INTRODUCTION

THE ROLE OF SCIENTIFIC RESEARCH IN WEAPON DEVELOPMENT: WHAT IS MILITARY R&D AND HOW DOES IT WORK?

In modern war technology based on science plays a bigger factor than ever before in the history of mankind. Capable scientists are, therefore, the most precious asset which a nation possesses to give it superiority over its enemies and victory or defeat is in their hands... The first responsibility of the scientist is to the nation of which he is a member... He has no choice but to assist his nation by developing the most effective defense techniques and also the most effective and, therefore, most destructive aggressive war weapons.

Ernst Chain, The Observer, June 1968.

We know that, over the full span of human records, there have been wars, and furthermore that human beings have used every means available to kill and overpower one another.

S.D.Drell, Facing the Threat of Nuclear Weapons, 1983.

... it was only after the Second World War had actually begun that the military leaders of the belligerents fully grasped the proposition which Professor Isidor Rabi long afterwards expressed as follows: "The combining of military techniques and science makes it easy to apply scientific principles to kill people — who are not strong structures."

P.Noel-Baker, "Science and Disarmament", Impact, 15:4 (1965)

The decisions which we make today in the fields of science and technology determine the tactics, then the strategy, and finally the politics of tomorrow.

Solly Zuckerman, Scientists and War, 1966.

INTRODUCTION

Over the centuries there have been many important innovations in weaponry: the spear, the bow and arrow, the catapult and other siege machinery, the gun and the cannon, steam vessels and metal-hulled ships, the submarine and the aircraft. Each of these is credited with having revolutionized warfare, the nature of armies, and the relations between warring groups and between States. (1) Yet it seems that at no time in man's history have the affairs between States been so heavily influenced by military technology as in the years since the end of the Second World War.

This book provides an examination of the relation of scientific research to weapons development. With extremely few exceptions — such as Lewis Mumford — the suggestion that long range rocketry coupled with nuclear explosives is more knowledge that is good for the human species is strongly resisted by contemporary scientific leaders, philosophers and politicans — both East and West. The suggestion of placing limitations on knowledge and its applications stands against too many processes and tenets that fuel the progress of our civilization. Technology assessment is still in its infancy as a contribution to the determination of policy, and even then, in hardly any situation other than after the fact.

As regards the relation to war, the role of science as servant to the state — particularly in the context of war and weapons — was foreseen by a few insightful individuals. Generalizing from the German experience, the exiled historian, Hans Kohn, wrote in 1937:

> "Even science does not unite any more — the old Republic of Letters is gone. Science tends to become in some countries as Ernst Kriek called it "Wehr, Waffe und Werkzeug zum volkspolitischen Aufbau" (arms and tools for the national political upbuilding)... It is an instrument for national purposes... Science has become as much as economics, a potential de guerre." (2)

It was an assessment that was to become infinitely more meaningsful than it was even in the contexts of the First and Second World Wars. The "some countries" in which the process unfolded were essentially all those willing to expend the economic resources necessary to establish the scientific programs and develop the scientific manpower and facilities to produce advanced weapons systems. Some years later the political scientist Hans Morgenthau summed up the same developments as follows:

> The development of radar and the atomic bomb at the instigation and under the management of the government at the beginning of World War II initiated a new relationship between scientific and technological innovation and the government. Today, both intellectually and economically, the government dominates the development of science and technology. If the government does not support a supersonic or atom-powered airplane it will not be built. The National Aeronautics and Space Administration (NASA) determines the objectives and methods for the exploration of outer space, satellite communications, and in good measure astronomy.
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> .....
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> Military power is no longer primarily measured by the possession of territory, the number of men under arms, and the number of weapons available, but by scientific breakthroughts and technological innovations: national prestige derives largely from scientific and technological achievements. Nations, by continuing their historical engagement in armaments races and competition for prestige, must perforce embark upon scientific and technological competition. Thus the value of science and technology has enormously increased in the calculus of national power.
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> In the past, the influence of science and technology on national power remained static over long stretches of history. For instance, the predominance of Europe throughout the world remained for centuries firmly based upon its technological superiority. Today, the distribution of national power derived from science and technology has become, at least potentially, dynamic to an unprecedented degree. This is the result of a number of scientific revolutions, past and anticipated, following each other in ever more rapid succession. (3)

The juxtaposition was always rather clear to see. Kenneth Boulding wrote that "Political intervention in science is always destructive because politics depends on a legitimated threat system, whereas science does not". (4) The political response of the needs of the state was diametrically opposed to a generalized scientific idealism. For example, a member of the Military History Institute of the USSR's Ministry of Defense wrote in 1970:

> Under conditions of the rapid development of new weapons, radio-electronics and new combat technology, V.I. Lenin's injunction that the army which fails to acquire all types of means and methods that the enemy possesses or may possess is irrational or even criminal, has become even more significant. (5)

Senator Henry Jackson's opinion was exactly the same:

> In todays world the tide of political power flows with the tide of scientific and technical power. A decade ago we took our nation's scientific and technical leadership almost for granted. Today it is being effectively contested. We must bestir ourselves, lest Sputnik and the cosmonaut mark only the beginning of a long list of Soviet firsts, and lest we fall short of our best in putting science to work for peace and welfare and individual freedom. (6)

It is difficult today to grasp the degree of change that has been institutionalized since WWII — over a period of some 45 years. James B.Conant describes two examples that illustrated the casual relationship that existed in WWI between government and science.

> In World War I, President Wilson appointed a consulting board to assist the Navy. Thomas Edison was the chairman; his appointment was widely acclaimed by the press — the best brains would now be available for the application of science to naval problems. The solitary physicist on the board owed his appointment to the fact that Edison in choosing his fellow board members had said to the President: "We might have one mathematical fellow in case we have to calculate something out."
>
> Another story illustrating the popular attitude towards science and invention in 1916 concerns chemists, not mathematicians or physicists. At the time of our entry into World War I, a representative of the American Chemical Society called on the Secretary of War, Newton Baker, and offered the service of the chemists in the conflict. He was thanked and asked to come back the next day. On so doing, he was told by the Secretary of War that while he appreciated the offer of the chemists, he found that it was unnecessary as he had looked into the matter and found the War Department already had a chemist. (7)

Yet it was in WWI, as the British Navy was driven to modernization by Adm. Sir John Fisher, the former First Sea Lord, newly appointed chairman of the Board of Invention and Research, that Adm. Fisher also fulfilled Kenneth Bouldings prediction of the requirement of a threat.(8) At the same time as Adm. Fisher requested that British arms manufacturers supply the inventions he thought necessary, he also produced a stream of propaganda in collaboration with the sensational journalist W.T.Stead to persuade Parliament and the public that the British Navy should institute such programs.

One should also recall that rapid innovation in military weapon systems has definitely not been customary, and was resisted by military or civilian authorities on numerous occasions in previous centuries. The point here is not that resistance to change was not usually overcome with time — it usually was — but that institutions precisely intended to provide rapid change were certainly not traditional. The reasons for opposition to innovation were varied. In 1139 Pope Innocent II declared the recently developed crossbow "hateful to God and unfit for Christians" and forbade its use. (9) This edict of the Second Lateran Council was, however, then amended to permit use of the crossbow against the Moslems. The secondary limitation also soon broke down as Christians took up the crossbow against one another before it was superseded by more efficient means of killing.

In other cases innovation was resisted as it was recognized to present a threat to existing forces. A French king ordered his navy to pay an inventor of a submarine type vehicle so that it should <u>not</u> be developed, and a British Admiralty Board described the introduction of the steam engine as fatal to England's Navy. In his campaign to speed British submarine development, Adm. Fisher pointed out that the British Admiralty also successively opposed the introduction of the turbine, wireless, and aeroplanes, in addition to the submarine. In some earlier cases opposition was due to poor technical understanding. The British Admiralty had vetoed iron ships on the ground that iron sinks and wood floats, and in 1837 Sir William Symonds, the Surveyor of the Royal Navy, criticized a proposal to drive a steamship by a screw-propeller with the assessment that

> "Even if the propeller had the power of propelling the boat, it would be found altogether useless in practice, because the power being applied in the stern it would be absolutely impossible to make the vessel steer."

Incorrect technical assessments have continued into the more recent past. In 1939, years after the sensational demonstration by Gen. William Mitchell which led to his courtmartial, US Rear-Admiral Clark Woodward still claimed that "As far as sinking a ship with a bomb is concerned, you just can't do it." Perhaps the most well known case of this sort was the assessment by Vannevar Bush in 1945, the director of the US Office of Scientific Research and Development (OSRD) during WWII, that intercontinental ballistic missiles (ICBM's) could not be developed.

> "There has been a great deal said about a 3000 miles high-angle rocket. In my opinion such a thing is impossible for many years. The people who have been writing these things that annoy me have been talking about a 3000 mile high-angle rocket shot from one continent to another, carrying an atomic bomb and so directed as to be a precise weapon which would land exactly on a certain target, such as a city.
>
> I say, technically, I don't think anyone in the world knows how to do such a thing, and I feel confident that it will not be done for a very long period of time to come... I think we can leave that out of our thinking. I wish the American public would leave that out of their thinking." (10)

Bush used his position as head of the post-war Joint Research and Development Board and then the Research and Development Board to limit funds for ballistic missile research that he apparently believed had no immediate military applications. (11) This is strikingly evident in the table below which demonstrates that virtually no US funding went to long range ballistic missile R&D until 1953 or 1954, which in hindsight seems truly remarkable.

At the same time equally misguided technical assessments — if not in altogether precisely the same years — drove military R&D and expenditures for other projects, for example the projects for Nuclear Energy for Propulsion of Aircraft (NEPA) and Aircraft Nuclear Propulsion (ANP). Research was initiated as early as 1946. The Research and Development Board of the Defense Department recommended that the project proceed on a priority basis, the Congressional Aviation Policy Board reported to Congress that NEPA deserved "the highest priority in atomic research and development", and a report prepared at the Massachusetts Institute of Technology and commissioned by the Atomic Energy Commission contended that a nuclear aircraft was feasible and could probably be achieved within fifteen years. (12) It took that long — including a "threat" campaign in 1958 with repeated though totally false reports that the USSR was flight testing an analogous nuclear-propelled aircraft — before the project could finally be killed by the incoming Kennedy administration in 1960. NERVA, the nuclear rocket engine development program, continued in development through the 1970's. (13)

The systems of weapons procurement that have evolved in the United States and the USSR in particular in the last thirty years have led to extremely complicated and at times contradictory development patterns. In general, in the United States the military services are reluctant to improve existing systems when there is a chance to press for the purchase of a new system. The examples are numerous (The C-141 and C-5A aircraft, Maverick missile and Wall-Eye bomb, Cobra /Tow and Cheyenne helicopter, air launched cruise missiles and B-1 bomber, etc.) and occur in every service — naval, air, and ground weapons. Steinbruner and Carter present a masterful study of the determinants of the characteristics of the Trident submarine and missile exemplifying these factors. (14) At the same time, in 1977 the United States had 36 different conventional anti-tank weapons in procurement or under development, at the same time as enhanced radiation nuclear warheads were being proposed for the same anti-tank role largely

Defense Obligational Program for Missile Systems Fiscal Years 1946-60
(in millions of dollars)

Fiscal Year	IR/ICBM Programs	Other Surface to-Surface Missile Programs	All Other Missile Programs	Grand Total, All Missile Programs
1946 & prior	2.	19	51	72
1947	0	20	38	58
1948	0.3	36	45	81
1949	.1	45	53	98
1950	0	65	69	134
1951	.5	185	598	784
1952	.8	239	818	1,058
1953	3.	403	760	1,166
1954	14.	336	717	1,067
1955	159.	398	911	1,468
1956	526.	387	1,368	2,281
1957	1,401.	603	2,502	4,506
1958	2,150.	639	2,391	5,180
1959 (total)	2,946.	685	3,269	6,900
1960 (total)	3,303.	509	3,173	6,985
1961	3,424.	383	3,155	6,962

Source: U.S. Congress, Senate, Committee on Armed Services, Preparedness Investigating Subcommittee, Hearings: Missiles, Space, and Other Major Defense Matters. 86th Congress, 2d sess., 1960, p. 509. The following explanation of Table 6N.1 is included:

> Program data reflected in this table cover the development and capital costs involved in missile programs, i.e., the cost of bringing missile systems to operational status plus the costs of procuring missiles and related equipment for operational purposes. These data include all procurement, construction and research and development programs directly associated with missile programs. These figures do not include military pay, operation and maintenance costs for operational missile units and sites, and include only those shipbuilding and aircraft costs directly associated with providing missile capability.
>
> Fiscal year 1960 data are preliminary estimates; fiscal year 1961 data represent projected programming.

Also Robert F. Futrell, Ideas, Concepts, Doctrine: A History of Basic Thinking in the United States Air Force 1907-1964 (Air University, Maxwell Air Force Base, 1974), p. 240, reports a staff study completed by the Air Force in June 1947 recommended first priority of development for bomber launched air-to-surface and air-to-air missiles; second priority for a 150 mile tactical surface-to-surface missile; third priority for bomber and missile interceptor missiles, and fourth priority for long-range surface-to-surface missiles.

Table taken from Jack H. Nunn, The Soviet First-Strike Threat: The US Perspective, New York: Praeger, 1982, p. 190.

due to the same kinds of bureaucratic forces that had produced the multiplicity of different anti-tank weapons. These patterns, which derive from weapon acquisition policies rather than from R&D, nevertheless have a very great impact on R&D. We should take note of one last historical point. Bronowski wrote in 1962 that

> "... for some time it has been said, of each new weapon, that it is so destructive or so horrible that it will frighten people into their wits and force the nations to give up war for lack of cannon fodder. This hope has never been fulfilled, and I know no one who takes refuge in it today." (15)

In 1898 the economist Ivan S.Block published a six-volume treatise, *The Future of War in its Technical, Economic and Political Relations,* in which he predicted that new rapid fire weapons and defensive firepower "would produce tactical and strategic deadlock, economic collapse and political revolution. War had become politically impossible." (16) This suggestion has been made successively, for the machine gun because of its great killing capacity on the battle field — for the bomber airplane — because it could reach the cities of a nation far away — even for the radio — because rapid communication would supposedly enable nations to be forewarned and alert their forces, thus overcoming surprise, and therefore allegedly making war unfeasible — and finally for the nuclear weapon. It is a sentiment which people continue to express, as in this 1969 example concerning chemical weapons:

> If, as I think likely, it becomes necessary that every soldier in the field shall be required to wear full protective equipment at all times at which he is not inside a group protective installation, then the threat of CW will have gone a long way towards making war critically unattractive. (17)

In at least one case, that of Alfred Nobel, the inventor of dynamite, the notion of "a weapon to end all weapons" was even expressed as a wish. Nobel wrote to the Baroness von Suttner, a pacifist

> "My factories may well put an end to war sooner than your congresses. The day when two army corps can annihilate one another in one second, all civilized nations, it is to be hoped, will recoil from war and discharge their troops." (18)

On another occasion he said: "I wish I could produce a substance or a machine of such frightful efficacy for wholesale devastation that wars should thereafter become altogether impossible." (19) As astute an observer as Sidney Drell commented that in the nuclear weapon perhaps mankind had finally achieved what Nobel hoped for. It would seem nevertheless that nuclear weapons are only the last — and most dangerous — weapon for which such hopes have been expressed in the face of all contrary historical evidence. Nuclear weapons have in fact in large part prompted the enormous post-WWII acceleration of weapons acquisition and military R&D, the urgency of major antagonists to acquire them and to attempt to maintain superiority in them, and in the accompanying systems and capabilities on which their performance depends. Neither war, nor the preparation for war, has ceased since the advent of nuclear weapons: quite to the contrary.

In 1983 the United Nations General Assembly adopted a resolution on the "Renunciation of the Use of Scientific Achievements for Military Purposes". The resolution "called on all states to undertake efforts to ensure that ultimately scientific and technological achievements may be used solely for peaceful purposes." (20) The Romanian delegate to the Committee on Desarmament stated that

> "The demilitarization of science represents a necessary and integral part of any effort to halt the arms race because military research and development constitute the real source of the present competition, which is essentially qualitative and almost exclusively technological." (21)

The relationship of scientific research — military R&D — to weapons development is widely misunderstood, and the greatest misunderstanding often appears to be in these quarters interested in arms control. "Science" cannot be "demilitarized". Its applications might — hopefully — be controlled, but it is not the primary cause of the arms race. In an April 1984 address Sweden's ambassador to the Committee on Disarmament said:

> The foundation for an intensified nuclear-arms race in the years and decades to come is being laid in "the laboratories of death", on the test ranges of the major Powers and in the "think tanks" of nuclear use theoreticians conceptualizing new strategic and tactical doctrines for the fighting of a nuclear war on Earth and in space. (22)

Another very similar statement can be considered almost a parody, composed of clichés strung together without any sense or understanding.

