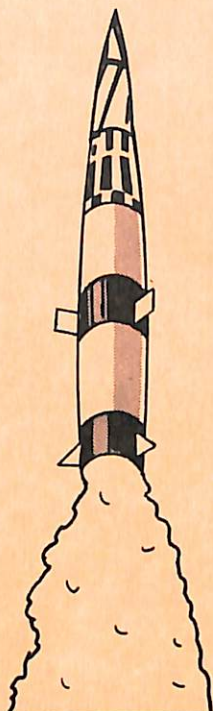


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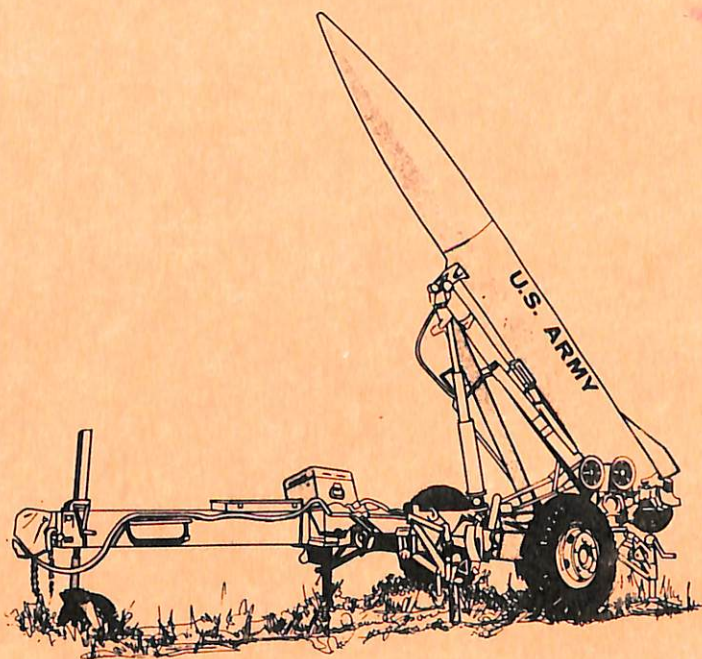
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ARMY SCIENTIFIC ADVISORY PANEL



REPORT OF

AD HOC GROUP ON ARMY'S PROPULSION PROGRAM



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Final Report
of
Army Scientific Advisory Panel
Ad Hoc Group
on
Army's Propulsion Program

Group Members

Dr. Maurice J. Zucrow, Chairman *
Dr. David Altman
Dr. Paul M. Gross
Mr. Jack I. Hope
Dr. Bruce A. Reese
MAJ Donald P. Whalen, Military Staff Assistant

* Dr. Zucrow participated in all group meetings, but became ill prior to preparation of the report. Dr. Reese acted as chairman during Dr. Zucrow's absence.

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**Additional Reference Material (Available upon request from
Executive Secretary, ASAP)**

1. **Presentations of the Army Scientific Advisory Panel Ad Hoc Committee on Propulsion (U), Report No. RK-SR-69-1. U. S. Army Missile Command, 27-29 August 1969.**
2. **Documentation for Liquid Propulsion Laboratory Presentation to Army Scientific Advisory Panel (U), Technical Report 3961, Liquid Rocket Propulsion Laboratory, Picatinny Arsenal, 2-3 September 1969.**
3. **Roster of Professional Personnel, Liquid Rocket Propulsion Laboratory, Picatinny Arsenal, Dover, New Jersey, August, 1969.**
4. **Picatinny Arsenal Technical Report, Liquid Rocket Propulsion Laboratory Presentation to Army Scientific Advisory Panel at U. S. Army Missile Command, 27-29 August 1969.**

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I. SUMMARY AND CONCLUSIONS

1. The Army must maintain its capability in liquid propulsion technology in view of future missile requirements in the current Army missile plan involving controllability. The Army cannot afford to preempt the option for selecting and successfully developing liquid propulsion systems, in view of the fact that the Army missile plan includes eight systems requiring controllability in which liquids are fully competitive.
2. The ASAP Ad Hoc Group strongly recommends the continuation of an active, adequate and appropriate exploratory development program directly under Army control and does not recommend transfer of exploratory development responsibilities to the Navy. The Navy future missile plan shows no greater requirements for liquid propulsion than does that of the Army - in fact somewhat less. Further the total Navy in-house capability is at best comparable to the Army. However, the Navy conducts more outside contracting, and as a consequence its liquid propulsion activities are more visible and have attracted more attention.
3. We do not have a high level of confidence that the controllable solid systems can be brought to operational status in a reasonable time and without compromise of the inherently desirable feature of solids - low cost, ruggedness and reliability. We believe that the liquid program should receive sufficient attention to provide a viable alternative.
4. The exploratory and advanced development propulsion programs are significantly under funded. This inadequate funding has dramatically come to light in reviewing the major difficulties experienced by each of the three services in recent major programs (LANCE, SRAM and CONDOR). These difficulties resulted in significant delays and over-runs and were all basically propulsion problems with systems that require controllability (two liquid and one solid propulsion system). Consequently we recommend that advanced development funds be provided so that suitable efforts can be initiated in a timely fashion prior to commitment to engineering development.
5. The Army liquid program should be re-structured to contract a significant portion (a minimum of one-third) of its funding to support outside work on exploratory development concepts. The benefits to be derived include: (a) stimulating interest and technical participation (IR&D Program) by outside groups in Army problems (b) increasing Army exposure to novel technology and (c) establishing the close working relationships with industry required to make the Army a sophisticated buyer.
6. In order to minimize interservice overlap in liquid propulsion we recommend semiannual meetings of those individuals in the Army, Air Force, NASA, and Navy laboratories that originate the exploratory and advanced development programs.

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7. More critical technical management attention should be given to increasing the effectiveness of the Army liquid propulsion program by a more concentrated orientation on areas that have caused development problems and have not been adequately resolved. Specifically, more emphasis should be placed on positive expulsion, compatible gas generators, combustion stability (feed system and acoustic), storage and handling under simulated operational conditions, and compatibility of propellants and materials.
8. A significant increase in communications between the propulsion groups at MICOM and MUCOM has been developed during the past few years. Even with this increased communication, however, the Ad Hoc Group felt there was a lack of unanimity in direction of a single coordinated exploratory and advanced development propulsion program for the Army aimed at specific solution of problems contained in the Army Missile Plan.
9. We have encountered an attitude of reluctance by a number of Army management personnel to select liquid propulsion systems. This attitude is recognized by the industry to the extent that it considers it futile to recommend liquid power plants in Army missiles even where controllability is required and the Army Missile Plan listed liquid as an acceptable option. We believe this attitude is to the detriment of the Army in that, unless changed, it may preclude the opportunity to select the liquid option where it is superior.

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II. RECOMMENDATIONS

The Army Scientific Advisory Panel ad hoc group on the Army's propulsion program specifically recommend:

1. The Army maintain its capability in liquid propulsion technology, and continue an active, adequate and appropriate exploratory development program. The Army should not transfer exploratory development responsibilities to the Navy.

2.* The Army liquid program in exploratory development concepts should provide for contracting a significant portion (a minimum of one-third) of its funding to support outside work.

3. The Army increase its funding in advanced development so that suitable efforts can be initiated in a timely fashion prior to commitment to engineering development. These funds can be obtained by reprogramming to provide a more suitable ratio among exploratory advanced and engineering development.

4. That semi-annual meetings be held between those individuals in the Army, Air Force, NASA, and Navy laboratories that originate exploratory and advanced development programs.

* Dr. Zucrow does not concur in this recommendation. He believes that the Technical Director of the R&E Directorate of the Missile Command must have the flexibility to distribute his exploratory development funds in the manner most useful to the Army without consideration of an arbitrary minimum on contracted work.

III. INTRODUCTION

In accordance with the request of Secretary Poor (Tab A), and COL Lunn (Tab B), an Ad Hoc Group of the ASAP was formed to review the U.S. Army's program in exploratory development on liquid missile propulsion. Committee members are listed in the front of this report. Meetings were held at the Pentagon, Redstone Arsenal, Picatinny Arsenal, and Naval Weapons Center (China Lake) with many Army and Navy personnel. An outline of these meetings is contained in Tab C and a complete copy of all data presented is available in the files of the ASAP Executive Secretary.

The Committee wishes to commend Dr. Wharton, Mr. Forsten, Dr. Leonard and their associates for their clear presentations, thorough understanding of the subject, and the very complete and well prepared written material presented to the committees.

Following the meetings as referenced above, the committee met again at Redstone Arsenal on September 24-26 to prepare the draft of this report. After coordination by mail, the committee held a final meeting at the Pentagon on 12-13 November 1969 to prepare a final draft and to present a verbal report to representatives of the executive committee of ASAP.

A. Background

In reviewing the total exploratory development program for OSD, DDR&E has suggested that a greater selectivity in program elements would offer the U.S. a greater return for the reduced funding now available. Specifically, they have suggested that the Army drop its exploratory development program in liquid rocket technology and depend on the Navy for support in this area (Tab D). Such funds could then be available for work in solid propulsion technology.

Communications between the Department of the Army and DDR&E took place during the summer of 1969 (Tab E) with no agreement being reached. As a result, this Ad Hoc Group was formed to provide an independent evaluation of the DDR&E suggestion.

B. Preliminary Assessment

After receiving the briefings outlined in Tab C, and prior to deliberation on preparing the report, the group made the following preliminary assessments:

A complete list of all pertinent Army and Navy facilities was obtained and reviewed. It appeared that each service had adequate capabilities and that this factor would not be an element of consideration in our decision. Similarly, the group's limited contact with both Army and Navy personnel working in liquid technology divulged both staffs to be competent with no appreciable difference in their capabilities. Consequently, relative

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technical competence was not a factor in our recommendations. Further discussion on the management aspects of the liquid technology program, however, is contained in section VII.

The basic sense of the conclusions and recommendations of the group was unanimous. The following sections of the report briefly summarize why the group believes that the maintenance of a strong liquid rocket propulsion exploratory program in the Army is in the best interest of the Nation. The report consists of (a) a brief discussion of future missile plans of the Army and Navy, (b) the requirements of these plans for propulsion technology, (c) considerations involved in the transfer of the Army's liquid rocket program to the Navy, and (d) an analysis of the propulsion program of the Army and suggestions of the group as to methods of strengthening that program.

