Basic Research *and* Defense Developments

By François N. Frenkiel

PLANNING defense developments ten or twenty years from now requires the prediction of the future progress in various fields of science. While such a prediction should be influenced by the experience gained from present and past progress it would be of little value to make a simple extrapolation from the present to the future. The future of scientific and technological developments will be what we make it. The best way to forecast them is to take into account the potentialities of rapidly advancing fundamental research. The best way to influence them is to increase those potentialities by close contacts between fundamental research, applied research, and engineering.

The Defense Department must try to have the best possible weapons, at present, in the near future, and in five to twenty years from now. The necessary efforts to have such weapons at present have been made. To have them in the near future, technological improvements, for which new basic research is desirable but rarely required, may be sufficient. To develop the best weapons five to twenty years from now the Defense Department must increase *now* its sources of basic knowledge. The best warheads of 1935 could be improved each succeeding year without much basic research. Extensive research was, however, necessary to develop a VT-fuze ten years later. This fuze was, in its turn, further improved without requiring extensive basic research. But to build Terrier, Nike, or Talos missiles the results of many fundamental studies were required. Future vehicles of ten or twenty years from now may be as different from Terrier as Terrier is now different from the 1935 weapons. Each development goes through similar stages. Its conception requires fundamental knowledge, its growth needs basic and applied research, its design demands engineering imagination, its development uses new technological methods, leading finally to the best weapon in its class when put into service. Frequent improvements will keep this weapon at the top for some time, but usually new ideas lead to even better developments outdating the earlier ones before they are needed. Each military department must insure that there always be new and better weapons to replace those unused, new and better concepts to design these weapons, and new and better fundamental research to produce these concepts.

The Offices of Naval Research, of Ordnance Research, and the Air Force Office of Scientific Research have been quite conscious of the importance of fundamental research and are giving to it continuous support at universities, in industry, and in private and Government agencies. (In addition basic research is supported by the National Science Foundation, the National Advisory Committee for Aeronautics, the Atomic Energy Commission, and some other civilian agencies.) Through this support the Defense Department contributes to the over-all growth of fundamental knowledge. To help the progress of technology, this knowledge must find its way to the applied scientist and the engineer. At the same time, technological problems must find their way to the basic research worker to provoke studies which will result in new and better defense concepts. Publication of reports and papers, scientific meetings and symposia contribute much to the communication between basic research, applied research, and engineering. However, the research results which are still unwritten, the ideas which are still unsaid, and the problems which remain to be well defined, need for their development an intermixing of researchers and engineers, for which common grounds in the same laboratories are required. A long-range program may require the following through from basic research to applied science, to engineering, to development, production, and military application with continuous cross communications. This pattern of

F. N. Frenkiel, editor of the AIP's recently established journal *The Physics of Fluids*, is a consulting physicist at the Applied Physics Laboratory of The Johns Hopkins University and serves as a part-time consultant to the Applied Mathematics Laboratory, David Taylor Model Basin. He states that the opinions expressed in this paper are his own and do not necessarily represent the opinions of the agencies with which he is connected.

operation brings together science, the military, and technology which is already in itself an important foundation for future achievements. The merit of such a pattern lies in the communications between its elements. Each of them is important to the constitution of the operational pattern, since no communication wire is of value if, at one of its ends, there is no one to communicate with.

This need for having, in addition to specialized basic research agencies, a coexistence of research and engineering, presents some dangers to the efficacy of long-range basic research. We refer to the lack of qualified scientific personnel and to the natural tendency for speeding up the development of a weapon near completion. Both are a temptation to sacrifice the long-range future to the immediate needs. Succumbing to such a temptation, an agency may rapidly produce this weapon, but in the process of doing so is apt to spend all its own efforts on each successive stage of the design and development. From an applied research agency it moves into research engineering, from there it transforms into a development organization trying to continue by improvements of the same weapon to keep it at the top of its class. After some years the weapon is outdated and the agency unprepared to take over the research necessary to conceive and develop new and better means of defense. If this is the situation of few agencies only, it may damage only their own future effectiveness as research laboratories. One must, however, be cautious to avoid that an overeagerness to use up all research potentialities for development purposes compromises the future of basic sciences to an irreparable degree.

