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Lockheed
MSD-2015
July-Sept 1956

3. PROPULSION SUBSYSTEM

3.1 Orbital Boost Engine

The major change made in the design and development program during the reporting period is the replacement of a gas-fed propellant system by a pump-fed system for the OTV and Pioneer vehicles with subsequent replacement of the Aerojet-Vanguard engine by the Bell XLR-81 Hustler engine. This change is a consequence of the increase in orbital vehicle weight to 9,300 lb with a corresponding increase in required orbital boost impulse from approximately 750,000 lb-sec to 1,500,000 lb-sec. Since the proposed operational mode (separation close to apogee) excludes prolonged boost periods it is necessary to increase the thrust of the orbital boost engine from a value of 7,500 to approximately 15,000 lb.

With respect to the capability of existing combustion chambers for attaining this thrust level, the data in Table I are pertinent.

TABLE I

COMPARISON OF AVAILABLE COMBUSTION CHAMBERS WITH RESPECT TO FEASIBILITY FOR 15,000 LB THRUST LEVEL

Engine & Application	Aerojet AJ 10-37 Vanguard 2nd Stage	RMI RR132 Super Performance	Bell XLR-81 Hustler (1)
Design Values			
Vac. Thrust, lb	7500	8,000	15,150
Chamber Pressure, psia	200	560	489
Chamber Pressure Required for 15,000 lb Thrust, psia	400	900 - 1,000	489
Required Alteration and Development for Obtaining 15,000 lb Thrust	Change in Injector Increased wire-wrapping for increased struct. strength. Cooling marginal, may require redesign of and retooling for new chamber.	Increase in nozzle exp. ratio from 4.3:1 to 25:1; replacement of 90% H_2O_2 by 99% H_2O_2 oxidizer. Development of catalyst. Change in injector. Cooling may be marginal and require combustion chamber development.	None

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The RMI engine requires, in addition to its high chamber pressure, an unusually high pressure drop between pump outlet and combustion chamber which is partially due to the solid catalyst decomposition bed for the oxidizer. Viewing also the necessity for a very substantial increase in nozzle expansion ratio and for conducting a development with an hitherto not used oxidizer, it appears justified to drop this engine from further consideration.

An analysis has been made for the modified Bell XLR-81 Rocket engine, to determine the total propulsion subsystem weight (including propellants, tanks, and pressurizing equipment) as a function of thrust and of the type of pressurization system used. The assumed pressurization systems are:

1. Gas-Fed (G. F.) using helium as pressure gas
   - a. Stored at ambient temperature
   - b. Stored at ambient temperature and heated in a heat exchanger so that a gas temperature of 150°-220°F is maintained in the propellant tanks.
   - c. Stored in a tank precooled by liquid nitrogen and heated in a heat exchanger so that a gas temperature of 150°-200°F is maintained in the propellant tanks.
2. Pump-Fed (P. F.) by gas generator driven turbo pumps.

The results are plotted in Fig. 3-1. Two sets of curves are shown for combustion chamber specific impulses of 278 and 285 lb-sec/lb, respectively

The diagram indicates that at the 5,000 lb thrust level the type of pressurization system has little influence on the total propulsion subsystem weight. At 15,000 lb thrust, however, the use of the pump-fed system permits a reduction in weight between 600 and 1200 lb compared to gas-fed systems of varying state of refinement which corresponds to an increase in payload from approximately 1300 to 1900 lb for the gas-fed systems to 2500 lb for the pump-fed system. From these considerations it can be clearly seen that a pump-fed system should be selected.

Technically, both the Vanguard and Hustler combustion chambers are equally well suited for incorporation in a pump-fed propulsion system. Comparing the modified Hustler engine (combustion specific impulse of 285 lb-sec/lb) with the Vanguard engine in its final state of development (combustion chamber specific impulse of 278 lb-sec/lb) it appears that this difference in specific impulse is approximately compensated for by the somewhat lower chamber pressure of the Vanguard engine. In other words, the right-hand diagram of Fig. 3-1 can be used with good approximation for both engines. With respect to availability of the complete pump-fed engine, however, the Bell engine appears to be substantially superior. Important factors for the appraisal of the two engine systems are presented and collated in Table II.

