DRAFT MEMORANDUM

(R. E. Gibson to A. Kossiakoff)

This draft of a memorandum to A. Kossiakoff contains a philosophical discussion of APL, its mission, its relationship with the Navy, and its approach to research and problem solving.

DRAFT

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LAUREL, MARYLAND

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Dear Kossy,

I am putting down on paper a few thoughts inspired by our conversation last Friday, attempting to capture the rationale which has underlain the Laboratory's policies since the beginning.

(1) We must start with an axiom - a belief founded on wide experience, a belief which must either be accepted or rejected at the outset. The axiom I chose can best be expressed by the words "When a strong man armed keepeth his palace, his goods are in peace. But when a stronger than he shall come upon him, and overcome him, he taketh from him all his armor wherein he trusted and divideth his spoils." (Luke 11:21)

History is full of examples of the compelling pertinence of this axiom; indeed, recorded history is practically an account of the rise and the fall of civilizations whose military strength decayed and their "palaces" plundered by men of superior strength.

Despite all talk and theory to the contrary, a dispassionate observer of trends in the world today must conclude that the forces that operated to make the above statement a valid expression of past experience are by no means abated, in fact they seem to be increasing in virulence. Many examples will doubtless occur to you.

The "palace" of immediate interest to us is the United States of America - or its extension, the "Free World." It contains many priceless treasures which men and women have worked hard to create, and fought and died to protect, both here and elsewhere. The present generation is the guardian of these treasures, a high national standard of living, the right to "life, liberty and pursuit of happiness," the privilege of free enquiry by intellectuals and freedom of expression of the results of enquiries. I do not intend to make an exhaustive catalog of these treasures, but I would call special attention to one, namely our institutions of learning, especially colleges and universities where scholars of all kinds have access to abundant resources to support the intellectual activities of men and women, gifted to use them, and the freedom of choice that set their objectives and teach their findings. Such institutions can only exist and flourish in palaces kept by a "strong man armed." We only need to remember the plight of the universities in countries whose military power has been insufficient to protect them from invasion and consequent economic disaster.

Although many of us find much to criticize in the treasures of our Country, I think that fundamentally all of us realise that their loss would be irreperable, at least in the next generation or so.

(2) Of the various agencies of the Department of Defense which have the responsibility of keeping the military strength of the United States and its allies strong enough to deter and, if necessary, defeat those who would plunder its treasures, the Navy possesses a flexibility for demonstrating the credibility of the power of the United States in peace and war, a flexibility which surpasses that of the other two operating agencies, the Army and the Air Force. The appearance of a battleship in any port of the world is a symbol of power but not an irreversible commitment to use it, as may be the flight of war planes or the landing of an Army. A Polaris submarine cruises in non-territorial waters, it is a threat deterring irresponsible aggression, but it may be withdrawn without prejudice at any time.

Furthermore, the Navies all over the world have sought the advice and action of natural philosophers and engineers to strengthen their abilities to perform their mission and reciprocally have made great contributions to the progress of our knowledge of Nature. We need only recall Archimedes and the fleet of Syracuse, the role of Navy men in the founding of the Royal Society, Captain Cook in the geographic exploration, Admiral Beaufort in meteorology, and the promotion of the voyage of the Beagle, which gave Charles Darwin a solid foundation for his advances in biology, to realise the kindredness of spirit between adventures on the sea and the adventures of mind in science. For two centuries its sea power has been a symbol of the United States' will to defend its own, and a symbol of its economic growth, labor skill and management ability. Even the rise of air power has not eradicated this worldwide impression.

Invasion is not the only threat a declining Navy may bring. Lack of ability to fight small wars, to defend our commerce, and the right to trade anywhere and a general worldwide impression that the U.S. will not, or cannot, defend itself can lead rapidly to destructive economic and political competition and alliances. The "strong man" must have strength to keep enemies out of his palace, but he must also have the wisdom to recognize the forces and trends which could deprive him of his treasures by attrition.