> An important aspect in the operation of military R&D is what may be called the 'Frankenstein drive': an autonomous impulse which McNamara defined as having 'a kind of intrinsic mad momentum of its own'. In fact, we can easily identify four constant trends which govern the work of the military R&D. These may be described as: the impulse to technological competition; the stabilizing and invigorating effects of the long lead-times; the follow-on imperative and growth propensity; the block-building and cross-fertilization effect. (23)

These quotations are essentially obscurantist, and demonstrate a gross misunderstanding of the processes of weapons acquisition and the role played in them by military R&D.

With these three themes by way of introduction:

- the foresight of a few historians and political scientists in understanding the role that science would come to play as a servant of the state in providing more advanced means of warfare,
- the traditional conservatism that military leadership had shown over hundreds of years regarding the introduction of new technological innovations,
- and the misguided but recurring hope that states would be deterred from waging war by the human costs levied by some "weapon to end all weapons",

and with a note regarding the degree of misunderstanding that is common regarding the role of scientific research in weapons acquisition, we can turn to look in some detail at what has happened in the post WWII period.

The relations between scientific research as it is presently understood and technology are of relatively recent origin, and until quite recently more often than not science has followed technology. The relations are complex and feed in both directions. Military technology from 1400 to 1800 did focus scientific attention on certain problems, and one early study estimated that it influenced about 10 per cent of the research conducted by members of the Royal Society in seventeenth-century England. (24) The estimate is substantially low, since Merton neglected to count investigations in astronomy and navigation, of great interest to navies at that time. It has also been suggested that the percentage of similar studies sponsored by the early French and German scientific academies was even higher. (25) Thus even then 'basic research' and 'pure science' were also related to military problems; the classical physical study of the free fall of bodies, made famous by Galilei, is necessary for the determination of the trajectory and velocity of a projectile.

Several significant innovations in military technology took place during the First World War: aviation, gas warfare, the tank, and the birth of military electronics of many sorts through the initial efforts at signal location and interception. The earliest role of aircraft in WWI was for artillery field spoting. Targets were located from the air and directions radioed to the artillery units on the ground. The opposing side attempted both to intercept and to jam the radioed information. The development of radio — the work of Marconi in the UK and of Deforest in the US — was to an important degree an outcome of WWI. In addition, airplane combat in the air resulted from interceptor aircraft carrying arms t. attempt to stop the reconnaissance aircraft.

The first airborne vehicles used for long range bombing were German dirigibles. These had higher payloads and longer flight times over the target than the most powerful winged aircraft of the day. They were, however, also easier to divert, as they depended on radio navigation, and to attack. Their vulnerabilities led to the development of the Botha bomber aircraft by Germany by the end of WWII. Another important German development was made in chemistry. Germany could not have gone to war in 1914 or have remained a combatant for very long unless the process of 'fixing' nitrogen from the air to produce nitrates for the manufacture of explosives had been a practical success, though the Haber process by which this is done is not ordinarily considered to be 'military' technology. Similarly, before going to war anew twenty-five years later Germany was again forced to utilize chemical engineering in the manufacture of liquid fuels from coal. (26) However, the organizational arrangements and thus the opportunities for scientific advice to the military were very limited in the First World War, in all countries involved, and quite different from those which existed in the Second World War. (27)

Despite the rapidity with which changes appear to occur retrospectively, both world wars and the inter-war period provided evidence of the overwhelming technological conservatism of military leaderships.

The changes that followed have, however, been remarkably rapid from an institutional point of view. As late as 1938, more than 40 per cent of United States federal funds for research were being spent by the United States Department of Agriculture. As the war approached the United States Army rejected increasing its minute R&D budget in favour of procurement:

> The Army apparently assumed that the coming war would be fought with existing weapons and would not be greatly influenced by technology, least of all science-based technology. No judgement could have been more wrong. This event throws in stark relief the revolution in science-government relations that was about to be precipitated by the advent of World War II. (28)

Between 1939 and 1945 the United States Army and Air Force was alone responsible for no less than 25 per cent of all money spent by the federal government for R&D, and had become the major military service investor in R&D, much of it in the field of electronics. (29)

The inter-war period also provided a rare example of the success of a technological innovation in civilian service which led to its acceptance by the military. This kind of sequence is practically impossible today, owing to the magnitude of the effort primarily directed towards weapons development itself. The example involves the advances in aircraft design in the mid-1930s, the successful development of the all-metal, internally braced, fully cowled monoplane with retractable landing gear, variable-pitch metal propeller and enclosed cockpit pioneered by civilian aircraft in the United States. These innovations, which were refined and combined by American manufacturers responding to the needs of aviation in a country of vast distances, permitted a veritable quantum jump in the performance of fighter, bomber and transport aviation, and were accepted rapidly by all the major air powers of the time for use in military aircraft. (30) In a study of US military aircraft development in the same period the author decided that

> "... the pace of development for any weapon during the between-war years is chiefly determined by the extent to which its mission or operational function is known and defined. When there is no effective system for determining doctrine, the pace of development is necessarily slow." (31)

The Second World War saw the application of the aircraft carrier, the development of radar, the jet engine, the proximity fuse, the beginnings of miniaturization, rockets, the nerve gases, the nuclear weapon and a systematic method of analysis of weapons performance and requirements called operation analysis or operations research. (32) Perhaps as important as any of the individual weapons were the science-government relations that led to their development, the continuation of R+D in the after-war period and the concepts of 'technological preparedness' and 'technological superiority' which resulted directly from the war experience and the very weapons which had been developed in it, particularly the atomic bomb. (33)

It was at this point that the relations between scientific research and military technology became paramount. Without scientific research, advanced weapon systems would not have come into being and their continued development, beyond the basis provided by already existing scientific knowledge, would cease.

Most important of all were the derivations of two of the wartime innovations, the intercontinental ballistic missile (ICBM), deriving from shorter-range surface-to-surface rockets, and the thermonuclear or hydrogen bomb deriving from the nuclear weapon. Their particular characteristics were to condition nearly all the political and strategic moves made by the major nuclear powers in the post-war years. The United States — U.S.S.R. confrontation supplied an immediate military context, which quickly removed any abstract or theoretical attitudes to these weapons. Constant military preparedness was the lesson the world's major military powers found accentuated by the nuclear weapon, although other lessons might have been favoured. Among other things, this quickly came to mean continuous scientific and technological preparedness in sophisticated weaponry. The United States Air Force Field Manual 1 - 1 stated "Technological and practical improvements must be continuous". The magnitude of the damage that could be caused by nuclear weapons and the rapidity with which these could be delivered from 1945 to 1958 — the times were measured in hours and days for a bomber force; after 1958 it was measured in hours and minutes for intercontinental missiles — were the two key technological elements that, together with the political perceptions of extreme hostility during the Cold War, formed the postwar setting. A classic expression of this composite as seen from the American side appears in the following summation:

> The development of the atomic bomb during World War II signified a radical change in the importance of technology to national security. Although the atomic bomb had only a small role to play in that war, recognition of the disaster that might have befallen us had our enemies developed the bomb first together with the beginnings of thought about the implications of this new magnitude of firepower for future conflicts, raised technology to new heights of importance in the minds of government and military leaders. They imagined that in future wars victory would go not to the nation with superiority in material, location, or military leadership but to nations possessing superior technology. Our subsequent confrontation with another nuclear power, the U.S.S.R. and our general preoccupation with large nuclear conflicts strengthened these feelings. Mirroring this concern was the rise of spending for military research and development (R&D) from half a billion dollars in 1945 to more than six and one half billion in 1966. (34)

In 1946, a lengthy, confidential memorandum on American relations with Russia was prepared for President Truman by his Special Counsel, Clark Clifford. Summarizing the views of the Secretary of State, the Secretary of War, the Joint Chiefs of Staff and other high level officials, as well as Clifford's own view, the memo

> urged the President to arm America for possible war (with the U.S.S.R.), to enter negotiations reluctantly, and to avoid diplomatic compromises which might be interpreted as American weakness.
> ... the (future) acquisition of a strategic air force, naval forces and atomic bombs in quantity would give the U.S.S.R. the capability of striking anywhere on the globe.
> ... The Soviet Union's vulnerability is limited due to the vast area over which its key industries and natural resources are widely dispersed, but it is vulnerable to atomic weapons, biological warfare, and long-range air power. Therefore, in order to maintain our strength at a level which will be effective in restraining the Soviet Union, the U.S. must be prepared to wage atomic and biological warfare.
> Whether it would actually be in this country's interest to employ atomic and biological weapons against the Soviet Union in the events of hostilities... would require careful consideration ... But the important point is the U.S. must be prepared to wage atomic and biological warfare if necessary ... proposals on outlawing atomic warfare and long-range offensive weapons would greatly limit United States strength. (35)

The memorandum contains one of the earliest conjunctions of deterrence with war fighting capability : preparations must be made "to wage atomic and biological war". One important caveat should be made to this early post war document: it was not in fact acted upon, at least not immediately. The U.S. — U.S.S.R. "arms race" did not get underway directly after World War II. It began for the most part after the initiation of the Korean War, in June 1950. The same was therefore obviously the case for renewed programs in military R&D. Louis Ridenour, one of the major figures in the WWII nuclear weapons project and at the time one of the commissioners in the US Atomic Energy Commission, spoke to a meeting of the Atomic Scientists of Chicago on Nov.24, 1950.

> "Science," Ridenour had said, was "the shield of the free world." Was it too much to ask that science take part in mobilizing for the defense of freedom?
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> By the time the American Association for the Advancement of Science assembled in Cleveland for its annual meeting during the Christmas holidays, several proposals for mobilization of scientific manpower had become popular topics for discussion. Both the American Institute of Physics and a special group advising General Lewis B. Hershey had recommended expanding the Selective Service System to include a scientific or technical service in its own classification system. Lawrence R.Hafstad, acting as chairman of the Interdepartmental Committee on Scientific Research and Development, had warned Symington* that the nation could not afford to deplete its supply of scientific manpower. He urged the creation of a national scientific service to assure a continuing flow of young men and women into the scientific professions and the best use of all scientists in the military services.
>
> Commissioner Smyth took a broad view of the question in a speech at the scientists' convention. He admitted that scientists did not like to concentrate their efforts on instruments of war and that every scientist feared regimentation by government. But the nation's experience in World War II had proved that the full cooperation of scientists was absolutely essential in preparing for modern warfare. "Today," Smyth said, "we face a possible struggle for survival, and so our first concern as scientists must be to ask how we serve this country." He proposed a scientific service corps in which all the nation's scientists would be registered and some assigned, hopefully without coersion, to defense projects.

Within the Commission the crisis in Korea was producing a similar effect. Kenneth S. Pitzer (Director of Research in the AEC) urged that the laboratories should

> ... make more use of consultants and the universities should be prepared to undertake classified research. (36)

The destructive magnitude of nuclear weapons and their constant — and nearly instantaneous — availability drove the bilateral perceptions which led to their continued development. This produced yet greater destructive capabilities, yet more availability and still further development. Weapons and countermeasures must, it was especially felt in the West, always be capable of the peak permitted by technology at any given moment. A strategic exchange might occur at any time and its outcome would depend on relative technological superiority. In the same way, any diplomatic gain to be made by the threat of using such weapons — or the successful withstanding of such a threat — would depend on the relative technological capabilities of the nation's most sophisticated weapons and countermeasures. These precepts prevailed, and they demanded a continuous peacetime military R&D program. They also bred the spectre of 'technological surprise.' Quite often that spectre was self-induced by the knowledge of one's own research program. The initiator in the weapons R&D race nearly always induced or stimulated the subsequent development of similar systems by his opponent.

In summary, the key factors that contributed to this situation, and which together maintained it, were

- the political perceptions of executive groups in East and West, which were the prime cause and which fed the Cold War throughout,
- the decision-making process in these executive groups on matters of strategic weapons and their accompanying systems, and the impact of the military services on these decision making processes,
- the dependence of post-World War II weapons development on scientific research.

These factors produced the pattern of post-war weapons development in the U.S. and U.S.S.R. Weapons innovation, procurement and deployment in turn played a major role in setting the framework of political developments for years to come. (37) Specifically, they governed and predetermined the outcome of all arms control and disarmament negotiations.

The nuclear weapons — the warheads and the delivery systems for them — are clearly the most significant elements concerning the major powers in the post-war years. However, there have also been extensive developments in non-nuclear weapon systems since the end of the Second World War. (38) Most of these have again come from the United States and the U.S.S.R., but some have been paralleled by development in the United Kingdom, France, the Federal Republic of Germany and Sweden. Some examples are:

1. Extensive computer-controlled air-defence networks with large, early-warning, over-the-horizon radars for ballistic missile warning, and forward emplaced radar networks for anti-aircraft defence. Smaller field mobile, radar-controlled anti-aircraft missiles, with ranges as high as seventy miles, and analogous shipborne weapons.

2. Avionics: Electronics and air-borne computers play a dominating role in advanced combat aircraft: navigation, reconnaissance, bad-weather operations, engaging opposing aircraft, fire control, weapons guidance. Airborne anti-submarine warfare has undergone enormous development, with long-range, long-duration patrols, expendable sonobuoy systems, other buoy telemetry, airborne dipped sonars, infra-red and magnetic anomaly surveillance. Electronic counter-measures. Self-guided target-seeking air-to-surface missiles for use against naval and land targets.
3. Increased deployment capabilities: airlift, sealift, and rapidly deployable air bases. Greatly increased use of the helicopter. Computer-aided logistics management.
4. Advanced weapon guidance, using lasers for targeting of ordnance in field weapons and ground-support aircraft. Night-time target acquisition and fire-control devices. Radars for artillery and mortar location. The development of 'cluster' dispersable anti-personnel weapons of numerous sorts. Multiple anti-tank weapons, and precision guided munitions.
5. Nuclear power for naval vessel propulsion.
6. Chemical warfare: further developments were made by the United States and the U.S.S.R. of the nerve gas agents which had been developed in Germany in the Second World War.
7. The military use of space: satellites are used for military communications, for photographic reconnaissance in visible, infra-red and ultra-violet spectra, for electronic intelligence and for navigation and guidance. There are classified meteorological-satellite programmes and geodetic-survey satellites which supply information for ICBM guidance. Much manned space effort is directed towards strategic military uses. The development of anti-satellite weapon systems and monitoring systems.
8. As a result of the advent of ballistic missile carrying submarines, the oceans joined space as the second major new environment that was colonized by weapon systems in the post-war years. As was the case in space, this required military R&D to solve the problems of designing systems which could function in a new environment, in this case in the oceans, often at great depths, for long periods of time. Examples were bottom-mounted acoustic surveillance systems and computer processed signal filtering to process the information derived from these. Towed sonar arrays, and buoy sensor systems to provide ocean characteristics data for anti-submarine warfare environmental prediction.

New weapons developments have also been tested during the active wars that have taken place in the decades since 1943. For example, the U.S. packaged CS gas in some thirty different munitions for battlefield application during the Vietnam war (39), and the recent mideast wars have seen extensive use of electronic countermeasures — drone systems for counteracting radar controlled surface-to-air missiles.

Scientific research: the indispensable source of advanced weapons development.

How are all these weapons developed? What do their capabilities depend on? What is the contribution and role of scientific research and of military R&D?

This can best be explained by a comprehensive and detailed set of tables and figures which have been gathered specifically for this purpose. They have been divided into five groups:

Group I — What is one looking for.
Group II — Where does one look.
Group III — How does one organize the search.
Group IV — How does the process work.
Group V — What is the result (the weapons).