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IV. FUTURE MISSILE REQUIREMENTS

A. Service Programs

1. **Army Future Missile Program.** The Research and Engineering Directorate of the Army Missile Command publishes The Army Missile Plan which presents a technical analysis of the future missile needs of the Army to determine the resources required and the areas of technology requiring support. The plan includes an analysis of the relative priorities of the requirements, the systems, and the component development tasks that must be accomplished before new systems can enter their contract definition phases and includes an estimate of the cost of these efforts. The "requirements" considered in formulating the Missile Plan are not only those that have formal Department of the Army approval but also potential requirements that have been proposed. The current Missile Plan has a list of sixteen weapon systems,* for which 70 system design options and over 500 subsystem technology tasks are evaluated. A list of the missile concepts for satisfying current requirements is presented in Table 1. The table lists 11 missile systems with a concept name, for identification purposes, and a brief remark describing the purpose or type of system.

A number of missiles were designed (conceptually) to fulfill each of the requirements of the aforementioned 11 systems. The group was briefed on the propulsion concepts of these eleven subsystems and, in addition, was briefed on the propulsion requirements of Improved Spartan and a new payload subsystem, a multiple independently targetable reentry vehicle (MIRV).

The conclusions of The Army Missile Plan regarding the choice of propulsion subsystems for the 11 missile systems and Improved Spartan and MIRV are tabulated in Table 2.

*All of the 16 are not missile systems.

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<u>CURRENT REQUIREMENT DOCUMENT</u>	<u>ARMY PLAN DATE</u>	<u>CONCEPT NAME</u>	<u>REMARKS</u>
<u>AIR DEFENSE</u>			
DPQMDO	A85 (75-85)	MANPADS	LIGHTWEIGHT MAN PORTABLE WEAPON SYSTEM
DPQMDO	A85 (75-85)	LOFAADS	LOW COST WEAPONS SYSTEM OF CHAPARRAL TYPE
<u>MULTI-PURPOSE</u>			
QMDO 212 b (3)	A85 (75-85)	ATAADS	ANTITANK ASSAULT AIR DEFENSE SYSTEM
QMDO 412 b (3)	A85 (75-85)	USASAT	UNIFIED SYSTEM FOR ATTACK SURFACE AND AIRBORNE TARGETS
<u>LAND COMBAT</u>			
PQMDO	A85	IMP LAW	SYSTEM TO REPLACE CURRENT LAW
QMR 336 b (10)	A85	ACVWS/LR	SINGLE WEAPON SYSTEM FOR ARMORED COMBAT VEHICLES
PQMR	A75	SEAS	AIRCRAFT ARMAMENT WITH A VARIETY OF WAR-HEADS - DIRECT FIRE
DPQMDO	A85	MISTIC	SYSTEM FOR DEFEATING POINT TARGETS WELL FORWARD OF FEBA
PADO			
QMDO 412 b (14)	A85	AERIAL ARTILLERY	ARTILLERY WEAPON CAPABLE OF BEING FIRED WHILE MOUNTED TO VTOL AIRCRAFT OR FROM GROUND
DPQMDO			
QMDO 412 b (14)	A85	MARS	LIGHTWEIGHT AREA ROCKET LAUNCHER FOR SUPPORT OF AIRBORNE AND AIR ASSAULT TROOPS
DPQMDO'S		FAMS	ARTILLERY SYSTEM WITH RANGE 10 KM - 700 KM
MICOM/FT. SILL			

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As noted in Table 2, for those systems requiring propulsion controllability, the liquid propulsion system appears to be a better option in two cases, and is competitive in six others. These design studies have been made with various degrees of thoroughness and more conceptual design, exploratory development, and possibly even some advanced development are required before an optimum propulsion system can be selected. The important observation that can be made from The Army Missile Plan is that, at the present time, the designers for eight of the missile propulsion subsystems should evaluate liquid propulsion as an option.

2. Navy Future Missile Program. The ASAP Ad Hoc Group did not acquire a document similar to The Army Missile Plan from the Navy Propulsion Group at China Lake, California. That group did present the Navy future missile program, employing Table 3 as a basis for discussion. The liquid propulsion group at China Lake is concentrating on candidate missile programs for support of the future requirements listed as air to air missiles (AAM), medium to long range, although they are maintaining the technology for support of an Advanced Compound Engine (Combined liquid rocket booster engine and ramjet for long range air to air applications) and are supporting a hybrid propulsion package.

Because the group recommends the Army's retaining its own exploratory development in liquid propulsion, there will be no detailed discussion of Navy efforts in the Program Analysis section of the report. A brief summary of Navy program highlights is presented below.

The principal effort of the Navy's liquid propulsion group is directed toward the integration into a semi-flightweight system of the advanced bi-propellant liquid components, gas generator, variable thrust thrust chamber and positive expulsion tanks that have been under exploratory development for the past 2 or 3 years. The purpose of this program will be to investigate the overall propulsion system, the interaction of the several advanced subsystems, and to demonstrate the propulsion system over the range of environmental conditions expected of Navy air-launched missiles. The task is intended to not only investigate the interactions of the subsystems, but also to demonstrate that an advanced liquid propulsion system can be made to function reliably. The propellants employed are chlorine trifluoride and NOTSGEL-A, which is a jelled fuel of mixed hydrozines and aluminum (60%). The program is an integrated effort of the propulsion industry and the Navy laboratories.

Other efforts of the Navy liquid propulsion group are (a) the maintenance of technology for the support of the Advanced Compound Engine (ACE) for long range air-to-air applications, being developed at The Marquardt Corp; (b) a jet interaction investigation using warm gas at the forward end of the missile, (c) a program directed primarily at minimizing cost and maximizing safety in a hybrid propulsion package and (d) a new fuels program at Rocketdyne with the objective of developing a dense neat fuel with a density impulse similar to the metallized systems. The Advanced

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TABLE 2

RECOMMENDED PROPULSION SUBSYSTEMS FOR FUTURE ARMY MISSILE SYSTEMS

Current comparisons of storable Liquid and Solid Propulsion for Future Army Missile Systems conclude:

- 0 Liquid Propulsion gives the BETTER option for:
 - 0 SIPS Reaction Control System
 - 0 MIRV Attitude Control Systems
- 0 Liquid Propulsion gives a COMPETITIVE option for:
 - 0 SIPS 3rd Stage Propulsion
 - 0 LOFAADS
 - 0 MARS
 - 0 MISTIC
 - 0 FAMS
 - 0 USASAT
- 0 No Liquid Propulsion Option for:
 - 0 SEAS
 - 0 MANPADS
 - 0 IMPROVED LAW
 - 0 AERIAL ARTILLERY
 - 0 ACVWS/LR
 - 0 ATAADS

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TABLE III

CRITICAL MISSILE OBJECTIVES 1975 - 1980

	AAM	ASM	SAM	SSM	STRATEGIC
	SHORT RANGE	MEDIUM TO LONG RANGE			
RANGE	Up to 10 miles maneuverability limited	100-125 n.m. propulsion limited	100-150 n.m. at alt 60 n.m. on the deck propulsion limited	150 n.m. propulsion limited	35-40 n.m. low alt 150 n.m. high alt propulsion limited
SPEED	Up to M=4.5	M=2.5 to 5.0	M=2.5 to 5.0	M=2.5 to 9.0	M=2.5 to 6.0
					Terminal on the deck M=7
WEIGHT/SIZE	250 lbs dia: 5 in max length: 120 in.	1000 to 1400 lbs dia: 13 to 18 in. max length: 175 in.	1400 to 1800 lbs dia: 13 to 18 in. max length: 175 in.	1400 to 3000 lbs dia: 13.5 in. to 18 in. length: 186 to 300 in.	1400 lbs dia: 13.5 in. length: 186 in.
					Poseidon (max)
PAYLOAD	100 lbs	400 to 500 lbs	500 to 700 lbs	400 to 500 lbs	550 lbs
					Multi-nuclear
MANEUVERABILITY	TVC	*TMC & TVC plus Aero Surfaces	TMC & TVC	TMC & TVC	TMC & TVC
					Attitude control on re-entry & boost

*TMC - Thrust Magnitude Control

*TVC - Thrust Vector Control

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Compound Engine employs a bi-propellant liquid booster with a ramjet sustainer, with the ability to re-ignite the liquid booster during the terminal encounter.

The Navy also has two programs termed "housekeeping efforts." They are (a) the Liquid Engine Materials program which follows activities of other groups in high temperature chamber materials and materials compatibility programs and (b) the Liquid Propellant Evaluation Laboratory which reviews new propellants through numerous safety and storage tests.

B. Technical Requirements

The technical justification for continued development in liquid propulsion technology is the inherent flexibility of a liquid propulsion system to stop and restart and to permit modulation in thrust level. This capability is required in both main propulsion and reaction control systems.

1. System Flexibility

Currently the thrust of liquid propulsion systems can be varied over a wide range (over 50:1 in the LANCE system) with either a programmed, controlled, sequence, or continuous variation in thrust. If a variation as large as 50:1 were to be taken in a single thrust chamber there would be a penalty in performance; however, because of the flexibility in liquid systems it is possible to transfer easily the flow of propellants to a smaller thrust chamber when the additional weight compensates for that loss in performance.

The thrust modulation capability, tied to a proper guidance system, will allow increased accuracy and a larger spectrum of ranges when fired in various atmospheric conditions. Thrust modulation has been developed and is now being employed in several missile systems. This permits such low cost guidance concepts as DC automet where the thrust is varied to match the drag of the missile.

The DDR&E Memorandum (Tab D) states that "controllable solids are now available." This statement is misleading since there are various degrees of controllability and only the simpler types have been operational and hence can be considered "now available." Specifically, thrust termination and pre-programmed thrust levels for boost-sustain applications (accomplished by suitable grain design or multiple castings in the chamber) have been reliably used. However, techniques to accomplish arbitrary and multiple stop-start capability and thrust modulation over a 7:1 range are now in the exploratory development phase.

In the field of modulated thrust levels with arbitrary stop-start capability in solid propulsion technology, the Group found active programs in both the Army and Navy; but found all of these to be in the exploratory stage of development. Both the pintle nozzle concept and the dual chamber

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(gas generator) have demonstrated the feasibility of continuous thrust variation, over a ratio of approximately 7:1 and stop-start capability at high altitudes. However, if these requirements are combined with a requirement for a high burning rate propellant that must terminate at low altitude, the reproducibility, and hence reliability, has yet to be demonstrated.

