ANNOTATED BUMBLEBEE INITIAL REPORT

In the first half of 1944, when World War II had not yet run its course, the technical focus of APL shifted from proximity fuzes and gun directors to guided missiles. To recall the events of nearly 40 years ago that set the stage for the development of the Talos antiaircraft guided missile (and of Terrier, Tartar, and Aegis, its offshoots), we reproduce the Bumblebee Initial Report that was issued soon after the assignment of a new task to APL in January 1945. The Annotations accompanying the report are intended to assist the reader in reconstructing the origins of a program that had a profound and lasting effect on the technical direction of APL. *Walter G. Berl*

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY

SILVER SPRING, MD.

Operating Under a "Section T" Type of Contract
With the Bureau of Ordnance U. S. Navy

BUMBLEBEE
REPORT
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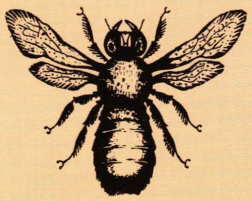
BUMBLEBEE

INITIAL REPORT



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Report No._____
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BUMBLEBEE INITIAL REPORT

As of February 15, 1945

Foreword

This is a statement covering the formulation and general planning of the "Bumblebee" program, as undertaken by the Johns Hopkins University Applied Physics Laboratory under a research contract of the Section T series with the Bureau of Ordnance, Navy Department. It provides an introduction to the activities associated with this problem, indicates the scope and background, and should serve to illuminate the series of progress reports on Bumblebee which will be issued at regular intervals.

The Applied Physics Laboratory, Johns Hopkins University, has acted for the past three years as a consulting technical group for the Research and Development Division of the Bureau of Ordnance, while operating as the Central Laboratory for Section T, Office of Scientific Research and Development. After December 1, 1944, the Laboratory continued its work under a new type of research contract directly with the Bureau of Ordnance, Navy Department. The primary emphasis in its technical program has been directed toward the protection of the Fleet against enemy aircraft. The VT fuze and the Mark 57 fire control system are specific developments to meet this particular military requirement. It has been recognized, however, that the nature of warfare is rapidly changing, and that while refinements can be introduced into fuzes and fire control systems, there is a growing possibility that the effectiveness of our present navy might be very seriously reduced by a large scale introduction of new types of enemy guided missiles during the late phases of this war. The use of the HS 293 and FX 1400 weapons by the enemy foreshadows advanced forms of aircraft attack against naval vessels for which inadequate protection will exist.

In July 1944, the Chief, Bureau of Ordnance requested an initial analysis and evaluation by Section T of the problem of protecting a task force against guided missiles launched from enemy mother-planes beyond the range of present fire control. Accordingly, with Dr. Bush's approval, a small group of Section T technical men explored this problem and submitted a report to Admiral Hussey and Dr. Bush.

It was the opinion of this group that some technical agency should give immediate and concentrated attention to the problem of developing a guided, jet-propelled, antiaircraft missile, preferably with supersonic speed, on a time scale which anticipates at least limited military use in the later stages of the present war.

This conclusion was reached as the result of consideration of a guided missile weighing 2000 pounds and traveling at a rate of 1850 ft. per sec. In this tentative design it was proposed that the missile would be launched to this velocity by means of rockets and driven to its target by a ram-jet motor. A payload of 600 lbs. of explosives was assumed. The auxiliary rocket-launching equipment would weigh an additional 2000 lbs., and would be dropped early in flight. A maximum flight time of 63 seconds would be required at an overtaking range of 38,800 yds. This was computed on the assumption that the misille would be fired at a target flying at an altitude of 10,000 yds. to intercept at a horizontal range of 20,000 yds.

It is of great military importance to the United States to learn whether guided, ram-jet missiles of supersonic speed are feasible as a weapon, since it would indicate what might be expected, for example, from the enemy in the way of surprise attacks on an invasion fleet. If an intensive effort were made by a suitable technical group, even a negative result would be valuable, in that it would provide evidence that no nation could bring such devices into effective use against us in a predictable length of time. 8