Beginning with Group I, seven tables and two figures try to demonstrate what kinds of knowledge are sought by military R&D. Table 1 provides nineteen examples which describe the progression from basic research to application in a weapon system. Tables 2, 3, 4 and 7 provide similar information in great detail. Table 6, a list of critical technologies intended as a guideline for export control,provides one at the same time with a listing of technologies explicitly linked to the United State's own military R&D efforts. Another way to understand what is being sought is to consider some weapon, for example aircraft such as fighter-interceptors or bombers, and to list the basic characteristics that are normally used to define their capabilities: range, payload, engine capacity (power), loiter time over target area, speed, repair time per flight hour, cost, etc. Any characteristic of fuels, metals or other materials, design, munitions, computerization, etc. that will increase or — in the case of repair time and cost — decrease these parameters is sought after. Figures 1 and 2 — showing characteristics of turbine jet engines, and the weight, accuracy and reliability of inertial navigation systems — and table 5 — the parameters of sensors for space vehicles — provide more sophisticated examples of the same kind of effort. In the case of inertial navigation systems the effort would be to reduce the weight while increasing the accuracy and reliability of these systems. Reduction in weight would in turn increase missile range, permit additional countermeasures or a higher yield warhead to be carried. The sensors for space vehicles are for the measurement of a variety of space environmental factors:

cosmic rays
radiation belts
solar particles
magnetic fields
micro meteorites
spectrographic components
ionospheric characteristics
radiation budget
atmospheric pressure
atmospheric structure

There are three or four individual instruments used to measure each of these parameters. The performance of each instrument can be improved in various ways. This begins to give one a sense of the multitude of small incremental bits of research which are accumulated to provide some particular capability. In this case years of research on all the above space environment parameters — and others in addition — were necessary to make satellite and manned space operations usable. (40)

If we turn now to the second group of tables, captioned "Where does one look", one quickly sees that the answer is quite literally every concievable branch and subbranch of scientific inquiry. Military R&D may be concerned with bacterial growth in the deep oceans, an ion species in the ionosphere, plasma behavior at the margin of space, an arborivirus in a bird parasite in Central Asia, and the most abstruse theoretical mathematics. The relevance of all are easily identified. The United States Office of Naval Research (ONR) was often given as a prime example of disinterested support of "basic research" by defence sources. In 1949 ONR was the principal supporter of fundamental research by US scientists: it was alone funding 40 percent of the nation's total expenditure in pure science. (41) However, it was established in 1946

> ... in recognition of the need to plan, encourage, and support basic research in our universities, our in-house laboratories, and the private industrial groups in those areas of knowledge that seem to be most relevant to long range Navy requirements. (42)

Branch offices were established in over a dozen cities in the United States and in European capitals to monitor research sponsored by defence and non-defence agencies in industrial and university laboratories. Navy research was stated to be 'mission-oriented', and branches of physics, geology, chemistry, psychology, mathematics, acoustics, marine geology, marine biology, ocean chemistry, physical oceanography, undersea research vehicles, life support systems, deep moored and drifting buoys, remote sensing of the sea surface, advanced data handling, and new environmental prediction techniques were listed as providing data for naval operations . (43) Harvey Brooks has provided a series of examples indicating the rewards drawn by the Navy for its military needs from its support of basic research. (Table 4) (44).

The United States Air Force soon followed suit in establishing a similar organization. AFOSR — the Air Force Office of Scientific Research — was proposed in 1949 and established in 1951 with the explicit purpose of allocating a portion of the US Air Force R&D budget for

> ... contracts with educational institutions for research in broad general fields on problems which, without being directed toward definite applications, are of definite interest to the Air Force. (45)

The United States Army lists some eighty nine scientific disciplines grouped into twelve categories in which it supports research. (Table 1). The United States Air Force Office of scientific Research lists some sixty areas of scientific research in which it has performed a 'colonizing' role: these are areas in which it has an interest and in which it subsidizes research, both in the United States and abroad. (Table 2).

There is no longer any distinction whatever between basic scientific research which may have military relevance and that which does not. This is not because science has changed but because the military 'requirements' and what is militarily relevant has. Weapons are now universally dispersed in all environments — space, sea depths, arctic, jungle — and new weapons, communications systems, sensors and support equipment involve so many new energy forms and materials that there is no area of scientific research that is not now of interest to the military. The answers to questions of how materials and energy will behave in these newer environments into which weapons systems have moved can only be answered by what is clearly basic research. None of the support of basic science by defence ministries is accidental. It is quite rational and purposeful, and its aim is not primarily the support of scientific research per se. It must feed the goose to obtain the golden egg. The United States Office of Naval Research and the Air Force Office of Scientific Research have released a series of publications over the years with the same explicit message. (46) In these reports and papers the agencies do not claim to be funding science in which they see no relevance for their operational requirements. They see their role as quite the opposite and clearly say so.

The same situation prevails to varying degrees in the U.S.S.R. and in the United Kingdom, France and in the Federal Republic of Germany. (47) The seven major R&D establishments of the British Ministry of Aviation spend some 40 per cent of their operating costs on general research, defined as research carried out to increase scientific knowledge, or research in fields of recognized technological importance, that is, 'basic research'. (48). British naval weapon R&D officials explained in turn that

> ... in this underwater field one needs such a big investment in

> facilities and basic technology and basic research in order to provide the foundation on which to build weapons developments. (49)

Representatives of the British Navy's Admiralty Underwater Weapons Establishment (Portland) explained their interest in helping a British university establish a professorial chair in Ocean science by the following:

> The propagation mechanism of underwater acoustics and associated signal processing problems and transducer systems all involve aspects of signal processing theory and radiation theory which go beyond the limits encountered in electro-magnetics and which are not normally taught in the necessary depth at universities. The medium that causes these difficulties, the ocean, produces its peculiar currents and pressure and temperature variations, and salinaty variations, due to complex interactions between the water medium and geophysical heat sources, gravitational effects from the earth, inertial effects, gravitational effects from stars, and the outside weather, which are extraordinarily complex, which again are imperfectly understood and are studied and thought about only in very limited parts of the academic world. (50)

The same service laboratory indicated the following R&D contracts at British universities.

> Research contracts have been placed by A.U.W.E. in the last five years with the Universities of Nottingham, London, Liverpool, North Wales, Birmingham, Bristol, Newcastle, Salford, Sussex, Southampton, and Brighton C.A.T., on the following subjects — Rapid analogue/digital computer, Magnetic structure of alloy steels, Electro-mechanical filters, Behaviour of transducers, Effects of baffles on fields of acoustic arrays. Acoustic radiation impedance during transients, Ultrasonic techniques (acoustic camera). Oceanographic research, Sound velocity in core samples, Non-linear techniques, Target classification, Piezoelectric ceramics, Battery research and Residual magnetism in alloys. (51)

The mix of basic and applied R&D is evident.

Sponsoring symposia, and the publication of symposia proceedings, is also a significant activity used to enhance research in particular subject areas. In 1966 a single service, the United States Air Force, alone sponsored some thirty-eight conferences and symposia in various branches of science. (Table 6) (52)

> Through judicious support of phenomena-oriented research and other activities such as symposia, the Air Force can colonize the activity in a research area, with the result that the Air Force research support, amplified by that supported by non-AF funds, can effect very significantly the rate of development of important scientific areas.
>
> ... the distribution of fields of interest is dominated by those areas clearly relevant to the USAF. At the same time, the wide variety of fields of interest to the Air Force is reflected. (53)

Similar mechanisms exist in NATO through AGARD, the NATO Advisory Group for Aerospace Research and Development. AGARD now organizes some forty meetings each year in its member nations and has held 250 major technical meetings in the past twenty years. Similar mechanisms also exist within the Warsaw Pact.

It is a point of interest that very basic research in the social sciences, such as anthropology did not escape this nearly universal search for relevant and applicable information. Early post war research by Margaret Mead, Ruth Benedict and Rhoda Metraux was funded by the Human Resources division of the Office of Naval Research. (54) Massive anthropological and political science indicator studies were undertaken, as well as field studies of more immediate impact to ongoing US military operations, such as those in Southeast Asia. (55) Perhaps even more than in the natural sciences these studies exemplified the basic and important truth in the bon mot: "One Man's Basic Research May Be Another Man's Applied." (56)

Basic research funded by the United States and carried out in overseas institutions is explicitly directed towards military applications. The United States Department of Defense "Requirements for Research Studies to be Conducted Abroad at Foreign Institutions" spells out exact and stringent criteria requiring any prospectively funded overseas research to be 'clearly significant in meeting urgent defense needs of the U.S.'. (57) The European office of the Air Research and Development Command is, in the words of its statement of mission,

> established to procure in Free Europe research and development in support of the mission of the Air Force and provide a scientific liaison fostering mutually beneficial relations between the United States and European scientific communities.
>
> The mission of the parent ARDC is to support the conduct of basic research on behalf of the Air Force, to develop new and improved devices, processes, and techniques and to maintain qualitative superiority of material. (58)

The purpose of the European office, established in 1952, was "to tap the additional and often unique scientific resources available in Western Europe". The most extreme efforts are sometimes made to dissociate such funded defence research from its projected applicability. A research project in the chemistry of the upper atmosphere funded by the United States Air Force Office of Scientific Research in New Zealand and admitted by AFOSR to have 'important aero-space implications', was reportedly described by Canterbury University publicity as being 'concerned with pollution caused by supersonic airliners'. (59) In reality, interactions of molecular species in the upper atmosphere are of interest to the military for their effects on missile testing, re-entry problems, military communications involving the ionosphere, and satellite reconnaissance. Very similar research carried out by another university researcher in Oslo, Norway, was claimed to be 'pure science' and 'of no military interest'. In another example an eminent scientist with full understanding of the nature of research on problems of chemical and biological warfare wrote:

> ,.. The Microbiological Establishment at Porton (England) has been generous enough to finance research projects in various well-established university laboratories in this country for the pursuance of fundamental bio-chemical and biological studies. These would be judged important and sound on any academic standard, and they have no, or only the most tenuous, relation to biological warfare problems. Examples cited included works on ... enzymes involved in nerve transmission, studies on the fate of toxic drugs in the body and structural studies on ricin... (60)

The studies may well be 'fundamental', but the author could hardly have picked examples more pertinent or more related to research in chemical warfare problems, (rather than biological warfare), had he tried to.

It is useful to look at some of the definitions or description used for administrative purposes in the US regarding science and military R&D.

> <u>Military Sciences</u>
>
> "This activity supports research of potential military applications in the physical, mathematical, environmental, engineering, biomedical and behavioral sciences. The objective is to provide the basic understanding necessary to efficiently develop new systems and improve military operations. For example, research in electronics will provide more reliable and higher performance components for sensors, weapons and communications systems; research in oceanography will increase the effectiveness of anti-submarine systems ..." (61)
>
> "The objectives of the (Defense Research Sciences Program) is to take maximum advantage of the unique capabilities of each of the various performers of research: academia, in-house laboratories, industrial laboratories, and nonprofit research institutions. The objective of the program is to provide
>
> - a source of new concepts which introduce major changes in technological and operational capability
> - fundamental knowledge for the solution of identified military problems. (62)
>
> "<u>Technology Base;</u> our technology base is the foundation for future Air Force capabilities. One objective of the technology base effort is to solve specific technical problems. Another is to provide new revolutionary technology. In doing so, we will support a third objective, to prevent technological surprise." (63)

An extremely important point made over and over again in this introductory chapter — at times implicitly and at times explicitly — is the extremely vague boundary between 'basic' and 'applied' research. A demonstration of this was the outcome of the passage of "the Mansfield Amendment" to the annual military procurement and research authorization bill by the US Senate on Nov. 6, 1969. This amendment, Section 203, stated in its operative portion that all research funded by the US Dept. of Defense must have a

"Direct and apparent relationship to a specific military function or operation". (64) The action, more or less in response to the Vietnam war, was a clear effort to slow the pace of military R&D. The result, in the plain words of the Defense Science Board,was that

> When the original Mansfield Amendment mandated that all research supported by DOD be relevant to some military problem, the response of DOD (oversimplified) was to define all research being done under DOD auspices as relevant. (65)

More specifically, the Department of Defense said that it was not able to formulate specific guidance to try and attain uniform application of Section 203 by all its program officers "because it was not possible to make precise, long range predictions about the results and ultimate application of basic research". (66) At the same time it had always been the practice of the program officers and the Dept. of Defense to budget all basic R&D according to program element numbers that linked the research to specific technical and strategic military needs. These statements are rarely seen even by the scientist whose work is described.

> DOD can ... justify all contracts through an elaborate system of accounting, which ties even the most fundamental work to a specific, military objective; and, finally, DOD, as a matter of policy, discourages scientists from stating military uses for their research. (67)

The most significant development however, was that the Mansfield Amendment lasted only one year. In the DOD Authorization bill for FY 1971, Section 203 was changed. Instead of the phrase "... direct and apparent relationship to a specific military function or operation" it read "... in the opinion of the Secretary of Defense, a potential relationship...". The House-Senate conference report unanimously concluded that the Dept. of Defense should be given "... greater assurance that basic research may be conducted to provide the broadest body of scientific knowledge to support future military needs." (68) In the intervening year it was estimated that basic science funded by the Dept. of Defense and by the various military services decreased by no more than two percent.

For a detailed example of the way in which the problem was handled, one can look at the 118 new "Project Themis" centers begun in academic institutions beginning in 1966. Support for research was provided in areas where the Dept. of Defense had clear identifiable needs. The initial choices were detection, surveillance, navigation and control, energy and power, information processing systems, military vehicle technology, material science, environmental services and social and behavioral sciences. "Projects in other areas were acceptable if they served military needs." The Dept. of Defense made the purpose of the program explicit: "The development of new centers of excellence capable of solving important defense problems in the years ahead". (69). However, the research funded was considered basic research, and following the passage of the Mansfield Amendment Project Themis funding was drawn in. However, the result was for the most part only that "Work started under Themis is difficult to trace, since projects formerly funded under Themis have in many cases been transferred to other budget headings." (70)

We can now turn to the third group of tables entitled "How does one organize the search." Using the United States as a starting point, military R&D is performed in three groups of performers. Using the governments military R.D.T. and E. budget for Fiscal Year 1978 as an example, the overwhelming amount, by expenditure, 70.5% was carried out by industrial defense contractors. 25% was carried out in what are referred to as the "in-house" laboratories of the military services (Army, Navy and Air Force), NASA and the Atomic Energy Commission and its successor agencies. An additional 1.7% was spent in the Federal Contract Research Centers which are defense research institutions established by the Dept. of Defense for particular purposes. (The Jet Propulsion Research Laboratory, Lincoln Laboratory, etc.) The third and smallest fraction, 2.8%, was spent on R&D carried out in Universities. These general proportions have been more or less constant. (71) About 10% of the total is usually considered to be 'basic research'; the remaining 90% development, test and evaluation. (72) Different countries in the West apportion their military R&D expenditure between these same three performing groups to varying degrees. (73)

For the tables in Group III, I have picked a set that describe the "in-house" laboratories of the United States for the most part, since they again permit one to obtain a picture of the substantive coverage of these institutions and thereby a notion of the kinds of research carried out in them. (74) Tables 1 through 6 list the "in-house" laboratories of the United States, and tables 7, 8 and 9 those of Britain. The USSR divides its military research between laboratories belonging to the arms production ministries, individual defense production installations, the USSR academy of Sciences, Universities, and design bureaus, and some of these are indicated in fig. 4 and 5 of Group V, discussed below. The number of in-house laboratories and the capital investment that has been put into these is very great: the capital investment of one single US Air Force aeronautical laboratory in 1969 was $ 415 million. (78) The main point is not the precise numbers of the laboratories — as lists for different years vary in number — but to demonstrate their coverage. The 1976 US Department of Defense source which we have used shows 50 Army, 35 Navy and 29 Air Force laboratories for a total of 136. (76) NASA and the AEC maintain roughly an additional 35 laboratories. Britain maintains 26 different defense research establishments, excluding those of its Atomic Energy Authority. (77) Other nations which maintain smaller though still substantial military R&D programs usually combine these under a single establishment rather than having multiple laboratories serving individual military services, for example the Netherlands' National Defense Research Organization (TNO), Sweden's Defense Research Establishment (FOA), Australia's Defense Standards Laboratories, The Canadian Armament Research and Development Establishment, Japan's Technical Research and Development Institute (TRDI), India's Research and Development Organization, Ministry of Defense, though these organizations may still encompass more than one facility. Other nations that maintain particularly sizable military R&D organizations are Israel and South Africa. NATO maintains a sizable joint military R&D oversight board, AGARD, the Advisory Group for Aerospace Research and Development. (78) NATO also maintains two alliance R&D establishments, the Undersea Warfare Center at La Spezia, Italy, and the SHAPE Technical Center at The Hague, Netherlands, which began primarily as an air defense research center. NATO's science activities are also substantially oriented towards defense research interests. (79) There also exists a joint French-West German military R&D institute, the German-French Research Institute of Saint Louis. The Warsaw Treaty Organization on the other hand, through its Military Scientific Technical Council, under the primary control of the USSR, maintains a far more operational control over military R&D programs, priorities and initiatives in its member states (see page 38 below).