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same vehicle loaded to a gross weight of 7650 lb and boosted by the SM-65A. The combined weight of the structure, propellant tanks, propulsion systems and pressurization systems for this vehicle has been estimated at 870 lb.

A probable arrangement for the Orbit Test vehicles and the early Pioneer vehicles entails the placement in the booster adapter section of 650 lb of inertial guidance equipment and 350 lb of attitude control equipment to be used during the coast period. This will enable the guidance equipment to provide the orbital stage with a guidance program for the final thrust period at apogee. This load of 1000 lb will remain with the booster at separation which occurs just prior to starting the satellite stage propulsion system. Gross weights for the Orbit Test vehicles and the early Pioneer vehicles are therefore reduced by 1000 lb for this arrangement. Weight breakdowns for three OTV systems (varying with booster and nature of flight) are shown in Table I. Two Pioneer vehicle weight breakdowns are shown in Table II. One is for the early guidance system remaining in the booster as described above and the other is for the more advanced, lighter guidance system which is carried in the satellite stage.

If battery life is the limiting factor and state-of-the-art batteries are used the OTV will have a duration of 4 days when boosted by the SM-65A and 14 days when boosted by the SM-65C, whereas the Pioneer vehicle will have a duration of approximately 30 days.

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A pump-fed propulsion system for the Bell engine is available in time for the first OTV flights. While the performance of this engine is not high, it is sufficient to place an appreciable payload into orbit and therefore to fulfill the requirements of this phase of the ARS development. The improved subsystem, adequate for the Pioneer through Early Advanced phases, is obtained by direct evolution of this first engine and requires little, if any, changes in the vehicle.

In the case of the Aerojet-Vanguard engine, a pump-fed 15,000 lb thrust propulsion system can definitely not be made available for the OTV flights and it would be optimistic to predict that the pump-fed system can be completed in the same time as the Bell Pioneer engine. With the Aerojet engine, therefore, a different propulsion system ought to be selected for the OTV phase which would introduce a "dead alley" development for a small number of vehicles and discard the opportunity for an evolutionary development of the refined Pioneer system.

The Bell engine appears also to be the better choice with regard to available man-power, development capacity, test facilities and probably also production potential. Aerojet appears to be loaded with work to capacity and the acceptance of a contract in the high priority ARS program might result in an interference with the 107 program. Bell, on the other hand, does not have any major development at hand after the completion of the Hustler program and faces the necessity of reducing its development staff and closing down test facilities if no new project can be obtained.

The production capacity for the Hustler engines is adequate to turn out four engines per month, which would allow two engines per month for the ARS project.

Consequently, the Bell XLR-81 Hustler engine has been selected for the orbital boost propulsion subsystem for the OTV through Early Advanced phases of the ARS program.

For the OTV vehicles, the existing XLR-81 engine using IRFNA - JP4 propellant will be used with only a minor alteration required for increasing the burning time from 65 to 100 seconds. This engine consists of a single thrust chamber, gas generator including starting solid propellant charge, turbine driven pumps, propellant control valves, and auxiliary equipment to start, operate and shut down. These components are assembled within the engine thrust mount which is a welded, tubular structure constructed of 8630 steel. This mount lends itself well to the addition of structures or brackets for other equipment or components and it can easily accommodate the hinge mounts for the four control engines. The aluminum thrust chamber is of drilled-wall construction and completely machined, regeneratively oxidizer-cooled and rated at 15,150 lb thrust in vacuum for a duration of 65 seconds at 500 psia chamber pressure. With a nozzle expansion ratio of 14.85:1 and an engine propellant mixture ratio of 4.25, a specific impulse of 263 lb-sec will be obtained in vacuum. The combustion in the engine is started by a preflow of unsymmetrical-dimethylhydrazine in the fuel line. This will probably obviate the necessity for using a nozzle closure

In order to adapt this engine to the ARS application, the primary change required is to enable it to operate for 100 seconds. Tests have shown that permanent damage occurs between 85 and 120 seconds with the existing gear train. However, with the addition of oil splash or a gear dip type of lubrication, tests have been run from 3 to 8 minutes with no damage. It is therefore proposed to provide this lubrication system as a modification kit to the existing unit. The oiler will consist of a small cylinder and piston assembly filled with oil. Fuel pressure from the pump discharge will be applied to the piston forcing oil to the gears. The development of this unit constitutes no problem and will not delay delivery of a complete engine.

