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OLF STUDY
RESEARCH AND TECHNOLOGY
IMPLICATIONS REPORT

FINAL REPORT

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This document is Volume III, OLF Study Research and Technology Implications Report, of the final technical report of the Orbiting Launch Facility (OLF) study conducted by The Boeing Company for the Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama, under Contract NAS 8-11355. The study was conducted under the technical supervision of Mr. William T. Carey, Jr.

The final technical report consists of four volumes:

Volume I: OLF Study Technical Report Summary

Volume IIA: OLF Study Rechnical Report (Sections 1 through 4)

Volume IIB: OLF Study Technical Report (Sections 5 through 7)

Volume III: OLF Study Research and Technology Implications Report

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OLF RESEARCH AND TECHNOLOGY IMPLICATIONS REPORT

1.0 INTRODUCTION

The purpose of this volume of the OLF final report is to ". . . delineate those areas of research and technology wherein further efforts would be desirable based on the results of the (OLF) study". A study of the objectives and results are briefly summarized and followed by a discussion of research requirements for the OLF development beyond the capabilities anticipated from such pre-OLF programs as Gemini, Apollo, AES, and MORL as currently conceived.

2.0 OLF STUDY SUMMARY

The Orbital Launch Facility (OLF) study was performed for the Marshall Space Flight Center of the National Aeronautics and Space Agency as part of an overall investigation of orbital launch operations (OLO). The purpose of the OLF study was to provide the data, regarding an orbiting facility's design, development testing, and operating requirements, necessary for more accurate evaluation of the various possible methods of initiating manned interplanetary and lunar-ferry missions. The following paragraphs provide only a brief summary of the OLF technical study; detailed descriptions are presented in Volumes IIA and IIB of the final report.

2.1 Study Objectives

1) Produce a conceptual design of an initial OLF for supporting a manned Mars/Venus flyby mission.

2) Determine the operational activities that dictate gravitational design criteria and postulate whether a zero-gravity or artificial-gravity type of OLF is required.

3) Identify the supporting research and technology problems associated with the development of the initial OLF and prescribe R&D tasks required to solve these problems.

4) Develop a design evolution for the OLF from early orbital research laboratories through possible OLF concepts for advanced missions support.

5) Establish ORL experiments necessary in the development of the OLF.

6) Determine the feasibility and design effects on the OLF of conducting scientific research and experiments on the OLF.

2.2 Study Approach and Results

Accomplishing the primary study objective, conceptual design of an initial OLF, required numerous supporting studies, including operational analyses, parametric configuration investigations, on-board systems studies, and design integration. Special studies including gravitational (artificial-g) analysis; R&D scientific experiments; definition of ORL experiments; and development of a research, development, test, and engineering (RDT&E) plan for the OLF were accomplished to fulfill additional study objectives. Finally, advanced OLF concepts were studied to determine the possibilities of evolution from the initial OLF concept.

The operational studies investigated activities required of the OLF and its basic crew in performing its role in the overall orbital launch operations. These activities involved the assembly, checkout and routine operation of the OLF, including the scheduled service and maintenance operations and anticipated unscheduled maintenance and repair. From these studies it was found that the orbital assembly and checkout of the OLF could best be accomplished in about 55 hours from

Earth launch by a crew of five men; a crew of only four men could adequately operate and maintain the OLF during routine operations. Maintenance requirements were found to be about 5.02 manhours per day on the average, with 4.66 manhours per day being scheduled and the remaining 0.36 manhours per day unscheduled. The initial spares inventory of the OLF, required to provide a 0.99 probability of having the correct spare when replacements are needed, was calculated to be 3517 kg (7754 lbs). The logistics plan for resupply of spares and expendables was established with a 90-day cycle time with the quantities to be resupplied dependent upon the total number of persons on board the OLF and the type of activity in which it is engaged. Half of the OLF crew would be rotated every 90 days, leaving an orbital duty period of 6 months for each crew member.

