the EOR mode. Thus, EOR could provide the ability to assemble the lunar mission vehicle of such payload size as to incorporate the desired redundancies and to best cope with inherent payload growth and propulsion system inefficiencies. Thus, the EOR mode would permit matching the desired payload size with the expected mission requirement. The present LOR (MDL) mode to the Moon is believed perfectly feasible if performance of the launch booster and subsequent propulsion systems do not dictate extensive elimination of redundancies and backup equipment. The present Saturn C-5 booster is considered restrictive in this light.

8(*a*). Question. Which mode offers the best possibility for early mission accomplishment?

Answer. If both LOR (MDL) and EOR modes were initiated at the same date, it is my conclusion that the EOR mode would offer the best possibility for early mission accomplishment. Even with the present headstart that the LOR (MDL) mode has, the writer believes rapid implementation of the EOR mode is essential to provide the Nation with an unquestioned ability to attain the Moon and explore it in detail. A single landing, if completed at an early date, may satisfy national prestige but our scientific curiosity of the Moon will not be satisfied without an extensive, efficient Earth-Moon transport system.

9(*a*). Question. Using one or two Saturn V's as the case may be, which mode provides the greatest payload weight growth margin?

Answer. Two Saturn V's, using the EOR mode, with properly designed upper stages and modules, should show considerable payload weight growth margin over a single Saturn V using the LOR (MDL) mode.

10(*a*). Question. In addition to getting to the Moon and back, what other advantages accrue from use of the LOR technique?

Answer. No specific advantages can accrue from use of the LOR (MDL) technique that would not evolve as a matter of development of the EOR mode.

11(*a*). Question. Why is a two-man landing system with a third man in lunar orbit preferable to a three-man landing system?

Answer. A two-man landing system with a third man in lunar orbit is preferable to a three-man landing system only if (1) the LOR (MDL) lunar orbit descent and rendezvous system is employed; (2) the command module requires manning during the lunar excursion module descent to improve the subsequent rendezvous operation; or (3) further reduction of redundancies and backup equipment to provide payload space for extra crew member appears excessive, thus jeopardizing mission success probability. An alternative approach, faced with the payload limitations of the Saturn V booster, would be consideration of a one-man descent to the lunar surface, thus permitting improvements in safety through provision for greater backup systems.

11(*b*). Question. Or a one-man landing system?

Answer. A one-man landing system probably would give greater safety and higher probability of success, based on the single Saturn V LOR (MDL) payload limitations. Sufficient landing aids can be provided the single pilot to execute the landing and subsequent rendezvous. Additional propellant, life support gear, and maintenance and repair equipment for use by the single crewman are considered far more important than the extra crew member.

12(*a*). Question.What factors govern propulsion system selection—cryogenic versus storable?

Answer. The following factors govern the selection of cryogenic or storable propellants for primary propulsion systems: (1) for a fixed payload the specific impulse Isp dictates the booster stage size; (2) payload penalty tradeoffs associated with providing cryogenic storage capability and resulting boiloff versus increased structure requirements for lower specific impulse storable propellants; (3) ground handling considerations, and others.

13(*a*). Question. Is mission accomplishment using the LOR technique dependent on Earth-based tracking stations?

Answer. Early stages of the Earth orbital boost and subsequent escape boost and midcourse correction phases may be dependent on Earth-based tracking stations. Subsequent tracking of the Apollo command module while in lunar orbit and during descent and following rendezvous operation cannot be effectively aided by Earth-based tracking stations.

14(*a*). Question. What if the Russians go EOR? Should this affect our planning as to method?

Answer. If the U.S.S.R. elects to pursue the EOR mode, I believe a U.S. decision to give emphasis to the Earth orbital mode should be made primarily on the basis of military significance. I believe our decision to give emphasis to the EOR mode for our civil space program, in light of a Russian decision in favor of EOR, should be made on merit of the system to provide a stronger foundation for our overall space program, and this decision should be weighed in support of the system possessing growth potential and flexibility.