There is a serious concern that when variable thrust components are included in solid rockets, along with the requirement for movable mechanical parts in the chamber, and propellants with high pressure coefficients that reliably "stop" but operate well over wide pressure and temperature ranges, the simplicity, reliability, and ruggedness of solid rocket may be lost. The Advanced Ballistic Missile Defense Agency submitted a Request for Quotation on a variable nozzle thrust area program that will define many of the trade-offs for controllable solid motors, and will give insight into the potential loss in simplicity, ruggedness, and reliability.

It is, of course, possible to design missiles to accomplish various Army requirements with solid propellant engines with existing capabilities, e.g., use of multiple engines. However, these may not, because of weight penalties and reduced flexibility, be the most cost effective. It appears to the Group, therefore, that both the controllable solid motors and the liquid propellant systems require more exploratory and advanced development to give the missile designer the flexibility of control (up to 50:1) that may be required to optimize missile systems.

2. Control Systems

In addition to main propulsion requirements for Army missiles there are thrust requirements for reaction control and thrust vector control. Combined jet reaction and external burning control systems are also being studied.

In reviewing these system requirements, the Group found the reaction control capabilities of a liquid system to be desirable for use on high altitude applications such as Improved Spartan and MIRV. A study contract on a high altitude homing missile concept, LoRAH, found that a liquid attitude control system was the lightest and most flexible of several alternatives and it was recommended by all three contractors that conducted the study.

The advantages of liquid jet reaction control systems are their adaptability for multiple position location and their arbitrary on-off capability. To assure that specialized applications of liquid propellant systems are available for Army use the Group believes exploratory development programs should be continued to make available these control systems.

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V. LIQUID ROCKET EXPERIENCE

In evaluating the potentials of liquid and solid systems for use in rocket propulsion it is necessary to apply a wide range of criteria, such as system cost, flexibility in achieving the range of mission requirements, simplicity of maintenance, field ruggedness, and reliability.

While the criteria of mission suitability and system cost are usually reasonably well substantiated and documented during development and prior to production, realistic evaluations of maintenance problems, transportation and handling ruggedness, and overall reliability are difficult to obtain until the system has been subjected to sufficient field use.

A brief review of American and Soviet experience with operational liquid systems is therefore instructive.

A. U. S. Experience

While U. S. experience with liquid fueled missiles has been extensive and by and large satisfactory, the Army has had moderate success with a number of its liquid fueled missiles. Early systems such as the CORPORAL and REDSTONE that required field fueling with resulting awkwardness, slow response times, and large numbers of vehicles, compared poorly with the solid fueled SERGEANT and PERSHING that replaced them. Low system reliability with the CORPORAL and REDSTONE was probably more a result of being first generation missiles that would have had problems with any propulsion system, than anything else, but their inadequacy is remembered. On the other hand, the JUPITER never became widely known throughout the Army and the reputation of liquids benefitted little from its successes.

The BULLPUP, with its prepackaged fuels and direct pressurization, has performed reliably for the Navy, but, here too, the propulsion system did not receive the credit it was due as operational limitations associated with missile guidance reduced overall effectiveness. A current program to update the missile into the BULLDOG is under serious consideration.

More recent development of the LANCE by the Army and the CONDOR by the Navy have done little to improve the liquid image. Admittedly these propulsion systems have had technical difficulties which by now, however, are largely resolved in the LANCE. The CONDOR liquid propulsion system development has been halted largely because of the nature of the Fixed Price contract. At this point in time, the important experience gained in overcoming these problems will be valuable in future developments.

The poor image of the Army's liquid propelled missiles has produced a reluctance in certain key individuals to accept proposals for liquid propulsion systems even when they appear superior to competing solid systems.

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The key point is that no tactical missile using modern liquid propulsion technology has been fielded by the Army and thus there has been no demonstration of ruggedness and reliability under Army operating conditions. On the other hand the BULLPUP propulsion system has demonstrated ruggedness and reliability in Navy air to ground missions.

B. Soviet Experience

A review of parallel developments in Russian rocket propulsion over the past two decades indicates a different and more favorable experience with liquid propulsion systems and that these systems can be made rugged, reliable and operational under field conditions. Intelligence estimates indicate that the Russians during this period have deployed defenses totaling tens of thousands of surface to air missiles in the U.S.S.R. and satellites, and have successfully trained troops from their allies to handle and maintain these highly mobile systems.

Intelligence information shows thousands of known firings of missiles in North Vietnam with little indication of duds or failures. These missiles are "old" designs (15 years old) and thus do not have the mission flexibility expected in newer systems. However, they have successfully limited the use of higher altitudes causing our aircraft to operate lower where they come within range of highly effective, ground based anti-aircraft fire.

Intelligence reports also reveal that the liquid SAM's are sufficiently simple and rugged that the troop operating them are not "hand picked" nor is their training period long. The missiles are transported for short distances fully fueled, but for longer movements, or for stand down periods the oxidizer is removed and stored in a tank on the transporter. Indications are that a SAM site in Vietnam, with this relatively obsolete systems can be moved overnight, be ready for operation the next day, and can achieve a high degree of firing reliability.

During the twenty-year period that the Soviet Union has developed and fielded SAM systems they have shown a marked preference for liquid propulsion. The third of the SAM series, the SA-3, utilized a solid propellant instead of liquid propellant sustainer, however, the Soviets returned to the use of a liquid sustainer in the SA-5 (SA-4 and SA-6 employ ramjet sustainers). The same pattern was followed in modifications of the SA-2 where a solid motor replaced the liquid sustainer and then, in turn, a liquid replaced the solid motor. This cycle has also occurred in the Soviet Union's long range surface to surface missile programs. Only one deployed system was solid, and the latest is again a liquid propulsion system.

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The MICOM intelligence group concluded that the Soviets generally consider liquid propulsion systems to be more reliable and simpler than solid systems. Obviously the Soviet Union's background, requirements, and technology are different from those of the United States. The important point is that the liquid systems, where required, can be and have been made reliable and usable in the field.

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VI. PROGRAM ANALYSIS

The Exploratory Dev. budget, 6.23, for FY70 in liquid propulsion for both MICOM and MUCOM (LRPL), amounts to approximately \$2.3M of which about \$0.6M is to be spent at MICOM and about \$1.7M at MUCOM. The character of the effort at MICOM is research oriented with major emphasis on the exploration of principles and demonstration in laboratory scale hardware. The effort at LRPL, on the other hand, is oriented more toward engineering components and demonstrations in prototype hardware. Periodic meetings are held between the two laboratories to communicate technical results and coordinate their respective technical programs.

The system briefings at MICOM provided an excellent insight into the propulsion requirements for the various Army missile systems, and indicated those with a liquid option. The technical review summarized state-of-the-art in current storable propellant liquid motors. A brief history of the LANCE development problems as well as a cursory review of the Navy CONDOR Program elucidated the following technological problem areas in the development of liquid propulsion systems:

1. Positive expulsion devices
2. Combustion instability (acoustic and feed system coupled)
3. Compatible gas generator
4. On-Demand gas generator
5. Storability
6. Field handling ruggedness (g-loading response of prototype systems)
7. Performance sacrifice in throttling
8. Thrust chamber and nozzle insulation

In addition to these more specific technical problem areas, there are the important general system requirements:

- a. Reliability
- b. Low Cost
- c. Accuracy
- d. Safety
- e. Maintainability

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After the discussion of general technological problem areas in storable liquid propulsion systems, the group was briefed on the technical effort at both MICOM and MUCOM (LRPL). The following discussion provides a brief summary of the character and quality of effort.

A. MICOM Programs

Positive Expulsion. The main effort in positive expulsion was stimulated by consulting activity on the LANCE Program. In the course of this activity, the Laboratory became aware of problem areas in piston and metal bladder design, leakage, and materials for bladders and sealants. A similar effort was conducted at LRPL who participated with MICOM in a consulting and monitoring activity on LANCE. An independent expulsion concept was developed and tested at the laboratory in subscale hardware. The approach is based on a spin expulsion concept in which the propellant is oriented along the walls by centrifugal force. This approach is suitable for missiles such as the LANCE, which spin, and has the obvious advantage of not requiring a separation diaphragm. Several experimental hot firing tests with a solid gas generator and IRFNA have shown chemical reactions which are smooth but non-explosive between the gas generator and the acid vapors. Further testing is required to assure safety, reproducibility of tank pressure during the period of expulsion, and high expulsion efficiency.

Compatible Gas Generator. The development of a compatible gas generator would provide an extra margin of safety in the expulsion system in that it would permit minor leaks to occur in the piston or bladder without the hazard of explosions. If such a gas generator were available, most of the currently developed propellant barrier concepts would probably be acceptable. Two approaches were noted. The first is based on generation of a neutral gas, nitrogen, evolved through the reaction of ClF_3 and a sodium or lithium azide. This effort is at an early stage. It is of dubious practicality because of the classical problem of non-steady and non-reproducible operating conditions typical of liquid reactions with packed bed materials, and because of questionable acceptability of ClF_3 in applications requiring long term field storability.

The second approach involves the use of hydrazine solutions containing oxidizers to generate a relatively neutral gas with low content of fuel-rich gases. Development of this approach required the use of an efficient thermal bed and work is underway on this component. It has the advantage of appreciable operational flexibility since it is on-demand and has a liquid with a low freezing point.

Gelled Fuels. All three Services have conducted programs in gelled fuels because of the obvious advantage of increasing the impulse-density of a liquid system. The typical gel is a 60% suspension of aluminum in UDMH. The use of a gelled fuel in LANCE, would increase the range by 50 to 100 per cent. The major problem areas with gelled fuels are long term storability under temperature cycling, a high temperature coefficient of

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viscosity at low temperatures, and the achievement of good combustion efficiency. The viscosity varies greatly over the environmental temperature range which changes hydraulic characteristics and consequently thrust programming.

Vortex Injector. A novel injector is being investigated employing centrifugal injection of the propellant in a flat pancake type thrust chamber. The claimed benefit of this approach is that it permits an appreciably shortened chamber length allowing greater volume for propellant in a fixed length system. The system advantage in a general case appears questionable, especially in view of problems of relatively low combustion efficiency.

B. MUCOM Programs

Expulsion Systems. In conjunction with MICOM, LRPL has consulted on positive expulsion problems incurred in the LANCE Program. The MUCOM Program has considered various expulsion methods including direct pressurization (BULLPUP), use of a bladder with hydrazine decomposition gases (CONDOR), and use of a piston with solid propellant gas generator (LANCE). The actual "firings" at the Laboratory have emphasized the bladder with a "roll and peel" diaphragm approach. Hot firing tests with both IRFNA and CTF were performed successfully. With the background of experience, the personnel of MUCOM are monitoring the ABMDA Program for positive expulsion suitable for the third stage of SPARTAN.