The role of defence science advisory structures have at times played an extremely important and even instrumental role. Several of the Special Assistants for Science and Technology to the US President — the "Science Advisor" — have written memoirs which describe their role and the questions under consideration on weapon development during their tenure. (80) It is clear that the major concern of the office — Office of Science and Technology (OST) — and the senior advisory board that they headed — the Presidents Science Advisory Committee (PSAC) — was the assessment of questions regarding weapon development. (81) The overlap in membership in such bodies as the President's Science Advisory Committee, the Defense Science Board serving the office of the Secretary of Defence, and the Science advisory boards of the individual military advices — Air Force, Navy, Army — was considerable. The same individuals also quite often served on policy assessing and recommending committees of the National Academy of Sciences / National Research Council, including its Committee on Science and Public Policy. (82)

Perhaps most well known to the general public was the dispute in 1949-50 that concerned the recommendations as to whether the United States should or should not construct a thermonuclear weapon. (83) The committee concerned in this issue was the General Advisory Committee of the Atomic Energy Commission, composed for the most part of individuals that had been instrumental in the WWII development of a nuclear weapon. The most significant period in the history of PSAC was probably the years 1957 to 1963.

Advisory groups played an extraordinary and crucial role in the 1950 to 1960 decade, particularly during the Eisenhower presidential terms. These committees were instrumental in nearly all cases that made major new overall policy initiatives, overturned or revised existing priorities and assessments, or directed development of new technologies. The most famous of these groups were the von Neumann or "Teapot" Committee — more formally the Strategic Missiles Evaluation Committee, or SMEC — in 1953 and 1954, the Killian or Surprise Attack Study — Meeting the Threat of Surprise Attack — in 1955, and the Gaither Committee, in 1957-58. (84) The reports of John von Neumann's committee in 1954 touched off the enormous national effort to perfect intercontinental ballistic missiles capable of delivering nuclear weapons to virtually any point on the globe.

> By 1952 or 1953, quantitative analysis had indicated that cruise missiles would be less accurate, less dependable, and more costly (in terms of combat effectiveness) than ballistic missiles. But virtually all of the research leading to such conclusions was conducted outside the regular Air Force, either by independent study groups or by committees created at the insistence of senior civilian officials. The Atlas ballistic missile program is perhaps the best known example of projects so affected. Although proposed as early as 1946, Atlas was continually subordinated to cruise missiles, at first because of assumed technological inadequacies, later because of technological misjudgments intermingled with shortcomings of doctrine. In each instance decisions were reflected in allocations of funds, or non-allocations.
>
> ...
>
> Until at least 1951 the Air Force was inherently incapable of accepting the commitment of any substantial part of its development-production budget to such exotic weapons as intercontinental ballistic missiles. The establishment of a separate Air Research and Development Command in 1951 removed that particular obstacle. Technology, or its uncertainty, remained an obstacle until 1952, after which time those who looked

> closely enough into the matter could find evidence that an intercontinental missile was no longer a particularly high risk investment in unlikely technology. In retrospect, it is quite plain that the difficulties of developing a ballistic missile were somewhat less appalling than the unacknowledged difficulties of developing a comparably accurate, reliable, and effective cruise missile. Put baldly, Atlas was much easier and cheaper to develop than Navajo would have been, or Snark, the evolutionary cruise missiles Atlas competed with. (85)

The largest number of the early advisory groups however was a series of roughly twenty special panels established to examine more or less broad military-technological problem areas. (See table) They were initially known as the "summer study" groups, but were soon being empaneled at all times of the year. For the most part these analysis and recommendation groups were an initiative of the US Navy. (86) Some particularly significant examples of these studies and the systems that resulted from them are:

— project Charles (1952) which conceived of the concept of a chain of radar stations in the Canadian Archipelago north of the Arctic circle, which became the DEW (Distant Early Warning) line. The project group also recommended the establishment of the Lincoln laboratory, which has continued to work on air defence and radar to the present day.

— project Hartwell (1950).

> The very first of the undersea-warfare studies, Project Hartwell, established a coherent perspective on practically the entire range of facets, technological as well as operational, which were found to affect our ability to safeguard the use of the seas in the presence of enemy submarines. For years to come, this gave much structure and vitality to the Navy's ASW program, providing a road map for many of the ensuing developments, some of which reached the operational stage in the later years. Notable among these are the use of helicopters in ASW; torpedoes, with an initial air trajectory, such as ASROC and the later SUBROC; radars specifically pointed up for snorkel search; the tactics of SSK and the use of airborne hunter-killer units; the potential of atomic weapons as well as of new power plants, such as fuel cells and closed-cycle engines; and the development of improved communications for submarines. (87)

Hartwell also recommended the establishment of a permanent laboratory, in this case the Hudson Laboratory, which subsequently carried out much of the basic marine geophysics and oceanography research on which underwater acoustic systems development depended.

— project Lamplight (1954)

> As soon as the Lamplight Report appeared and could be reviewed, a vigorous effort got underway to formulate and launch R&D programs responsive to its recommendations. Perhaps most decisive among the many new departures that took their inspiration from the Lamplight study are the computer-centered command control systems: The tactical systems for the control of Fleet air defense operations at sea and

The "Summer Study" Panels

	Name of Study Group *	Year	Purpose of Study
1.	Lexington	1948	Nuclear powered flight
2.	Hartwell	1950	"Security of Overseas Transport": Detecting submerged submarines, ASW
3.	Metcalf	1951	Military role of infrared detection
4.	Michael	1951	Problems in ASW
5.	Charles (Air Force)	1952(?)	Continental air defence
6.	East River (Army)	1952(?)	Civil defence (post thermonuclear attack)
7.	Vista (Army)	1952(?9	Weapons, techniques and tactics for the support of ground troops
8.	Lamplight	1954	Strategic defence
9.	Nobska	1956	Threat and opportunities offered by the nuclear submarine
10.	Monte	1957	Mine warfare and countermeasures
11.	Monte-Plus-5	1962	Mine warfare and countermeasures
12.	Pebble	1965	Mine warfare and countermeasures
13.	White Oak	1958	"Security of Overseas Transport" (same as Hartwell, 1950)
14.	Atlantis	1959	Ocean Surveillance
15.	Sorrento	1959	Non-acoustic submarine detection
16.	Walrus	1960	Use of the merchant marine in wartime
17.	South Lincoln	1962	Command, control and communication for the Polaris SLBM fleet
18.	Starlight	1962	Use of space satellite capabilities by the Navy
19.	Sonar Signal Study	1963	ASW
20.	Forecast (Air Force)	1963	Future space needs of the Air Force (See ASAT paper, pg) The function of this group was more post hoc and propagandistic
21.	Sea bed	1964	"... determined the countries requirement for future seabased strategic deterrents beyond Polaris/Poseidon "

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* Panel served US Navy unless otherwise indicated.

> of the air space over invasion beaches, the centers for the management of ocean surveillance data, and the current generation of Fleet headquarters command posts. Numerous other recommendations, relating to the electronic collection, transmission, and processing of data for air defense purposes, were given prompt support — with lasting effect on the Navy's entire electronics program. (88)

— Project Nobska, in 1956, probably the most famous of all the "summer-study" groups, assembled the mosaic of technical capabilities on which the feasibility of the Polaris submarine launched ballistic missile system was decided. (89)

The four major elements were:

- the nuclear reactor power plant for the submarine, providing true long endurance submersion;
- solid fuel for the missile, reducing the hazards of carrying liquid fuel missiles on board a submarine, which was considered a prohibitive risk;
- the Submarine Inertial Guidance System (SINS), and an equivalent miniaturized inertial guidance package for the missile, to provide sufficient accuracy for the missile;
- a thermonuclear warhead of sufficient yield but small enought size to be useful in the missile.

As in the case of the all the other major missile developments — the ICBM, ABM, and long range strategic cruise missile — the ability to develop the submarine launched ballistic missile system depended on the more or less simultaneous "maturation" of several key independent technologies, all of which depended on a chain of antecedent R&D developments of their own. This pattern had been noted historically before in relation to changes in the entire nature of combat between the European states, rather than in terms of the development of a single weapon system.

> Only with the almost simultaneous appearance just before 1850 of practical rifled weapons, an extensive rail system, efficient steam propulsion for ships and electrical communications, did technological change begin to force major changes in the nature of warfare. Of course invention ocurred in most cases much earlier, but we are speaking here of the development, general acceptance, and deployment that can explain the timing of related changes. (90)

(This pattern will be discussed in further detail in the section that follows dealing with the fourth set of tables.)

Many of the scientists who served on these panels had been involved in military R&D during WWII. Quite often, after a sort of aprenticeship on one or more of the study groups, the same individuals were named to the Defense

Science Board (DSB), individual service science advisory boards, NATO science advisory positions, and in the most select cases, to PSAC. The function of the specially empanelled study groups was to some degree subsequentally institutionalized in the various defense science boards and in ad hoc subcommittees of PSAC and the DSB that were given special problems to investigate.

There were in some cases other extraordinary mechanisms or sources of pressure outside of the channels of routine weapon development by the military services that pushed particular technologies. The US Central Intelligence Agency had been a driving force behind the development of space satellites for intelligence purposes, "at times to the embarassment of the Air Force," as two ex-CIA administrators wrote in 1974.

> Due in great part to the technical advances made by scientists and engineers working under Bissell, the CIA largely dominated the U.S. government's satellite reconnaissance programs in the late 1950s and well into the 1960s. Even today, when the Air Force has taken over most of the operational aspects of the satellite programs, the CIA is responsible for many of the research and development breakthroughs. (91)

In the discussion of the tables in group II the mechanism of support for conference and conference proceedings as a means of furthering research areas that the military is interested in was already noted. Another significant source of support for military research and development is the result of programs in graduate education. The importance is not in terms of its proportion of military R&D related expenditure — of which it would be extremely small — but as a means of increasing the manpower pool available for future military R&D employment. In the mid-1960s AFOSR provided at least partially for the research of more than a thousand doctoral candidates in the United States and of many more candidates at the master's level. These students were "developing their expertise in areas particularly relevant to Department of Defense interest." (92) In the early 1960s, 65 per cent of all research support in academic engineering in the United States came from DOD and NASA, and only about 6 per cent came from industrial sources. Over 30 per cent of academic research in the physical sciences was still dependent on the Defense Department as late as 1970, and the patterns of Defense Department support still set the precedents for much of the support from other government agencies. (93) The guiding of programmes in graduate education to supply manpower and to develop expertise tailored to specific military research and development requirements can be assumed to exist in all countries doing defence research. It was noted in the British report quoted previously, and it was demonstrated in several Canadian reports in the early and mid-1950s which pointed out that "the principal limiting factor in Canadian BW (biological warfare) research was the fact that there were not enough medical bacteriologists in Canada to meet even the civilian needs of the population", and proposing financial support for the training of bacteriologists and more efficient use of available BW relevant facilities at Canadian universities. (94)

The fourth group of tables brings us to the point where R&D has begun to produce weapons, or their components. The tables in Group IV are divided into two parts. The first part consists of examples of the research and development histories of nine US weapon systems or components.

The figures are adapted from more detailed versions prepared as part of a study entitled <u>Management Factors Affecting Research and Exploratory Development.</u> (95) The study was prepared in April 1965 by the consulting firm Arthur D.Little Inc. for the Director of Defense, Research and Engineering of the US Dept. of Defense. The weapons systems or components for which development histories are presented are as follows:

1) Mark 46-0 Acoustic Homing Torpeds
2) Inertial Guidance and Navigation
3) Transistors and Other Solid-State Components
4) ACM-28 "Hound Dog" Air-To-Ground-missile
5) Solid Propellant Rockets (Propellant)
6) Solid Propellant Rockets (Controls)
7) Sergeant Missile
8) Polaris Missile
9) Minuteman Missile

The A.D.Little study, a part of the larger and more well known Project <u>Hindsight</u> study, was commissioned by the US Dept. of Defense in an attempt to ascertain to what degree and in what manner basic research led to innovations of use in the development of weapons systems. The following remarks are taken from the description of the A.D.Little researchers regarding their findings:

> "... In each case an attempt has been made to display in graphic form a historical tree showing a main stream of development which contributed to one of these systems, leading back to origins in exploratory activity. The particular innovative research and exploratory development activities which we have identified as R&D Events are indicated on these trees. Thus, these show the time sequence of the R&D Events, the interconnection of R&D Events and other research and development activity into connected progressions, the weapon system subsystems, circuits, devices, and materials which benefited from these progressions of research and development...
>
> Two things are immediately obvious from these graphical presentations. First, there are very few spectacular "key" Events, technological breakthroughs, or other innovations which could be described in dramatic terms.

The bulk of the innovations were relatively minor, and seem in retrospect quite uninteresting. Originally, we were determined to find R&D Events of great importance, and tended to ignore avenues of investigation which would turn up only relatively routine activity. The spectacular Events failed to materialize in large numbers, and we now realize that the number of unspectacular R&D Events could have been multiplied considerably if the study had been carried out with more modest expectations. In fact, the study of the Bull-Pup Missile carried out by the DDR&E steering group adopted such a point of view, and unearthed proportionately a much larger number of R&D Events.

A second observation is that the R&D Events contributing to a particular weapon system development are spread over a long period of time. The actual time spread is underestimated in these charts, for we made no particular attempt to carry our historical efforts back more than twenty years. Indirectly, this shows that there is no well defined research phase or exploratory development phase in the history of the development of these particular weapons systems. This point is further emphasized by later evidence showing that a significant proportion of exploratory development activities only take their definitive form after problems arising in later stages of system development, or even in operational use, have to be faced.

....

For half of the Events the technological base had existed five or more years prior to Event initiation: that is, except for the particular innovative idea which formed the kernel of the Event, all the other science and technology involved had existed and been available for five or more years... In many cases a recognition of a specific need followed some time after a more general need had been widely recognized. In these cases the Event was responsive to the more specific need rather than the more general. For example, the design and demonstration of a low-cavitation propellor, was based on general work started at Naval Ordnance Research Laboratory at Pennsylvania State University. This work primarily took the form of theoretical analysis and experimental studies of hydrodynamics at the Garfield Thomas Water Tunnel, and it was carried on for six years in the absence of specific requirements for high-speed quiet propellors.

In 1954, the Bureau of Ordnance made a specific request concerning the feasibility of a high-speed, low-cavitation propellor for use in torpedoes. With this stimulus, an experimental propellor was designed and demonstrated in about a year. ... ORL had claimed for about five years before that they could design such a propellor, but no actual design appears to have been undertaken until the specific need was pressed. Since then, the design of high-speed, low-cavitation propellors has become commonplace.

Logically, making a need more specific reduces the range of acceptable solutions. Nevertheless, in this case and in most of the others, the work which actually achieved a utilized result was stimulated by the specific need. Furthermore, this work resulted not only in a specific propellor, but in general design methods so broad that no further work on this class of propellors is likely to be called exploratory development.