In December 1944, the Bureau of Ordnance was directed to proceed with the development of guided, jet-propelled antiaircraft missiles on an urgent basis, and the other Bureaus of the Navy were asked to give all possible support and assistance in carrying forward this program. The Bureau of Ordnance, recognizing the highly technical character of this problem, and cognizant of the fact that various aspects of the guided missile program are matters of prime concern and responsibility to several Government and Service groups, decided to handle this assignment in an unusual manner. The Chief of the Bureau proposed that this program should be made the overall responsibility of a contracting agency outside of the Navy Department, supported by Navy funds and with the responsibility for their activities accepted by the Bureau of Ordnance. This would allow freedom in the technical planning of the work, and would make possible a maximum degree of cooperation and joint participation in the program by other agencies in the general field of guided missiles. The former central laboratory of Section T now operates under a direct Bureau of Ordnance research contract; and the Chief of the Bureau therefore asked the trustees of the Johns Hopkins University to accept an assignment for the Applied Physics Laboratory to undertake a major program on jet-propelled antiaircraft missiles. At the end of December, the Johns Hopkins officials made a tentative decision to accept this assignment (Task F, code word "Bumblebee"), contingent upon being able to obtain additional technical personnel and facilities. 9

The Bureau of Ordnance and the Applied Physics Laboratory technical men recognized that cooperation and, wherever possible, joint acitivity with the agencies already interested in the general problem of guided missiles, is essential if effective results are to be obtained in a minimum time. Although this program was initiated and is supported by the Bureau of Ordnance, the work is of such broad scope and so closely allied to projects already under way in this country and in the United Kingdom that active cooperation with these other agencies is not only desirable, but necessary. This view was presented in letters from the Chief of the Bureau of Ordnance to the Army Air Forces, Army

Ordnance, National Advisory Committee for Aeronautics, the Office of Scientific Research and Development and the Navy Bureau of Aeronautics. All interested groups were asked to participate in the Bureau of Ordnance program with the Applied Physics Laboratory, and each was informed that its participation in the program would be given recognition. 10

The Applied Physics Laboratory will make every effort to work closely with all the technical agencies concerned, and with the various committees investigating the field of guided missiles, such as the Gilliland, Dewey, NACA, and other groups. It is recognized that the Applied Physics Laboratory, being a temporary war agency, is not expected to become a permanent central group 11
for guided missile work as a whole. However, if it can provide an effective technical arm in the immediate future by presenting an opportunity for detailed and continuous technical exchange in an active working laboratory located in close proximity to all of the Washington agencies, it should be of value to each group working in this field.

Representatives of the Laboratory have examined the literature available, and have been in touch with technical men in this country and abroad who are actively engaged in guided missile programs. Through OSRD channels, discussions were held directly with the G.A.P. Committee at two of its sessions in England. Informal liaison with associated technical agencies has been established, and more active collaboration is anticipated as the Applied Physics Laboratory technical program develops.

For several reasons the Applied Physics Laboratory, with the approval of the Bureau, has decided to limit the Bumblebee program to a jet-propelled AA missile of supersonic speed: in the initial phases of the work major emphasis will be given to ram-jets (athodyds), although an alternate based on liquid 12
rocket propulsion will be initiated as soon as personnel needs can be met. 13

During the first year (1945), the technical attack will be on the basic elements necessary to any guided supersonic missile, without major emphasis on a specific missile design. Empirical and laboratory investigations are already in progress, and it has been arranged for the Navy to survey and evaluate the situation at the end of the first year.

The basic problems to be determied are: (a) the thrust of a ram-jet versus the accompanying supersonic drag; (b) supersonice stability and control arrangements versus drag; (c) whether guidance at supersonic speeds presents basic difficulties or practical limitations not yet perceived. It is hoped that at least preliminary answers to these questions may be available by the end of a year of investigation (January 1946).

The Applied Physics Laboratory plans to add roughly three hundred people to the modest group now working on Bumblebee. In addition to maintaining a strong program at the Laboratory, the assistance of university and industrial groups on various technical phases of the problem is being arranged for under associated research contracts of the "Section T series" with the Bureau of Ordnance.

Expansion of the central laboratory space is now in progress; additional building facilities have been obtained at Forest Grove, Maryland, a short distance north of the present location in Silver Spring, which will accommodate the expanding needs of the Bumblebee Project, including a ram-jet laboratory. General administration of the Bumblebee Project will remain at the central laboratory.

The Bumblebee problem has been initially divided into several parts and assigned to groups working under technical supervisors as follows:

1. Burner: Fundamental problems of propulsion, involving stationary ram-jet experiments, thrust measurements, and fuels. Experiments will be performed simulating as nearly as feasible the conditions to be met in flight. This necessitates large blower and compressor facilities and the use of an open-circuit, supersonic wind tunnel, primarily for burner experiments.

