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Modernization of Weapons and the Qualitative Problems of Arms Control

by George Lindsey

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Dr. George Lindsey
55 Westward Way
Ottawa, Ontario
K1L 5A8

PREFACE

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Dr. George Lindsey is a visiting senior research fellow at CIIPS and was formerly the Director of the Department of National Defence Operational Research and Analysis Establishment (ORAE).

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CONDENSÉ

La plupart des accords importants sur la limitation des armements portent essentiellement sur le nombre d'armes, les caractéristiques et les facteurs qualitatifs de ces dernières n'étant contrôlés qu'à partir de catégories définies de façon générale. Toutefois, pour évaluer l'équilibre des forces et pour une limitation des armements efficace, il sera de plus en plus nécessaire de reconnaître l'importance de la capacité des différentes armes et de déterminer à quel point leur performance peut être améliorée par une modernisation.

Au début de 1992, il est possible de retracer l'évolution de plusieurs familles d'armes pendant la Guerre froide, qui a duré assez longtemps pour que plusieurs générations d'armes se remplacent successivement. Les tendances modernisatrices ont, d'une part, rendu les armes offensives plus efficaces et, d'autre part, favorisé la stabilité des mesures de dissuasion stratégique.

Pour faciliter tant l'évaluation de l'équilibre des forces que la conception et la vérification des accords sur la limitation des armements, il serait utile de définir des caractéristiques de performance observables qui révéleraient le degré d'efficacité des armes. Cependant, la plupart des caractéristiques importantes sont interdépendantes et interchangeables. En conséquence, aucune ne peut, à elle seule, indiquer le degré de capacité d'une arme.

Les effets de la modernisation d'une arme doivent être mesurés par rapport à l'efficacité de ses «ennemis naturels» qui, eux aussi, peuvent être perfectionnés.

Les ICBM et les SLBM, par exemple, ont évolué de façon remarquable en trente ans, bien que le nombre de leurs vecteurs soit resté pratiquement le même au cours des dernières années. Toutefois, les ogives multiples ont accru la force de frappe des États-Unis, au début des années 1970, et de l'URSS, quelques années plus tard. De plus, les deux superpuissances ont énormément amélioré la précision de leurs armes et ce, de façon soutenue. La puissance des lanceurs au décollage s'est stabilisée, probablement grâce aux traités SALT. Les générations successives de sous-marins stratégiques ont un tonnage de plus en plus important et une capacité d'emport de missiles de plus en plus grande. En outre, la portée des SLBM s'est accrue.

Il n'existait pas de missiles antimissiles balistiques, et les missiles balistiques n'étaient pas transférés entre pays.

Graduellement, la portée, la vitesse et la charge utile des bombardiers lourds américains ont augmenté, les facteurs clés étant le ravitaillement en carburant en vol et la propulsion à réaction. Le nombre maximum de bombardiers stratégiques américains a été atteint en 1959 (plus de 8 000), et il a diminué progressivement depuis (à moins de 300 aujourd'hui). Depuis vingt-cinq ans, le nombre de bombardiers soviétiques à grand rayon d'action et équipés d'armes nucléaires demeure stable (environ 160).

Les avions tactiques se sont modernisés plus rapidement et d'une manière plus soutenue que les bombardiers stratégiques. Pour que les bombardiers et les chasseurs puissent exécuter leurs principales missions, ils doivent pouvoir éliminer leurs ennemis naturels, c'est-à-dire les missiles et les canons terrestres et aéroportés. La vitesse des avions à hélices a augmenté et, peu à peu, les moteurs à réaction leur ont permis d'atteindre des vitesses frôlant Mach 1. Ils ont rapidement atteint Mach 2 après que l'on est passé maître des vols supersoniques, mais on a jugé peu utile de dépasser Mach 2,5. On s'est efforcé de hausser les plafonds pour permettre aux avions d'échapper au tir des canons antiaériens, mais il n'y a pas de plafond que les missiles surface-air ne puissent dépasser. La puissance de combat d'un chasseur-bombardier moderne dépend davantage de son armement et de son système avionique que de sa performance aérodynamique.

La modernisation des avions de combat tactique commence dans l'un des pays les plus industrialisés. Cependant, au fil des ans, des modèles moins modernes sont transférés dans d'autres pays selon un processus hiérarchique lié aux alignements politiques.

Des progrès techniques marquent l'histoire des principaux chars de combat depuis leur entrée en service, pendant la Première Guerre mondiale. À la Seconde Guerre mondiale, leur poids était passé à cinquante tonnes environ, et le calibre de leur canon principal, à 75 mm, ou plus. Depuis, on a peu augmenté leur poids, et le calibre des canons varie entre 105 et 120 mm. La conception des chars est fonction du besoin de mobilité et des dangers que présentent les ennemis naturels, soit une grande variété d'armes antichars, ainsi que d'autres chars.

La répartition des chars dans le monde ressemble à celle des avions de combat, les pays donateurs (ou vendeurs) conservant les plus récents modèles et les destinataires (importateurs) ne disposant que des modèles moins récents.

INTRODUCTION

A complete treatment of the subject of modernization and the qualitative arms race would cover a substantial portion of the scientific, engineering, and manufacturing activities of the industrialized world. In a recent publication[1] the US Department of Defense made a comparison of the levels of technology in military systems deployed by the Soviet Union and the United States in 1990. The military systems are listed in Table 1. There are thirty-one of them, grouped under the major headings of Strategic, Tactical, and C3I (i.e. Command, Control, Communications, and Intelligence). Tactical systems include sub-groups headed land forces, air forces, naval forces, and an additional system is Training Simulators.