Light Weight Materials. A program on high strength alloys has been pursued with the end objective of permitting construction of light weight tankage and thrust chambers in order to increase the impulse to weight ratio. Because of the critical requirements of compatibility with propellant materials, this program has been concerned mainly with corrosion studies which have been valuable in generating background data for long term storability. There is some question, however, whether in practice the original objective of increasing impulse to weight ratio appreciably will be achieved with very high strength alloys in view of the compromises that would probably be required.

Liquid Propellant Gas Generator. The MUCOM Program has been concerned with the efficiency of thermal and catalytic beds for hydrazine type monopropellant decomposition and in the overall feed system design requirements. System tests have been performed to study the problems of pressure reproducibility, expulsion efficiency, and heat transfer. This work has been illuminating, although it has been concentrated on the use of hydrazine which is not suitable for low temperature operation. It appeared that this area could benefit from closer coordination with the MICOM Program which evidenced a reasonably heavy expenditure of effort in low freezing point hydrazine solutions.

Tactical Turbopump Technology. A low cost turbopump development program has been pursued because of the performance benefits of operating

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at high chamber pressure and low tank pressure. Ideally, the turbopump with variable flow and restart capability is desired. The work to date shows promise but a valid comprehensive system analysis providing for a tradeoff between cost and performance should be conducted. The development of low cost reliable pumps and turbines has long been a laudable goal and is probably worth reconsideration in view of system feed problems with direct pressurization.

Reliability Analysis. The analytical approach to reliability of MUCOM suffers from the usual objection of a typical preoccupation with mathematical detail at the expense of a realistic system model based on physical experience.

General Support. Three programs were discussed in this area related to improvement in missile systems currently under various stages of development. One is a selectable total impulse device, which can be used on MARS, that signals the control system when a certain prescribed impulse has been delivered. This is accomplished by an electronic pressure integrating device. Preliminary laboratory tests have indicated a one deviation of 1.35% under ideal laboratory conditions with precalibrated instruments. Further experience will be needed to improve the accuracy and determine the reliability of the device when subject to storage under changing environmental conditions. The second area involves the study of TVC systems suitable for missiles requiring directional control. The Laboratory has emphasized liquid TVC because of its simplicity and rapid response rates. The third area of investigation has been gelled propellants because of the performance improvement derived from high density impulse.

Rocket Assisted Projectile. As a further extension of the Rocket Assisted Projectile (RAP) Program, LRPL stimulated interest in the DICORAP, Directional Control Rocket Assisted Projectile employing a bipropellant engine. In this connection, the Laboratory participated in selecting and monitoring a contractor to develop a prototype vehicle which was fired successfully in June 1969. The program represents a substantial improvement in range capability employing an existing launching device, the 107 mm mortar.

Use of Liquid Propulsion Technology in Support of Other Requirements. A group of programs were discussed that are not directly related to liquid propulsion, but are in support of Army requirements that require liquid rocket technology. These programs have made significant contributions to the Army's needs, and while they do not, by themselves, justify the continuation of a liquid propulsion program, they should be considered in weighing its overall value.

Work has been done on such diverse projects as boosted artillery and mortar projectiles, liquid explosives, liquid gun propellants, nuclear weapon destruction systems, liquid mines capable of universal orientation and self sterilization, fuel air explosives, and detonation traps for tunnel destruction devices used in Southeast Asia. The colocation of the Liquid Rocket Propulsion Laboratory with the Munitions Command makes it

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possible to use engineers from the laboratory on special projects in all these areas as required.

One particularly promising application of liquids in the mine program is in the ADAM project. It is desirable to have each mine "pop-up" above the ground before detonating. As it is not possible to tell in advance what orientation each mine will have, as placed, the only way to insure that it always goes up correctly is to have liquid propellant that collects at the bottom of the cavity under any conditions.

General Comments. In summary, the MICOM/MUCOM Programs appear to be of good quality and are well orientated toward current missile requirements. However, a few gaps in technology were noted. A primary one relates to combustion instability as evidenced in the LANCE, considering both acoustic and feed system types. A suitable program designed specifically for the IRFNA-UDMH propellant combination should include both mechanical absorbing devices and chemical additives. The latter approach is of interest because of its demonstrated effectiveness in the CORPORAL Program, its current use in certain Russian engines, and because its simplicity in "retrofitting" an existing system. There was also no mention of throttling techniques which minimize the performance sacrifice at the low thrust end of the range. Finally, there should be a more concentrated effort to answer the typical objection to a tactical liquid system; namely, lack of ruggedness in field handling and poor long term storability. Because of the wide spread belief that liquids are deficient in this area, it would be highly desirable to generate a program to test prototype models under typical g-loading conditions simulating field handling environment. On a priority basis, it is recommended that these gaps should be filled prior to "appreciable" expenditures in such other areas as flourinated oxidizers, gelled fuels and the vortex injector.

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VII. MANAGEMENT CONSIDERATIONS

In reviewing the overall problem of liquid propulsion program management, the Group considered both administrative and organizational changes to improve effectiveness. The actions considered ranged from the possibility of transfer of the Liquid Propulsion programs to the Navy to recommendations for improving administrative control and coordination over the programs within the Army. The Group also reviewed the categories of program funding and has decided that a more effective program balance would result by initiating an Advanced Development program and increasing the amount of outside contracting. The rationale that led to these recommendations are discussed in this section.

A. Administrative Changes

1. Transfer to Navy. The Group considered transferring the entire liquid propulsion program to the Navy with the attendant benefit of using the funds thus freed for other critical areas in propulsion as controllable solids. An estimate was obtained from the Army Propulsion Laboratory on how the 2.3 million dollars currently budgeted for liquid technology would be expended in boosting solid propulsion technology if liquid technology were transferred to the Navy. It was stated that funds would be divided among several current solid programs, and the Group concluded that the improvement in solid technology would not offset the loss in liquid technology. The primary question, however, in considering this move is the Army's interest in maintaining liquid propulsion as a realistic option for future missile systems. Assuming this interest to be real, we believe it necessary for the Army to maintain administrative control over the programs for the following reasons:

a. Loss of Competence. Many highly qualified technical personnel would be lost either through reassignment or transfer to industry. If such a loss takes place, it is unlikely that the Army will have available strong and able advocates of liquid propulsion who can initiate valuable concepts in this area. Not only will the development of the liquid option suffer but also the soundness of evaluation of proposals. The most serious loss would probably be in the Army's capability to guide, supervise and monitor propulsion development contracts.

b. Loss of Responsiveness to Army Requirements. If the Navy were assigned the responsibility to provide for the Army's needs in the liquid propulsion area, it is doubtful that Navy personnel assigned this task would be sufficiently familiar with the user's requirements to propose the optimum or perhaps even effective systems to meet these needs. Beyond this, if a system were developed by the Navy for the Army's use and system failures or troubles occurred, the correction of these difficulties could present problems of assignment of responsibility and could lead to inter-service friction before they were resolved.

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In summary, therefore, transfer of the liquid propulsion activity to the Navy would lead not only to a less effective administration of liquid programs for Army needs, but also would certainly decrease the probability of the Army's selection of a liquid propulsion system even if it were superior. Such an outcome would impose a highly undesirable limitation on the Army's future ability to develop effective missile systems.

2. Administrative Control. There were two areas where the Group observed the possibility of improvement in program efficiency resulting from closer administrative attention. One is in coordination and more detailed overall direction of the MICOM/MUCOM activities, and the other, although mainly an OSD function, relates to improved coordination of the liquid propulsion programs among all the Services to minimize non-beneficial duplication.

a. MICOM/MUCOM Coordination. Coordination between the MICOM and MUCOM activities is primarily attained by periodic meetings held at both Laboratories. In principle, the generation of concepts and laboratory proof are basically the responsibilities of MICOM and the successfully demonstrated concepts are further evaluated on an engineering scale in prototype hardware at MUCOM. This was generally found to be true, although a fair overlap existed in the engineering conducted at MICOM and more noticeably in the research at MUCOM. Although the Group noted this overlap, it was not viewed as a serious detriment since a certain amount of duplication in the "gray area" is required for good coordination. It was observed, however, that the overall program could benefit from a firmer centralized direction that could apply relative priorities to the individual efforts. This centralization would improve the smoothness of transitioning concepts from the research stage at MICOM to the engineering stage at MUCOM. Such control is not necessarily a spontaneous outgrowth of good communication, which does exist between the laboratories, but must be consciously imposed for effective and positive coordination.

b. Interservice Coordination. Duplication of work among the Services and NASA is a particularly serious concern at a time when lack of funds has caused reduced levels of effort. There is a danger, however, that in seeking to eliminate duplication, management can cut short programs that are usefully competitive. Few would suggest that a single approach should be followed to the exclusion of all others in attacking an important unsolved problem of propulsion technology; on the other hand, with the present dollar limitations, we cannot afford the luxury of multiple groups working independently in all areas. Striking the correct balance that allows for useful competition and eliminates needless duplication requires judgment that can be exercised only by managers thoroughly familiar with the exploratory development programs of all Services.

There are many methods of keeping program managers informed of the work of other Services. A new approach that appears promising is the Development Concept Paper on Rocket and Ramjet Technology currently

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being prepared by the Office of the Director of Defense Research and Engineering. Bringing together in a single paper the exploratory development programs of all Services will allow top level management review and identification of gaps and duplications. Another useful approach employs the Interagency Chemical Rocket Propulsion Group. The frequent meetings of this group allow many at the working level to meet with their counterparts and discuss programs. Information exchange at such meetings promotes meaningful competition and reduces reinventions of the wheel. Another formalized and useful method of exchanging information that appears to reduce unknowing duplication is the wide dissemination of technology resumes prepared periodically at the work unit level by the Services.

What does appear to be lacking for interservice coordination is a specific meeting of those managers directly charged with the responsibility of developing their services' exploratory development programs. A semi-annual meeting of the Director of the Army Propulsion Laboratory and his counterparts in the Navy, Air Force, and NASA would provide a more effective coordination of the programs of these four groups.

B. Program Categories

A further management area in which the Group felt that increased program effectiveness could result was in increased budgeting for certain program categories. One is the Advanced Development Program (ADP) approach and the second is outside contracting. The other Services fund these two categories to a greater extent than the Army and find that, with appropriate direction, a more cost effective program can result. In brief, the ADP program provides an effective focus of technology to the mission considered and the use of outside contracting increases technical exposure.