The parametric configuration studies took basic functional requirements established by preliminary operational analyses and from other space station studies, established a typical design which satisfied most of those requirements, then varied the design by changing such parameters as crew size, type of on-board power, artificial gravity provisions, hangar volume, and on-board fuel-storage provisions for the orbital-launch-mission vehicle. The building-block approach of utilizing existing or planned hardware in the OLF design was also investigated in this portion of the study. Gross comparisons of the resulting concepts were made in terms of size, weight, design and operational complexity, reliability, serviceability and state-of-the-art. A baseline concept was then selected. The resulting baseline configuration of the OLF using two manned orbital research laboratories (MORL) modules with interconnecting structure and docking hub was a compromise of various parametric configurations established in this evaluation. Through design iteration studies of this baseline concept eventually evolved the <u>initial</u> OLF design. With the baseline OLF configuration and systems operational requirements established, detailed systems studies were then performed to determine what systems could meet the prescribed criteria. Generally, with minor modifications or additions, the MORL subsystems, as described in the Douglas MORL studies of Reference R2 were found to be adequate. A double unit Isotope/Brayton Cycle, 11-kw electrical power system would be located in the hub section of the OLF with modified shielding and added distribution equipment. The guidance and navigation system would be essentially the same as MORL's. The MORL stabilization and control systems would be modified by deleting the control-moment gyros, relocating reaction-control and orbit-keeping jets, and changing the system's control logic. Additional atmosphere-distribution and temperature-control equipment would have to be provided in conjunction with the two MORL environmental control systems to meet the anticipated OLF needs. Some extension of the atmospheric-contamination-removal system's capability may also be required. The OLO checkout and monitoring equipment that Lockheed proposed for location aboard the OLF (Ref. R2) should provide adequately for the OLF checkout and monitoring requirements. Guidelines for more detailed synthesis of communications and data management systems, beyond that proposed by Lockheed in their SCALE study of Reference 2, were developed in this portion of the study and some modifications to present ground networks were identified.

The primary effort of the design integration portion of the OLF study was the iterations of the baseline design concept to accommodate and integrate the requirements set forth by the operations and on-board systems studies. Special design studies were devoted to (1) payload packaging of the OLF for Earth launch on the Saturn V and (2) a MORL module extension systems for extending the modules once the payload is injected into the desired orbit. Similar efforts were devoted to the design of an umbilical tower for servicing the orbital launch vehicle and to OLF docking systems. The final recommended OLF design involves two MORL modules, used as primary living and working quarters, located at opposite ends of a cylindrical structure and docking hub section. For Earth launch the MORL modules are telescoped within the cylindrical section and the crew rides atop the launch configuration in a six-man Apollo command module. In this configuration the payload measures about 38.5 (126.4 ft.) long with a diameter of 7.5m (24.6 ft.). In the extended or orbital configuration the length of the facility is increased to 54.0m (177.3 ft.). Over 425m3 (15,000 ft3) of experiment/work volume is provided in each of the cylindrical sections of the OLF between the MORL modules and the central hub section. The separation of the MORL modules was prescribed by the ground rule requiring spin capability for artificial gravity. The advanced versions of the OLF reduce the launch package length to 35.6m (116.7 ft.), but retain the extended dimensions for the required spin capability.

One special study of artificial gravity requirements of the OLF operation concluded that, unless artificial gravity is required for physiological reasons, there seems to be more advantage in not rotating the station and operating in the zero-gravity mode. Another special study determined what the inherent capabilities of the OLF were for performing R&D and other scientific experiments on board the OLF. It was found that the initial OLF would require supplementary power, experiment handling, and mounting equipment and may require more accurate attitude stabilization for postulated experimentation. Other provisions appear adequate.

Another important part of the study was the investigation of orbital experimentation required to develop the OLF and the development of a research, development, test and engineering (RDT&E) plan for the OLF. Twenty-one orbital experiments or series of experiments from six operational categories were identified and defined in the experiment study. All of these would be required in the 1969 to 1972 time period to provide the desired OLF operational capability in 1975. The requirements of these experiments all were found to fall within the capabilities of the AES as currently conceived. The RDT&E plan, established to meet a 1975 operational date, covers a period of four years from hardware design go-ahead to OLF launch and is estimated to cost $861 million.