One of the objectives of this paper is to relate modernization and the qualitative arms race to the problems of the assessment of military balances and to arms control. The most important arms control agreements that have been negotiated dealt with strategic forces or tactical land and air forces. The most generally accessible data regarding inventories of military systems concern major weapons such as strategic nuclear delivery vehicles, combat aircraft, tanks, and naval combatants.

The approach to this study of modernization will be an historical one, seeking lessons from the past experiences of modernization, extending over several "generations" of weapon systems.

1992 is a good year in which to examine the modern history of weapon modernization. For four decades, modernization was driven by the pressures of the Cold War. The rich nations devoted a substantial proportion of their gross national product and a larger proportion of their technological capabilities towards weapon modernization, by indigenous research, development, and production, and by purchase. And, when they were able to substitute new first-class modern replacements for equipment whose age and technology had degraded it to second class, the older (but still perfectly usable) second-class equipment was often passed on to a poorer ally. For the ally, substitution of their third-class equipment by second-class replacements also represented a modernization.

With the end of the Cold War, and the signing of significant agreements for arms reductions, defence expenditures and sizes of armed forces are expected to decrease. However, this does not necessarily imply less efforts to modernize weapons in the future. The United States has indicated that it intends to apply its defence budget cuts to personnel and weapon procurement, but will continue with research and development. Many of the weapons to be eliminated under the terms of the CFE treaty are likely to be transferred to other countries, for whom their acquisition will represent a modernization. There is likely to be a desire to maximize the quality of the (smaller)

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1 *Soviet Military Power 1990*, United States Department of Defense, Washington, 1990, p.46.

forces which remain, and to retain the national capability to arm reconstituted forces with the most modern equipment, should the need arise in the future. Also, in addition to the incentives related to national security, international relations, and the balance of power, there is the opportunity for profit in the sale of advanced military equipment.

For several good reasons, arms control has concentrated on the quantities rather than the qualities of weapons. It will be shown that it has been possible to make very significant additions to the military capabilities of a weapons inventory by modernizing or replacing the equipment, without increasing the numbers deployed. The force balances in place at the time of the signing of an arms control agreement may change in subsequent years without any violation of the terms of the agreement. A quantitative arms race can be replaced by a qualitative arms race.

Instances will be pointed out in which modernization resulted in important improvements to strategic stability. It should not be concluded that modernization is necessarily undesirable or dangerous.

To keep the study within reasonable bounds, to concentrate on military systems already involved in arms control, and to consider systems for which historical data is available, the discussion will focus on strategic systems (ICBMs, SSBNs, SLBMs, strategic bomber aircraft, ALCMs, and to some extent on their nuclear weapons), tactical air systems (fighter/attack and interceptor aircraft), and tactical land forces (tanks and anti-tank guided missiles). Naturally, bombers and tactical combat aircraft are affected by surface-to-air missiles, tanks by attack helicopters, and all of these by C3I. Tactical naval forces are very important, and demonstrate modernization as well as the others, but they have not as yet become subject to arms control. What is included in the paper is only a small selection of the thirty-one systems, but it should suffice to illustrate some of the aspects of modernization and how they affect both arms control and the assessment of force balances.

I ASSESSING CAPABILITIES AND CONTROLLING ARMAMENTS BY NUMBERS AND BY QUALITY OF WEAPONS

Numbers and Quality of Conventional Weapons

The planning and conduct of military operations in war requires continual assessment of the combat power of both friendly and enemy forces. In peacetime, for the preservation of national and international security, and for the maintenance of security balances established through arms control agreements, it is also important to be able to assess the combat potential of various military formations, and to be able to ascertain whether balances are being changed. It is obvious that the capability for war of a nation, an army, or a collection of military hardware, depends on both the numbers of men and weapons and on their quality.

The relative importance of numbers and quality can be debated at great length. According to Lanchester's Law, devised for engagements between forces equipped with individually aimed long-range weapons, combat power is directly proportional to the lethality of each individual weapon, but varies as the square of the number of weapons. This would suggest that numbers are more important than quality. In previous centuries, opposing European armies were usually armed with similar weapons, with the result that battles and campaigns were determined by generalship, logistics, and the number (and quality) of soldiers, rather than the quality of weapons. A king preparing for war put more priority on making alliances with other powers, especially those with sizeable armies, equipped much as his own forces, rather than on attempting to acquire or develop superior weapons. And the advance of technology was so slow that any improvement in the performance of a weapon was likely to be marginal, and would soon be observed and copied by the rivals.

The importance of the quality of weapons was evident in conflict between societies at distinctly different levels of technological development. A few Europeans with firearms were able to conquer far larger numbers of warriors not so equipped.

However, in Vietnam and Afghanistan the possession of technically superior weapons was insufficient to achieve victory, although it should be added that this superiority was partially offset by the provision to the North Vietnamese and Afghan *Mujahaddin* of certain key modern weapons such as surface-to-air missiles. The decisive victory of the UN coalition in the Persian Gulf was due to superior quality of equipment, men, and organization, rather than to numbers of weapons or soldiers.

Attempts to achieve victory on the occasion of the first appearance of a weapon of a radically new type have failed because the number of the new weapons introduced into combat was insufficient to accomplish truly decisive results. Examples were the first use of tanks, and of poison gas, in World War I, and of V1 and V2 missiles and jet-propelled fighter aircraft in World War II.