2. Aerodynamics: The study of supersonic drag stability and control problems, and designs of wind tunnels and ducts. In the later stages it is expected that this group of necessity will also assume the overall design of the weapon. The facilities of the proposed supersonic wind tunnel will be used in some phases of this work, together with free-flight experiments.

3. Models: Primary emphasis on ram-jet thrust and drag by free-flight experiments at supersonic speeds. Measurements will be made on athodyd models in flight, using radio telemetering methods, together with radar and photographic tracking observations. This group will provide data to supplement the stationary burner experiments. Fuel injection, altitude controls, tracking and telemetering problems are among the secondary concerns of this group.

4. Guiding and Control Systems: Radar guidance, target tracking and gyro-servo systems for control and stabilization.

5. Facilities: Test fields and flight observing facilities, also experimental laboratory and large blower facilities.

6. Launching: This group has been organized to develop and study launching techniques.

In carrying forward a major program of the type indicated, it is planned to allocate specific areas of the problem to industrial and university groups, with several contractors invited to share with the Applied Physics Laboratory a sense of overall responsibility for the success of the program as a whole. The Applied Physics Laboratory expects to invite a major aircraft company to participate in solving the aerodynamic problems and the eventual design of the missile, and to assist with experiments using large blowers and the supersonic wind tunnel. A large industrial concern specializing in prime movers or heavy machinery will be asked to undertake a general program, including the design of a

complete weapon, but with a special emphasis on the ram-jet and propulsion problems. At least one organization specializing in fuels will be asked to accept a contract to develop various types of fuels, and to join in the ram-jet experiments.

A group at Princeton University has begun investigations of telemetering in cooperation with the Models group at the Applied Physics Laboratory.

At the University of Virginia, investigations have been initiated on the burning of fuels in a small-scale burner laboratory. Data from these experiments will be correlated with those obtained by the Burner group at its stationary burner laboratory in Forest Grove, and later with data from the large-scale burner work.

Since no facilities exist for full-scale ram-jet experiments, blower equipment, a power plant, and a facilities building are being provided at Daingerfield, Texas, through the Bureau of Ordnance. These facilities will provide 200,000 cfm at 30 lbs. per sq. in. (gage), and in addition, a high-pressure blower will be fabricated and installed which will convert the 30 psi gage output of one of the 100,000 cfm low-pressure blowers to 120 psi gage. The initial blowers will provide air for low-pressure (high altitude equivalent) ram-jet experiments and for the 24"x36" wind tunnel being designed by the Aerodynamics group. The series combination of the low-pressure and high-pressure blowers will provide air for high-pressure (sea-level equivalent) ram-jet experiments. A test field has been established at Island Beach, New Jersey, and a major test field in the western part of the country is proposed for later experiments.

It is hoped that this report presents a sufficient introductory picture of the interests, aims, and initial progress of the Bumblebee project. A monthly survey of progress will be sent regularly to persons on the present distribution list, and to a limited number of additional persons who may be specifically authorized by the Bureau of Ordnance to receive this information. Requests for Bumblebee reports should be addressed to the Supervisor of Technical Reports, Applied Physics Laboratory, Johns Hopkins University, 8621 Georgia Avenue, Silver Spring, Maryland.

ANNOTATIONS

1. In June 1940, the National Defense Research Council (NDRC) was established by the Council of National Defense, which, in turn, had been created in 1916 "for the coordination of industries and resources for the national security and welfare." In President Roosevelt's letter appointing Vannevar Bush, then the president of the Carnegie Institution of Washington, to be the chairman of this Committee, NDRC was directed to "supplement the activities carried out by the Army and the Navy by extending the research base and enlisting the aid of the scientists who can effectively contribute to the more rapid improvement of important devices, and by study to determine where new efforts on new instrumentalities may be usefully employed." The organization was designed to bring together civilians in universities and research establishments to work on projects that would be of value to the military services.

Its six divisions, subdivided into numerous sections, covered a wide spectrum of science and technology of concern to the Armed Services. In placing contracts, one factor was uppermost in the Committee's thoughts — the need for speed. Contracts were let, permitting key scientists to remain in their laboratories as far as possible. Exceptions, however, were made in such areas as antisubmarine warfare, radar, and rocketry, where large centers were established through contracts with universities. In rocketry, for example, the California Institute of Technology and George Washington University were pressed into service as contract managers.