In many of the Events the burst of successfully utilized exploratory activity ... started only when the three following elements were present:

a. An explicitly understood need, goal, or mission;

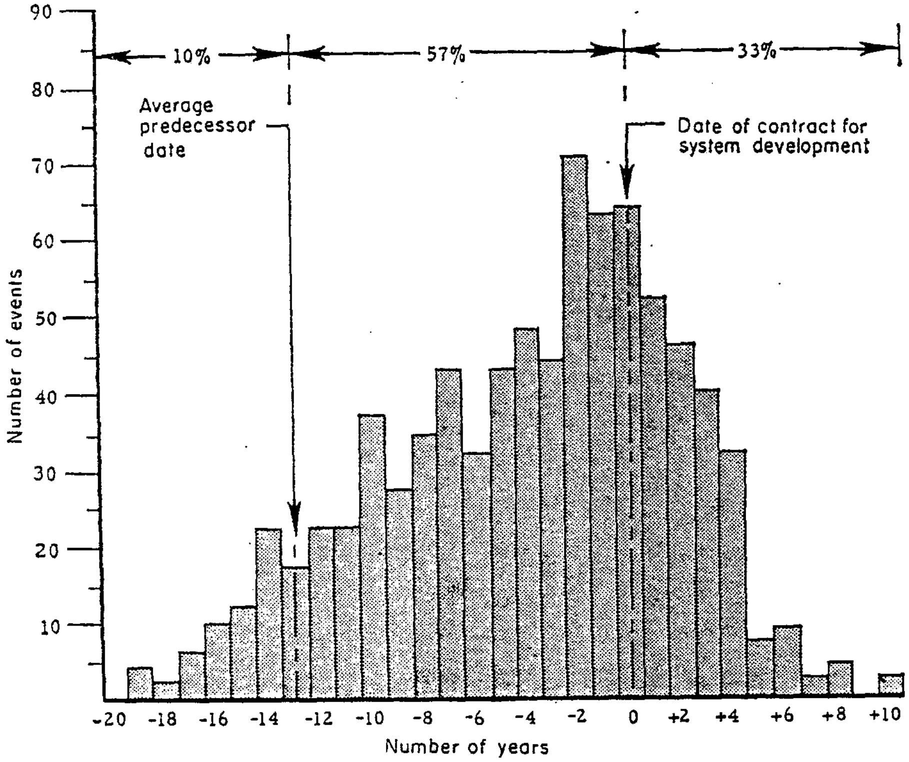


Fig. The time distribution of the Events identified in Project Hindsight with respect to the development-contract dates of the systems in which the Events appear.

Source: Project Hindsight report.

TABLE
Complexity-Maintainability Trend

Aircraft Group	*Group Average MMH/FH*
F-5A, B, E	18
A-7B, C, E	23
F-4B, D, E, J, N	38
F-14A, F-15, F-111A, D, E, F	48

Highest: F-14A = 59.97

Lowest: F-5A, B = 16.0

Source, J.M.Epstein, 1984.

b. A source of ideas, typically a pool of information, experience and insight in the minds of people who could apply it; and

c. Resources, usually facilities, materials, money, and trained and experienced men, which could be committed to do a job.

As an illustration, consider the evelopment of techniques for the preparation of sound thick sections of highly oriented pyrolytic graphite. This activity was carried out in the Materials Section of a nuclear power group in the Research Division of a large defense contracting firm. The nuclear power group was working on a concept for a liquid-metal fueled, gas-cooled nuclear reactor.

The particular need in this case was for a suitable impermeable protective coating for graphite, to permit its use as a primary material of construction. The properties of graphite make it particularly suitable to serve certain functions in a reactor; impermeability was desired to control the diffusion of the gas coolant. This particular formulation of the need was jointly arrived at by the people in the Materials Section and other scientists and technologists actively engaged in reactor design. The over-all goal, which was shared by the Materials Section, was to demonstrate the superiority of a nuclear reactor based on some novel concepts.

The parent Project Hindsight study surveyed some twenty weapons or components in all, including those listed above. (96) Fifteen of the twenty produced 638 research events; 39 percent had been made in Dept. of Defense in-house laboratories, 49 percent in industry, 9 percent in universities and research contract centers, 2 percent in non-defense federal laboratories, and one percent in foreign laboratories. The project report stated that "A clear understanding of a DOD need motivated 95 percent of all events." (97) The report was taken to be a negative appraisal of the usefulness of Dept. of Defense support of basic research. The total expenditure for this purpose by DOD between 1945 and 1966 was greater than that of the National Science Foundation, which had been established explicitly with the purpose of supporting basic research. The basic science on which the weapon systems developed up to 1966 had depended for the most part had been done before 1945.

Let us then look at the total data base of 710 Events.

First, we find that 9 percent of the Events are classified as science Events and 91 percent as technology Events. The science Events are distributed as follows: 6.7 percent of all Events were motivated by a DOD need and are therefore classified as applied science: 2 percent were motivated by a commercial or non-defense need and are also applied science. Only 0.3 percent of all Events were classified as undirected science. Of all science Events, 76 percent were motivated by a DOD need. If we look at the technology Events, we find that, of all Events, 27 percent were directed at what we call a "generic, DOD-oriented technology," that is, a broad class of defense needs not related to a particular system or system concept — for example high-power radar components, improved solid propellants, or titanium alloys.

Forty-one percent of all Events were motivated by a system or system concept in the early or "advanced development" stage, and 20 percent by systems in the later, or "engineering development," stage. Finally, 3 percent of all Events were motivated by non-DOD end-item need. Of the technology Events 97 percent were motivated by a DOD need. Overall, nearly 95 percent of all Events were directed toward filling a DOD need.

We found that in the great majority of cases the initial recognition of need came from an external group associated with systems design, but that the technical initiative for the solution came primarily from the research-performing group. That is, the need-recognizers made the researchers aware of the nature of the problems but did not dictate the nature of the solutions.

We find that 86 percent of the Events were funded directly by the Department of Defense and an additional 9 percent by defense-oriented industry. Only 3 percent were funded by commercially oriented industry, and only 1 percent by other government agencies. One percent were funded by other sources. It is interesting that, although the non-defense sector had available an estimated 40 percent of all science and technology funds expended in the U.S. during the period covered by the study, only 5 percent of the Events identified by Project Hindsight were funded there. Per dollar of input effort, the non-defense sector produced less than one-tenth as many defense-utilized innovations as did the defense sector.

.....

We made a crude estimate of the military effectiveness of the successor system in a defined role, divided by its total procurement and operating cost, and made a similar estimate for the predecessor system in the same role. We obtained improvement factors of 1.6:1 for the transport aircraft, 10:1 for the sea mine, and, for the search radar, 40:1 when we require current performance from the old technology and 5:1 when we require the old performance with current technology. We believe that an average improvement factor of 2:1 would be a conservative estimate for the systems we studied. If this same improvement factor were to apply to all the equipment in the total inventory of some $80 billion, we can see that the approximately $10 billion of DOD funds expended in the support of science and technology over the period 1946 to 1962, when most of our Events occurred and which, in fact, financed most of these Events, has been paid back many times over. We believe our study shows, also, that, had the Defense Department merely waited passively for the non-defense sectors of the economy or government to produce the science and technology it needed, our military equipment would be far inferior to what it is today. We believe that the traditional DOD management policy of keeping applied science and technology closely related to the needs of systems and equipment in development (a policy which, of course, is also characteristic of industry) is basically sound if one wants an economic payoff on the 10-year (or shorter) time scale.

.....

When a weapon system is compared with its predecessor of 10 to 20 years earlier, its ratio of performance to cost and its mean time to failure typically are greater by factors of 2 to 10. Moreover, the operating manpower needed to obtain the same calculated military effectiveness usually drops by a factor of 2 or more. That is, the increase ineffectiveness/cost is often 100 percent or more. Yet when one examines the equipment design in detail and tries to determine why this large change

> has occurred, no one item seems capable of accounting for more than a small fraction of the net change. Thus, for example, if one were forced to use the older steel compressor blades in the C-141 turbofan engines, rather than the titanium-aluminium-vanadium alloy mentioned above, the performance of the aircraft would be reduced only slightly, perhaps a percent or so. Still, the C-141 designed in 1964 has a ton-mile cost of only 60 percent that of the turboprop C-130 designed in 1954, which did use steel compressor blades. A careful examination of the C-141 design shows, however, that there are a large number of identifiable significant technical contributions which together explain the improved performance. (98)

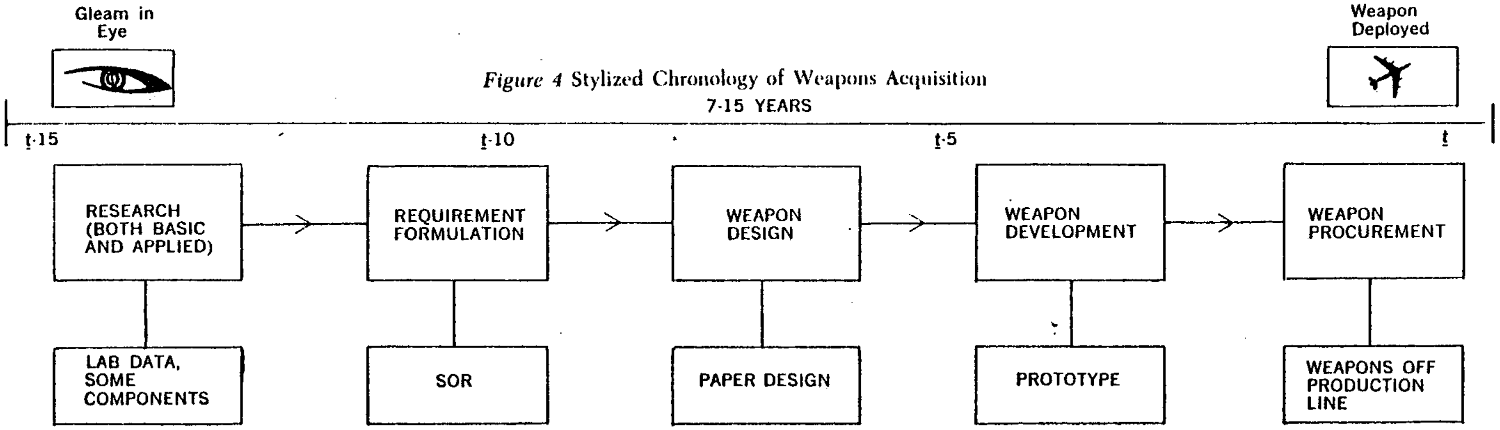
With the passage of an additional fifteen to twenty years since the Hindsight studies were made, and the technological and cost increments that have materialized during those years, the latter conclusion has been rather strongly contested by the newer studies of US Dept. of Defense weapons acquisition written in the late 1970's and early 1980's, such as those by Spinney and Fallows: (99) For example, a recent US Congressional Budget office study points out that the US Army's new M-1 tank costs 35-41% more to operate, is three times the initial cost, its gas mileage is half that of its predecessor, and for every hour of operation the M-1 requires an average of 2 hours and 42 minutes of maintenance in comparison to 24 minutes for its predecessor. (See also aircraft Mean Maintenance Manhours per Flight H.values)

The Hindsight studies clearly demonstrated that the R&D contribution to weapons development was greatest when the efforts were oriented to defined defense needs. In addition, the production of scientific and technological information utilized in weapons systems was substantially more efficient when research efforts were funded and managed by defense agencies than when non-defense interests and orientations dominated. This should not be terribly surprising: it is the raison d'etre of every national managed military R&D program worldwide.

Other studies have in effect inverted the historical tracing of scientific and technological derivations of weapon systems by forecasting — projecting future requirements for defense needs — in order to select and plan R&D priorities so as to obtain the identified capabilities. (100) Yet others have utilized the same understanding of the process of R&D-to-weapons development in scientific intelligence, even in the context of arms control. (101)

Part II of the tables in Group IV present eleven tables and figures which compare US and USSR development of analogous weapons systems. These serve as a bridge to the subject of weapons systems acquisition, which is also the basic concern of the tables and figures presented in Group V. Fig. below provides a very generalized synoptic overview of the process from idea to

Figure 4 Stylized Chronology of Weapons Acquisition



RESEARCH (BOTH BASIC AND APPLIED)

MAJOR ACTORS:

NASA
DDR&E
services
contractors

Most of the basic research necessary to achieve a weapon deployable at t is nearing completion. The character of this research is determined with substantial autonomy by the organizations which staff and perform it: NASA, DDR&E (including ARPA), the services and contractors.

Typically research is aimed at achievement of capabilities that the services would like to have; in turn the research labs' enthusiasms fuel service preference.

REQUIREMENT FORMULATION

MAJOR ACTORS:

service operational command
service headquarters
OSD

The service subunit unilaterally formulates requirements for a new weapon system, ordinarily a follow-on version of the subunit's current main-line weapon.

These requirements are most often keyed to the dominant mission scenario of the pre-existing weapon, and more particularly to improve capabilities with regard to a few parameters associated with performance of the dominant scenario.

WEAPON DESIGN

MAJOR ACTORS:

contractor
service

The requirement is transformed into a paper design for the weapon. Designs are created by competing contractors.

The specifics of a proposed design reflect the contractor's desire to obtain the contract and the relative weight he assigns the service and DOD views in contractor selection.

The design of the winning contractor becomes the design developed.

WEAPON DEVELOPMENT

MAJOR ACTORS:

contractor
service

The contractor proceeds with development, monitored by the service subunit. The necessary factoring of development into manageable pieces tends to fix the characteristics of the weapon at the outset.

As development draws to a close, prototype weapons are produced and tested. Service autonomy in testing allows the service to determine what is acceptable or unacceptable and to what extent such details as accuracy may be fine-tuned. This autonomy insures service control over the information about the weapon's performance, on which procurement decisions are in part based.

WEAPON PROCUREMENT

MAJOR ACTORS:

OSD
Systems Analysis
Armed Services &
  Appropriations
  Committees
service

The weapon, aggregated with the other weapons developed, comprises the list of procurement alternatives.

Procurement decisions are made through bargaining between OSD, the Armed Services Committees, and the services.

Source: Graham T. Allison and Frederic A. Morris, "Armaments and Arms Control: Exploring the Determinants of Military Weapons", Daedalus, Summer 1975, pp. 99-129.

deployed weapon system. It would require an additional volume to summarize the subject of weapons acquisition process, and we can only give it the briefest mention here. (102) There are several important points which derive both from the material already presented as well as from this literature that should be emphasized.

The first was already discussed briefly in terms of the development of the submarine launched ballistic missile (SLBM) and the intercontinental ballistic missile, and that is the more or less concurrent achievement of separate technological "breakthroughs" that make a single major innovative system feasible. Two other very significant examples were the US ABM system of 1966-68, and the new intercontinental range strategic cruise missile. In the case of the ABM three separate technological capabilities came together to make the system feasible:

a) an electronic phased array radar in place of the previous mechanically rotated radars. This not only increased the speed of operation of the radar by orders of magnitude, but also the number of objects that the radar could simultaneously track.

b) a very high thrust, high acceleration, low altitude interceptor missile (Hibex), instead of having to rely on high yield exo-atmospheric interception. This also permitted atmospheric reentry to winnow out decoys from real warheads.

c) improved computers and computer software which enabled very much improved reentry vehicle signature discrimination; this also reduced the need for interceptor missiles to target decoys.

The long-range small-bodied intercontinental strategic cruise missile which was developed in the mid-1970's was dependent on two major developments. The first was a very small long endurance jet engine, and the second was the Tercom long-range terrain matching radar navigation system.

A second extremely important point is the multiplicity of systems that can derive from a single strategic requirement, or "mission". If one takes ASW as an example — or the closely related major USSR military mission to both track and attack US attack aircraft carriers and US SLBMs — one can quickly list the follow array of systems:

- <u>as weapon platforms:</u> submarines, patrol and attack aircraft, surface ships, helicopters;
- <u>weapons:</u> torpedoes, depth charges, SAM's, stand-off missiles, SSM's/SLCM's;

— as major adjuncts and C^3I systems; VLF, Rorsats and Eorsats, navigation and communication satellites, stationary sea-floor mounted sonar arrays, towed arrays, bouy systems, computer systems and software for sensor evaluation, other sonar and radar, electronic countermeasures, etc.

Oceanography underlies the functioning of many of these systems, and as soon as satellites come into play, space and ionospheric sciences, satellite controls and power sources, materials, etc. all became relevant R&D areas. For every one of these systems, once the R&D for the development and deployment of the initial system prototype has been done, there will be continuous R&D intended to provide improvements in the performance and capabilities of the system. I have elsewhere used the US Polaris/Poseidon system to demonstrate these continuous improvements in a large array of interacting and supporting systems. In some ten years no less than 5,000 changes were reportedly made to the Polaris/Poseidon missile alone. (103) The performance capabilities of radar, for example, have reportedly doubled every four years since the end of WWII. The example of improvement in the basic parameters of aircraft was presented on page 15 . The same pattern would again apply to every one of the above mentioned systems involved in ASW. An excellent brief survey of the interaction of offensive and defensive roles (or "missions") and technology in the development of naval warfare since the 1970's was recently published. I have selected several examples from the more extended description of interacting systems that Lautenschlager describes for the period 1920-1980.