The early efforts at arms control between the two World Wars were directed at both numbers and quality of weapons. The German army was to be limited to 100,000 men. But naval strength was to be limited by tonnage, and calibre of guns, rather than by the number of ships or guns[2]. It was clear that in comparison to a ship of smaller tonnage a large warship could be provided with guns of longer range and greater hitting power, could have thicker armour, more powerful engines, and carry fuel for longer endurance. The designer could choose among these advantages, but whichever he selected would come at the cost of an increase in the tonnage of the ship. A feature of the thinking of that period was that like would fight against like, a belief not borne out in subsequent naval wars.

The Proliferation of Nuclear Weapons

The invention of nuclear weapons introduced a radical discontinuity to the spectrum of weapon capability. Instead of measuring damage potential in terms of kilograms (kg) of chemical High Explosive (for artillery shells), or tons (for heavy bombers), it was necessary to use kilotons, even megatons. All weapons that were not nuclear were lumped together under the term "conventional"[3]

After the second world war, the dominant concern for arms control was the proliferation of nuclear weapons. The Non-Proliferation Treaty committed signatories who did not already possess nuclear weapons to refrain from acquiring any at all, but left the signatories[4] who had them in 1968 free to increase both their number and quality,albeit with a general undertaking to reverse the process in the future. In the Threshold Test Ban Treaty of 1974 the USA and USSR agreed to limit

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2 The Washington Naval Treaty of 1921 allowed the USA and Britain 525,000 tons of capital ships, Japan 315,000, and France and Italy 175,000 tons. The same countries were permitted 135,000, 81,000, and 60,000 tons for aircraft carriers. No capital ship could exceed 35,000, and no carrier 27,000 tons. The guns of capital ships were limited to a calibre of 16 inches. The London Conference of 1930 set tonnage limits on cruisers, destroyers, and submarines. See *Sea Power: A Naval History*, ed. E.B.Potter, US Naval Institute Press, Annapolis, 1981, pp.234-235.

3 Chemical and biological weapon are often excepted, in which case there are four categories of weapons: nuclear, biological, chemical (NBC) and "conventional". Sometimes, especially in arms control language, the first three are categorized as "weapons of mass destruction".

4 Of the five states which possessed nuclear weapons in 1968, three (the USA, USSR, and United Kingdom) signed the NPT. France and China did not sign.

nuclear tests to energy yields less than 150 kilotons. The INF treaty, in force since 1988, and START, signed in 1991, agree to reductions in the capabilities of the USA and USSR to deliver nuclear weapons at intermediate and long ranges. Subsequent plans have been announced to remove short-range "battlefield" nuclear weapons from Europe.

The ABM Treaty

The ABM Treaty of 1972 amounted to a prohibition of active antiballistic missile defence, but with certain exceptions. Up to 100 interceptor missiles could be deployed in each of two areas in each country (reduced to one area in a subsequent protocol). New ABM radars could be introduced, but only for early warning, and with a limit to their power and antenna size. Development, testing, and deployment of sea-based, air-based, space-based[5], mobile land-based, and multiple launchers were all specifically prohibited, as was the extension of the capabilities of other systems, such as those designed for defence against aircraft, to make them able to intercept *strategic* ballistic missiles. However, systems to intercept *tactical* ballistic missiles would not be forbidden[6]. Modernization and replacement of the existing ABM radars and missiles was allowed. In the event that ABM systems based on "other physical principles" are created, specific limitations on them were to be discussed[7]. Thus the ABM Treaty was very much concerned with the quality and characteristics of weapons, and with their modernization. There has been much heated debate about the extent to which development and testing can proceed before it violates the provisions of the treaty.

Strategic Nuclear Weapons

SALT I, SALT II, the Intermediate Nuclear Force (INF) Treaty, and the Strategic Arms Reduction Talks (START) concentrated more on delivery systems than on nuclear warheads, and, when warheads were explicitly identified, the limitations were on numbers, with no reference to size, yield, or characteristics of radiation.

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5 This item has been the cause of much controversy between the USA and USSR, and within the United States. The Strategic Defence Initiative is conducting experiments on space-based ballistic missile defence, which at some stage could be considered to have become development rather than research.

6 The use of the American Patriot antiaircraft system to intercept Iraqi SCUD missiles in the Gulf War did not infringe the ABM Treaty, nor will research and development on systems deigned for defence against any ballistic missiles with operational ranges less than 5500 km.

7 Research is proceeding on the use of energy beams as ABM weapons. These represent a new physical principle, and could be based in space or on aircraft as well as on the ground.

The efforts to limit nuclear delivery systems were aimed at numbers more than quality. This was due in large part to the increasing ability of the reconnaissance satellites possessed by the two superpowers to detect and count large objects such as ICBM silos, bomber aircraft on their airfields, and submarines in construction yards or in port. Thus it would be possible to verify that the other party was complying with an agreement to limit the *numbers* of these large and countable objects. SALT I called for a freeze in numbers, at the levels deployed or under construction in 1972 (preserving a considerable numerical advantage for the Soviet Union), while SALT II set equal total numerical limits, slightly below those in place in 1979. START was for equal total limits significantly lower that those deployed in 1991.

The operational capabilities of the systems were much more difficult to observe than the number of launchers, although it became possible to assess many of the characteristics of ballistic missile delivery systems by reception and analysis of telemetry signals emitted during test firings. Once the Limited Test Ban Treaty of 1963 brought an end to the testing of nuclear weapons in the atmosphere, it became more difficult to discover the characteristics of foreign nuclear explosions, although great efforts have been expended to develop instrumentation for the detection of small underground explosions and the measurement of their energy yield.