1. Advanced Development Programs. The Department of Defense R&D budget is divided into four categories of interest. These are entitled:

6.1 Research

6.2 Exploratory Development

6.3 Advanced Development

6.4 Engineering Development

The first two categories represent research activities in developing concepts and demonstrating them in both the laboratory and test stands. The fourth category relates to the development of the propulsion system for an approved operational vehicle. Advanced development programs, therefore, represent a bridge between the R&D effort on concept development and the final engineering development for an identified operational system. This activity is obviously of considerable importance since it involves testing in prototype hardware and in a realistic environment related to an identified mission but prior to the expensive commitment for system development.

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This phase divulges important and potentially costly technical problems that frequently come to light only when the propulsion components must perform in an environment that closely approximates the typical detailed specifications of a system. Examples include use of flight weight hardware, performance in low and high temperature environments, restricted configurations, start-up and shut-down transients, instability sensitivity, performance of the subsystems as a complete system, etc.

The Navy and Air Force have specifically identified Advanced Development budgets in propulsion technology during the past few years, and NASA has recently done the same. Except for certain isolated cases, as for instance ABMDA's current controllable solid programs, the Army has not specifically identified Advanced Development funds in propulsion technology for systems that are not already project or product managed. We believe, however, that the omission of a formally identified Advanced Development line item in propulsion can incur serious penalties if technical problems are later uncovered in Advanced and Engineering System Development. As an example, the LANCE propulsion system was committed to development on the basis of R&D effort on a gas generator, piston expulsion of propellants, and general experience with IRFNA and UDMH (but not in the required configuration). Problems arose in development of the total coupled system in the areas of positive expulsion when exposed to high temperature storage, and combustion instability in the annular booster motor chamber. The resolution of these problems during Engineering Development, where the program delays affected the schedule of a total system project office and large numbers of dependent personnel, has been very costly. The solution of these problems during an Advanced Propulsion Development Program, on the other hand, could have been accomplished at far smaller cost because the schedule would have been "uncoupled" from the development of the other major systems in the vehicle. More significantly, the ADP can, in general, determine whether the component is ready for development technically in the required time frame and therefore permit the option for selecting an alternate approach if it proves unsatisfactory. It is recognized that the ADP approach will not guarantee a "smooth sailing" development program, but it is believed that its use will appreciably decrease the probability of surprise problem areas.

2. Outside Contracting. The ASAP Ad Hoc Group was impressed with the many derivative benefits already gained from the liquid technology program. Even though ingenuity had been displayed in the "spin off" programs, it is believed that new ideas are required in solving problems in the basic liquid propulsion technology areas. Areas such as expulsion, combustion stability, thrust modulation and, in particular, the integration of these areas with a reliable propulsion control and guidance system should be examined for new solutions. Although substantial progress is being made in the Army laboratories, the Group believes that a much greater breadth of experience will be applied if a portion of the Army's exploratory development program in liquid propulsion is performed by outside contractors. If small contractors were known to be available from the Army in exploratory development, many contractors would become more interested in the Army's

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problems. They would devote a portion of their overhead on proposal funds and IR&D effort in searching for solutions to Army requirements, and many contractors would supplement contracted effort in the exploratory stage in hopes of strengthening their position for later production contracts. The extension of Army exploratory work into the contract field would therefore result in the presentation of new ideas and an increase in the level of effort per dollar, and perhaps most important would serve to make the Army a more sophisticated buyer by establishing closer working relationships with a larger segment of the propulsion industry.

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TAB A

Maurice
Dear Dr. Zucrow:

An immediate significant problem of concern to the Chief of Research and Development and myself is the Army's liquid propulsion program for missiles and rockets. Because of the strong interest in this area, we secured approval of the Executive Committee of the Army Scientific Advisory Panel at our spring meeting, 11-14 May 1969, to form an ad hoc group to study this problem.

The statement of the problem and its considerations, proposed terms of reference, and a list of proposed members for the group are contained in the inclosure.

We would like to see you chair this group. If you can accept, I would appreciate hearing from you at your earliest convenience. Please feel free to comment on the problem in general and the terms of reference specifically. Since this will be your group, let me know your feelings on the proposed membership; making any changes, additions or deletions you feel appropriate. We will then proceed to form the group in line with your wishes.

I would be delighted if you would find time to assist us in the study of this problem. I look forward to your favorable reply.

Sincerely,

(Signed) Charles L. Poor

1 Incl
as stated

Charles L. Poor
Acting Assistant Secretary of the Army
(Research and Development)

Dr. Maurice J. Zucrow
Consultant
801 Arguello Street
Santa Barbara, California 93103

TAB B

STUDY PROPOSAL SUBMITTED BY
LTC Lunn, Chief, Air Defense and Missiles Division

Proposed Name - ASAP AD HOC Group on Army's Propulsion Program

Problem - To determine to what extent the Army should continue exploratory development of liquid propulsion systems for missiles and rockets and to what extent it should concentrate on solid propulsion and depend on the Navy for support in liquid propulsion technology.

Considerations -

1. The Director of Defense Research and Engineering, after considering the limited funds available to support exploratory development of missile and rocket propulsion systems, has suggested that the Army consider continuing development of only solid propulsion systems and depend on Navy support in furthering liquid propulsion technology. Under such an arrangement most of the funds now supporting liquid propulsion development would be available for solids.
2. The Army presently has only one missile system under development, the LANCE, that uses liquid propulsion; however, there are several candidate systems and sub-systems for which liquids appear competitive or superior. A careful assessment must be made of the Army's future requirements, to include surface-to-surface, anti-tank, surface-to-air, and ballistic missile defense missiles. In most cases, the primary advantage of liquid propulsion is its versatile controllability; therefore a necessary corollary of this assessment must be a consideration of the projected state of the art of controllable solid propulsion.
3. After consideration of mission requirements and technology status, an analysis is required to determine whether the potential losses of capability incurred in the Army's eliminating its effort in liquid propulsion technology are more than offset by the potential gains in solid propulsion made possible by augmented funding.
4. If the Army is to retain its liquid propulsion exploratory development program, a re-examination is required of the management structure to insure that there exists an optimum system for achieving maximum unity of effort between the liquid propulsion groups currently working at the Liquid Rocket Propulsion Laboratories under the Munitions Command at Picatinny Arsenal and the Army Propulsion Laboratories under the Missile Command at Redstone Arsenal.
5. If the Army is to depend on the Navy for support, consideration must be given to the channel required to insure that Combat Developments Command,

representing the user, is kept fully informed of liquid propulsion options and advantages as it prepares requirement documents for future missile systems.

Proposed Terms of Reference - In its study of the problem, the group should:

a. Examine future Army missile and rocket propulsion requirements and the potential state of the art of propulsion technology during the time frame of 1970-1980.

b. Assess whether the Army can optimize its exploratory development program in propulsion by retaining its liquid capability or by concentrating entirely on solids while depending on the Navy for support in liquids.

c. Explore methods of insuring maximum integration of effort within the Army if liquid propulsion exploratory development is retained, and channels that will be required to keep liquid propulsion options fully open if it is not.

Candidate Membership

Chairman - Dr. Maurice J. Zucrow
Consultant
Santa Barbara, California

Dr. Bruce A. Reese
Director, Jet Propulsion Center
Purdue University

Dr. David Altman
United Technology Center
Sunnyvale, California

Mr. Jack I. Hope
Consultant
Hillsboro, Ohio

Dr. Paul M. Gross
Professor Emeritus
Department of Chemistry
Duke University

Military Staff Assistant - MAJ Donald P. Whalen, CRDADM

Period of Study - Two weeks of intensive review in August and September 1969 with written report 45 days later.

TAB C

AGENDA OF GROUP MEETINGS

1. 26 August - Department of the Army, Washington, D.C.
Briefings by Headquarters, Army Materiel Command, Headquarters, Combat Developments Command, and Mr. C. Branson Smith, former Special Assistant for Propulsion Technology, Office of the Director of Defense Research and Engineering.
2. 27-29 August - Redstone Arsenal, Huntsville, Alabama
Briefings by Missile Command, Munitions Command and the Advanced Ballistic Missile Development Agency on Army missile propulsion requirements and programs.
3. 2-3 September - Picatinny Arsenal, Dover, New Jersey
Briefings by Munitions Command on liquid propulsion work being conducted by the Liquid Rocket Propulsion Laboratory.
4. 9-10 September - Naval Weapons Center, China Lake, California
Briefing by Naval Weapons Center on Navy liquid propulsion programs.
5. 24-26 September - Redstone Arsenal, Huntsville, Alabama
Briefing by Missile Intelligence Division of Missile Command. Executive Session to write draft report.
6. 12-13 November - Department of the Army, Washington, D. C.
Write group report and present conclusions and recommendations to Assistant Secretary of the Army (R&D) and Chief of Research and Development.

TAB D



DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

11 March 1969

MEMORANDUM FOR The Assistant Secretary of the Army (R&D)
The Assistant Secretary of the Navy (R&D)
The Assistant Secretary of the Air Force (R&D)

SUBJECT: Exploratory Development Programs in Liquid Rocket
Propulsion

At the last R&E Policy Council Meeting, we agreed to consider the possibility of eliminating cases of overlap of objectives and programs among the Services in Exploratory Development.

Attached is a staff paper discussing possible overlap in liquid rocket propulsion and recommending that the Army consider dropping their program (and depend upon the other Services). The funds thereby made available, would be used to strengthen their program in solid ordnance.

While we do not contemplate any direction to the Services in this area, we anticipate that increasing selectivity will be necessary in our Exploratory program and feel that this should be a consciously planned rather than chance development.

I propose that we discuss this "test case" at the next Council Meeting.

Attachment
a/s

E. L. Tucker
John S. Foster, Jr.

TAB E



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OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

March 5, 1969

MEMORANDUM FOR THE RECORD

SUBJECT: Exploratory Development Programs in Liquid Rocket Propulsion

The 6.2 funding trend in rocket propulsion is as follows:

	<u>FY 66</u>	<u>FY 67</u>	<u>FY 68</u>	<u>FY 69</u>	<u>Pres Budget FY 69</u>	<u>Pres Budget FY 70</u>
Army	14.4	13.6	9.6	12.5 ⁽¹⁾	12.6	12.7
Navy	12.4	12.1	10.6	10.6	11.3	11.7
Air Force	<u>36.8</u>	<u>34.3</u>	<u>24.9</u>	<u>27.2</u>	<u>32.1</u>	<u>28.6</u>
Total	63.6	60.0	45.1	50.3	56.0	53.0
				----- down 21% in dollars		
				----- down 38% in effort		

The content of these programs is summarized in Table I attached.