Evaluation of the results of this study has led to the conclusion that the conceptual design developed in this study is feasible; enhances the probability of total mission success by its simplicity of orbital assembly, checkout and operation; and is within the predicted state of the art for the 1975 time period. Some of the particular areas of OLF development in which concerted research and technology development effort should be directed in order to achieve the desired OLF operational capability are discussed below.

3.0 OLF RESEARCH AND TECHNOLOGY REQUIREMENTS

Although each of the studies described briefly in the preceding paragraphs were concerned to some extent with identifying the research and technology problems that may be encountered in the development of the initial OLF, the basic development philosophy and assumptions, regarding the capabilities to be developed within current planning of pre-OLF programs, are described in detail in Paragraph 7.0 OLF Developmental Program, and Paragraph 6.3, Definition of ORL Experiments, respectively of Volume II-B of this report. It is therefore, considered inappropriate to elaborate again on these subjects in this portion of the report. However, it should be noted that the orbital research requirements identified in the study were based upon a comparison of the capabilities required for the initial orbital launch operations with those anticipated to be developed from the Gemini, Apollo, AES, and MORL programs as currently being studied. Detailed assumptions of these capabilities are presented in Paragraph 6.3.2.1 of Volume II-B. Likewise, in the basic RDT&E plan for the OLF, since the initial OLF concept does incorporate two MORL modules, a level of systems development commensurate with that required for an operational MORL was assumed. No attempt was made to identify all the technological problem areas in the MORL and earlier systems development unless the problem was common to, and of particular significance in, the OLF development.

3.1 Initial OLF Concept Review and Research Recommendations

The research and technological requirements of the initial OLF are discussed in the following paragraphs under the categories of aeronautics, biotechnology and human factors, electronics and control, materials and structures, nuclear systems and propulsion and power generation as prescribed by the NASA. Problems that may be encountered in the development of advanced OLFs for supporting the more ambitious, future interplanetary and lunar ferry missions are briefly considered in Paragraph 3.2.

<u>3.1.1 Aeronautics</u>. - OLF operations, which may be of particular concern in the field of aeronautics, involve the boost phase and to some extent the orbital operation. Following liftoff from the launching pad, the OLF, which is then a packaged payload of a Saturn V Earth-launch vehicle, is accelerated through the atmosphere to the desired orbital velocity. During this ascent period the OLF, as well as the thrusting booster vehicle, are subjected to severe dynamic loads that can, if not properly assessed and designed for, cause severe damage to the systems and perhaps abort the mission. These aerodynamic loads are, in part, a function of the geometric configuration of the payload-booster system. Preliminary investigations of the recommended initial OLF indicate the stresses on the S-II stage structure, imposed by the payload configuration during passage through "max-q," reach significant proportions and may cause a failure in the S-II structure unless that structure is modified slightly. It is necessary, therefore, that detailed analyses of aerodynamic loading on the payload and the booster be accomplished prior to the detailed design of the facility.

During orbital operation, perturbations of the OLF's orbit by aerodynamic drag loads are of some concern. Although the density of the atmosphere at the desired altitude is extremely small, the accumulated drag forces acting over the large exposed surface of the OLF for extended periods of time can be significant. This is of special concern inasmuch as the OLF will be expected to meet very stringent orbital position requirements during the relatively narrow launch windows for the interplanetary missions. Similar orbital perturbations can also be expected over extended time periods from solar winds. Detailed analyses of these conditions should, therefore, be performed to ensure adequate consideration of these effects in the OLF operations planning and design.

On the basis of the considerations discussed above the following aeronautical research is recommended:

1) Continued evalaution of dynamic-load effects on Saturn Vs and their payloads for various payload configurations including the recommended OLF launch configuration. This research should include both theoretical analysis and wind-tunnel testing.

2) Detailed theoretical and empirical evaluation of orbital perturbations and decay that might be expected of the recommended OLF configuration at various likely orbital altitudes.