Let us come back to our initial question concerning the state of technology ten to twenty years from now. The answer to this question depends largely on each military department, since together with other Government departments and scientific organizations it is contributing to science and technology. The reserve of fundamental knowledge will increase continuously whether each military department does or does not contribute to basic research. However, the speed of this increase and the benefits which each military department will receive from this knowledge are largely dependent on its active participation in basic research. We referred to the fact that laxity in basic research may result in an inability to face the needs for new concepts some years later. This now seems to be the situation in hydrodynamics. The need for new ideas in naval architecture and underwater ordnance is enhanced by the enormous possibilities offered by nuclear power. The lack of sufficient basic and exploratory research in hydrodynamics during the last few years is, however, now delaying the development of such new concepts. Since the number of agencies interested in hydrodynamics is limited, this deficiency in a few of them is sufficient to retard severely future naval development.

The present status of scientific knowledge shows that nuclear power will play an important role in defense problems. Whether it concerns the propulsion of air, surface, or underwater vessels, or the use of nuclear energy in warheads, the Defense Department must continue to be interested in this field. It should, however, at the same time intensively study other fields of science which must be developed to make it possible to use this power efficiently. In the present discussion we shall mainly refer to these other fields of science, particularly to aerodynamics, ballistics, and fluid physics.

Aerodynamics is the science concerned with interactions between air and moving bodies. Friction between a solid body in motion and the surrounding fluid generates drag and heat. Results of studies of the boundary layer between solid surfaces and fluids help to reduce the drag and in consequence decrease the power required for the motion of vehicles in air or water. Heat generated by high-speed projectiles may become so intense as to melt, vaporize, or burn their surfaces. One of the reasons why projectiles can be made to move faster at higher altitudes is that in a less dense upper atmosphere there is less heat generated in the boundary layer. However, motion in rarefied gases brings new research problems which weld aerodynamics to other fields of science. In rarefied gases distances between individual molecules may become so large that the gas does not behave like a continuous fluid in its interactions with the surface of the projectile. The usual meanings of the temperature of a fluid, its viscosity, and its friction with a solid surface lose most of their significance. We must now consider the mechanics of the interaction between individual molecules and the solid surface which concerns the molecular nature of the solid itself. These problems will require basic research results in statistical mechanics as well as in solid-state physics.

One must take into account another fundamental change in the nature of the interaction between air and moving bodies at very high speeds. At such speeds the air molecules may be dissociated, excited, ionized and otherwise modified, and instead of having to study the interaction with air we must be concerned with a new kind of fluid presenting chemical and electrical properties. The physical characteristics of this fluid have many similarities with those of fluids studied by astrophysicists. This new part of fluid physics is not generally included in the classical studies of subsonic, supersonic, or hypersonic aerodynamics or even in superaerodynamics (which studies the problems of high-speed in rarefied air). Its development is of great importance to the future state of our knowledge required by the new problems of high-speed flow.

When a projectile with built-in propulsion is launched into space, it usually starts from rest, then accelerates through subsonic speeds, crosses the transonic speed regime, and reaches supersonic or even hypersonic velocities. At transonic speeds the flows which characterize subsonic and supersonic regimes coexist and the projectile acquires shock waves which will accompany it in its motion. Our knowledge of aerodynamics at subsonic, supersonic, transonic, and hypersonic regimes still contains some important gaps, particularly in the case of the latter two. When we are concerned with motions at constant speeds these gaps lead to technical difficulties which can sometimes be filled by empirical methods, however imperfect they may often be. However, the aerodynamics of a projectile, which accelerates through all these speed regimes along a trajectory with decreasing air density, becomes so complicated that even empirical stop-gap methods themselves require research studies. After the propulsion fuel is used up the projectile continues to climb into the upper atmosphere slowly decelerating and may reach the highly rarefied upper atmosphere where none of the laws of classical aerodynamics or superaerodynamics have any meaning. On its way back to the Earth's surface the projectile is at the same time rapidly accelerated by gravity and submitted to the friction with the atmosphere and other decelerating effects. The study of the flow past the projectile during its re-entry into the increasingly dense atmosphere is usually even more complicated than during its upward motion. The problem of heat transfer may become quite critical since the increasing temperature at the surface of the projectile is an important limitation governing its performances. Chemical and electrical changes of the air properties, to which we referred before, complicate even more the nature of the flow.