The effect of the 6.2 funding reductions is analysed in Table II.

A correlation of the liquid propulsion portions of these programs on a dollar and mission applicability basis is shown in Table III.

Similar correlations in other areas of rocket propulsion support the selectivity distribution proposed in Table IV.

Recommendation: As a first step toward greater selectivity, it is recommended that Army withdraw from 6.2 activity in the Liquid Rocket Missile Propulsion field. Continued Army competence in this field would be assured by assignment of Army personnel to Naval Weapons Center.

(1) ABM Exploratory effort initiated.

DOWNGRADED AT 5 YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS.
DOD DIR 5200.10

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Elaboration: Table III indicates that Army has only secondary requirements for Liquid Missile Propulsion systems.

The inherent nature of Army's operations has consistently led the Service towards the ruggedness and comparative simplicity of solid propellant systems. The performance penalty for the Army in using solids is small since the short range of Army missiles (and their resulting low propellant mass fraction) makes their performance relatively insensitive to the lower specific impulse of solids. In contrast, their normal employment--the delivery of HE in barrage type fire, makes cost an all important criteria. Serviceability and cost are therefore normally the deciding factors in the Army's applications. On this basis, solid propellants will normally be selected.

At the present time, the Army's only major developmental liquid rocket system is LANCE. Liquid propulsion was selected for this system for one special reason--the guidance system which they wished to use required variable thrust, and at the time, only a liquid rocket system, could satisfy their requirement.

The Army's present 6.2 Liquid Rocket Program is, in large part, a reaction to LANCE problems. The only new application anticipated is barrage rockets. The potential application here is based on the convenience and accuracy advantages of having velocity ranging, and the clear desirability of smokelessness. But, as of this date, the feasibility of smokeless solids is proven, and controllable solids are now available if, in fact, velocity ranging is worth the additional system cost. Thus far the Combat Development Command has shown no particular interest.

With respect to future requirements, it seems probable that the Army's basic serviceability and cost requirements will lead their long range field missiles back to solids. The use of liquid propulsion systems in barrage rockets seems very unlikely. The Army thus has no apparent primary requirement for liquid propulsion systems. (Future requirements for ABM are not yet clear--and are not intended to be covered by these comments.)

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The Navy, on the other hand, has an increasing requirement for liquid propulsion systems. In contrast to the Army, the Navy's operating environment permits them to use the more sophisticated, fully controllable, higher performance liquid propulsion systems. Basic applications are air-to-air and air-to-surface involving weight and volume sensitive launch platforms, and premium targets, all of which support high-cost/maximum-performance systems. Hence liquids. Their advanced air launched systems are clearly moving in this direction.

Air Force requirements are similar to Navy requirements, plus requirements for post boost propulsion and attitude control rocketry which involve similar technology.

Conclusions:

1. Army has only secondary requirements for liquid rocket propulsion.
2. Navy and Air Force have primary requirement for liquid propulsion, and together their programs adequately cover technology base in this area.
3. Army should withdraw from 6.1 and 6.2 activity in Liquid Rocket, Missile Propulsion, and concentrate on Tactical, Solid Rocket Motor development.
4. This redistribution of effort would increase the Army's capability to perform its primary missions.

Possible Implementation: As far as the overall Rocket Propulsion Program, and, in particular, the Army's Liquid Rocket Propulsion, are concerned, the implementing action would be the closure of the Liquid Rocket Propulsion Laboratory at the Picatinny Arsenal. This laboratory employs 37 professionals (71 total) and operates on a budget of less than \$3.0M almost all of which is in-house.

BRANSON SMITH
Special Assistant for Propulsion
Technology
Office of the Deputy Director
(Research and Technology)

Attachments
a/s

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Table I
Program Content and Objectives

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	Army (1)			Navy (2)			Air Force		
	68 FY69	Content	Primary Objective	68 FY69	Content	Primary Objective	68 FY69	Content	Primary Objective
Propellants	3.9 4.5	1/4 each - Smokeless, burning- rate, mech- anicals, process	Smokeless and con- trolable for field applica- tion.	3.0 3.1	1/4 Liquid 3/4 solid	Support below	3,740 4.1	1/3 Liquid 2/3 solid	Higher per- formance ICBM, PBP and space launch.
Solid Tech- nology	2.8 2.8	Control- able solid compon- ents	Improved tube launched missiles featuring (above char- acteristics.	2.2 2.5	Com- ponents for con- trolable solid.	Longer range, greater maneuv- erability tactical ordnance.	5.0 5.5	Nozzles, cases and control- able features	Higher mass fraction ICBM stages Efficient solid PBP.
Liquid Technology	2.6 2.8	Control- able pack- aged gel compo- nents	Improved barrage rockets.	1.5 1.6	Com- ponents for pre- packaged metal slurry	High impulse density for tactical air- craft ordnance.	5,540 6.0	Com- ponents improve- ment,	Higher per- formance maneuver- ing, attitude control and PBP
Advanced Technology	0.4 0.4	Air aug- mented and hybrid motors	New pro- pulsion concept applic- able to Army.	8.8 3.7 ?	Design studies and Systems evaluation.	Program direction.	2.0 3.1	Air aug- mentation and hybrid	Longer range or higher acceleration of air launch- ed tactical ordnance

) FY69 includes additional 1.7 for ABM propulsion
) Navy element includes additional funds for ramjet

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The manner in which the Services have absorbed the above noted reductions are indicated in Table II below.

Table II
6.2 Rocket Propulsion Funding Trend by Performer
(in millions)

Army:

	<u>Performer</u>	<u>FY 66</u>	<u>FY 68</u>
I.	<u>Contract</u>		
	A. Redstone Arsenal-GOCO	5.0	3.4
	B. All Other	2.1	0.6
II.	<u>In-House</u>	6.6 (48%) ⁽¹⁾ (85%) ⁽²⁾	5.4 (57%) ⁽¹⁾ (93%) ⁽²⁾
	Total	13.7	9.3 ↓ 32%
	<u>New Contract Starts</u>	3.0	0.4 ↓ 87%

Navy:

	<u>Performer</u>	<u>FY 66</u>	<u>FY 68</u>
I.	<u>Contract</u>	8.4	6.5
II.	<u>In-House</u>	4.2 (33%) ⁽¹⁾	4.0 (38%) ⁽¹⁾
	Total	12.6	10.5 ↓ 17%
	<u>New Contract Starts</u>	1.2	1.0 ↓ 17%

Air Force:

	<u>Performer</u>	<u>FY 66</u>	<u>FY 68</u>
I.	<u>Contract</u>	29.2	16.2
II.	<u>In-House</u>	7.6 (21%) ⁽¹⁾	8.7 (35%) ⁽¹⁾
	Total	36.8	24.9 ↓ 32%
	<u>New Contract Starts</u>	12.0	4.2 ↓ 65%

(1) In-House as percent of Service total.

(2) In-House plus Redstone GOCO as percent of total Army

Table III

Liquid Rocket Missile Propulsion Program - All Services

FY 69				Mission Applicability									
	Army	Navy	Air Force	SAM			SSM		AAM		ASM		Space
		(thousands)		ABM	SR	MR	MR	LR	MR	M=3	MR	M=3	
<u>Basic Technology:</u>													
Fuels	0	50	125	-	-	-	-	○	-	-	-	-	○
Gels and Slurries	0	200	0	○	-	-	-	-	○	○	○	○	-
Oxidizers	0	125	100	-	-	-	-	○	○	○	○	○	○
Combustors	0	0	350	○	-	-	-	○	○	○	○	○	○
Gas Generators	350	50	450	○	-	-	-	○	○	○	○	○	○
Related Technology	250	650	490	○	-	-	-	○	○	○	○	○	○
← A → ← N → ← AF →													
<u>Systems Design and Test:</u>													
Engine Analysis	673	75	0										
Gas Generators	400	50	0						- AS ABOVE				
Tankage Expulsion	485	650	80										
Thrust Chambers	215	0	550										
Slurry Motors	0	250	0										
Other	350	0	0										
	2.7	2.1	2.1	(millions)									

Need: - possible application
 ○ probable application
 ⊙ urgent application

Service:

Army ○
 Navy ○
 Air Force ⊙

- AS ABOVE -

Table IV
Areas of Specialization

<u>Mission:</u>	<u>TACTICAL</u>		<u>STRATEGIC</u>		<u>SPACE</u>	
<u>Basic Types:</u>	Solid Ordnance	Packaged Liquid	Solid Booster	Cryogenic Liquid		
<u>Critical Technologies:</u>	1. High density impulse 2. Controlability 3. Extreme burning rate 4. Smokelessness 5. Low EM attenuation 6. Wide temperature tolerance 7. Low cost	1. High density impulse 2. Simple feed system 3. Long storage life	1. High specific impulse 2. Minimum inert weight 3. Efficient thrust vectoring 4. Long storage life	1. Maximum specific impulse 2. Minimum inert weight 3. Wide operating range 4. Man rated reliability		

Service Emphasis:

Army

Navy

Air Force

X
↓
0
↓
0

↓
X
↓
0

↓
0
↓
X

X

- X Primary effort
 0 Secondary independent effort
 . Areas of interService dependency
 → Cross Service personnel assignment

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13 MAR 1969

CRDADM-3

MEMORANDUM THRU: ~~CHIEF OF STAFF~~ Lt General A. W. Botts

FOR: ASSISTANT SECRETARY OF THE ARMY (R&D)

SUBJECT: Exploratory Development Programs in Liquid Rocket Propulsion

1. Reference: Memorandum, DDR&E, 11 March 1969, subject as above.

2. In the above reference, Dr. Foster proposes discussion at the next meeting of the R&E Council of the Army's dropping its exploratory development program in liquid propulsion. Such a termination of the Army's efforts in liquid propulsion at the present time would be unwise for the following reasons:

a. One of the most successful outputs of the LANCE program has been DC-Automat guidance. This provides accuracy matching that of many inertial systems at a small fraction of the cost. However, it requires a propulsion system with a response time and flexibility that can be provided in the foreseeable future only by a liquid engine.

b. Terminal guidance is another aspect of missile technology that holds great promise. Recognizing this, the Army recently established an exploratory development program in this area. The most logical propulsion system for any future missile equipped with this terminal homing is a liquid engine capable of providing variable thrust levels during flight. While work is continuing to develop solid propulsion systems with this selectable impulse capability, there is no immediate prospect of a candidate with the flexibility of the liquid system.

c. In addition to its use in the present LANCE, liquid propulsion is being strongly considered for five future missile systems. These are the SHADOC, a possible follow-on to CHAPARRAL, the follow-on to PERSHING, the follow-on to LANCE, the short range, point-target, terminal homing missile currently called MISTIC, and the Unified System for Attacking Surface and Airborne Targets. Without an Army exploratory development program, further serious consideration of liquid possibilities is unlikely.