The launch weight of a ballistic missile sets a limit to the weight of payload, and the range to which it can be delivered. But for ICBMs, once intercontinental range has been achieved there is little advantage in any further increase[8] However, a large payload can be used to deliver a very large nuclear warhead, or several independently-targeted warheads, or for penetration aids to confuse defences. As SALT I was being negotiated the Soviets were deploying the SS-9 ICBM, whose 200,000 kg launch weight was about six times that of the Minutemen missiles making up the bulk of the American ICBM force. SS-9, and its successor the SS-18, were characterized as "heavy" ICBMs, and were limited in number to the 308 deployed by the USSR. The definition of "heavy" concocted in SALT II was anything heavier than the heaviest "light modern" ICBM, clearly the Soviet SS-19, thought to have a launch weight of about 90,000 kg and a throw-weight of about 3,400 kg. START cut the number of Soviet heavy ICBMs to 154, and established the limits for light ICBMs at a launch weight of 106,000 kg and a throw-weight of 4,350 kg, which weights are somewhat greater than the weights of MX and SS-24, but far below SS-18.

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8 It is possible to attack a target distant by a quarter of the Earth's circumference by using a trajectory going three-quarters of the way around, and approaching the target from the opposite direction. This capability was built into some Soviet ICBMs, and is called the "Fractional Orbital Bombardment System", or "FOBS". It is less accurate than the direct trajectory and has about three times the time of flight. FOBS was prohibited by SALT II.

The most significant characteristics of modern strategic missiles are the number of nuclear warheads carried by each missile and the accuracy with which each warhead can be delivered to its intended target. SALT II and START set limits to the number of warheads, counted by the numbers of MIRVs launched in tests of the various missiles. The total magatonnage has been sharply reduced, but this was due to the technological improvements in accuracy, and not to arms control.

Modernization and replacement of missiles was allowed, but in the case of START with the proviso that no new types of heavy missile, or increases in the launch weights or throw-weights of heavy missiles are permitted. START set specific criteria for the degree of change that would be accepted before an ICBM or SLBM was considered to have become a new type[9].

Intermediate Nuclear Forces

The delivery systems eliminated by the INF Treaty were mobile ground-based ballistic and cruise missiles, which were normally housed in distinctive basing complexes, but not associated with large fixed silos. While these missiles could be detected and identified by a satellite which passed overhead in clear weather, while they were out in the open, the only way to infer the total number deployed was by observation of the number of permanent bases. When data was exchanged as required by the Treaty, the Western estimate of the number of Soviet missiles was revealed to be rather inaccurate[10]. Various numerical limits were discussed for GLCMs, Pershings, SS-4s, -5s, -12s, -20s, and -23s, but in order to secure a treaty with adequate verification it was finally necessary to set the number of INF missiles to *zero*, and to permit On-Site Inspections and other cooperative measures of verification far more intrusive than any that had ever been accepted before. Once measures such as intrusive inspections and portal perimeter monitoring were possible, opportunities were presented for determining many details of the characteristics as well as the numbers of weapons. It is, of course, true that all of the weapons limited by the INF Treaty are supposed to be destroyed, so that knowledge of their characteristics is likely to be of little practical value for potential enemies.

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9 START establishes that an ICBM or SLBM will be considered to be a new type if it has a different number of rocket stages, a different type of propellant, a change in the length of the first stage or of the entire missile, or of the launch weight, of 10%, a change on diameter of 5%, or an increase in throw-weight of 21%.

10 "Verifying the INF Treaty and START", by Owen Greene and Patricia Lewis, in *A Handbook of Verification Procedures*, ed. Frank Barnaby, Macmillan, London, 1990, p.233. See also *SIPRI Yearbook 1988*, Oxford University Press, New York, 1988, pp.38-44. The US Department of Defense had overestimated the number of SS-20s and SS-4s deployed, underestimated the number of SS-12s and SS-23s, and had been unaware of the production of a new Soviet GLCM.

Conventional Forces in Europe

The CFE Treaty faced problems of verification considerably more difficult than either SALT or INF. The numerical limits for the various categories of weapons were large numbers[11], instead of zero. Combat aircraft, helicopters, guns, tanks, and armoured combat vehicles would be much more difficult to identify by remote sensing, and to distinguish from permitted military or civilian articles of similar dimensions and shapes, as compared to ICBM silos, submarines in port, and large IRBMs. Consequently it was necessary to follow the precedent of the INF Treaty, and authorize cooperative measures of verification.

Although the limits agreed in CFE are numerical rather than qualitative, definitions had to be established of the five categories of weapons to be subject to limitation. While most of the definitions which appear in Article II of the treaty proper consist of descriptive words, it was necessary to add some numerical characteristics. For example, to be categorized as a battle tank an armoured fighting vehicle must weigh at least 16.5 metric tons, and be armed with a 360-degree traverse gun of at least 75 mm calibre. However the main means of specifying which weapons are to be limited was to draw up a "protocol on existing types of conventional armaments and equipment", listing types of weapons which are, and are not, limited by the treaty. A summary of this protocol is given in Appendix 2.

This method of controlling the quality of armaments is very dependent on the definitions of the weapon categories. If a new armoured combat vehicle were produced, its owners could describe it as a battle tank, an armoured personnel carrier, an armoured infantry fighting vehicle, or a heavy armament combat vehicle, in each of which cases the fleet of all such new vehicles would be subject to the same numerical limitation as the others already in that category. But if it were presented as an APC or AIFV "look-alike", this would constitute a claim to have its numbers excluded from limitation. The other parties to the treaty might challenge the categorization as a "look-alike". But if a country produced some sort of "super-tank", with a capability far superior to any existing tank, they would be within their rights to simply categorize it as "one battle tank", counting the same as all the other (now far inferior) battle tanks. Or, conceivably, if it were sufficiently novel, they could claim that the new device was not any kind of tank and not be subject to limitation at all.