No difficulty is anticipated in extending the life of the thrust chamber assembly to 100 seconds. Various tests have demonstrated the durability of the existing chamber and accumulated durations of over one hour have been reached on a single thrust chamber.

It is considered that a complete XLR-81 engine assembly can be delivered within ten months from date of order.

For the Pioneer and Early Advanced vehicles a modified Bell XLR-81 engine will be used. The modifications consist of increasing the nozzle area ratio from 14.85:1 to 20:1, the substitution of unsymmetrical-dimethylhydrazine (UDMH) for JP4 fuel, and the incorporation of a speed governor to the control system. This will result in an increase in vacuum thrust from 15,150 to 15,400 lb, an increase in performance from a specific impulse of 263 lb-sec/lb to a specific impulse of 277 lb-sec/lb, and an improved mixture ratio control which will probably reduce the amount of residual propellants in the tanks to such a low value that no additional system for propellant utilization control will be required for the Pioneer and Early Advanced Vehicles.

A number of changes are required in the engine before it can satisfactorily operate with UDMH fuel for a duration of 100 seconds. The injector must be accommodated for the new mixture ratio of 2.57. However, this is considered a minor modification since injectors have been fabricated and fired successfully using this propellant combination in the XLR-81 thrust chamber. Preliminary tests indicated that sufficient cooling is available for the combustion chamber regardless of the reduced mixture ratio, but this will be verified by extensive testing under the new condition. A new gas generator, with a mixture ratio of 0.14 is necessary; however, based on performance during preliminary tests, changes for a production unit will be minor. The pump outlet ports must also be rebored to accommodate the mixture ratio change. This may require a new fuel pump casting. Other changes are necessary to the turbine pump assembly to ensure adequate strength of the fuel pump gear to handle the increased load. The addition of the speed governor to the control system requires only a minor change in the gear box assembly and will not effect the overall development time. On the basis of information available at this time, it appears that the pump impellers, oxidizer pump casing and other propellant was selected for the OTV phase and the propellant feed system was changed in order to avoid any interference between the orbital thrust and orbital thrust control subsystems.

The control engines require development since no engines of suitable size and performance are available. However, the performance of this subsystem is not critical with respect to the over-all performance of the ARS vehicles. Consequently, state-of-the-art designs can be used for the first phases, which leaves sufficient time for the development of more refined engines and subsystems components for the later high-performance vehicles.

For this reason, 90 per cent hydrogen peroxide monopropellant was selected for the OTV phase control engines. Engines of this type, incorporating an integral solid catalyst bed, can be produced with negligible, if any, development. This system has the additional advantage of unlimited on-and-off operation which permits the performance of additional functions such as short duration attitude control during Atlas booster shutoff and separation.

The thrust chamber is designed to deliver 300 lb of thrust in vacuum at a chamber pressure of 100 to 150 psia with a nozzle expansion ratio of between 10:1 and 20:1. A vacuum specific impulse of at least 160 lb-sec/lb is obtained. The engines are assembled in individual hinge mounts permitting a deflection of at least $\pm$ 45 degrees. Other components are the propellant control valves and the hydraulic actuators. These engines are scheduled to be available 10 months after placement of the orders.

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The development of an improved control engine system for the Pioneer through Early Advanced vehicles will be initiated simultaneously with the design of the OTV control engines. Major goal of the improvement will be the reduction in over-all system weight attained by the application of a higher energy bipropellant system Since cooling of these small size combustion chambers becomes a problem with higher energy propellant combinations, different approaches will be made. A gas-fed propellant system using separate tanks, however, will be considered in each case.

Possible solutions, based on the use of the IRFNA-UDMH propellant combination, are:

1. Use of uncooled, ceramic inserted thrust chambers, giving a specific impulse of approximately 250 lb-sec/lb
2. Use of regeneratively cooled chambers, giving a specific impulse of approximately 250 lb-sec/lb. This requires a complete new development since the presently developed types of combustion chambers are not adaptable to very small dimensions.
3. Use of cooled chambers with the coolant provided by a by-pass flow of main propellant, giving a specific impulse of approximately 280 lb-sec/lb.