3.1.2 Biotechnology and Human Factors. - Four general areas of study are of particular interest in the category of biotechnology and human factors. These areas include biomedical research, behavioral research, biological research, and personnel operations and training research. A great portion of the orbital research presently in planning involves this category, the objective of which is to determine and develop man's capabilities in the space environment and thereby establish the extent to which man should be used in the exploration of space and our solar system. Inasmuch as a major portion of this planned research is also vital to developing the OLF's operational capability, the primary concern at this point is to identify areas of research peculiar to or of particular importance to the OLF development. The extended lifetime of the OLF and extensive personnel activities therein require crew member duty cycles of longer duration than planned pre-OLF programs (Gemini, Apollo, AES, and MORL). The extended exposure of man to the orbital environment will require added investigation of crew survival and performance capabilities, conditioning, training, and whatever biomedical and behavioral monitoring is required during such operations. Studies of biological functions of crewmen during extended orbital staytimes, particularly at the higher orbital altitudes where radiation exposure in extravehicular activities is more severe, will be of considerable concern. The possibility of using a rotating mode of station operation for artificial gravity poses numerous problems requiring study. The techniques, procedures, and supporting equipment will have to be developed for personnel to move about, transfer cargo from one position to another, and perform useful functions at various radial distances from the rotational axis for both intra- and extravehicular activities. Emergency procedures for survival or evacuation from an uncontrolled rotating station will need to be developed.

One of the prime advantages of the permanent-facility mode of orbital launch operation is the higher probability of mission success afforded by providing extensive and immediate maintenance and repair capability in orbit. Providing this capability requires development of qualified operating, maintenance and repair techniques and procedures and support equipment and establishment of acceptable crew training and qualification provisions. Much research will be required to determine crew proficiency levels and primary training requirements, proficiency retention, multiple skills training possibilities, orbital retraining, and final crew and equipment qualification. The extent of orbital crew training required will depend primarily upon the acceptability of ground-based simulation trainers, which will have to be verified through early orbital and Earth-based research.

1) Continued man-in-orbit research extending the data acquisition beyond that presently planned for in the pre-OLF programs to cover biomedical, biological, and behavioral aspects of extended crew duty cycles in orbit and at higher altitudes than presently planned. Accurate plotting of radiation intensity profiles at the expected orbital altitudes by unmanned satellites appear mandatory.

2) Experimental research to determine the limitations on crew activities in the artificial-gravity environment of a spinning station at various distances from the rotational axis. Biomedical and biological effects would certainly have to be investigated. Techniques, procedures, and supporting equipment should be developed for man's locomotion and functioning in this environment for cargo handling transfer, and emergency evacuation. Much preliminary work can be done and some is being done in Earth-based centrifuge facilities, however, orbital experimentation presently seems necessary for final evaluation of all the combined conditions that would exist.

3) Extension of research concerning orbital maintenance and repair activities to cover both the zero-gravity and rotational modes of operation and extension of crew orbital work capacity and tools and machines that will function reliably in the orbital environment.

4) Simultaneous testing of crews in the orbital environment and in Earth-based orbital environment simulations should be performed in various modes of operation using techniques and procedures learned in Earth-based training under simulated conditions. Verification of the adequacy or inadequacy of Earth-based training for orbital operations will be of utmost importance.

5) Further testing and analysis to determine the feasibility of man's existing and properly functioning from the biomedical standpoint in a zero-gravity environment. Also, equipment such as centrifuges and trampoline-type devices for providing a substitute for gravity should be investigated. Since the OLF study indicates that from an operational and cost standpoint, a zero-gravity concept is desirable, it may be that the well being of the crewman will be the deciding factor.