Total Prohibition

In attempting to distinguish between the applications of arms control to numbers and to characteristics (or quality) of armaments, special attention needs to be paid to those agreements

11 20,000 battle tanks, 30,000 armoured combat vehicles, 20,000 pieces of artillery, 6,800 combat aircraft, and 2,000 attack helicopters.

which prohibit *all* items of a particular category. In these cases the quantitative limit is *zero*, and the objective of verification is to establish the total absence (or to detect the presence) of *any* of the prohibited items, rather than to count the number of permitted items.

The Antarctic, Outer Space, Seabed Arms Control, and Latin American and South Pacific Nuclear Free Zone Treaties ban all nuclear weapons from certain specified regions[12]. Some of them prohibit weapon testing and other military activity as well. The Non-Proliferation Treaty forbids the non-nuclear weapon states (NNWS) who are signatories[13] from acquiring *any nuclear weapons at all*. The Outer Space and Sea Bed Treaties ban "weapons of mass destruction" as well as "nuclear weapons". Although there have not been serious arguments about what constitutes a nuclear weapon, one can easily imagine controversies arising as to the characteristics defining what exactly is a "weapon of mass destruction".

The Geneva Protocol prohibits the *use in war* of any asphyxiating, poisonous, or other gases, and of bacteriological methods of warfare. It did not ban the *possession* of such agents. The Biological Warfare Convention bans development, production, stockpiling, acquisition, or retention of microbial or other biological agents or toxins, unless they have prophylactic, protective or other beneficial and peaceful purposes. But these agreements, and the negotiations for a Chemical Weapons Convention, are plagued with difficulties of definition as well as of finding adequate means to verify compliance[14]. It would be difficult to measure the total quantity of chemical or biological agents in a stockpile. Because of the close relationship with medical, veterinary, and agricultural research, and the natural and very legitimate desire to improve protective measures, there is little prospect of controlling research into biological warfare. Charges of illegal use of chemical weapons have proven difficult to either confirm or to repudiate.

The INF Treaty prohibits all ground-launched ballistic and cruise missiles belonging to the USA and the USSR with ranges between 500 and 5500 km. The terms appear to be clear-cut and unambiguous[15].

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12 See *SIPRI Yearbook 1990*, Oxford University Press, New York, 1990, Annexe A, "Major multilateral arms control agreements", by Ragnhold Ferm, pp.635-639.

13 Prior to the disintegration of the Soviet Union in 1991, 141 states had signed the NPT, 3 of which were Nuclear Weapon States (NWS). 18 members of the UN have not signed, including 2 NWS. There are strong suspicions that some of the other 16 non-signatories, and quite possibly some of the 138 NNWS signatories do have or are attempting to acquire nuclear weapons.

14 See *SIPRI Yearbook 1990*, Chapter 14. "Multilateral and bilateral talks on chemical and biological weapons", by S.J.Lundin, pp.521-543.

15 It might not be difficult to add range to a missile listed and tested with a maximum capability slightly below the specified limit.

The treaties which have had to confront the most complex interaction between the numbers and the quality and modernization of armaments are SALT, START, and CFE. Since the history of the strategic nuclear weapons programs are accessible in considerable detail, they will be examined in the next chapter, for the interaction between numbers and characteristics of weapons.

Systems Designed to Counter Opposing Weapon Systems

Most well-established weapon systems have natural enemies which they must be able to avoid or overcome in order to accomplish their primary mission. Sometimes their primary mission is to destroy their own homologue operated by their opponents, in which case this is one of their natural enemies. But in most cases they are threatened by other weapon systems, sometimes specifically designed for that purpose alone.

For example, submarines were first designed to threaten surface ships. They proved extremely effective against merchant ships, but somewhat less so against surface warships, which soon armed themselves with antisubmarine weapons, and began to design warships specifically for antisubmarine warfare (ASW). The best ASW platforms turned out to be aircraft and opposing submarines.

Then the development of the nuclear-armed submarine-launched ballistic missile produced a new role for a new class of submarine. Today's SSBNs do not threaten, nor are they threatened by opposing SSBNs. But they are threatened by antisubmarine systems based on aircraft, surface ships, submarines designed specifically for ASW, and by mines.

When assessing the strategic capabilities of a weapon system it is necessary to take account of its natural enemies, and judge the extent to which its effectiveness is likely to be reduced by these counter-systems.

A direct numerical comparison between the inventories of similar offensive weapon systems may not give a meaningful indication of their relative strengths if one side possesses far better defensive systems. And. because one of the main incentives for modernization is the contest between measures and countermeasures, between offence and defence, and between systems and their natural enemies, strategic balances can be upset by significant improvements in systems designed for defence rather than offence.

An example would be the number of SLBMs. SLBMs cannot be used against other SLBMs in flight, or against SLBMs in a submarine at sea. But the strategic value of an SLBM force could be drastically reduced if an opponent were to acquire an effective ASW system able to threaten the submarines when they were at sea.

Most of the negotiated arms control agreements have been directed towards offensive systems, such as ballistic missiles, bomber aircraft, and cruise missiles. In the case of the CFE treaty the weapons to be controlled (combat aircraft and helicopters, armoured fighting vehicles, and artillery) can be used both offensively and defensively, but there was no control over their other natural enemies such as antiaircraft or antitank weapons.

SALT I recognized the necessity to incorporate the defensive element into the control of strategic nuclear systems, by negotiating in parallel an interim agreement to limit offensive ballistic missile systems and the ABM Treaty to limit the deployment of defensive systems designed to intercept ballistic missiles. But agreements to limit or reduce the numbers of heavy bombers or strategic submarines have no associated limitations on the deployment or modernization of antiaircraft or antisubmarine weapons.