> As an offensive system, the carrier operated torpedo planes ...
> A single torpedo hit could disable all but the largest ships, but like surface and subsurface torpedo craft, the airplane had to launch its weapon from close range to have a reasonable chance of success. During the long, straight run in the relatively slow biplane would be exposed to concentrated fire from anti-aircraft guns that were being installed in ever-increasing numbers. Development of the dive bomber gave the carrier an alternative means of attack. Bombing from level flight was unlikely to hit a moving ship, but a high speed dive could be consistently effective. Aircraft of the 1920s could not stand the stress of pulling out of a dive. Gradually, airframe structures were refined, however, and in 1932 the U.S.Navy introduced the first attack aircraft that could deliver a 1.000-pound bomb in a dive.
>
> .....
>
> To be a main offensive system for combat and not merely a harassing agent during the preliminaries, carrier strike aircraft would have to carry a reliable torpedo or 1.000-pound bomb. Less of a weapon load was little threat to a large armored warship, including a carrier. The strike aircraft would have to cruise at over 120 knots, combat-loaded. The normal cruising speed of most combat-loaded biplanes was less than 100 knots, giving little margin over headwinds and fast-streaming battle fleets. A combat radius of at least 250 miles was essential. Peacetime maneuvers showed that range was needed to search for the enemy and to maintain separation necessary to prevent enemy battleships from pouncing

> on one's carriers. Finally, the strike aircraft needed a top speed near that of contemporary fighters. Slow speed over the enemy fleet made biplane bombers easy targets for defending fighters and director-controlled anti-aircraft batteries.All carrier aircraft in service before 1938 and several later models were deficient in at least two of these four requirements.
>
> .....
>
> Between 1956 and 1959, Soviet Tu 16 bombers were equipped with anti-ship missiles, but like their German predecessors, these naval aircraft were tied to land bases. Carrier strike aircraft were first deployed with air-to-surface missiles in 1959. The first was the AGM-12 Bullpup, with a 250-pound warhead and a range of 6 nautical miles. It was soon followed by the Bullpup B, carrying 1,000-pounds of explosive to 9 miles. Thus, an aircraft could remain outside the range of a ship's anti-air-craft gun batteries and guide its ordnance with precision onto a moving target. This meant that without air cover, a ship now needed surface-to-air missiles for defense. Today, French carrier aircraft are equipped with the 39-mile Exocet AM39. U.S. carrier aircraft currently have four types of air-to-surface weapons available, including the 60-mile Harpoon. In 1957, both the American and Soviet navies put the first operational cruise missiles on surface combatants, but neither the Regulus I, nor the SS-N-1 had the range of carrier aircraft if employed against moving targets such as ships.
>
> .....
>
> The last group of satellite systems to be developed is intended for ocean surveillance. Aside from photographic satellites, which are really intelligence gatherers, the surveillance platforms use radar, infrared, and passive electronic detectors. The Soviets orbited Cosmos 198, probably their first radar ocean reconnaissance satellite (RORSAT) in 1967. Their first paired RORSATs were operational in 1974. Cosmos 954 which came down in Canada in 1978, was a later version of a high-powered RORSAT. The White Cloud program put an array of passive electronic ocean reconnaissance satellites (EORSATs) into orbit in 1976. Other US programs in the 1980s are Clipper Bow for high-resolution radar and Teal Ruby for infrared sensor patterns. (104)

Perhaps the final point to be made here is that the determinants of weapons acquisition are *many*, that they *vary* from weapon to weapon — at least in their proportions and in which of the several factors dominate a particular case — and that they may vary over time. We have already identified the importance of special mechanisms in the history of the "summer study" advisory groups when the innovations were quite major and broke entirely new ground. (105) Once the weapon exists, and the mission identified and well established and with such standard systems as artillery, tanks, ships, aircraft, the "follow-on" imperative — the replacement of one generation by a successor — is a primary driving force. These same patterns are as clearly evident in Soviet decision making on major weapon acquisition as they are in the United States. (For example, see Holloway, on major political intervention in cases of initiatives and the studies of Michael MccGwire on USSR ship succession: Ref. 125 and 129 below).

This brings us to the fifth and final group of tables and figures. These have been selected to serve a double purpose. First they are meant to display the end result of the military R&D and acquisition process: the weapons. In addition these tables (tables 8 through 43) indicate in sequence the successors within each weapon category — different classes of ships, aircraft, missiles and ground weapons — since the end of WWII for one nation: the USSR. Since a very great portion of the material in the four case studies that follow as the remainder of this book, and even in this introductory chapter deals with the United States, the fifth set of tables was specifically selected to describe the R&D structure and its products — the weapons — in the USSR. This was the second purpose. To this end the first half of Group V (figures 1 to 12 and tables 1 and 2) recapitulates to some degree the themes of groups I to IV. They describe the R&D organization of the USSR and something of its laboratory structure. The comparisons of status of US and USSR military technologies that US military authorities began to provide in the early 1970's (see table 2) invokes the R&D required to attain those levels of capability and knowledge. If, for example, such a comparison of 21 different technologies ranks the US as "leading" in eleven, the USSR "leading" in eight, and "even" in three (as was reported in 1976), this tells one that the USSR must under one organizational framework or another support a military R&D structure of roughly similar purpose, operational goals and overall output as does the United States. The series of tables on Soviet strategic weapons (figures 8 to 12 and tables 4 to 7) provide information on characteristics, successive generations, length of development time, and numbers of kinds in R&D and in production in different years. Such indices of output again explicitly demonstrate the massive and concerted R&D effort that must stand behind such a program.

Military Research And Development in the USSR

Much of this introductory chapter has been based on material and examples derived from US military R&D programs. The technological demands of advanced weapons development are the same irrespective of national boundaries, as are therefore the kinds of research that must be done to achieve the solutions to the technological problems. The USSR has by and large therefore had to carry out the same kinds of military R&D regarding space environments, electronics, materials, ocean characteristics etc. as has the United States (106). There are no other ways to obtain the weapon systems in question. The only caveats to this general statement are the acquisition of foreign technology, which will be discussed below, and the choice of different technical solutions by the USSR in a number of cases to those chosen by the US to obtain some military capability. Translations of USSR R&D in the early and mid-1960s in areas such as missile guidance, geodetics, chemical and biological warfare, etc. demonstrate the very great similarity in particular pieces of work which set out to elucidate the same physical phenomenon. (107). Kassel surveyed research in several fields of science with very strong linkages to military R&D in both the US and USSR.

> The U.S.projects were selected if they had overt military sponsorship. The selection of the Soviet projects was based on their having the closest possible resemblance to their U.S. counterparts. The equivalence in each pair is fairly precise: both projects deal with the same problem and both are in the same stage of the RDT&E cycle. Also, each expresses some awareness of the other's work through citations, although the Soviet side is clearly more aware of the work in the United States than vice versa. (105)

Kassel also sought a means of estimating what portion of the unclassified literature related to military R&D.

> To shed some light on this matter, we made a count of articles specializing in laser research and published in the Institute of Electrical and Electronics Engineers' Journal of Quantum Electronics for 1971, and broke them down according to the sources of support for the research on which they were reporting... 45 percent of the published papers reported on research that was either directly supported by the military or performed in the laboratories of one of the services, such as the Avionics Laboratory of the U.S. Air Force. ... The Soviet papers published are in many cases the precise equivalents of the kind of U.S. research papers.
>
> The 163 Soviet facilities that originated published papers in the laser field in 1971 are largely a part of the Academy of Sciences and the university network of research institutes. Military association of any kind with such facilities, if it exists, is never explicitly revealed in Soviet practice. ... The Soviet projects were thus pursued under the highest scientific auspices possible in the Soviet Union, but no military association was indicated anywhere in the sources. ... To be sure, there is classified laser literature in both countries; in the United States its authors are largely the same individuals who publish the open-source papers.... In view of the parallel between the two countries with respect to the open literature, there is no reason to assume that the situation is different between them as regards classified publications. (109)

This is also demonstrated by the tables already referred to, that are prepared by the US Dept. of Defense, that compare US and USSR status in "basic technology areas" on which development of military systems depends, and in deployed weapons systems. (See tables, group IV, tables 3 and 4.) These attest to the R&D that preceeded both categories of products. (110)

The USSR has maintained the most extraordinary secrecy regarding the organization, management and functioning of its military R&D and weapons acquisition process all during the post WWII period, and it has taken over twenty years of research to reconstruct the basic outline of the operation of this system. (See tables, Group V, figures 1 through 7). The eight weapons production ministries have been identified (with those responsible for producing nuclear weapons and strategic missiles carrying such euphemistic titles as "Ministry for General Machine Building" and "Ministry for Medium Machine Building".) Senior administrative personell in these ministries and in the coordinating bodies have often held their posts for ten or twenty years, and in some cases even longer. The overall coordinating role of the "Military Industrial Commission",(Voenno-Promyshlennaia Kommissiia; VPK) seems definite. It seems clear however that <u>all</u> esential decisions regarding weapon succession, characteristics, numbers and timing of development and deployment are considered the <u>sole</u> province of the military leadership. (111)

Ellen Jones writes that

> The Soviet description of their own military R&D process emphasizes the salience of policy goals in shaping military R&D priorities. While it is difficult within existing data limitations to determine with precision the motivating factors behind specific program decisions, the Soviet model of a policy-driven R&D environment appears to be a fairly valid one. (112)

In some cases specific military R&D institutes and design bureaus, analogous to the US military service "in-house" laboratories have been identified. (113) It also has been possible to identify the definitions for the funding categories in the USSR military R&D cycle. (114) An extremely interesting discovery was the finding that the USSR coordinates military research and development in the Warsaw Treaty Organization member states through its domination of two managerial committees established under the rubric of the WTO. These are The Technical Committee, and the Military Scientific Technical Council. (115) It is presumed that the first agency coordinates technical requirements while the second coordinates military research and development. Defense industry production in the WTO member states is coordinated by the Military Industrial Commission of COMECON. (116) The fact that research personell of the WTO member states engage in coordinated military R&D programs provide one of the few bits of information regarding military R&D management and organization in these states. Marshal Kulikov mentions 19 Polish military institutes that participate in joint military R&D projects, and he names eight of them: Tank and Automotive Technology, Armament, Air Force, Communications, Engineering Technology, Hygiene and Epidemiology, Aviation Medicine, and System of Material-Technical Supply of Troops. (117). A large network of astronomical, astrophysical and other institutions in WTO member states clearly collaborated in the USSR's satellite tracking network, for example

- the Czechoslovak Research Institute of Geodesy,
- the satellite tracking stations of the observatory of the Hungarian Academy of Sciences,
- analogous facilities in Poland and Rumania,
- East German Academy of Sciences Computing Center, Potsdam,
- Polish Academy of Sciences Computing Center, Warsaw. (118)

Other institutions in all of the WTO member states collaborated in space tracking, space physiology and in other programs. In another field Polish contributions to Soviet research on shock and detonation waves was made by the Instytut Maszyn Przeptywowych (Institute of Fluid Mechanics) which is known to have direct military support from the Military Technical Academy, an educational and research arm of the Polish Ministry of Defense. (119) These few brief descriptions provide some of the little evidence that is available regarding military R&D in the WTO member states aside from the USSR.

Estimates of USSR military R&D expenditure are very poor; The CIA routinely states that

> the estimate for Soviet RDT&E outlays is the least reliable of our estimates... The information on which the estimate is based — published Soviet statistics on science, statements by Soviet authorities on the financing of research, and evidense on particular research projects — suggests that military R.D.T,& E. expenditures are large and growing. (120)

Estimates of USSR military R&D expenditure expressed in dollars are relatively meaningless. (See group V, table 1 for estimates of USSR military R&D expenditure in rubles.)

However, several other descriptive criteria seem usable:

- it is estimated that R.D.T. & E. outlays account for almost one quarter of total USSR military expenditure:
- it is estimated that the USSR spends twice as much for military R&D in 1981 as it did ten years previously, in 1971;
- the increase in floor space devoted to key Aerospace R.D.T.& E. facilities between 1973 and 1983 grew at a roughly constant rate of 3.5 percent per year; (121)
- as many major USSR weapon systems were in development in the early 1980's as had been in development in the previous two decades. (122)

In attempting to assign costs to USSR military R&D one common assumption has been that just as USSR defence industry is assumed to be more efficient than USSR civilian industry, so USSR military R&D was assumed to be more efficient than its civilian R&D. For example, writing in 1973 Robert Perry had stated:

> Comparisons of Soviet and U.S. military technology can be made more credible, and appreciably more useful, if they take account of striking and important differences in the style and characteristics of research and development in the two countries. In particular, a priori assumptions about the relative inefficiency of the Soviet military research and development process may be invalid. In several important respects U.S. practices may be inferior. One important distinction lies in the evidence that the Soviet military research and development system is markedly more efficient than its civil-sector equivalent, which may well be the reverse of the situation prevailing in the United States. At least in terms of the underlying costs of generating development. (123)

Another group of researchers however believe that exactly the opposite situation prevails — at least as far as the efficiency of USSR military R&D is concerned. A recent study based on interviews with a sizable number of recent Soviet emigrées that had been employed in military R&D programs in the USSR claimed to

> ... provide detailed corroboration of recent work (Odom, 1981; Ofer, 1980) suggesting that the efficiency of Soviet military R&D is much lower and its cost (both direct cost and opportunity costs) much higher than previously believed... some 30% (of a sample of 200 individual researchers) were employees of "post-office box" institutes, "closed" (defense-related) research establishments, or other organizations charged with military research responsibilities... military-related research appears more extensive and more widely diffused among many different types of research bodies than even the existing Western literature on the Soviet military-industrial complex would suggest... there exists a special budgetary allocation devoted to military research within the general budget of virtually every research institute. Others among our respondents were employed in civilian institutions doing military-related R&D. They described a system in which part of an establishment (a floor, a building or even an entire complex) might be engaged in secret work and require a special pass (propusk) for admittance. Thus there is far more military-related R&D performed in the Soviet Union than is apparent even from analysis of all the military institutions. A large amount of military R&D, like much military industrial production, is "piggy backed" onto regular R&D activities.
>
> Several conclusions might be drawn from this description of the situation. One is that Soviet expenditures for military R&D — both real amounts and opportunity costs — have been underestimated. (124)

The products of this effort are displayed in the tables. These can be grouped into three types:

(a) one group of tables presents a large portion of the catalogue of major Soviet weapons, for land, sea and air forces — artillery, tanks, missiles, different categories of ships and aircraft etc. — and in each case shows the progression of successive types for each weapon system:
See tables, group V, tables 9 through 43.

(b) the second group provides comparisons between USSR and US military research and weapons development:

1. for tanks	tables,	group IV,	fig. 1 and 2
2. for cruise missiles	"	"	fig. 3, table 1
3. for fighter aircraft	"	"	table 2
4. basic technology	"	"	table 3
5. deployed military systems	"	"	table 4
6. aircraft development	"	"	table 5
7. number of tactical systems developed	"	"	fig. 4
8. ICBM's	"	"	fig. 5
9. SLBM's	"	"	fig. 6

(c) the third group of tables and figures — perhaps the most interesting and informative from the point of view of understanding the relation between the driving forces of strategic weapon acquisition and R&D — present more detailed portrayals of weapons succession within a single kind of system, and display the time devoted to R&D, initial operational capability, and overall systems succession:

- for cruise missiles	tables,	group	IV,	figure	3 and table 1
- for ballistic missiles:	"	"	V,	"	8,9,10,11,12
	"	"	V,	tables	3,4,5,6,7,8

The past ten years have seen the publication of a sizable number of major studies providing superb reviews of USSR weapon development.
These have surveyed

- strategic weapons (125)
- theatre nuclear weapons (126)
- space systems (127)
- tactical aircraft (128)
- ships (129)
- tanks (130)

These studies are able to provide very substantial insight into the motivations of USSR military R&D and weapons acquisition for many major systems. In some cases — such as exemplified by MccGwire's studies of the types of submarine and surface vessels developed by the USSR — policies were guided by a desire to develop a combination of systems to counter US aircraft carriers capable of nuclear strike and US SLBM's, as well as developing systems capable of protecting the USSR's own SLBM fleet. In this case submarines, surface vessels, aircraft, and weapons had to be designed to meet the requirements of complex interactions with US naval systems. In the case of tactical strike aircraft the USSR developed a new generation of aircraft capable of matching the longer ranges and heavier payloads of western strike aircraft, particularly those of the US. They were deployed in the mid-1970's. In this case the mission can be defined more simply, and the primary design considerations probably did not have to take into account interactions with opposing aircraft. The main objective was to obtain a long range strike aircraft capability. In a third example, the resurgence of tactical and theatre nuclear weapons in the mid and late 1970s, the USSR appears to have been guided to a greater degree by its own defined military aims. The new strike aircraft had nuclear delivery capability, the SS-20, Backfire aircraft and SS-21, 22 and 23 missiles were all developed in the early 1970's, and USSR nuclear artillery was introduced in the late 1970's — just as these were being deemphasized by the US and NATO. Despite various qualifications that could be made one can describe a progression in these three examples of USSR weapon system design and procurement from systems driven by a combination of responses to US systems and the definition of the USSR's own initiatives, to ones more independently determined by the USSR without recourse to countering western systems, though they may have countered — or paralleled — western missions.