It is intended to initiate an experimental study to determine the best solution compatible with achieving a complete development within the required schedules. [redacted]

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The propellant feeding and pressurization system for the OTV through Early Advanced control engines will be designed to avoid any interference between the flow control system of the main engine and of the control engine. In addition, provisions have been made to permit control engine operation independent of main engine operation. For this reason a self-sustained pressure gas feeding system will be used with separate propellant tanks and regulators and possibly a separate pressure gas tank. The pressure gas will be unheated helium. Initial operation of the control engines prior to main engine operation in a gravity-free field will be made possible by means ensuring positive displacement, for example by incorporating bladders in the propellant tanks through which the pressurization gas is fed. These bladders may be bypassed, or ruptured after a sufficient gravity field has been established by the starting of the main engine.

4. AUXILIARY POWER SUBSYSTEMS

The major changes in the WDD Development Plan for the auxiliary power subsystem (APS) are: (1) the replacement of primary batteries by secondary batteries for the OTV phase and (2) the inclusion of a study program for the chemical auxiliary power system. In addition, d-c converters have been added as potential components for battery systems.

4.1 Battery APS

The tight schedules for the OTV vehicles preclude the use of other than commercially available batteries. The primary batteries now being produced are, however, inherently unreliable and require a time consuming and costly process of statistical sampling before use in guided missiles. With secondary batteries, on the other hand, a high degree of reliability can be obtained directly because of the possibility of a thorough pre-flight checkout of each unit. Since this type of application does not impose high requirements on cycling capability, the silver-zinc system can be used. This type has a relatively high energy-to-weight ratio, i.e., approximately 25 watt hours per lb, which is only slightly below that obtained with the originally proposed primary battery. Consequently, secondary silver-zinc batteries are now being proposed for the OTV vehicles with Yardney-Electric Company as the primary supplier. For the Pioneer-phase battery auxiliary power systems, the improved silver-zinc battery which was proposed originally has been maintained. This appears justified because the increased lead time permits the development of special batteries with improved reliability and also the specification of a higher degree of quality control than is normally applied to commercial types.

Possible measures for obtaining a higher degree of reliability include improved mechanical design and the use of solid plates which should be possible in this low-discharge rate.

An additional possibility is the development of a silver-iron type battery. The favorable characteristics of the latter system are:

1. The absence of side reactions would indicate the absence of gas evolution. This could permit sealing the battery and remove any question concerning gas polarization during operation in a zero-gravity field.

2. From the general characteristics of the Edison cell and tests of the silver-peroxide electrode, the self-discharge rate should be very low.

3. The mechanical characteristics of the battery under adverse environmental conditions should be better than those of the silver peroxide-zinc-type battery.

4. Since neither electrode reaction product is particularly soluble in the electrolyte, the battery should function as

a secondary battery to afford the added reliability of complete test. This recharge characteristic would be limited by silver migration-separator failure.

Electronic d-c converters are proposed as a component in battery systems to reduce the battery voltage and, hence, improve the reliability of the battery. Feasibility and reliability of this relatively new component have still to be demonstrated before a final selection can be made.

4.2 Chemical APS

If batteries, nuclear power, solar energy, and radioisotope heat generation are considered as possible sources for the auxiliary power, it appears that a considerable factor of uncertainty prevails over an important part of the ARS development program.

The high power requirements of the Pioneer through Early Advanced vehicles can not be met with slightly improved batteries. The nuclear and solar types, on the other hand, are unlikely to be available at that time. There remains for this phase the proposed use of radioisotope heat generation and of highly improved batteries. However, with these two very promising systems, development has not yet started. It is therefore intended to investigate the possibility of an additional alternative development covering the power demands of this phase of the development.

For this purpose, an 8-month study program will be conducted to determine the actual performance limits and developmental requirements of an open cycle chemical auxiliary power system. This system, as described in the original proposal, still appears to be a very promising solution.

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6. GROUND SPACE COMMUNICATIONS SUBSYSTEM

6.1 Determination of Orbit Parameters

In a previous report, methods were described for obtaining a rough determination of orbit parameters and for determining linearized differential corrections from successive observations (Ref. 1). The analysis assumed that the motion of the satellite could be described by a perturbed Kepler ellipse. The inclination of the plane of the orbit to the plane of the equator was assumed to be constant; however, it was assumed that (1) the line of intersection of the orbit plane and the equatorial plane rotated; and, (2) the apsidal line rotated within the orbit plane. Using the model described, one would be led into serious errors in the case of low latitude orbits. However, the maximum error resulting for an 83° orbit would be approximately 0.4 miles in projected position on the earth. Most of this error could be eliminated by considering that the angle of inclination of the orbit oscillates by a small amount around the average angle of inclination (Ref. 2).