II THE MODERNIZATION OF STRATEGIC BALLISTIC MISSILES UNDER NUMERICAL LIMITATIONS

Until the late 1960s the two superpowers were able to deploy strategic weapons systems without being subject to any limits on their numbers or characteristics. Until the signing of SALT I in 1972 modernization of existing weapons and the development of new weapons was constrained only by the prohibition of the placing of nuclear weapons in orbit, or on or under the seabed. Restriction of nuclear weapons testing to underground explosions with an energy less than 150 kilotons came in 1974.

The Programs of Modernization and Replacement of ICBMs

Between 1959 and 1967 the United States built a force of 1054 ICBMs, a total which they never subsequently exceeded. The USSR was well behind in 1966, overtook the US in 1969, and had over 1500 ICBMs deployed at the time of the signing of the SALT I Interim Agreement in 1972. This agreement was to "freeze" the inventories of both ICBMs and SLBMs at the levels existing at that time, but allowed installations already under construction at that time to be completed. The Soviet ICBM total peaked at 1607 (in 1975) and had declined to 1398 in 1979.

SALT II established equal overall numerical ceilings on strategic nuclear delivery vehicles, with a sub-limit on ICBMs with MIRV, START lowered the overall limit on vehicles, and added limits on warheads, including sub-limits on warheads on ballistic missiles and on mobile ICBMs[16]. Further unilateral proposals for reductions announced by President Bush on 27 September 1991 included total elimination of MIRVed ICBMs, followed a week later by President Gorbachev's unilateral counter-proposal to reduce the total number of strategic warheads below the START limits and freeze the number of rail-mobile ICBMs.

Figures 2A and 3A show the number of ICBMs deployed by the two nations. The numerical data is given on Tables 2 and 3[17]. It can be seen that over a period of twenty-five years both have elected to retain a nearly constant total number of ICBMs, roughly 1000 for the USA and 1400 for the USSR. But these numbers will be reduced over the next seven years, in order to comply with the provisions of START.

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16 The overall limit on the number of Strategic Nuclear Delivery Vehicles (which include ICBMs, SLBMs, and heavy bombers) was 2250 in SALT II, reduced to 1600 in START. START replaced the SALT II limit of 820 MIRVed ICBMs by limits of 6,000 total accountable warheads, 4,900 warheads on ICBMs and SLBMs, and 1100 on mobile ICBMs. This left freedom to increase the number of missiles carrying MIRV, as long as the total number of vehicles and warheads complied with the limits.

17 Each Figure is labelled with the same number as the number of the Table in which the relevant data are listed.

Replacement and modernization were explicitly permitted in SALT I, with the restriction that no light ICBMs could be converted to heavy ICBMs[18]. SALT II placed more qualitative restrictions, especially on the proliferation of multiple warheads. Each side was permitted to deploy one new type of light ICBM, with no more than ten MIRVs, but no heavy mobile ICBMs, no conversion of light to heavy ICBMs, no heavy SLBMs, or SLBMs with more than 14 warheads. There were other restrictions, including some on cruise missiles. Specific deployed types of ICBMs, SLBMs, and heavy bomber aircraft were identified. START permits modernization and testing of existing heavy ICBMs, but prohibits any increase on launch weight or throw-weight, or deployment of new types of heavy missile. It forbids new types of ICBM or SLBM with more than ten warheads.

Whereas the START treaty contains voluminous detail, negotiated over a period of nine years, in contrast the (unnegotiated) unilateral statements were quite brief. The subsequent presidential statements regarding further unilateral reductions did not specify details regarding provisions for modernization.

SALT I, SALT II, and START divided the history of strategic offensive weapons into four periods. With no restrictions on either numbers or characteristics, development and deployment were unconstrained up to 1972. Between 1972 and 1979 numbers were "frozen", but the freedom to modernize or replace weapons was restricted only by the freezing of the number of heavy ICBMs. Subsequent to 1979, both had to remain within the (same) agreed total number of ICBMs, SLBMs and bombers, which required a slight reduction on the part of the Soviets by 1981. But after SALT II the freedom to alter the mix (within the total limit) and to introduce new types was subject to significant restrictions. If START is ratified there will have to be considerable reductions in numbers, and the freedom to increase the number of warheads has been severely constrained.

The restrictions placed on modernization, replacements, and freedom to alter the mix of weapons should not be regarded as if they had been imposed by an external power. They were agreed by the two parties, after much negotiation, each with full knowledge of how the treaties would affect their on-going and future programs. But factors which could not be known were the future steps that would be taken by the other party, and technological advances that would present both opportunities and dangers. The Interim Agreement of SALT I had a duration of five years, ending in 1977. SALT II was signed on 18 June 1979, and was designed to expire on 31 December 1985.

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18 There has been considerable difficulty over the definition of "light" and "heavy" ICBMs. Eventually it was agreed that the Soviet SS-9 and SS-18 are "heavy" (with launch weights about 200,000 kg and throw-weights over 6,000 kg), the American Titan II (launch weight 150,000 kg and throw weight 4,000 kg) was "old", and that the Soviet SS-19 (launch weight about 90,000 kg, throw-weight about 3,400 kg,) was the heaviest light ICBM. Anything larger than this would be considered to be "heavy". START set the limit at 106,000 kg launch weight and 4,350 kg throw-weight.

Although it never was ratified by either the US Congress or the Supreme Soviet, there was an inclination on both sides to continue to observe its provisions, especially when negotiations were in progress towards a succeeding treaty[19]. In 1986 an American deployment of ALCMs exceeded the SALT II limits. START was signed in 1991, to have a duration of fifteen years, with provision for further extensions.