<u>3.1.3 Electronics & Control</u>. - Generally, the OLF on-board systems and overall operational mode are not too different than those proposed for the MORLs whose basic systems form the nucleus of the OLF systems. The initial OLF concept includes two MORL modules and requires only minor modifications or additions to the MORL on-board systems. Little additional research in on-board systems development is anticipated. Extravehicular maintenance and repair activities may require the availability of some external electrical power. Making and breaking electrical connections and operating electrical powered equipment in the space environment may require added study. Communications systems are essentially the same as MORL's except that the antennae may require some additional developmental research. The direction and control of rendezvous and docking of various vehicles with the OLF may require additional research to optimize the mode of control and to develop acceptable position

sensing and control systems. Launch control and tracking from the OLF may also impose additional requirements for developmental research. Attitude stabilization and control of the OLF and all of the docked OLO hardware (tankers, mission spacecraft and booster, logistics spacecraft) during the orbital assembly and launch operations will require the development and qualification of unique control-logic programs and integrated control systems. Additional data collection, processing, and transmission research would most probably be required in software programming for data editing and formulating. Ground network requirements must also be analyzed, optimum operational modes established and multiple high speed and teletype data links between ground stations and the mission control center designed.

In most cases, the research required in the electronics and control category, as identified at this level of study, appears to be little more than an extension of the present or planned research required for pre-OLF programs up through MORL. On the basis of the considerations discussed above the following research is recommended in this category:

1) Development and testing of external power umbilicals, connectors, and operating techniques and procedures.

2) Optimization studies of rendezvous and docking control modes and equipment.

3) Investigation of orbital launch and tracking functions and development of the required equipment.

4) Development of acceptable control-logic programs for maintaining the required attitude and position in orbit during orbital launch operations with OLO hardware docked to the OLF and design of integrated control systems.

5) Software programming for data editing and formulating and integration of orbital and ground-network data management facility requirements.

3.1.4 Materials and Structures. - Structural loading and the effects of environmental exposure are of concern. The major problems of structural loading precipitate primarily from the severe stresses imposed upon the structure during the high acceleration periods and high aerodynamic loading periods of the boost phase from Earth to orbit. The brief period during boost referred to as "max q" is considered to be the most critical period of structural stresses. During that short interval the aerodynamic side loads on the payload and the booster cause severe internal structural stresses. Research requirements in this regard are discussed under the aeronautics category of Paragraph 3.1.1. Other stress loading of the facility's structure would occur during the spin-up or spin-down of the facility in the artificial-gravity mode of operation and during orbital correction maneuvers. These stresses are significantly less than the boost loads, but should be analyzed for long-term effects. Additional strucutral stresses may occur during orbital correction maneuvers while other OLO hardware is docked to the OLF. Other stress loading will result from structural thermal expansions and contractions when precise facility orientation is required. Although these stresses may be small, their effects must be analyzed to determine their overall effect during the extended lifetime of the facility. Stress experienced from the loads imparted through normal docking operations are not expected to introduce any particular structural design problems, since final docking velocities are low and the docking mechanisms can incorporate considerable length in the shock-absorber stroke.

Numerous problems may arise from extended exposure of the structures and various OLF materials to the orbital environment. The effects of natural environmental factors such as radiation, vacuum, temperature, and meteoroids on exposed OLF components will have to be evaluated as well as the effects of artificially produced environmental detriments such as jet exhausts and explosion debris. The normal vacuum, radiation, meteoroids, and temperatures anticipated in the desired orbit, are not expected to affect the OLF primary structure too severely; whereas abnormal conditions such as meteoroid showers and high levels of induced radiation from close association with an unshielded nuclear reactor or an explosion of another orbiting system may have damaging effects on the structure. Each of these conditions would have to be investigated and evaluated with due consideration of the probability of encountering such conditions. The exposure of other materials used in coatings, bondings, seals, etc., are of particular concern because of their expected deterioration under prolonged exposure.

The ultrahigh vacuum of orbital space presents significant problems in the evaporation of some materials or volatile components of the materials, evaporation of absorbed gases on the surfaces of some materials, evaporation of lubricants, and possible cold welding of materials. Particular vacuum problems are anticipated in some of the OLF systems. For example, the umbilical service tower, which may be exposed for prolonged periods, is required to telescope and bend with precision control at hinge joints in the structure and has flexible-sealed joints in all of the electrical power and fluid transfer lines. Although temperature extremes may impose some problems of low-cycle fatigue from thermal expansions and contractions, the random orientation of the OLF as recommended in this study may minimize such problems. In the initial erection and assembly operations and in subsequent extensions of telescoped or otherwise extendable strucutres, structural expansions and contractions may impose problems where close tolerance fits are necessary. Generally, however, the temperature problems do not appear to be any more severe than similar problems on Earth. Even so, these problems must be analyzed and the equipment designs should allow for such.