From previous analysis, it has been determined that RMS errors of 0.1° in angular measurement for a single pair of observations spaced two or three minutes apart and range errors in the order of 0.1 mile lead to a maximum position prediction error of approximately 50 miles during one complete orbit period. Extrapolating from these results and assuming a minimum time in orbit of 5 days, it is desired to specify the minimal angular accuracy required of the tracking system to reduce position uncertainty to less than 0.1 mile As a rough approximation, the position uncertainty varies inversely as the square root of time (assuming repeated observations) and directly as the position measurement error. If the effect of error in range measurement is small, the radar or direction finder device must have an angular accuracy of about 0.5 milliradian.

6.2 Selection of Tracking System

In selecting a tracking system for the ARS program, compromises are necessary in arriving at an optimum choice. Table 1 summarizes the features of a number of the more applicable tracking systems using radio direction-finding and ranging techniques. Table 2 compares the systems on a basis of relative increase in unavailability, relative increase in complexity, relative increase in susceptibility to jamming, relative increase in vehicle weight, relative increase failure rate, relative increase in acquisition difficulties, cost per unit, and settling rate. Settling rate is defined as the reciprocal of the time required to arrive at a set of "good" values for the orbit parameters. As an example of how the chart is interpreted, consider the column labeled " -Unavailability." Assuming that it would require n months to procure an NRL Minitrack System and (24 + n) months to procure an AN/FPS-16 (XN-2) radar, the MSQ-1A radar procurement would require (0.5)(24)+n months or 12 months less than that required for the AN/FPS-16.

In using Table 2, it is well to observe that a number of the entries are based upon rough estimates or an indefinite reference quantity. In column 1, it was assumed that an NRL Minitrack system would be available in six to twelve months while an unmodified FPS-16 radar would require an additional two years for delivery. The column labeled

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" - Complexity" is to be interpreted qualitatively in that the FPS-16 radar system is defined to be one unit more complex than the NRL Minitrack System required for equal coverage. The reference Minitrack System is defined to include interstation communications, special computer facilities, timing and synchronization equipment and all the other special considerations which make up a complete system. From the two preceding examples, it can be seen that the information in Table 2 is to be interpreted as a broad estimate based upon many considerations which are often more qualitative than quantitative.

Based upon the figures in Table 2, it appears that a combination of approaches (c) and (d) would cost less than any other single choice. With the early availability of an extended range model of the AN/MSQ-1A radar for initial flight tests and the introduction within a reasonable time scale of the Nulling Interferometer, a reasonable tracking program can be established at moderate cost. Since an adequate beacon for orbital tracking will be unavailable early in the program, it will be desirable to use the MSQ-1A radar tracking system together with a modified COTAR system as an acquisition aid and as a means of obtaining redundant tracking data.

In the early operational phases of the program, power supply life and weight considerations indicate the need for eliminating the pulse beacon-transponder package. However, when non-conventional long-life power supplies become available and as vehicle performance improves, weight and power supply considerations will not be the limiting features.

Accordingly, the pulse radar approach will be dropped in the early operational vehicles in favor of direction finder and CW ranging techniques which impose practically no weight or power supply penalties on the vehicle. If operational experience indicates the need for a pulse radar, the FPS-16 or equivalent can be introduced for use with the advanced vehicles.

REFERENCES

1. Lockheed MSD-1481, Second Pied Piper Quarterly Progress Report, 15 December 1955, SECRET

2. M.I.T. Report 52-115-13A, Instrumentation Lab, Guidance and Attitude Control Study, Progress Report No. 3, 1 August 1955

7. FLIGHT TEST PROGRAM

7.1 Vehicles

Previous flight test programs have been planned on the basis of flights utilizing several different types of vehicles. These included an RTV (X-17) flight for environmental research, an Orbital Mode Test Vehicle (consisting of an ARS vehicle boosted by a cluster of solid propellant rockets), an Orbital Test Vehicle (consisting of an ARS vehicle with an Atlas booster), and various models which would evolve from the OTV. The OMTV was also called STV or Systems Test Vehicle.