Ballistic missiles with intercontinental range employed technology developed for intermediate range ballistic missiles such as the American Thor, and Jupiter, and the Soviet SS-3, -4, and -5. The launching of the first satellite into earth orbit (the Soviet Sputnik in 1957) showed that intercontinental ranges were attainable. The primary problems for long-range missiles were to obtain sufficient payload and accuracy adequate to give the warhead a reasonable probability of destroying the intended target.

For the first ICBMs, accuracy, as measured by Circular Probable Error (CEP), was no better than a few kilometres, so that it was necessary to deliver a thermonuclear warhead of large energy yield (equivalent to the explosive power of hundreds of kilotons of TNT[20]). But the early thermonuclear devices were very heavy, and the possibility of delivery to intercontinental range with a ballistic missile had to await significant improvements in the yield-to-weight ratio of the warheads. Consequently the first ICBMs were very large. They used liquid rocket fuel, which is more energy efficient that solid, and offers easier control of its burning rate. But a severe disadvantage of the liquid fuels available in the early 1960s was that they required refrigeration. It took many hours to prepare the missile for launch, and, once fuelled, it was not possible to retain the volatile fuels in a ready state for very long. The liquid fuel was also dangerous to handle, and the missile, necessarily of light construction, was extremely vulnerable.

Weapons with these characteristics invited a preemptive attack, whether by missile or aircraft, and in the event of a surprise first strike would not have been able to retaliate before they were destroyed. In time of crisis there would be a strong incentive to launch them before they were lost, so that the deterrence that they produced was distinctly unstable and dangerous.

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19 In 1986 the White House announced that the US would no longer be bound by the provisions of the unratified SALT II treaty. Nevertheless whenever new acquisitions threatened to breach the SALT limits, domestic political pressure was brought to make compensating reductions. Negotiations for SALT III were renamed "START" (Strategic Arms Reduction Talks, recognizing the desire for reductions rather than continuation of present levels), and led to signing of an agreement in July 1991, by the presidents of the United States and the USSR. It has not yet been ratified by either party, and there is doubt as to who now represents the former USSR.

20 While a small yield (a few kilotons) is best achieved with fission, and intermediate yields (tens of KT) benefit from fission "boosted" by some thermonuclear material, large yields (hundreds of KT up) depend on a large contribution of fusion (thermonuclear) energy.

With all these disadvantages, and no restrictions on development, modernization, or replacement, it is neither surprising nor regrettable that new and improved versions were produced and deployed at a rapid rate through the early 1960s.

It is by no means automatically true that modernization of weapons (or other military equipment) makes the whole system more dangerous or unstable.

Modernizations of American and Soviet ICBMs, SSBNs, and SLBMs are discussed in greater detail in later sections of this chapter.

Ballistic Missile Defence (BMD)

SALT I was the first arms control agreement to associate limitation of offensive weapons with limitations on their natural enemies (in this case ballistic missile defences). A driving consideration was the fear that building of defences would weaken strategic deterrence, motivate an increase in the number of offensive missiles, or both. The probable overall result would be great expense to preserve the existing state of mutual and stable strategic deterrence. Another conceivable result, even more undesirable, would be to demolish mutual stable nuclear deterrence altogether.

Of all the types of weapon system that have ever existed, ballistic missile defence must be the one for which modernization is the most pervasive and continuing characteristic. In fact, it is doubtful that BMD has ever attained a state in which wide-scale deployment could be considered to be justifiable on technical grounds.[21] In the case of the United States, especially since the creation of the Strategic Defense Initiative in 1983, the pace of research has been so fast that several parallel programs continue in hot pursuit of promising techniques, even though no active defences have been deployed since 1976.

Until the 1980s it appeared that the only possibility of effective destruction of a ballistic missile was by radar guidance of a ground-based anti-missile missile armed with a large nuclear warhead. But remarkable progress in missile guidance now makes it seem possible to obtain a "kinetic energy kill" by collision of an interceptor missile with the rapidly moving reentry vehicle. In addition, methods are being developed to direct laser or particle beams with energy and

21 The Soviet Union has had a BMD system deployed around Moscow since 1969, with nuclear-armed interceptor missiles ("Galosh", and more recently "Gazelle"). Components have been repeatedly modernized, but the deployment has never exceeded the limits of the ABM Treaty. The frequent changes confirm that the system has never been considered to be satisfactory (at least for very long). The "hands-on" experience of operating a complete system will have been valuable. In 1975 the United States deployed a system known as "Safeguard" in North Dakota, with a large phased array radar (PARCS), and thirty exoatmospheric "Spartan" and seventy endoatmospheric "Sprint" nuclear-armed interceptor missiles. The system was deactivated soon afterwards, except for the radar. Another deployment with up to one hundred interceptor missiles would be permitted under the ABM Treaty.

concentration that may be sufficient to destroy reentry vehicles at great distances. The X-ray laser may be the last ABM project to depend on nuclear energy. The history of active ballistic missile defence has been one of ceaseless modernization, without corresponding deployment. It has also been characterized by determined efforts to achieve its objectives without the need to depend on nuclear weapons.

Prior to the signing of the ABM Treaty in 1972 the designers of ballistic missiles faced the possibility that their weapons would ave to penetrate unrestricted defensive systems. However, fairly simple counter-countermeasures were available, such as the provision of decoys which would attract the interceptors away from the real reentry vehicle. But the most important counter-countermeasure was the introduction of multiple warheads into the ICBM and SLBM nose cones, thus presenting the defence with a number of separate targets arriving at the same time. A further counter-countermeasure, which could become important if BMD became a more significant countermeasure, would be to make the reentry vehicles manoeuvrable[22].