As mentioned previously, the normal radiation environment does not appear to offer significant problems with respect to the primary structure of the OLF. The extent of these problems can only be evaluated in conjunction with more detailed design studies wherein such variables as metal melting points, crystalline structure of the metal, prior thermal and mechanical history of the metal, the radiation environment, and neutron flux can be considered. In the case of organic materials, radiation does have significant deterioration effects, many of which are not yet understood. In some cases, materials additives may reduce some of the irradiation effects and in other cases, the materials used may actually have to be shielded. The detailed OLF design efforts will have to take these factors into consideration. Research in these areas should be continued and probably increased to provide suitable remedies for the hardware designers. The meteoroid environment and the effects of meteoroid impact are being heavily studied at the present time. The vast surface area and the extended lifetime of the OLF provide sufficient exposure to possible meteoroid bombardment that reliable flux data and structural-damage effects information would be highly desirable for the OLF hardware design effort. Coinciding with this, considerable research should be devoted to developing acceptable techniques and systems for detecting and locating punctures or other meteoroid damage and for making the necessary repairs.

Artificially induced environmental factors are also of concern to materials and structures. One such factor is the exhaust products from rocket thrusters, used in reaction control systems for attitude control and orbit corrections, and from the prime propulsion systems of the orbital launch vehicle, logistics spacecraft, and other intraorbital vehicles that may be required. Direct impingement of exhaust gases on OLF surfaces would most likely occur during docking operations and would only be from small reaction control system (RCS) thrusters. Indirect or "bathing" effects could result from both the RCS thrusters and prime propulsion systems. The effects of various exhaust products upon surfaces and materials anticipated for the OLF exterior should, therefore, be investigated and protective coatings, shields, and operating and maintenance techniques and procedures may have to be developed. Another area of particular concern in the orbital launch operations and of particular interest in the design of the OLF is the possibility of an explosion of another orbiting system such as a refueling tanker or the orbital launch vehicle's booster. Explosions of smaller proportions, such as exploding gas storage vessels are also of interest. Investigations of shock-wave attenuation in a vacuum, explosive distribution of debris, separation distances, and damage possibilities should be made to provide the necessary operational planning and systems design information.

All materials of the OLF which will be exposed to the facility's life sustaining atmosphere will have to be tested under the expected conditions for outgassing and contamination of the atmosphere. The materials used and contaminant removal capabilities of the OLF systems must be compatible.

Although many of the specific areas of research required in the materials and structures category for the OLF will be more clearly defined in more detailed OLF studies, the following general areas of research are recommended:

1) Continued analysis and testing of structures under stressed conditions caused by: aerodynamic loading of OLF-Saturn V during boost phase of Earth-to-orbit transfer; low acceleration orbital maneuvering, spinning-up, and spinning-down; and thermal expansion and contractions.

2) Continued and extended research in determining the effects on materials exposed to the ultrahigh vacuum of orbital space, to temperature extremes, to the radiation environment of the higher orbital altitudes (as planned for the OLF), and to the hazard of meteoroid bombardment as expected in the anticipated orbital region.

3) Accurate mapping of the extremes of these environmental factors of vacuum, temperature, radiation, and meteoroid flux at the desired OLF orbital altitude.

4) Theoretical and empirical evaluation of artificially induced environmental hazards such as jet exhaust direct impingement and indirect "bathing" effects on materials and explosion effects on systems design.

5) Specific research to determine the synergistic effects of all of the possible environmental hazards that may be encountered in any particular circumstance.

6) Contamination tests for outgassing and vaporization of OLF materials into the life supporting atmosphere.

7) Tests to determine the effect of the orbital environment on gaskets, lubricants, seals, surface coatings, bearings, and precision machined joints.

8) Additional tests and analysis on the phenomenon of hard vacuum welding.