During the past reporting period it has been necessary to evaluate the worth of various preliminary flights, particularly those of scale vehicles not having the same configuration as the ARS-Atlas combination. These deliberations have led to the elimination of the RTV and OMTV designs with consequent selection of a full-scale prototype configuration for all phases of the research and development programs. This vehicle is comprised of two parts: (1) an ARS airframe to which will be added new components and modifications as the program advances, and (2) an Atlas booster, beginning with the SM-65A, which will likewise undergo evolutionary changes with the passage of time. Some of the reasons for the elimination of the samller scale vehicles are:

1. The scale models do not offer the capability of orbital flight. Therefore, they would not remain in flight for

a sufficiently long period of time to record operating characteristics of components other than transient phenomena. Since key performance occurs after all transients have settled out or been calibrated, much data derived from an extended scale testing program would be of marginal use.

2. Scale models of a given vehicle are nearly as difficult to build as the parent article and thus constitute a separate development program. The inclusion of an STV using a solid propellant, clustered booster would thus tend to delay design of the full-scale vehicle.
3. Unavoidable differences between solid and liquid propellant boosters, load distributions, as well as obvious differences in configuration, tend to degrade correlation between a scale vehicle and its parent. Thus, some scale flights would have required full-scale duplication for the purpose of data correlation.
4. Auxiliary activities, such as provision of special facilities for firing different types of boosters, would have tended to generate higher program costs.

For these and other reasons, it was decided to concentrate on full-scale vehicles using the basic ARS airframe and Atlas (SM-65) boosters which would appear in the operational satellites. This will produce a minimum time and cost program with a maximum of technical progress.

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7.2 Move to Alternate Launch Site

It is tentatively planned to initiate the WS 117L flight test program at AFMTC, Patrick AFB, Florida. Primary reasons for this are the availability of operating range instrumentation and the existence of a Lockheed organization at that site.

In time, it is also planned to transfer the flight program to an alternate site, probably Camp Cooke, California where the WS 107A and possibly other ballistic missile weapon systems will already be located. Current plans call for the move to the California site at a time indicated on WS 117L Flight Schedule (TS Supplement to System Development Plan, MSD-2011 dated 1 November 1956). Initial location will be on Site 4, which will also be in use by WS 107A-1 organizations. Approximately 18 months later WS 117L will transfer to its permanent site in the southern area of Camp Cooke. The over-all change of location from Florida to California will affect the program in many ways, but the net result is estimated to be very beneficial. Some of the effects are as follows:

1. At the time of the transcontinental move, the project could sustain as much as a three-month loss of working effectiveness (although this would not be reflected in the flight schedule). It should be noted, however, that the project will leave Patrick AFB when that area will have become extremely crowded by numerous projects and activities. Camp Cooke, on the other hand, will be relatively uncrowded and will allow much greater operating

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efficiency. The initial time loss will be regained and ensuing operations will proceed much more rapidly than at Patrick.

2. During initial activities at Camp Cooke, a condition of limited interference will exist between WS 117L and the WS 107A-1 training program. This is caused by a necessary sharing of space and facilities. The condition will be relieved by the later occupation of the southern site. Further, it should be recognized that some training advantages will accrue to WS 107 because of additional vehicles supplied for handling in connection with the WS 117L program.

3. It is further acknowledged that some loss of time and effectiveness will result from breaking in new facilities, equipment, and instrumentation at the California site. Since this drawback must eventually be overcome, it is preferable to accept it early in the program, when it will cost less and have a minimal effect on ultimate operational dates.

4. While the move will involve some increase in military costs (for WS 117L facilities at Camp Cooke), the over-all cost to the program is reduced because of overhead, real estate, and general facilities shared with other operational weapons systems.

5. Launches from the Camp Cooke site provide many operational advantages. These are: (1) Range safety from the descent of falling hardware into the Pacific Ocean during high latitude flights;* (2) Camouflage provided by other similar weapon systems at the site; and (3) Southwesterly launches which provide desirable orbital course over various parts of the world.

Since so many factors support the change of launch site from AFMTC to the Western launch area, current plans call for this move at the earliest feasible date.

*From launches at Patrick, boosters would fall over land.