This unusual, imaginative, and extraordinarily effective mobilization of scientists and engineers was expanded in 1941 into the Office of Scientific Research and Development (OSRD) with the additional functions of liaison with Allied governments and an Office of Field Service with the responsibility of transferring technical developments to the Armed Services and evaluating their effectiveness.

In August 1940, an NDRC contract was signed with Merle A. Tuve of the Department of Terrestrial Magnetism of the Carnegie Institution of Washing-

ton to develop a fuze that would explode an antiaircraft shell by radio signals reflected from a nearby target ("proximity" or "VT" (variable time) fuze). With the assistance of a small number of his colleagues (R. B. Roberts, H. H. Porter, and L. R. Hafstad), Tuve demonstrated in a few months of breadboarding and field testing that such a miniature radio system could be designed and could survive the acceleration of the projectile being shot out of a cannon.

Because of the great military potential of the device and the need to translate the concept speedily into a reliable weapon, Tuve's Section T (the initials of a Section frequently reflected the name of the Chief) was expanded from about 100 persons at the end of 1941 to 365 one year later. A contract was negotiated with The Johns Hopkins University on March 10, 1942, to organize an Applied Physics Laboratory to pursue the fuze work on an enlarged scale. Close relations with industry were established to oversee the design and production of the fuze's components and to improve the reliability of the device. A staff of more than 600 was assembled in the Silver Spring, Md., Laboratory complex in June 1944.

Development and production were telescoped in an intensive coordination effort. Within two years from the enunciation of the initial concept, a workable fuze was in production. Its first successful demonstration took place on January 5, 1943, during an engagement in the South Pacific between USS *Helena* and Japanese war planes.

2. The close ties established with the U.S. Navy Bureau of Ordnance during the development and funding of the VT fuze resulted in a shift in the relationship of Section T and OSRD. The Section T operating philosophy had moved toward the concept of a central laboratory that was responsible for the development of an idea to the demonstration stage, followed by its rapid transformation into production and introduction into service use. This could only be achieved by the early selection of industrial contractors and by close and continued liaison with the ultimate user. Untried in military procurement, except for the Manhattan Project, this broad concept went beyond the immediate charter of OSRD and led, in December 1944, to a formal separation. By then, the staff had grown to nearly 1000. The Bureau of Ordnance negotiated a contract directly with The Johns Hopkins University. However, this "Section T Type" contract retained most of the features evolved during the OSRD period and has been maintained with few changes to the present day.

3. The VT fuze and gun directors were intended primarily for Fleet use during the Pacific operations, where they had a profound impact on the defensive capabilities of ships against conventional air attacks. However, the fuze was equally effective against the V-1 attacks on England that began in July 1944, and as a countermeasure against the German offensive in the Battle of the Bulge in November 1944. While there was reluctance to use the fuze on land for fear the Germans might discover its principle of operation, the war's end was near enough to overcome that objection. In fact, the Germans had made independent efforts to design a proximity fuze of their own, but there was insufficient support and urgency to bring their development to a successful conclusion.

When the APL fuze project was technically completed in 1943, it permitted a switch to new projects. The development of guided antiaircraft missiles and their integration into an effective Fleet system became the major APL effort until the 1960's. New programs were then added on satellite navigation and submarine evaluation and security, as were projects in biomedical engineering and in the fields of energy, environment, and safety.

4. As ideas for a guided missile development program crystallized into action during the early months of 1944, questions were raised as to whether any major new project could be completed in time to play a decisive role in the war. By then, it was evident that the early successes of the Germans in western Europe and in Russia had been checked and had, in fact, been reversed. Britain remained unconquered. The near-disaster for the Germans, in their costly campaign in the Ukraine and entrapment at Stalingrad, had led to continued retreats to the prewar Polish frontier by the beginning of 1944.

Similarly, in the Pacific, the military situation had greatly improved. From Pearl Harbor until the Battle of Midway (June 1942), the war had gone incredibly well for the Japanese — better, in fact, than in their most optimistic forecasts. Within six months, they controlled a vast area stretching from the Aleutian Islands in the north to New Guinea in the south, and from the Indian border in the west to the Gilbert Islands in the east. The defeat at Midway (so aptly named) was the turning point. The Imperial Navy lost four aircraft carriers and never recovered from that blow, even though reconquests of strategic Pacific islands had to be paid for frequently at hideous costs.