15(*a*). Question. How significant is the fact that LOR has no Earth abort capability like EOR?

Answer. No comment.

16(*a*). Question. What method provides the best payload margin to cope with the solar flare problem?

Answer. The EOR mode provides the growth potential through assembly in orbit of the necessary orbit launch weight to provide for sufficient radiation protection to cope with class 3 solar flares. The additional payload capability of EOR permits increasing the radiation shielding to the level desired yet accepting a minimal hazard during a given flight. Solar flare activity is anticipated to be at a maximum during the latter part of this decade and is expected to coincide with our first launching attempts to the Moon. EOR can provide the growth potential to best cope with the problem of radiation.

17(*a*). Question. Do you know of any specific payload of around 17,000 pounds which the Russians are presumed to have launched?

Answer. I am not aware of a specific payload of 17,000 pounds for any particular Russian vehicle. My reference to this value in an earlier question stems from a casual reference which cannot be verified at this time.

18(*a*). Question. Will a station-keeping ability be built into either the Gemini or Apollo programs so far as you are aware?

Answer. I do not believe a station-keeping system to give rendezvous and recovery compatible orbits is being considered for either the Gemini or Apollo programs. This was discussed with the Gemini project manager though no interest was shown in the concept at the time.

19(*a*). Question. Do you concur that the LOR method offers advantages from the standpoint of speed and economy over the EOR?

Answer. No; I do not concur that the LOR (MDL) mode offers speed or economy advantages over the EOR approach. I feel that the single vehicle approach to the Moon using the modified direct launch mode, as now in process, entails a higher risk venture than EOR and lacks the necessary growth potential in event these risks require circumventing by redesign or additional safety backups.

20(*a*). Question. Where would the advantage lie from the standpoint of safety?

Answer. The advantage must rest with the EOR mode since the possibility of significantly increasing the assembled payload to the necessary orbital launch weight as dictated by safety exists. Propulsion capacity can be assembled in orbit to match precisely the orbital launch weight requirement.

21(*a*). Question. Should redundancy be built into the Apollo landing module so far as propulsion is concerned?

Answer. The payload penalty incurred by providing a twin engine configuration with one engine as a redundant, or backup, propulsion system is not considered excessive. The weight required to provide a redundant thrust chamber and associated propellant feed lines and pumping system is not considered excessive for the lunar landing and subsequent rendezvous operation. A continuous thrust descent from the deorbit position to touchdown using a low thrust level, but throttleable, liquid engine system with only a single ignition would be perhaps a preferred approach. Payload penalty for a continuous thrust descent from a nominal 25-mile lunar orbit is not appreciable and costs only a few percent in excess of that for a two-impulse landing approach.

22(*a*). Question. Is the module technique being observed or ignored in our present Apollo program?

Answer. The module, or "building block," technique is presently being ignored in the Apollo program insofar as developing a capability for assembly in space. Independent modules are of course being constructed primarily because of the need for a separate command module to simplify problem of reentry, a separate lunar excursion module to reduce landed weight as dictated by Saturn V payload limitations, and a distinct propulsion module for lunar capture and escape. No specific program has been identified thus far with the objective of developing "building blocks" or modules having unit capacity with the expressed purpose of assembling these in space to meet the desired total capacity for a given mission. Of special value would be propulsion modules, life support modules, auxiliary equipment modules, and possibly laboratory modules, each with a specified capacity and capability for assembly in space. Multiple units of each of these four distinct module designs when assembled would provide the total system requirement for the specified mission thus providing an enduring growth potential for undertaking new missions in the future.

Mr. TEAGUE. Mr. Petersen, we appreciate your coming in, and thank you very much. This committee is adjourned.

(Whereupon, at 11:30 a.m., the subcommittee adjourned to reconvene at the call of the Chair.)