(3) The initial association of the founders of APL with the Navy may seem accidental to the casual observer, but in reality it is not. In the mid-1930's several officers in the Navy realised the deadly importance of the growing power of airplanes to destroy surface ships and that the problem of setting time fuzes presented an enormous handicap to anti-aircraft gunners. They looked for a fuze which would detonate a shell as it passed in close proximity to an attacking aircraft, but could not find a way, nor any agency which could implement this idea. Tuve, Hafstad and their civilian colleagues thought they saw a way and, backed by the civilian controlled Office of Scientific Research and Development, they not only invented a practical device but also devised an organization (APL) which also controlled its large-scale manufacture; in record time reliably operational fuzes were delivered to

the Navy. This experience started a partnership between the University and the Navy in which the Navy challenged the Laboratory for technological solutions to its operational problems and the Laboratory did its best to meet these challenges using its manpower and material resources to produce solutions that were intellectually satisfying and practically feasible.

Despite many vicissitudes arising from conflicts of personalities, oscillating changes of public opinion and the vagaries of Congress, this partnership has continued for many years and has covered a range of problems hardly dreamed of in the early 1940's. The concept and development of proximity fuzes was followed by the concept and development of far more powerful instruments of fleet antiair defense, namely guided missiles, which took the Laboratory into new fields of science, e.g., supersonic aerodynamics, the design and understanding of violent chemical reactions needed for high-speed propulsion engines, the design of stable control systems with high-speed reaction rates, the reception and interpretation of intelligence needed to guide the missile, and finally the concept and design of automated systems to balance the loads on the manpower and machines needed to provide the crews of ships with information on which to make decisions affecting the course of realistic Naval operations and to evaluate the performance of the machines and the men in realistic environments. Experience gained in these areas gave the Laboratory resources to meet challenges posed by the Navy.

The Polaris system of submarine-based strategic missiles is universally regarded as the most powerful instrument for deterring global warfare in the arsenal of the United States. It can take advantage of the concealment the oceans afford; furthermore, to neutralize it an enemy must attack it in the ocean and not on the populated land areas of the United States. (Incidentally, we should emphasize that the Navy in general has the capability of carrying decisive combat into enemy territory far beyond the border of the country it is defending and thereby minimize the threat of destruction of its population and institutions. The history of the British Isles amply substantiates this detail.)

Association with the Navy in the development and deployment of the Polaris System (and of its successor, the Trident System) involved APL in three very interesting problem areas. The first was directed toward an evaluation of the effectiveness of the complete Polaris System, both in the development and the operational stages. This turned out to be a very interesting study in systems engineering, requiring a detailed knowledge of the mechanism and performance of <u>all</u> the components of the system, including the men, of how the components worked together and the objective of the overall performance of the system. The results were expressed in figures; instruments were designed to record them automatically and in suitable form for computerized interpretation from engineering measurements to information understandable by the Navy operators. Naturally, discrepancies in the developing system were pinpointed in the course of these studies. Remedial action, often involving new principles of subsystem design, were tested out experimentally and were suggested to, and adopted by, the Navy. As a result, the performance of the Polaris System in action was understood and predictable in quantitative terms - a contrast to most other systems in the Department of Defense.

A second problem area arising out of the first is a comprehensive study of the defense of the Polaris or Trident submarine. It goes without saying that most of the work on this program carries a high security classification, but it has led the Laboratory into advanced areas of research on the physics and chemistry of the oceans - research which is being pursued vigorously; at the appropriate time interesting results will appear in scientific journals. It may be argued that such results should be made available immediately to the scientific community, but it can also be pointed out that since no other agency would have funds or interest to support this research, it would simply not be done, and delay in publication is a small price to pay.

The third project that received strong support from the Navy Polaris Program is the development, deployment and improvement of the Transit Navy Navigational Satellite. The system was conceived at the Laboratory as a result of the confluence of a problem and the concept of a solution. The problem came from the knowledge of the operational need of a Polaris submarine to have at all times very precise information about its position on the earth. The solution came from an experimental demonstration that by observing and interpreting mathematically the Doppler shift of a constant frequency radiation emitted by a satellite travelling in a known orbit, the crew of a submarine could determine its position with great precision. Having the resources necessary to carry this development to a satisfactory conclusion, the Laboratory proposed the idea to the Defense Department and received immediate support. This project, still supported by the Navy, took the Laboratory into space and offshoots of Transit led to the support of NASA in interesting areas of both research and development.