The summer of 1944 saw the successful crossing of the Channel in Europe and the approaching invasion of the Philippines in the Pacific. In mid-October, the Battle of Leyte Gulf, one of the fiercest sea battles in history, commenced. The Japanese Second Fleet, containing Japan's main naval strength, was decimated. It marked the end of the Imperial Navy as an effective fighting force, opening the home islands to effective invasion for the first time since Kublai Khan.

5. Postwar surveys of German and Japanese developments in antiship and antiaircraft guided weapons indicated that neither country had pressed vigorously enough for them to be of value in their war efforts. Indeed, the Germans had a long lead from their early commitment to the development of liquid-fueled rockets that culminated with the V-2's

bombing of civilian targets in England and the Netherlands. After successful flight tests in 1941, 5000 V-2's were assembled, half of which reached English targets in the time from September 1944 to the German surrender in April 1945.

However, despite a many-pronged development effort in surface-to-air and air-to-surface missiles, not a single German system was pushed into production on a large enough scale to have a decisive impact. The air-launched HS 293, a 10-foot-long glide bomb propelled by a hydrogen-peroxide-powered rocket and flying at a speed of 500 miles per hour, was put into limited production in 1941 and was instrumental in sinking several British merchant ships in the Bay of Biscay. But later versions with radio-controlled guidance did not become operational. The FX 1400, also radio-controlled and flying faster than 600 miles per hour, arrived too late to be of value. A variety of liquid- or solid-fueled and rocket-propelled missiles reached flight test stage in 1944 but did not become effective antiaircraft weapons. Despite a lead time of four to six years over the Allies, the German program never played an effective role in the prosecution of the war.

The Japanese effort in the high technology of guided missilery was almost nonexistent. During the desperate Leyte Gulf engagement and on virtually one week's notice, the kamikaze attacks were organized in October 1944. Pilots would guide their planes into direct collision with ships in the expectation that the resulting fires and explosions would cause great damage. It is estimated that 5000 sorties were flown in this style. While three capital ships were sunk and 300 other vessels were damaged, the tactic was a failure from a practical point of view.

The Ohka ("Cherry Blossom") bomb, introduced into the Okinawa campaign in the spring of 1945, was even less effective. Slung under a conventional mother plane and accelerated by solid propellant rockets to a speed of 600 miles per hour, it, too, depended on human guidance. Not a single ship was sunk by this device.

6. In view of the limited German effort and the virtual absence of a corresponding Japanese development, it is incorrect to describe the Navy guided missile initiative in the summer of 1944 as a response to kamikaze or Ohka attacks, since neither of those weapons had yet been deployed. Rather, the decision to proceed arose from the fact that technologies had advanced to a point where such a development was, in principle, feasible. M. A. Tuve wrote in a letter to Vannevar Bush on July 19, 1944, about

> *...the new Navy tactical situation which may arise if the enemy adopts guided missiles for attack against task forces from airplanes just beyond the limited range of anti-aircraft for us.... We have thought about this problem for several years, and only in the last eight months have reluctantly concluded that we may have to face it during this war instead of the next one in view of the weapons already in use by the Axis powers and ourselves.... The problem must be faced before very long if we hope for real defense against future air attacks in this shrinking world.*

Information about Axis developments was sketchy and incomplete, at best. Not knowing the magnitude of the German effort, it was unavoidable that actions based on a "worst case" assessment had to be taken. Tuve wrote on November 30, 1944 in a memorandum to Bush and to Rear Admiral G. F. Hussey, Jr., Chief of the Bureau of Ordnance:

> *Various discussions in Section T during the first six months of 1944 indicated the probable necessity for attack on a 'chaser' problem in the immediate future, even if the probability of success were low, since the stakes involved are so large; if high-speed guided missiles are more feasible than has been expected and the enemy discovers this first, the risk for us is very great.*

The request by the Bureau of Ordnance for a formal proposal was, in essence, in response to ideas generated by APL on how to prevent attacks on ships by guided missiles launched from planes beyond the range of conventional antiaircraft guns.