Both theoretical and experimental studies of the re-entry problems present many difficulties. For the first our knowledge of basic physics and of the mathematical methods of analysis must be perfected; the second requires a high-speed flow at as high a temperature as possible without destroying our equipment. Nature has, however, provided us with examples of re-entry phenomena which are valuable for these studies. We refer to meteors which entering the Earth's atmosphere at hypersonic speeds, ionize the gases in their wake and heat themselves up to such temperatures that the smaller meteors are consumed before they reach the Earth's surface.

Exterior ballistics is this part of ballistics which studies the motion of projectiles after they are ejected into space. Conventional studies refer to bullets after they leave the muzzle of a gun. Our projectile finds itself in a similar situation when its built-in propulsion system stops operating and as long as it is not guided. Ballistic trajectories of projectiles which reach hypersonic speeds, climb to the upper atmosphere and above, and have ranges of several tens or even thousands of miles are not as simple as trajectories of bullets. We have already reviewed some problems particular to the airflow past a projectile which influence its trajectory. We must also consider the turbulence of the wind and the jet streams wandering through the upper atmosphere which will modify this trajectory.

High-altitude satellites, projectiles, or other vehicles will not always find themselves in the rarefied air of an atmosphere otherwise similar to the one near the Earth's surface. Its chemical composition changes in the upper atmosphere. At 10 to 20 miles of altitude it contains enough ozone to corrode some of the parts of the vehicle by oxidation. At 60 miles the oxygen appears in the atomic state and may perhaps be used in the future as a source of chemical energy for propulsion. The magnetic properties of the ionosphere and the intense heat radiation will have to be taken into account in the studies of the behavior of vehicles in the upper atmosphere. The problem of electromagnetic wave propagation and its relation to upper-atmosphere motions is already now a subject for research studies. These problems combine hydrodynamics and magnetism and are related to a new field of physics, magnetohydrodynamics, which is also of interest to astrophysicists and geophysicists. With new discoveries in geophysics, following the International Geophysical Year, the scientist will have to consider new problems which influence his engineering developments and of which he may have little knowledge at present. To be at the forefront of the potential use of these discoveries all fields of physical sciences must have a working contact with geophysics.

Present designs of missiles are based on the knowledge accumulated to date. These designs can be improved even without too extensive basic research. If, however, basic studies in atmospheric physics and high-speed motion are fully supported, the expected results will be not merely improved designs, but the development of completely new missiles, satellites, and entirely new ideas for defense methods.

The responsibility which each military department carries in the defense of the country is not limited to producing the best possible weapons for the present. It imposes the duty of being prepared for the future as well. The effectiveness of future defense methods depends on the application of basic knowledge to defense technology. Since the most efficient use of the accumulated knowledge will be made by those who participated in its accumulation, each military department should require that basic research be an organic part of its research laboratories and that basic research studies be as urgently supported as applied research studies or engineering and development activities. Each military department must carry this responsibility at present, to be able in the future to put all of its technological abilities and its scientific experience into the service of the nation.

The Defense Department must be conscious of the importance of an active participation of each research agency in a self-justified program of basic and exploratory research. Supporting such research at universities is necessary but far from sufficient. Basic research should find its appropriate place in the applied research organizations. The amount of money spent in each organization on basic research is less important than the place which it is given in the responsibilities of the organization. The state of basic sciences will be what we shall make it. The Defense Department can do much to contribute to its rapid advancement. Basic research done in the past made possible some of the best defense developments. Not less should be expected of the future.