Experimental and theoretical research in high-energy particles, the nature of the Earth's magnetosphere, including auroral phenomena, and the nature of the upper atmosphere was carried on by the use of specially designed instruments installed on development Transit satellites with encouragement of the Navy, and on specific purpose satellites designed and flown under the auspices of all the Armed Services and NASA. A year or two ago the Space Department of APL issued a volume summarizing the results of its research program. It is a most impressive record of achievement.

You will recall that the Transit program was APL's <u>second</u> adventure into the upper atmosphere, the first being the program headed by Van Allen in 1947-51, also with strong Navy support. That pioneering work, based on instruments of APL design carried by V-2 rockets, launched from White Sands, and later on the APL-designed AROBEE launched from the <u>Norton Sound</u> at various latitudes investigated high-energy particle distribution, features of the Earth's magnetic field and of sheets of electrical currents in the atmosphere, the distribution of ozone in the upper atmosphere and other phenomena. You will remember that the techniques developed by Hopfield and Clearman and by Van Allen and his associates for the measurement of ozone concentrations are still used today.

To summarize, the relations of APL with the Navy have by and large been satisfactory to both parties on an absolute basis. On a comparative basis they have been more than satisfactory in that the Navy seems to understand that the development of techniques vital to its mission requires more than decisions on plausible ideas generated in an office, or presented by a contractor hungry for business. In the long run Navy officers, assigned to engineering and development duties, know that someday their lives will depend on how well new devices supplement their efforts in combat. I think this inclines them, instinctively perhaps, to trust the advice of those they feel to be interested only in approaching these problems in a really scientific way.

(4) The Carnegie Institution of Washington was founded in 1904 with the following charter:

"To encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

No university has a more liberal charter than this, and the Carnegie Institution has lived up to it. When I joined the Geophysical Laboratory of the Carnegie Institution some fifty years ago, fresh from the university, I soon learned something about the broader aspects of research. I learned about "multidisciplinary research," a term not used in 1925, only becoming popular a quarter of a century later. The broad objective of the Laboratory was to study the physics and chemistry of the Earth. We might call this the "strategic objective." In the words of L. H. Adams, my first boss,

"Studies of the earth have as their objective the determination of the nature of the processes whereby the whole earth and the materials of which it is composed have come into being and have acquired the forms, the disposition, and the mutual relations in which we find them. If we may be permitted to borrow terms from our biological colleagues and to expand their meaning somewhat, it might be said that earth processes are studied *in vivo*, *in vitro* and *post mortem*."

The staff of the Laboratory consisted of men educated in various disciplines, mathematics, physics, chemistry, petrology, geology, etc., who were interested in and, indeed, committed to the above strategic objective. Within this strategic objective the staff, either as individuals or as groups, were supposed to set "tactical" objectives which focussed their thought and action. These tactical objectives might or might not be expressed in words and, although generally discussed with the Director, were not considered as dependent on his approval unless a large expenditure for new equipment was likely to be involved. The train of thought leading to a tactical objective generally started with a *problem* - a discrepancy between current theory and the results of careful experiment or the realization that new areas of potential knowledge concerning the Earth could be exploited if certain experimental techniques could be developed - or the feeling that *in vivo* studies of processes currently going on in the Earth could be elucidated by studies of hot springs, volcanos, and even geodetic observations of the Earth's movements.