3.1.5 Nuclear Systems. - The only nuclear system proposed for use in or around the initial OLF is the Isotope/Brayton cycle electrical power system, which has been established as the desired power system for the MORL. Because it will be developed as part of the MORL program, the developmental research required will not be discussed here. Particular problems of direct concern in the OLF design primarily involve shielding and maintenance and repair of the radioactive portions of the system. The major problems -- arising from relocating the fuel block and conversion system in the centralized hub section of the OLF instead of the skirt section of the MORL -- are shielding internally and externally around the hub section to permit close-in routine personnel and systems operations. Other OLO hardware, including the logistics spacecraft and the orbital launch vehicle, will be docked for extended periods around the hub section of the OLF and personnel and cargo will be transferred between those vehicles and the OLF primarily through the hub section. Adequate shielding for these activities must be provided and reasonable protection should be provided for an emergency conditions in which the heat-dump panels are opened and the radiation in particular regions around the hub section greatly intensified. It is anticipated that the procedures and equipment established for the maintenance and replacement of units in the MORL can similarly be used on the OLF; however, this will require study and development and testing of specific techniques and procedures.

Specific areas of nuclear research that will be required beyond MORL requirements can be summarized as follows:

1) Fuel block configuration studies for adaptation to the hub section location recommended for the initial OLF. It may be possible to modify the shape of the fuel block currently planned for the MORL to a much more effective shape for the space available for the OLF power plant location.

2) Optimization of fuel block configuration and shielding with respect to anticipated personnel intra- and extravehicular activities around the hub section.

3) Research of normal and emergency operations to provide acceptable techniques and procedures for systems operation, maintenance, and repair and to establish systems safe operating limits and emergency procedures in the event those limits are exceeded.

3.1.6 Propulsion & Power Generation. - The developmental problems associated with the power generation system are assumed to be taken care of in the MORL development program inasmuch as essentially the same power generation system will be used on the OLF. OLF-peculiar problems in the electronics, power generation, and power source or nuclear area were discussed previously in paragraphs 3.1.3 and 3.1.5 respectively. One other particular area of OLF power generation that will require added developmental research is waste-heat dissipation. The integrated requirements of the environmental control and power generation systems for waste-heat disposal will have to be analyzed more carefully, taking into consideration radiator shadowing and reflection of other vehicles that will be in close proximity to the hub section of the OLF where the power generation radiator will probably be located. A wrap-around radiator presently appears most feasible, but other configurations may be reevaluated in the detailed studies.

In the area of propulsion the OLF's prime area of interest is its attitude control and orbit maneuvering systems. Although the relocation of MORL thrusters to more appropriate positions for OLF attitude stabilization and maneuvering will require considerable detailed analysis and testing, the major problem that is anticipated in this area is that of maintaining a desired attitude during orbital launch operations when other OLO hardware are docked or are docking with the OLF. Making orbit corrections during this complex operation also requires considerable analysis. The control problems of this operation have been discussed previously in paragraph 3.1.3, but appropriate sizing and location of thrusters, with control method trade studies, have also to be accomplished. These studies should analytically and empirically compare an integrated control mode in which the attitude thrusters of other OLO vehicles docked to the OLF are used to help stabilize and control the entire complex, with independent control strictly by the OLF itself. Thruster jet exhaust effects on external materials, coating, etc., of the OLF will also have to be investigated as described in paragraph 3.1.4.

Propellant storage on board the OLF and transfer through the umbilical service tower and by other means to the orbital launch vehicle and logistics vehicles will also require additional research. Such research would include optimization of storage container designs, storage pressures, temperatures, pumping methods and rates, leak-proof connectors, reliable gaskets and seals, and zero-g fluid quantity indicators.

Based on the previous brief discussions, the following areas of research are recommended within the category of propulsion and power generation:

1) Waste-heat disposal research, integrating the heat dissipation requirements of the power generation system and environmental control system of the OLF. Radiator configurations should be analyzed and an optimum system designed considering the shadowing and reflection effects of any other vehicles docked to the OLF.

2) Trade studies of integrated attitude stabilization and control methods, using docked vehicles and OLF thrusters, and independent control using OLF thrusters exclusively.