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SUBJECT: Exploratory Development Programs in Liquid Rocket Propulsion

d. The memorandum prepared by Mr. C. Branson Smith, Special Assistant for Propulsion Technology, DDR&E, specifically excludes anti-ballistic missile (ABM) requirements in liquid technology. This is not a reasonable exclusion, as liquid systems are uniquely suited in providing the start-stop-coast-restart cycles and variable thrust levels likely to be required in engaging maneuvering re-entry vehicles. In FY 69, the first year of the exploratory development project in support of ballistic missile defense propulsion, from \$300,000 to \$650,000 will be devoted to liquid propulsion out of a project total of \$1,700,000.

e. Mr. Smith's premise that the Army would be able to maintain its liquid capability by stationing personnel at the Naval Weapons Center at China Lake is also somewhat suspect. Three quarters of the Army's liquid program is conducted at the Liquid Rocket Propulsion Laboratory at Picatinny Arsenal, New Jersey. All members of the laboratory are civilian. Virtually all demonstrated a great reluctance to leave the area in 1960 when the Navy turned the area over to the Army, and again when a study was conducted to determine the feasibility of a move to Redstone Arsenal. A decision to stop the Army's liquid program would mean the loss of practically all of this talent as well as some 10 million dollars worth of facilities used in the program at Picatinny. Liquid facilities at Redstone Arsenal are worth an additional 5 million dollars.

f. Suspending the Army program would also reduce significantly the diversity of approaches and viewpoints in liquid propulsion technology. The Army has contributed significantly in the past to advances in this technology. Despite problems in the LANCE program, the propulsion system as presently configured represents a real step forward in engine design. A large portion of the supporting research that made the system possible, and the additional work that provided the cures for technical difficulties during the program was done at the Liquid Rocket Propulsion Lab.

3. It should also be noted that the Army has already narrowed the scope of its exploratory development in an effort to make maximum use of limited funds. Although recognizing the great potential of air breathing engines, the Army has deliberately reduced its efforts in this area to a level that barely maintains in-house competence and studies future applications. It appears unreasonable to further restrict the program to the point where only solid propulsion systems are considered.

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SUBJECT: Exploratory Development Programs in Liquid Rocket Propulsion

4. There is no question that reduced resources make it mandatory that every step possible be taken to eliminate duplication of service propulsion programs. The Interagency Chemical Rocket Propulsion Group (ICRPG), of which Mr. Branson Smith is a steering committee member, will again meet on 18-20 March. A specific goal of this group is to preclude inter-service duplication of effort. It would appear appropriate to postpone any further discussion of the Army's liquid propulsion program until after the meeting. Perhaps a sounder approach to prevent program overlaps is through careful coordination in the ICRPG and not by total elimination of an important Army program.

Signed

A. W. BETTS
Lieutenant General, GS
Chief of Research and Development

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SUBJECT: The Army's Liquid Propulsion Program

1. In amplifying the previous memorandum justifying retention of the Army's Liquid Propulsion program, it is perhaps appropriate to address first Mr. Branson Smith's Memo for Record that suggested its elimination. There are several instances where his logic or his facts are subject to question.

a. The statement that the Army's primary interest in liquids is for barrage rockets is totally incorrect. As discussed below our interest is in more sophisticated missile systems that require the flexibility that only liquids can provide. While it is still possible that our barrage rocket, MARS, may have a liquid system, it is more likely that we will decide to go with solids.

b. It is true as Mr. Smith states that our primary requirement for the near-term future will be solid propulsion, but his argument, on page 3 of his memo, that the Navy has an increasing requirement for liquid is specious. The introduction of POSEIDON and STANDARD systems and the existence of the three T systems and follow-ons indicate a continuing Navy concern with solids. Obviously the Navy also has an increasing requirement for liquids, but so does the Army. His paragraph as written, actually justifies retention of the Army program fully as well as it does the Navy's. His statement that higher performance liquid systems are particularly suitable for air-to-air missiles is particularly misleading, because it is quite likely that the impulse to weight ratio for missiles with the short range of air-air systems will continue to be higher for solid systems than for liquid ones in the foreseeable future.

c. Mr. Smith's casual dismissal of the ABM propulsion problem is not valid. It is true that our program is new and is not yet well defined, but we have the same requirement for post boost maneuvering that he assigns to the Air Force on page 3 of his memo. If anything our requirements are more stringent than those of the Air Force, and we are now beginning to address them. This is also discussed in more detail below. It should also be noted that the Navy does not have this requirement to any significant degree.

d. As discussed in paragraph 1b, the conclusion on page 3 that the Navy has a primary requirement for liquid propulsion is doubtful at best.

e. The conclusion that the Army would increase its capability to perform its primary missions by concentrating solely on liquid propulsion is not demonstrably true. Solid

f. The implementation suggested is not complete. Discontinuation of liquid programs would mean not only closing LRPL as stated, but also eliminating a talented group at MICOM working in the liquid area.

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g. In Table I no mention is made of the fact that our A211 Propellant program also includes work in liquid gas generators and slurry fuels - an effort funded at approximately \$250K this FY.

h. As noted in Table I, the Navy's liquid program is significantly smaller than ours (\$1.6M in FY 69 vs \$2.8M). The Army work force at MICOM and MUCOM in the liquid area is approximately 100 while the Navy has only about 35 at China Lake.

i. The figures given in Table II tend to place the Army in the worst possible light, as FY 68 was the nadir of Army exploratory development in propulsion. Had FY 69 figures been used, as seems more reasonable, they would have indicated that the entire new program for Ballistic Missile Defense was being contracted out, and our in to out of house ratio is not nearly as high as the table leads one to believe. The figures used for FY 66 do not jibe with those used on page 1 of the MFR.

j. Table III is incorrect in indicating no Army program in gels and slurries. In FY 1969, \$160K went to this effort. It also errs in indicating no Army interest in liquid Surface-to-Surface Missile systems. This is patently false with LANCE's continuing development. It is equally incorrect in indicating no Army interest in short range Surface-to-Air Missiles. The possibility of using liquids in both the follow-on to CHAPARRAL and in USASAT is being actively considered. It is also perhaps worth noting that the Army liquid program in FY 69 is larger than either the Navy or AF programs.

k. In table IV it should be mentioned that the Air Force is credited with two major areas of interest and two secondary, the Navy with one primary and two secondary, and the Army with one primary and no secondary. This does not appear reasonable by any standards.

1. Finally, the statement on page 1 of the MFR that continued Army competence in liquids could be insured by assigning Army personnel to China Lake is doubtful. To pursue a program of the present scope would require approximately the same number of people at China Lake as are presently at MICOM and MUCOM, and to reduce the scope and personnel would obviously lower the competence. In very real terms, such a step would almost certainly insure that the Army never again developed a missile using liquid propulsion.

2. The question has been raised of the competence of those working in liquid propulsion at LRPL at Picatinny. Certainly the best demonstration of competence is work performed, but the following factors also bear consideration.

a. Of the professional staff of about thirty-five, seven have advanced degrees, and virtually all are continuing their education during off-duty hours. Several are instructing or lecturing at the graduate and undergraduate level.

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b. The group is primarily an engineering one. Their admitted area of interest and competence is plumbing - design and demonstrating the feasibility of hardware to produce liquid engines. They make no pretense of being physical scientists or research chemists, and this aspect of liquid propulsion is handled by Dr. Wharton's group at MICOM. Mr. Frank James, director of MICOM's Propulsion Lab and direct supervisor of the Army's entire program, this week expressed his complete satisfaction with LRPL and stated that he personally is aware of the outstanding talent of Mr. Forsten and his group leaders with whom he deals personally.

c. The LRPL staff is largely composed of people who were with Naval Air Rocket Test Station (NARTS) at Picatinny when it was transferred to the Army in 1960. As such they have an average experience of 12-15 years in propulsion. Mr. Forsten was technical director of NARTS. He and his staff also have significant knowledge in the area of air breathers.

d. Members of the staff have acted as consultants to the Navy, Air Force, NASA, DASA, the FAA and to several propulsion contractors. Technical papers have been accepted and presented at virtually every symposium of the ICRPG and other groups. Mr. Forsten is a respected member of the ICRPG's Liquid Propulsion Committee.

e. LRPL's staff does not exist in splendid isolation in the Picatinny area. They are able to draw on other talent at MUCOM, including the Feldman Research Labs (and it should be realized that some 20% of the group's work is done for MUCOM and not MICOM - this will also be discussed later). The Reaction Motors Division of Thiokol is also located in the area and an interchange that has been of significant value to the service has been established.

f. The staff are recipients of numerous Army R&D Achievement Awards.

g. Criticisms of the LRPL capability must also be considered in the context of past internal Army squabbling over the liquids program. There have been and continue to be those who would prefer to see the entire program consolidated at Redstone Arsenal under MICOM. Several adverse comments have been made about LRPL in and out of the Army as part of this internecine warfare. The process of fully unifying the efforts of LRPL and the Army Propulsion Labs was not done over night, and it was not until 1966 that a fully satisfactory relationship was achieved. Today, there is the closest possible coordination between the two, Mr. Frank James is unquestionably in charge of the entire program and is fully satisfied with LRPL.