These studies also offered much greater insight into the very widely accepted notion that Soviet weapons design is more dependent on smaller incremental changes to previously deployed systems in comparison to US design which aim at more abrupt advances in capability.

> The Soviet Union generally favors a pattern of continuing design and development, with evolutionary models succeeding one another at regular intervals, and with a pronounced dependence on prototyping as an aid to production decisions. That is very unlike the style that has marked military aircraft development in the United States for the past two decades. The U.S. emphasis is on production rather than on R&D, and more benefits accrue to producers than to developers. Customers for military R&D in the Soviet Union have an evident aversion to high-risk technology. In the United States, military customers normally express a pronounced preference for large advances in technology, without much concern for risk, and are willing to pay a considerable price for them. Stylistic differences that distinguish Soviet from U.S. military R&D may be largely explained by such preferences.

> The dependence of the U.S. R&D process on continued production programs (from which research and development funding ultimately stems) is in marked contrast to a Soviet reliance on central, stable funding that allows the persistence of a relatively steady-state R&D process. (131)
>
> Soviet weapons acquisition is shaped by formal procedures, the planned economy, a powerful and demanding customer, and bureaucratic conservatism. Designers therefore face strong disincentives to use advanced technology or to look toward science for solutions to design problems. Incentives promote the art of design, whereby weapons developers make as much use as possible of available components and materials. The VPK (Military Industrial Committee) and the Party overcome some of the impediments to R&D arising from the unresponsive economy and other sources through their intervention and coordination. (132)

It would appear that this is a generalization with many exceptions, and that Soviet design behavior in developing tanks, surface ships, submarines, aircraft and strategic missiles is far from uniform. (133) Soviet strategic weapon development has often been decidedly non-incremental — certainly ICBM generations have been replaced more rapidly than those of the United States — while the US has followed a pattern of making more numerous modifications to emplaced ICBM and SLBM systems between generational replacement. Writing in 1973 Perry made a very insightful prediction regarding the consequence of a continuous stepwise USSR military R&D process:

> If U.S. R&D budgets are subject to attrition during the 1970s, as seems likely, the United States may be obliged to accept major changes in its acquisition policies and practices; otherwise the Soviets may be able to overcome whatever technological advantage the United States has acquired by reason of its relatively higher investment in military R&D during the 1950s and 1960s.
>
> The development of aircraft in the Soviet Union has institutional attributes very unlike most counterpart activity in the United States. It tends to emphasize evolutionary design, to be relatively free of the demand fluctuations that often inhibit the stability of aircraft design and development in U.S. firms, and to be less subject to customer pressures for risky advances in technology. Such evidence as is available suggests also that the Soviets characteristically invest fewer resources in individual aircraft programs than is the practice in the United States — at least through the point of initial flight testing. Thus for equivalent investments in aircraft R&D, the Soviets appear to be able to carry larger numbers of aircraft models through their prototype and flight test phases. Although the resulting aircraft systems differ in many respects from their U.S. counterparts, Soviet systems are not substantially inferior to U.S. systems of the same type. Differences in output—input ratios for research and development in the two countries may be more directly attributable to different styles and methods of R&D than to any inherent constraints on investment. (134)

Also writing about Soviet military R&D for Soviet aircraft, Alexander wrote in 1970:

> Crash programs, problem oriented ad hoc organizations, and high level political intervention that suspends the usual practices have been the devices used to achieve large jumps in technology.

> The major incentive to a designer is to have his design produced. Working in a competitive environment, and constrained by handbooks and lack of research facilities, the designer is led to a speedy output of uncomplicated designs that make as much use as possible of earlier work. He is also required to understand the tactical environment in which his aircraft will perform, since designing to an obsolete requirement will not lead to manufacturing orders.
>
> Soviet aviation R&D can be characterized by its management of uncertainty. The variability of uncertainty in different design projects is recognized. At the lowest level, transport aircraft are usually competitive only at the pre-project (paper study) phase. Fighter aircraft often push existing technology to new limits, and competitive prototype development has been the rule. With new technology, several designers are assigned projects that test different approaches. Different kinds of uncertainty are localized to those organizations best able to handle it. Concentration on simplicity, commonality, and design inheritance reduces the amount of uncertainty that must be faced in each project. The speed of design and the small size of design teams prevent the "over-engineering" of mechanisms. (135)

In 1981 former Under-Secretary of William J. Perry — apparently bearing out the 1973 prediction — suggested that Soviet fighter aircraft built in the decade 1970-1980 were in general more complex and more expensive than comparative US aircraft. (136)

One very noticeable characteristic is the large number of different kinds of the same weapon system often developed by the USSR, or alternatively, the large number of different kinds devoted to the same mission. This is evident in several different examples:

— the USSR has roughly ten different classes of attack submarine

— and also just about the same number of different classes of missile-launching submarines, both diesel and nuclear-powered, armed with cruise and ballistic missiles,

— the large number of different kinds of antiship missiles, launched from aircraft, submarines and surface vessels,

— the variety of theatre-nuclear weapons, land, air and sea launched (see table).

In listing several major generalizations regarding USSR defense industry Holloway places the acquisition of foreign technology as his second point. One of the most well known examples from the pre WWII preiod is the acquisition of the British Christie tank in 1931 and its modification leading to the development of the T-34, the Soviet main battle tank in WWII. (137)

> ... foreign technology has played an important role in the Soviet defence industry, particularly in three periods: in the years of the first three Five-Year Plans (and especially of the first) when the

> defence industry was being established; during the war with Germany, when equipment was obtained from the Soviet Union's allies; at the end of that war, when the acquisition of German technology was of great importance for the post-war weapons development programmes. Since then, acquisition of foreign technology has played a smaller role in Soviet weapons technology, although there have been reports that some recent advances, for example in missile accuracy, have resulted from imports of foreign machinery. It is difficult, without detailed study, to assess the importance of foreign technology for the Soviet defence industry, but Soviet efforts to acquire technology abroad suggest that it has not been negligible. Its importance was perhaps greatest in the 1930s and in the mid-1940s. Since the late 1940s the Western powers have tried to restrict the export of strategic technology and this has forced the Soviet Union to rely more on its own R&D. (138)

Holloway does mention the third period, which followed immediately after WWII, and it is clear that the acquisition of foreign technology continued to play a very important role for the USSR further into the post-WWII period as well.

> In 1944, Russian scientists had received information on the German V-2, and on other developments including the Sanger Project — an intercontinental bomber boosted by rocket power and intended to "skip" along the top of the atmosphere to achieve long range. The Russian scientists called these developments to the attention of the political leaders, and when Soviet forces overran the Peenemunde rocket bases in Germany, Soviet scientists went along to assess the German efforts and to help round up equipment and experts. By the end of 1945, several defense industry plants in the USSR were converted to rocket production under the direction and coordination of a special committee under the Council of Ministers. This committee was headed by the Chief Marshal of Artillery Nedelin and by the ubiquitous military-industrial managers Ustinov and Vannikov. German experts were put to work for the Soviet Union in design bureaus in Germany, but in October 1946, about 40,000 of them were transported to the USSR. (139)

Several recent examples demonstrate both the continueing importance of th mechanism of foreign technology acquisition for USSR weapon development as well as the ways in which it is integrated with the USSR's own R&D efforts. Estimates made during the Carter administration predicted that testing of a Soviet analogue to the US air launched cruise missile might begin in the mid- to late 1980s. It began in fact in 1981, and USSR deployment is now expected by the mid-1980s. (140) Crucial to long range modern cruise missile development are the "Tercom" terrain matching guidance system, and a very small turbofan engine.

> A simple Soviet TERCOM system to follow terrain could have been based on radio altimeters used in the Shaddock as well as a modest on-board computer to store mapping information. (The "Shaddock" is the Western designation for a large Soviet cruise missile, the SS-N-3, dating from 1960.)
>
> ... Finally, new developments in turbofan engine technology could have been followed over time by examining US drones captured in Vietnam in the 1960s or reading the open scientific literature. Moreover, the USSR could draw on other capabilities, such as existing turboshaft engines in military helicopters, to build a small turbofan engine.

> In addition to drawing on Soviet technical knowledge, the new cruise missile programme may have benefited from the acquisition of advanced Western technologies. The acquisition of modern microelectronics necessary to develop highly accurate guidance systems, as well as actual components of advanced inertial guidance systems, have been important priorities of the Soviet technology transfer effort. Moreover, acquiring the machinery to produce these systems also seems to have received a great deal of attention. According to a CIA report issued in 1982, "acquired equipment and know-how, if combined, could meet 100 per cent of the Soviets high quality microelectronics needs for military purposes". As for turbofan engines, General Kelly Burke, then US Air Force Chief of Staff, stated in early 1981 "we know the Russians have made serious efforts to get hold of engines of that type". These efforts seem to have been successful; according to the recent issue of Soviet Military Power issued by the Department of Defense, the USSR may have been successful in acquiring a Western turbofan engine. Whether acquisition of Western technology merely helped accelerate the Soviet development programme, as is the story in many cases, or represented the technical "breakthrough" needed to build modern cruise missiles, remains unclear. (141)

The acquisition of a Western engine also seems to have been crucial to USSR development of large high bypass ratio jet engines. In conjunction with the development of the Antonov transport aircraft (AN-40, or "Condor") beginning in 1975, the USSR unsuccessfully attempted to obtain small numbers of Rolls-Royce or GE high bypass ratio jet engines. As a consequence of the invasion of Afghanistan, the USSR captured several CF6-50 jet engines. Three years later the USSR developed the D-18T high bypass ratio engine, with a rateing similar to that of the CF6-50. (142)

What is perhaps remarkable is the degree to which Soviet military R&D apparently still relies on leads provided by American research. This is expressed in a paper by Anatol Fedoseyev, designer of most of the electronic tubes in major Soviet radar systems, and the most senior Soviet scientist involved in military R&D ever to defect or to emigrate to the west. His own account makes this clear despite his repeated efforts — to the point of apparent contradiction — to stress both his own and Soviet independent initiatives:

> First, we did not allow ourselves to copy samples of Western technology because this would only perpetuate backwardness and dependence on the West, which in the area of military technology is pure suicide. Second, the way the Soviets do research, design and production, and the types of materials available are much different from the West. Copying is simply impossible. Summing up this section, I could say that there are four main sources for generating research projects in Soviet military R&D:
> 1) an original idea based on the experience of a designer;
> 2) topics which emerge as a consequence of a larger project (e.g. the magnetron — from radar);
> 3) information about new developments in the West;
> 4) copying of foreign equipment. (143)

Two of the four mechanisms that Fedoseyev gives clearly depend on derivations from the West. In another example that he provides the context is entirely a derivation from the West:

> One can estimate the length of a project in Soviet military R&D in the following way. Say the Soviet Union were to obtain information about new Western equipment. (It takes two to three years for the Soviet bureaucracy to realize the significance of the equipment.) Another year or two will elapse before the decision is made to find an organization which is suitable and willing to undertake the project. This is already four or five years. Then the development of the equipment commences, which takes another five or six years (2-3 for the first stage and 2-3 for the second stage), and finally another year or two until it is finally accepted as part of the armament. The net result is that from the moment the Soviet Union gets wind of a new development in the West until the moment when that equipment becomes part of the Soviet armaments, up to 12 years elapse. (144)

In a review of Fedoseyev's earlier book, Kuchment notes this same sequence:

> In this recent book on the innovation decision in Soviet industry, Joseph Berliner described Soviet military research as "foreign" to the main body of Soviet industry, with the military R&D community enjoying higher priorities, competing directly with the West, and having access to higher levels of the Soviet political hierarchy. Undoubtedly, all these circumstances helped Fedoseev to form his own independent political views. On the other hand, his everyday experience showed the impossibility of isolating the Soviet R&D community from the rules of the game which prevail in Soviet society as a whole. The fear of originality, which characterizes all dogmatic ideologies, manifested itself in authorities' reluctance to support research in areas which had not already been explored in the West. Usually a period of ten years is required to transform a sample of Western equipment which has been smuggled into the country into a genuine Soviet product: it seemed as though the government deliberately perpetuated this lag, despite the efforts of enthusiasts like Fedoseev. The author speaks in great detail about the inflexibility of the whole system which manages R&D... (145)

In an example of the initiative of the working scientist in the Soviet military R&D sector Fedoseyev provides the following example:

> By the end of the 1960's, my thirty megawatt wave-quide magnetron still operated as part of the Soviet radar, monitoring movements of missiles and planes over Northwest America. I and two of my colleagues, outstanding Soviet designers themselves, then offered the military to develop a new set of tubes to raise radar performance considerably. My task was to raise the power of the transmitter, while one colleague decreased the noise coefficient and increased the amplification factor of the receiver, and the third worked on technological problems. When this project was in full bloom, the Council of Ministers decided to build a special institute for its development. (146)

For whatever reason Fedoseyev says remarkably little about the role of the weapon directorates of the Soviet military services as initiators of weapons requirements.

> The development of a project in the military R&D community is generally subdivided into two basic periods or stages: 1) scientific research (NIR) and 2) design development (OKR). Approximately 70% of the topics from the first stage go on to the second stage. The majority of second stage projects are recommended for mass production. The first stage usually lasts two to three years: the second stage is about the same. The head of the group or chief designer of a project develops the so-called technical task (tekhnicheskoe zadanie or TZ) during the first stage, and technical requirements (taktiko-tekhnicheskie trebovaniia or TTT) for the second stage. He must design and develop requirements which are to be coordinated with the military customer, other military organizations interested in the project, with the bureaucracy in the research institute where he works, and the Ministry. The TZ and TTT must be thoroughly detailed for performance and subsequent evaluation of the project. (147)

This implies that a very large percentage of projects in each stage are approved and as the first stage was labeled "scientific research, it also suggests either a smaller number overall as compared to the US experience, or more rigorous prior selection before the first of the two stages.

It is also interesting to note Fedoseyev's statement to the effect that

> I attempted a number of times to publish something but was unable. You can understand that the open technical literature of the Soviet Union is actually devoid of anything which is "important", and also why many successful researchers in the Soviet Union are unknown outside the USSR and in their own country as well. They are known only in a very limited circle of colleagues. (148)

This stands in direct contrast to the studies made by Kassel in the US and to other comparisons provided in these pages. The resolution of the apparent contradiction may lie in the sensitivity of the researcher or the criticality of the research in question.

There are several important points in these examples in addition to the evidence of continued major Soviet efforts to obtain foreign military technology. The first is the ability to merge externally acquired components with other portions of a system developed domestically. The second - the accumulation of relevant R&D experience as follow-on generations are developed — produces in its end result the same effect, <u>the reduction of development time</u> for increasingly sophisticated systems matching in general characteristics those developed in the USA. This was evident in the case of the cruise missile program referred to above, as well as in the rapider-than-expected USSR achievement of high MIRV warhead accuracy in mid-1978. Both of these can be understood as the accumulated effect of years of antecedent weapons development of related components and in related fields which then can be recombined in producing more demanding systems.