3) Optimization of thruster sizes and locations for the particular method of control selected.

4) Optimization studies of propellant storage and transfer methods and systems.

3.1.7 Miscellaneous. - In addition to the possible areas of research discussed, there are a few items not conveniently placed in one of those categories. These are discussed in this section.

The development of some of the mechanical systems of the OLF will require special investigations and trade studies to provide useful, yet compact, simple and reliable equipment. Considerable Earth-based research and possible orbital experimentation will be required for development of conveyor systems for transferring personnel and cargo through certain regions of the OLF, large and small access doors and seals for interior and exterior use, cherry pickers or ambulators for providing complete access to all parts of the large-volume areas of the OLF for inspection, maintenance and repair and special hand-operated tools and powered machine shop tools. This will primarily involve design and testing of systems that can survive and function adequately in the orbital environment and possibly in the rotating environment of a spinning station.

No particular recommendations are made at this time for these areas of anticipated research requirements. More detailed studies are required before reasonable recommendations can be made. However, some of the factors which must be considered in the design and development of these mechanical systems and which, in and of themselves, may require significant research include:

1) Effects on materials of rotational artificial gravity at various radii of a rotating orbital station.

2) Operational differences and the effects thereof in changing from a balanced or zero-gravity condition to a rotational artificial gravity condition.

3) Debris collection in zero-gravity conditions.

3.2 Projected Research Requirements for Advanced OLFs

The advanced OLF concepts, discussed in Volume II of the OLF final report are intended for the support of interorbital lunar ferry operations and for the support of an orbital launch of more ambitious interplanetary missions such as the manned Mars-landing mission. The growth of the recommended initial OLF concept into one that could meet the requirements of these advanced missions seems very plausible. Evaluation of the developmental requirements of the advanced OLFs was a very minor portion of this study, therefore the identification of areas of research requirements for these advanced versions was likewise only cursory.

Two general areas of possible research are concerned with the maintenance, repair, and replacement of radioactive components of the propulsion and power systems of advanced orbital launch vehicles and with the requirements for engine cold-flow tests imposed by the lunar ferry's requirement for engine change capability in orbit. Considerable research and design optimization will be required to adapt remote radioactive component handling equipment, shielded work areas, maintenance capsules, storage cellars, etc., which are presently anticipated for ground-based application, to acceptable mass and volume for boosting into orbit and to adapt them for maximum utility and maintainability in orbit. Methods of engine or radioactive components disposal and associated equipment will also have to be developed. Methods and equipment will have to be devised and developed for cold-flow testing nuclear engines in orbit without imparting severe perturbing thrusts to the facility. Comparing the development of ground-based counterparts of these pieces of support equipment with the more stringent mass and volume restrictions for orbital equipment, the development effort poses a formidable challenge requiring significant amounts of both ground-based and orbital research.

4.0 CONCLUSIONS

The suggestions of possible areas of necessary research and technology development, discussed in this report, evolved from the numerous substudies summarized in Paragraph 2.0 of this volume and described in detail in the technical report, Volumes IIA and IIB. Although, in most areas, the requirement definitions are still quite general, the scope of the research required for the OLF development became considerably more evident and the necessity for more detailed studies is apparent. The RDT&E program schedule for the initial OLF (as described in Paragraph 7.0 of Volume IIB) presents a rather crowded and hurried schedule to provide an operational OLF by 1975. With this as the designated target date, and considering the amount of study and research planning that must be done prior to hardware design, it appears that detailed definition of the OLF research requirements should begin as soon as possible. The amount of orbital research required in the OLF development, as intimated by the ORL experiment definition study (described in Paragraph 6.3 of Volume IIB), and the extensive planning and integration necessary for implementation certainly provides added incentive for an early beginning of these studies.

5.0 REFERENCES

1. Report on the Optimization of the Manned Orbital Research Laboratory (MORL) System Concept, Douglas Missile & Space Systems Division Report, SM46071 through SM46090, November 1964

2. Space Checkout and Launch Equipment, Lockheed Missiles & Space Company Final Report, LMSC-A747356-3.SSD-1586-65-2, August 1965