3. It is the present belief of MICOM that liquid systems will be required for two future Army missile applications, and are fully competitive in five others. The two for which liquid is virtually mandatory are the MIRV, multiple independent re-entry vehicle, and the final-stage anti-ballistic missile. In both, liquid gas generators are essential for providing attitude control. Liquids are competitive with solids in providing the main propulsion for MIRV and are definitely preferred in the ABM

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program for such vehicles as the third stage SPARTAN. Here it should be noted that LRPL did a large portion of the work this year in preparing liquid technical requirement papers to initiate contract work for ABMDA's exploratory development program. (See Incl 1)

The five systems for which liquid propulsion is considered competitive, SHADOC, MISTIC, LANCE and PERSHING follow-ons, and USASAT, were mentioned in the previous memorandum. All work done by LRPL for the A203 Liquid Propulsion program is directly related to these five and the two discussed in the previous paragraph. Recent accomplishments include:

a. Demonstrated statically and in flight test, a 6" dia. propulsion unit having 25.1 stepped thrust characteristic and smokeless exhaust to serve a MISTIC, SHADOC, or USASAT requirement.

b. Demonstrated statically a high performance, low cost precision thrust termination, propulsion unit.

c. Demonstrated a high performance, high chamber pressure (1800 psi min), potentially low cost thrust chamber for adaptation with low cost turbopump concept.

d. Completed preliminary design analysis, showing potential of low cost and high performance for a stage combustion cycle adapted to tactical missiles such as FAMS (a potential follow-on to LANCE) and follow-on PERSHING.

e. Developed long term storage compatibility of lightweight maraging steel tankage for use with hydrazine type fuels.

f. Demonstrated a self sustaining, integrated system concept of Liquid Propellant Gas Generator capable of being applied to an entire range of future systems.

g. In support of LANCE Project Office, demonstrated the flight failure mode statically, thereby defining the expulsion system deficiency. Was major factor in development of improved piston seal concept, correcting the defect. There is no doubt that LRPL's knowledge of the problems and techniques of positive expulsion is preeminent as a result of continued support of the LANCE program. They have a thorough grounding in tankage materials, bonded and sleeved bladders, optimally designed pistons, and direct pressurization. This positive expulsion is essential in future application of improved automet systems (AVC - acceleration vector control) which hold great promise for FAMS and PERSHING follow-on.

4. As mentioned earlier, it would be a mistake to think that all of LRPL's work is done in support of MCOM and missile liquid propulsion. Approximately 20% of their effort is for MUCOM. The emphasis here has been on

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rocket assisted mortar and artillery projectiles. The staff received for the Army the basic patent for the concept of a gun boosted, prepackageable liquid rocket, projectile that was previously demonstrated by LRPL through flight feasibility as an outgrowth of the in-house Exploratory Development efforts. As a follow-on, they assisted the Project Office conducting the Advanced Development program in providing a solution to critical ignition spike problems.

Additional work has been done on liquid mines that are self-sterilizing on the ADAM program where liquid propellants are the only feasible way provide the pop-up capability for randomly oriented mines, and on the Vietnamese tunnel destruction program where the staff quickly solved a detonation trap for the pipe containing nitro-methane. Prior to this solution there had been several back-blasts injuring soldiers employing the system. This valuable support to non-missile systems would be lost if the liquid propulsion program is cancelled.

5. As Mr. Smith has suggested our receiving future support from the Navy it is also appropriate to address the relative competence of the Army and Navy liquid effort. The Army with its LANCE history is in no position to cast stones, but it appears that the Navy has fared even more poorly with the CONDOR.

6. The question of what is our fallback position on minimum funding level for the liquid program must be answered in two parts. The present level of \$2.7-2.8M is already down to bedrock and cannot be further cut without significant impact. With this level, \$0.6M goes to MICOM and \$2.1M goes to LRPL. The program could survive with a meaningful program at a level of \$1.8M. \$0.4M of this would go to MICOM and \$1.4M to LRPL. This would mean releasing approximately one-third of the present staff. As a matter of interest the funding level of the liquid program is shown below.

<u>FY</u>	<u>\$ in thousands</u>
61	975
62	2,709
63	2,653
64	2,045
65	1,950
66	3,280
67	3,200
68	3,400
69	2,723
70	2,800

7. In conclusion the Army does have future requirements for liquid propulsion systems; this requirement cannot be met by assigning Army personnel to the Navy; LRPL has demonstrated technical competence and performs a valuable function, and shutting the Army out of every area of propulsion technology but solids would be a grave mistake.

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SUBJECT: Liquid Propulsion Support for Field of Ballistic Missile Defense (U)

A sound propulsion program to support advanced development of BMD interceptors must be continued if current and future programs are to achieve success through consideration of all feasible choices of types of propulsion. Specifically, exploratory development technology programs must continue with efforts to explore solid, liquid, and hybrid propulsion schemes which are responsive to characteristics peculiar to BMD interceptors. Advanced development can then expect to exploit the most promising of such efforts for incorporation into either ongoing technology work or flight test programs. The particular BMD regimes wherein liquid systems will play a role are the endo-atmosphere where highly flexible controls are a necessity because of extremely short response times and the exo-atmosphere where high throttling ratios must be utilized to permit successful sensor search and homing.

Liquid propulsion systems are particularly well suited for the former application above as control systems, especially where very fast reaction times are called for and where very high-g loadings (up to several hundred g) must be sustained. The phenomena of external burning and jet interaction which are under study for use as interceptor control modes likewise draw on the characteristic of liquid systems to provide the high Isp of which liquids are capable. The issue of base burning to overcome drag is another area wherein the capabilities of liquid propulsion systems are being investigated and assessed.

First indications in proposals for a new BMD interceptor (LoRAH) indicate very strongly that tradeoff studies will involve liquid as well as solid propulsion systems for certain critical elements. One essential requirement for these elements is a high throttling ratio (in excess of 20:1) which is more easily attained by liquid propellant engines.

Thus, although the BMD interceptor will undoubtedly use solid propellant boosters, there are also places for liquid propulsion systems in the BMD arena. A continuing Army propulsion program should include liquid systems and their components as an integral part of such a program because of the unusual specifications imposed by BMD requirements.

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OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

April 10, 1969

MEMORANDUM FOR DR. D. M. MacARTHUR

SUBJECT: Army Liquid Propulsion Program

The following comments refer to the Army staff paper on "The Army Liquid Propulsion Program", attached to Dr. Emerson's memo of March 21, to Mr. Poor and General Betts.

The paragraphing code corresponds to that of the referenced memo.

1. a. A review of future Army missile propulsion requirements (with Major Whelan of the Army Hq, Staff and Mr. Harold Jersin of AMC) indicated the following.

1. Army has not selected liquid propulsion for any new missile systems. However,

2. The Army considers it a candidate for a number of proposed weapons.

In all but one⁽¹⁾ of these applications, its candidacy is based on the assumption that controlability can not be obtained in a solid rocket. In all cases, the higher density impulse of solids, and the typically lower propellant fraction of short range Army weapons, leads to a straight performance advantage for solids. Serviceability and cost, of particular importance in Army applications, also strongly favor solids. But, if you assume that you have controlability with liquids, but not with solids, a case can be made for liquids for certain Army applications if you assume that you can make a low cost liquid system. The issue boils down to, what is the status of controllable solids, and low cost liquid systems.

At least four methods of achieving control of solid rockets have been successfully and fully demonstrated in the Exploratory programs. One form is already in Engineering Development (SRAM). The Army has been a leader in this work. In the current issue of its Long Range Technology Forecast (4th Edition, in 31, 1969) the Army says, "Before 1975 it should be

(1) The one exception is a post-boost-propulsion system for a follow on Pershing which may show a performance advantage for liquid, although this is not certain.

possible to vary the thrust, extinguish, and restart solid propellant systems in flight (page II-6-2).

Thus far the cost of liquid systems have run well ahead of solid systems. Although it appears that a low cost liquid system is a possibility, this is at least as far off as a controllable solid.

b. No one has suggested that the Navy does not have a requirement for solids. It does, and the proposed plan of increased specialization assumes that the Navy will continue to work in this area.

Because of the nature of its missions - high altitude longer range; the sensitivity of the launch platform - to missile weight; its operating environment - clean and fixed; and its typical target value - high, the Navy is more likely to end up choosing liquid systems than the Army. In its current SMEADO report (Jan '69) the Navy identifies 10 advanced development missile projects, three of which it specifically identifies as being powered with packaged liquid systems.

There is no certainty that the Navy will use liquid systems. But the probability, in our opinion, is much higher than in the Army's case. Thus, it is necessary for one Service to withdraw from exploratory activity in this area, in order to concentrate on something else, we would, and did select the Army.

c. In the most recent competition for an advanced high performance third stage for SPARTAN (the only component in the ABM system which presently uses liquids) all three contractors came in with solid systems. We do not consider this issue closed. Hence we did not make a recommendation on this point. In any event nothing in the proposed change in the exploratory program in any way restricts the Army's choice in this, or any other weapon system.

d. See b. above.

e. The Army is spending 2.7 million (or about 20%) of its exploratory propulsion money on liquid systems. This money could, and should be used to almost double its efforts in solid technology.

f. I am not aware of any significant effort at MICOM. Details would be helpful.

g. My mistake.

h. The Navy program is adequate in size.

- i. We are delighted with this development.
- j. See l. a. above.
- k. The Army's requirement is more specialized than that of the other two Services; which is their good fortune.

l. The Army is already out of Research activity in this field. The concept of inter-Service dependency is not new. If the Navy can get along with 35 people (see h.) it is hard to see why the Army needs 100. We propose the transfer of at most, two people to China Lake.

2. a. The question of competence is not involved in this issue and has not been raised by us.

b. The countries great talents in the hardware design and development are vested in the contractors, yet 97% of Army program is in-house.

c. The Army vigorously resisted taking over lab in 1960.

d. Fine.

e. -

f. Fine.

g. No one else in the Army has urged us to suggest the closure of LRPL.

3. I am not aware of a MIRV requirement for Army. See report on latest SPARTAN configuration. Controlable solid gas generators are available. Nothing in proposed action would prevent Army from using any type system it chose.

a. Fine.

b. Fine, but in no way unique.

c. Note the word "potentially".

d. See all above.

e. Fine, but in no way unique.

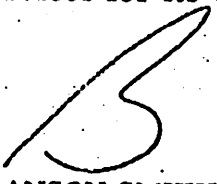
f. Fine, but in no way unique.

g. Many people have worked very hard on the LANCE system. Everybody in the business has a positive expulsion scheme.

4. Is the Army going ahead with a liquid RAP? This proposal does not relate to other MUCOM projects.

5. This proposal is based on requirements.

6. Let me repeat. We did not set out to cut the Army out of liquid propulsion, or anything else. We are trying to strengthen their program in solids. There are many opportunities in solids which the Army needs but can not pursue vigorously because of lack of funds. It should go after these and draw on the other Services for its clearly secondary requirements in liquid propulsion.



BRANSON SMITH
Special Assistant for Propulsion Technology
Office of the Deputy Director
(Research & Technology)