The first APL concept, suggested in early 1944, was a subsonic pilotless "fighter-missile," referred to as Falcon. A more detailed analysis of the problem was undertaken in the summer of 1944. It was concluded that a subsonic chaser would only be marginally effective against a target that could take evasive action. A detailed proposal (largely based on analysis by Jesse Beams, professor of physics at the University of Virginia) specified a supersonic velocity (1850 feet/ second), a promising powerplant (ramjet), a convenient fuel (octane), and a warhead weight of 600 pounds. The small amount of available design data at supersonic velocities indicated that a reasonably compact structure should be adequate to carry this payload to a distance of 20,000 yards. Radar guidance and a homing device were suggested, as were solid-propellant boosters. The code name for the proposed device was Torch.

Early in 1945, the project acquired the code name Bumblebee. Years later, as individual missile types were developed, mostly mythological names starting with the Letter T, were assigned to them (Talos, Triton, Typhon, and Terrier).

7. None of the needed components (powerplant, radar guidance, or booster) existed at the time the overall design was formulated. While there was hope that proof of concept would be available within a year, no tactical missile was foreseen in less than five years. In view of the expectation that the war would end in 1945 or soon thereafter, the likelihood of a useful device before the war's end seemed remote.

In contrast to the VT fuze, which took less than two years from invention to production, the complete guided missile system required a much longer development time. Talos, the culmination of the 1944

Falcon proposal, entered the Fleet in 1958, while the shorter-range rocket-propelled Terrier missile (an offshoot of one of the Talos test vehicles) became operational in 1955. Fully effective antiaircraft systems are only now being introduced into the Fleet.

While the APL proposal was the most ambitious in its specifications (supersonic speed, radar guidance), several other programs were discussed and initiated at the same time. Little Joe, Wac Corporal, and Tiny Tim, all subsonic and rocket propelled, were pursued by different sponsoring agencies, as were radio-controlled air-to-surface bombs (Razon, Tazon, Roc, and Gargoyle). The National Advisory Committee for Aeronautics developed a subsonic, radar-guided air-to-surface missile (Bat).

8. In an October 24, 1944, memorandum to Captain C. L. Tyler, M. A. Tuve wrote:

> *Even a negative result of this kind should be extremely valuable, as the attack aspects of these devices are of at least as great significance as the chaser (defense) aspects. Results of either type are highly necessary for the United States to possess as soon as possible whether ready before the end of the war with Japan or not.*

9. In a memorandum on "Intensive Program on Guided, Jet-Propelled Antiaircraft Missiles," dated January 11, 1945, Rear Admiral G. F. Hussey, Jr., wrote:

> *On the basis of technical considerations and work already in progress, the Commander in Chief, United States Fleet, directed on 4 December 1944 that the Bureau of Ordnance program on the development of guided, jet-propelled antiaircraft missiles is to be carried forward on an urgent basis and further directed that other Bureaus and agencies of the Navy give all possible support and assistance to the Bureau of Ordnance in connection with this program.*

Admiral Ernest J. King, at the same time, instigated a comprehensive survey, by a committee chaired by Prof. E. R. Gilliland of MIT, of jet-propelled missiles and their continuing postwar implications. Its overall purpose was to review the status of such missiles, with particular emphasis on their future possibilities and thus to aid the Navy in shaping requirements for the weapons and for research in the fields related to their use. At Air Force Headquarters, a similar study was undertaken when the high-level Scientific Advisory Group was established under the direction of Theodor von Karman.

10. Representatives of the Air Force and the British Scientific Mission in Washington were assigned to APL as liaison officers.

11. The question of "permanence" was discussed with great intensity for several years following World War II. The relationship and responsibilities of The Johns Hopkins University, APL, its associate contractors, and the sponsoring government agency (Bureau of Ordnance), and the makeup and the technical goals of the Central Laboratory staff were debated at length. For several years, the future of APL as a stable, large research laboratory under Johns Hopkins sponsorship was in doubt.

12. Soon after the formal Task F assignment to APL for the development of an antiaircraft missile, it was realized that the technology could readily be extended to other end-uses as well. Studies were assigned within a year for the design of a long-range ship-to-shore missile (Triton). Task extensions for the development of antiradiation missiles and antiballistic missiles were formulated at a later date.

13. The liquid-fuel rocket alternatives were never seriously considered. However, test vehicles propelled by solid propellants proved sufficiently adaptable to short-range applications that a separate program — Terrier — was organized to exploit the technology. Terrier became a dominant shipboard missile system.