Let me give an example of an in vitro problem. In the 1920's seismologists were beginning to make accurate measurements of the times of arrival of earthquake waves from a known epicenter to various observing stations and from these data to compute the velocities of the transverse and longitudinal waves at different depths in the Earth. As the depth increased, so did the velocity of the elastic waves. Adams conceived the idea that laboratory measurements of the isothermal compressibilities and densities of a series of rocks and minerals of different chemical constitution at high pressures could, with a certain plausible assumption, be used to determine the velocities of elastic waves through these substances. By matching the results of laboratory measurements with seismic observations, he thought it would be possible to get some insight into the chemical composition of the Earth at various depths below the surface. Within this tactical objective many questions arose and many experimental problems had to be solved, which I will not discuss in detail here. The results of the investigation showed that only a limited class of basic minerals had elastic properties compatible with those predicted from seismic observations, a conclusion which remains unchanged after the passage of fifty years except for extensions due to new experimental techniques. The investigation extended over a number of years.

Another "tactical" objective formulated by a number of members of the Laboratory, especially N. L. Bowen, was directed to obtaining insight into the process of rock formation. The basic data were provided by geologists and petrologists, who examined and described in detail the association of minerals in different rocks as found in the field. The in vitro experiments led to knowledge of the phases (minerals) formed when equilibrium was established in heterogeneous systems of known chemical composition, for example, a system containing the range of composition possible with mixtures of soda, lime and silica, etc. Very practical offshoots of the Geophysical Laboratory's work on silicate systems have been the rational foundation of the manufacture of Portland cement, optical glass and new glasses such as pyrex.

5. I have treated the work I saw at the Geophysical Laboratory at some length (perhaps too long) to give a background to two principles I have held for a long time. First, within any strategic objective one can find tactical objectives (research problems) that stimulate one's curiosity, imagination, and will to investigate and require cultivation of one's entire resources of mind and hand to think and to do. The integrity, imagination, skill and tenacity which one brings to the attack on a "tactical" objective is as, or probably more important than, the sources from which the problem comes. Second, generally speaking, the acceptance of a strategic objective not only places some limitation on number and variety from which an investigator can choose a tactical objective on which to concentrate his effort, it also imposes a greater discipline, a sharper intellectual challenge and more demands on his persistence than would be the case if he were able to change the stra-

tegic objective at will. In research in universities, especially, the investigator has the "freedom" to set both the strategic and the tactical objective of his research work, or even leave out the strategic objective altogether. Thus, if adherence to the boundary conditions set by a given strategic objective brings up great difficulties in the progress of the research, the investigator can circumvent them by changing at will the strategic objective itself, a course not open to the man committed to a strategic objective set by others.

To illustrate my points, let me discuss a crude example. Suppose a man sets out to understand the interaction in a complex system by making a computer simulation of its operation. (The system may be the flight of a guided missile or the cardiovascular system in a human being.) He makes observations of the behavior or postulated behavior of the system, obtains a bunch of measurements and parameters, and sets up a model for his computer. If he finds the computer simulation he has devised too complicated to operate, he has two choices. Either (a) he can reduce the number of parameters used, i.e., simplify the model until he is able to achieve a solution, or (b) he can stick with the complicated and hopefully realistic model and overcome the enormous difficulties of obtaining a solution. If he is committed to the strategic objective (a military one) of understanding the operation of a missile under realistic conditions or to the clinical objective of understanding the operation of a cardiovascular system in enough realistic detail to be of clinical use, he is constrained to course (b). If, on the other hand, he is not subject to constraint other than perhaps the time allowed for his students' theses, he can properly choose course (a), satisfying the objective, demonstrating that the computer simulation does give an understanding of the operation of a system, but saying little about the operation of the missile system or of the human cardiovascular system, the original strategic objective.

The knowledge gained by research, discovery and development may be applied in two main ways: (a) it may be applied to broaden the intellectual horizons of mankind, to eradicate superstition and fears and reveal a comforting picture of the order and the beauty of Nature; or (b), it may be applied to the expeditious production of material resources, commodities and services which give mankind the power to cope more readily with the essentially hostile environment in which it lives, to minimize human suffering, and to maximize its chances to realise more fully the official objective of life, liberty and the pursuit of happiness.