Alexander points out that

> A growing concern of Soviet analysts and military-science policy in the 1960s was that the "research-production cycle" was not flexible enough to cope with rapidly changing scientific opportunities. One particular anxiety was that "scientific opportunities and military requirements will not coalesce quickly enough to ensure the development of the most advanced weapons." Departmentalism and secrecy were seen to aggravate this problem. The existing process appeared to be effective in supporting priorities already decided upon, but the selection of new programs to be given the highest state priorities was a complex and hazardous affair. Some analysts contended that whereas in the past military requirements placed demands on scientific possibilities, since World War II, scientific research has been presenting more and more possibilities for weapons development. (149)

Holloway has noted that there have been a series of Soviet weapons such as the Galosh ABM, the SS-6 ICBM, and the Mya-4(Bison) bomber, in which technology could not meet the politically dictated system requirements. (150)

Political intervention by the most senior figures in the Soviet political system have also been instrumental in major Soviet military R&D decisions in the post WWII period. Holloway chronicles these in the case of nuclear weapon development, ICBM development, and space systems development. Figures such as Stalin and Kruschev often acted alone; other Politburo members acted at times as chairmen of small special committees of very senior political and military management officials. These special committees would appear to have played roles somewhat analogous to the "summer study", and other special scientific and policy advisory groups (von Neuman, Killian, Gaither, etc.) established in the 1950's in the US military R&D and weapons acquisition process to the degree, that in both cases the roles of these groups was to initiate major new programs and approaches, to change direction. The major difference is that the role of the US groups was to probe technological potentials or to formulate a threat assessment, or a combination of both. They were truly advisory bodies and the ultimate decision to support recommended initiatives lay elsewhere, with many intervening layers of military, executive (presidential) and legislative (congressional) decisions remaining. In the Soviet case the role of the special groups was essentially to deliver the political decision and the order to "do it", and to rearrange government allocation priorities so that the development decision could be carried out. At times — under Kruschev — there were also major decisions on overall force structure, such as deemphasis of the surface navy and long range aviation, reduction of military expenditure and armed forces personell (and emphasis on missiles) that can also be assumed to have had substantial impact on subsequent military R&D priorities.

Military R&D Substitution

There are several ways for a nation to obtain the benefits — or the products — of military R&D without spending the funds for carrying out an indigenous R&D program. These are as follows:

1. The purchase or import of completed weapons, as well as obtaining them as cost-free grants.
2. Producing weapons under licence, with or without local modifications.
3. Buying a very small number of weapons and attempting to copy them. (A variant would be buying or obtaining such weapons from an ally who has captured the weapons from an opponent in a peripheral war. For example, US equipment captured in Vietnam undoubtedly went to the USSR. US or Israeli equipment captured by Syria can be expected to go to the USSR as well, as well as the French Jaguar aircraft shot down by Libyan forces in Chad.)

A related mechanism is the purchase of production facilities. According to a senior US Dept. of Defense official

> The Soviets have become critically aware that their great deficiency is not in scientific knowledge but rather in production technology... This applies particularly to high technology areas having both military and civilian application, such as integrated circuits, software, aircraft, engines, avionics and specialized to name a few. We therefore see what appears to be a carefully designed Soviet approach to acquire production technology increasingly in the form of complete turnkey plant operations in these critical areas. (151)

Perhaps the most well known case regarding legal US sales to the USSR of equipment with military applications was the sale in 1972 of 164 Bryant Centralign-B grinding machines, capable of manufacturing the ball bearings used in ICBM guidance platforms to specifications of 25 millionths of an inch. The USSR had been attempting to purchase these machines since 1960. The Zil trucks manufactured at the Kama River truck plant, built by US contractors with a confractural provision that they were not to be used for military purposes, have been used for military logistics for Soviet forces, apparently including in the invasion of Afghanistan, as well as for a chassis for Soviet missile carriers.

4. Military related R&D can also be obtained by developing countries though nuclear energy technology cooperation agreements. Physicists and engineers from a large number of developing countries were trained in the laboratories of the former US Atomic Energy Commission, and in more recent years a considerable number of such agreements have been made among developing nations themselves, for example, between India and Argentina and between India and several other states.

5. The purchase — or more properly said, employment — of experienced researchers in a specific area of military R&D who are citizens of another country and who may or may not be employed in military R&D in their own more advanced home country, for example, the US or West Germany. This would theoretically be most worrisome in relation to such technologies as nuclear weapon development and chemical and biological warfare (i.e. strategic weapons) in which fields it has apparently taken place. However, it is more common in the area of advanced conventional weapons: "... scores of American technical experts ... went to Israel after France and several other countries curtailed military exports to Israel after 1967". Among the projects on which they worked was the Kfir jet fighter aircraft developed by the state-owned Israel Aircraft Industries.

> "Dozens of engineers, for example from Lockheed Aircraft Corporations 'Skunk works' design center, where the U-2 and SR-71... were developed went to Israel for a year to help develop the Kfir jet. Over the years, it is believed, many hundreds of Jews from the United States and other countries have gone to Israel temporarily to help on military projects." (152)

Other nations that have made use of similar mechanisms have been Argentina, South Africa, Egypt, Libya and India. Immediately after WWII of course, the USA, USSR, France and England made extensive use of captured or expatriated German scientists in the fields of rocketry, jet engines and aviation, and even to some degree of Japanese scientists and technicians.

Numerous developing nations send science and engineering students for training in various Western and East European countries to learn the technical skills necessary for application in military R&D. In the notorious "Telub"-case, Libyan military technicians were trained in military electronics in Sweden by a semi-state owned Swedish defense contracting firm. On several occasions developing nations have made efforts to "call home" native researchers that had settled and were employed overseas so as to obtain the trained manpower necessary for military R&D programs. Cases in point are Pakistan, just after India's first nuclear weapon test, and South Korea.

Developing countries have also made use of covert commercial operations, in particular in rleation to efforts to develop portions of the industrial and technical capability required to develop nuclear weapons. The cases that have become publicly known are Pakistan — with covert purchasing activities in Canada, England, the United States, Italy, Switzerland and West Germany — and to a lesser degree South Korea.

Developing nations of course make the greatest use of the first two mechanisms, the import of arms, and the production of arms under licence. A few are also capable of carrying on very extensive military research and development programs. India and Israel are the prime examples. However, we have noted that Israel has also made use of other of the mechanisms listed above, as have other developing countries, as well as one of the superpowers.

6. The final mechanism consists of espionage of various sorts. In the last few years attention has been focused on this aspect because of the extraordinarily extensive efforts of this nature by the USSR. (153). The USSR has been able to obtain design drawings of the Mirage F-1 (French), the Thomson radar and ECM system (US), the Honeywell laser gyroscope (UK), the Crotale low altitude surface-to-air missile (French), the Milan anti-tank missile (FRG), the Leopard-I tank engine (FRG). (154). They have purchased these in France, Switzerland, and in other countries. In one single coup in the United States the USSR was able to purchase documentation concerning the US KH-11 or "Rhyolite", reconnaissance satellite program, the Phoenix, Hawk, and Minuteman missile systems, and other systems. (155) If one calculates the R&D costs of the systems that have been compromised, it quickly becomes evident that the savings in military R&D expenditure must be enormous: the equivalent of many billions of dollars.

   The savings in military R&D expenditure that are provided by such espionage is derived from multiple benefits:

   a) it may reduce the need to make comparable weapons to counter the compromised system
   b) it will greatly facilitate the design of countermeasures
   c) it will aid in providing information for the design of ones own weapons.

In addition to the above "traditional" form of espionage, the USSR operates some 47 foreign trade associations, over 300 import-export firms, and with its eastern European allies, some 720 investment enterprises in western countries and in Japan. All of these are able to collect technical information. They are also — either directly or via false "dummy companies" established in western countries — able to buy restricted military-related technology in Western countries. The USSR also reportedly used "third party" transactions (through covert commercial organizations it establishes in various countries such as Sweden, Finland, the US, West Germany, Hong Kong, Japan, France and Switzerland) in the case in France to obtain some of the technology it used in fabricating the hulls of the new Soviet Typhoon and Alpha class submarines.

These operations are specifically designed to circumvent legal restrictions on the transfer of particular military related technology to the USSR. The very extensive and continued use by the USSR of these mechanisms indicates the utility of the practices as adjuncts to its own military R&D program.

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    The British source quoted above (ref.48 , pg. 5) offered a similar opinion: "I should have added that probably the most fruitful source for the special skills we want is the universities where we have contracts with them or contribute to conferences or symposia."

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    General Austin Betts, Chief of R&D for the US Army had made a related comment only several years before:

    > I think it is completely safe to say that the more a study reflects research or is conducted in the academic university atmosphere, the more likely a title will develop that is hard to relate directly to the underlying military need. For instance, the research entitled "Investigation of the Generalized Leidenfrost Phenomena: Film Boiling of discontinuous Liquid Phase on a Flat Plate" by Dr. K.J.Bell of Oklahoma State University had produced results providing the basis for improved performance of certain rocket nozzles, or another entitled "Analytical Studies in Burning of Initially Unmixed Reactants" is a very basic study related to vaporization of fine droplets in suspension. There has been strong interest recently in just such phenomena because of current military interest in aerosol sprays to defoliate forest areas.

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    It is also interesting to note, in relation to questions raised in other portions of this study, that in many instances both the National Science Foundation and the Department of Defense funded the same researcher for the same work and the same period of time. That is, there was substantial overlap in the funding of the two agencies.

71. Without contradicting the above statement regarding the overall distribution pattern (70:25:3.)

he shifts in funding for military R&D carried out in universities have been notable. At the time of Sen. Mansfields resolution, DOD's relative role had droped substantially, from 47 percent of all federal support to universities and colleges in 1955, to 14 percent in 1971. At the same time the role of the Dept. of Health, Education and Welfare had risen from 19 to 45 percent, and the National Science Foundation from 5 to 18 percent. By 1974 the DOD contribution to federally supported R&D in colleges and universities had reportedly sank to 9 percent. The turnaround developed in the last year of the Carter administration. The Presidents science adviser, Frank Press, had issued a report in 1978 urging the DOD to expand its research program, and in May 1979 Sec. Defense Brown ordered the military services to place more emphasis in their R&D on "broad science and engineering areas", with "potential" relevance to military functions (R.Reinhold, "Pentagon Renews Ties With Colleges; Sharp rise in Funds for Campus Research", New York Times, May 13, 1980; see also E.Ulsamer, "A Costly Aberation in US Science Policy", Air Force Magazine, 58:11 (November 1975), 42-44.) Under the Reagan administration, from 1980 to 1984, total government expenditure for R&D rose by 17 percent, the portion for national defense by 65 percent, while all other R&D fell by 30 percent (F.A.Long."Federal R&D Budget: Guns Versus Butter", Science, 223 (March 16, 1984) 1133). By 1984 the Dept. of Defense was spending 75 percent of all federal funds for research and development, a 30 percent increase in four years. (It had been 50 percent of total federal R&D funds in 1980). (D.S.Greenberg, Journal of Commerce, April 18, 1984, 4) DOD funding in universities had apparently risen 50 percent from FY 1980 to FY 1983.

The universities also provided one particular form of military R&D management opportunity. Karl Kaysen described this as the environment of a non-profit corporation with a high degree of income security to enable long term uninterrupted R&D, and pointed out that

> Among the most successful devices for organizing research and development laboratories of this type is the use of a university as a contractor. The Los Alamos and Livermore laboratories of the A.E.C., for which the University of California at Berkeley is the contractor, and the Instrumentation and Lincoln Laboratories of the Air Force for which M.I.T. is the contractor, all of which have weapons development tasks...
> (Karl Kaysen, "Improving the Efficiency of Military Research and Development", in E.Mansfield (Ed), Defense, Science and Public Policy, New York, W.W.Norton & Co. 1968.

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Lists in other years showed the Army with 44 laboratories, (Department of Defense Appropriations for FY 1972. Hearings, Committee on Appropriations, United States Senate, 92nd Congress, Pt. II), The Air Force with 24 (Defense Industry Bulletin, 8:1 (winter 1972), and the Navy with at least 26, ("The Far Flung Navy Research Network" Missiles and Rockets, 10:1 (1 January 1962):16-17.
Variation may be due to laboratory reorganization or consolidation over the years, as well as the establishment of new laboratories.

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(1) the assumption that some guidance system that was an extension of autopilot and autonavigator experience would be "easier" to develop than a closed loop inertial trajectory system:
(2) the assumption that derived or evolutionary advances in airframe technology would permit long-endurance, high-speed cruise missiles to be perfected before problems of high-stress launch and high-temperature re-entry could be solved for ballistic missiles.
(3) the assumption that high-efficiency turbojet or ramjet propulsions systems would emerge from development much sooner than dependable large rockets. and
(4) the assumption that the chief doctrinal modification required to move from bombers to missiles could be satisfied by substituting missiles for manned bombers in about a one for one ratio.

In time it became evident that each of these premises was thoroughly erroneous. They stemmed from assumptions about the value of experience in developing and operating the aircraft of World War II. From them were derived conclusions about the advisability — and risk — of depending on the evolution of missiles from aircraft progenitors, rather than investing in a ballistic missile program itself.

There were other considerations, too, of course... One is sorely tempted at this point to apply directly Professor Elting Morison's principal thesis about the resistance of a military society to major change. To people who had grown up with manned bombers before and during World War II and who had mostly stayed with them through the early part of the next decade, a cruise missile was a less painful and certainly a less abrupt departure from what they were familiar with than would be a totally alien ballistic missile. Those who favored the evolutionary approach to the creation of a new generation of weapons, predominantly missiles, were people to whom aircraft had

> a meaning as a way of life, a symbol, a preferred means of performing a military assignment. With minor exceptions, those who sought to bring on major or revolutionary change had no such commitments, being primarily engineers and scientists of one sort or another, and only secondarily airplane commanders. It is not really important whether the opponents of change consciously recognized the possibility that the appearance of a ballistic missile might lead to the decline and ultimately to the disappearance of the manned bomber. It is enough that those concerned sometimes acted as if they foresaw that possibility. So cultural resistance to the innovation presented by the ballistic missile was one reason for the relatively slow initial progress of that development, and failure to take appropriate account of the unpredictability of technology was another."

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89. Harvey M.Sapolsky, The Polaris System Development: Bureaucratic and and Programmatic Success in Government, Cambridge, Mass. Harvard University Press, 1972.

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91. V.Marchetti and J.D.Marks, The CIA and the Cult of Intelligence, New York, Bell Publishing Company, 1974, pg. 57.

92. W.J.Price, L.W.Barr, "Scientific Research and the Innovative Process," Science, 164:3881 (16 May 1969): 802-6.
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94. D.J.Goodspeed, A History of the Defence Research Board of Canada. 1958. Chapter 10" Biological Warfare Research.

95. Management Factors Affecting Research and Exploratory Development, A.D.Little Inc., for Dept. of Defense, Director of Defense, Research and Engineering, April 1965.
The original report also contained a short textual description of the development history of the XM-102, 105 mm. howitzer.

96. Systems Studied in Project Hindsight:
Hound Dog, air-to-surface missile
Bullpup, air-to-surface missile
Polaris, submarine-launched ballistic missile
Minuteman I, intercontinental ballistic missile
Minuteman II, intercontinental ballistic missile
Sergeant, tactical ballistic missile
Lance, tactical ballistic missile
Mark 46 Mod 0, acoustical torpedo
Mark 46 Mod 1, acoustical torpedo
M 102, 105 mm. howitzer
AN/SPS-48, frequency scan search radar
Mark 56, sea mine
Mark 57, sea mine
Starlight Scope, night vision instrument
C-141, transport aircraft
Navigation Satellite
M-61, nuclear warhead
M-63, nuclear warhead
XM-409, 152-mm artillery round
FADAC, digital computer for field operations

97 - C.W.Sherwin, R.S.Isensen, First Interim Report on Project Hindsight (Summary), Office of the Director of Defense Research and Engineering June 30, 1966. (Declassified final study just obtained; ref.to be inserted.)
- D.S.Greenberg, "Hindsights DOD Study Examines Return on Investment in Research", Science, 154:3750 (Nov. 18, 1966): pp. 872-3.
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- J.R.Bird and H.T.Darracott, "Developing and Using the US Army Long Range Technological Forecast". US Army, undated (1968 ?)
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A.S.Yakovlev. The Aim of a Lifetime. Moscow: 1972.

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In an acerbic generalization, Annie Kriegel has carried this argument even further, though her statement was made in a very general context, and not in regard to Soviet weapons procurement policies.

> The Soviet system then .. need not value change or the capacity for change. Imagination, invention, the "new," the "never seen before" do not interest it. Let others make the expensive scientific or technological "rists." If they prove usable, it is easy enough, and certainly cheaper, to send over an official, or secret team, to bring back the applicable formulae, plans, models or prototypes.

(Annie Kriegel, "The Nature of the Communist System: Notes on State, Party, and Society." Daedalus, 108:4 (Fall 1979): 146) Kriegels remark anticipates the discussion on pages 52-53.

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