In passing I should note that my observations, extending over nearly all the years since the Carnegie Institution charter, suggested that application (a) has met with less than the hoped-for success, and that the success of application (b), while superficially astounding, is open to grave misgivings by the thoughtful observer of the present state of the world.

6. In considering the Navy-sponsored research and development at the Laboratory and its influence on the Lab as a whole, I should first emphasize that APL works within two types of compatible "strategic

objectives." The first may be called the "grand strategic" objective, namely, APL is a national resource doing research and development of national applications for departments of the U.S. Government, including the DoD and its departments of Navy, Army and Air Force. Note that APL is primarily a national resource and only secondarily a worldwide resource. There is a difference. Within this grand strategic objective are a number of strategic objectives.

Examples are strategic objectives for the Navy - missiles, Fleet systems, Transit, Polaris, etc.; for NASA - GEOS, space research technology utilization; for NIH - the Biomedical Program. There is also a strategic objective of our own, namely to make and keep the intellectual and physical resource of APL adequate to enable us to accept with confidence any other strategic objective supported by the Navy or other Government agency.

7. In the 20th century, research - to discover new knowledge, systematise and understand it, and development - "the application of knowledge to the improvement of mankind" - are generally carried out by people based in institutions of one sort or another (as opposed to talented individuals rich enough to support themselves or fortunate enough to secure rich patrons on their own in the 17th, 18th and 19th centuries.) It has become customary to associate R&D activities with the type of institution in which these people work. These institutions fall into five categories, generally referred to as (a) universities; (b) research institutions; (c) industrial laboratories, including many independent labs working under contract primarily on business problems; (d) government laboratories; and (e) multidisciplinary national research centers.

The last category is very mixed and I will, therefore, limit myself to a discussion of APL.

We may ask how does the research (and development) sponsored by one type of institution differ from that sponsored by another? The answer is very difficult to find and even more difficult to express, possibly because the people who do the basic work in all of them have essentially the same educational background and spend most of their time in solving one sort of problem or another.

It may be illuminating to consider these types of institutions in terms of their general research policies and objectives. I have attempted to do this in terms of the grand strategic objective of the organization - the ultimate purpose the organization seeks to serve, often called its charter.

In seeking to achieve its grand strategic objective, the organization has one or more strategic objectives which define specific areas of Nature it seeks to explore and exploit. The number of strategic objectives depends on the size of the organization and its ability to support several departments with varying degrees of independence to concentrate on one strategic objective. The actual research and development work is planned and carried out in terms of tactical objectives which define specific problems that must be solved to realise the strategic objectives. We may note that a tactical objective may involve a hierarchy of problems, for example, the development of an engine for the propulsion of a useful missile (the strategic objective) involved many problems in chemistry, physics, mechanical engineering, aerodynamics, etc.

I may say a word about the setting of these various objectives because it is my opinion that the success of an organization depends to a large extent on the knowledge, ability or power of foresight and courage of the people who set its objectives. The grand strategic objective should be set by men of foresight who have knowledge of the needs (not exactly the wants) of mankind, knowledge of the world, the ability to secure and hold financial support, and an appreciation of the intellectual and physical resources needed for success. They must be able to recognize a general strategic objective which will be stable and probably be divergent over time (at least 10 or more years).

The setting of a strategic objective requires the attention of men who have the complete confidence of the guardians of the grand strategic objective, but also with added knowledge and experience in the broad areas of science it is to cover, and a more specific and perhaps deeper knowledge of the intellectual and physical resources needed to achieve it. Indeed, the setters of a grand strategic objective should have definitive knowledge of the potential "application to the improvement of mankind" used in the very broadest sense (education, advancement of knowledge, the value of a commodity or service, contribution to national defense) and also definitive knowledge of how to meet the objective by the possible extension of current knowledge and skill.

Those who set tactical objectives, having the confidence of those responsible for a grand strategic objective, must have the knowledge, experience and imagination to ask questions and suggest probable answers, formulate problems, and propose solutions and have the courage to pursue these solutions through all foreseen and unforeseen difficulties. For these people are those who will be responsible for the success of the answers.

R. E. Gibson