In the assessment of strategic force balances, a direct comparison of the number of ICBMs is especially meaningful inasmuch as they can be used in a first strike against the ICBMs as well as the air and naval bases of the opponent. The most important qualitative characteristics of an ICBM force are not its ability to penetrate defences, but rather its ability to survive nuclear attack before it is launched, and, once it has been launched, to destroy hard targets. For strategic submarines there is the requirement to be able to survive the operations of hostile ASW.

Modernization and Replacement in the ICBM Program of the United States[23]

The United States deployed three models of the Atlas, all liquid-fuelled with one and a half stages[24] of rocket propulsion. Atlas employed an ingenious method to minimize the weight of the missile structure. A thin airtight outer skin was subjected to positive internal gas pressure, which kept the structure rigid without the need for mechanical bracing. But the resulting missile was extremely vulnerable to puncture. Three basing modes were employed, the first extremely "soft", with the missile permanently exposed in the open, the second with it stored in a horizontal "coffin",

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22 The acronym is MaRV, Manoeuvrable Reentry Vehicle. The US Navy has designed manoeuvrable reentry vehicles for its Trident SLBMs.

23 *The History of the US Nuclear Arsenal*, by James N Gibson, Bison Books, London 1989.
US Nuclear Forces and Capabilities, by Thomas Cochran, William Arkin & Milton Hoenig, Volume I of Nuclear Weapons Databook, Harper & Row, Cambridge, Mass. 1984.
US Nuclear Weapons: The Secret History, by Chuck Hansen, Crown Publishers, New York, 1988.

24 Two booster rockets and one sustainer were all ignited at liftoff. This avoided problems of igniting the second stage in mid-flight.

and the third in a vertical buried silo. However, with the last two modes, before launching it was necessary to elevate the missile out of its coffin, and to raise it out of its silo. Atlas D was guided by radio command, but the E and F models used inertial guidance[25].

Titan I, with two stages of liquid-fuelled rockets, was designed with rigid internal bracing, rather than pressurization, and was stored in a hard underground silo, but had to be raised to the surface before launching. It used radio command guidance.

Titan II had a liquid fuel which could be stored in the missile, and the missile could be launched directly out of its hard underground silo. Titan II was more accurate than Atlas or Titan I, and had a more powerful warhead, thus possessing a combination of characteristics that overcame all of the most serious drawbacks of the first ICBMs, and kept Titan II in service for twenty-four years[26].

A major American step forward came with Minuteman, which was first deployed before Titan II. The series of Minutemen achieved progressively better accuracy, allowing warheads to be greatly reduced in yield and weight. As a result the missiles could be much smaller than Atlas or Titan[27]. They burned solid fuel, safer than liquid. All the Minutemen were stored in hard underground silos[28], from which they could be launched directly after a brief countdown. As shown on Figure 2A, Minutemen have provided the core of the American ICBM force since 1964, with 1,000 deployed for twenty years beginning in 1967. Starting in 1987, fifty were withdrawn to compensate for the introduction of fifty new MX missiles and remain within the SALT II limit, and more Minutemen will be deactivated to comply with the provisions of START. A probable move will be

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25 Guidance was only applied during the boost phase of the missile's trajectory. Radio command is vulnerable to interference and intentional jamming. Inertial guidance is completely self-contained. The continual improvement to the accuracy of ballistic (and other) missiles has been due in large part to remarkable increases in the precision achievable by inertial guidance. See *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, by Donald Mackenzie, MIT Press, Cambridge, Mass., 1990.

26 See *The History of the U.S. Nuclear Arsenal*, *op.cit.*, and *The Development of Ballistic Missiles in the United States Air Force, 1945-1960*, by Jacob Neufeld, Office of Air Force History, United States Air Force, Washington, 1990, Chapter VII. The Atlas D warhead had a yield of 1.4 MT, Atlas E and F, and Titan I about 4 MT. Titan II, with 9 MT, had the largest used in any American operational weapon. The "hardness" of the silos is measured by the peak blast overpressure which they can resist, expressed in pounds per square inch (psi). The hardness of the "coffin" was 25 psi, of the silos for Atlas F 100 psi, Titan I 150 psi, and for Titan II, 300 psi. Another means of reducing vulnerability was to site the silos (and their launch control centres) with a larger degree of physical separation.

27 The launch weights of the early missiles were 120,000 kg for Atlas, 110,000 kg for Titan I, and 150,000 kg for Titan II, whereas Minuteman I weighed only 29,500 kg. Minuteman II and III were slightly heavier (33,200 kg and 35,000 kg).

28 The original plan was to make Minuteman I rail-mobile, but this was abandoned. The Minutemen silos had a hardness of 2,000 psi, as contrasted to the 300 psi of those housing Titan II.

to eliminate all Minutemen II and retain all the Minutemen III, perhaps downloading the number of MIRVs[29].

In the twenty-nine year history of Minuteman there have been modernizations and replacements, but always keeping the total number of launchers to no more than 1,000. These are illustrated on Figure 2B. The first buildup was with Minuteman I, taking the US total to the level it maintained over the next decade and a half. In 1965, with 600 Minutemen in place, Atlas and Titan I were withdrawn, leaving the force invulnerable to any first strike that could have been delivered in that era. Minuteman II was nearly twice as accurate as Minuteman I, and began to replace the latter in 1966.

In 1970, Minuteman III introduced what was probably the most important improvement to the offensive capability of strategic missiles. This was the Multiple Independently-Targeted Reentry Vehicle (MIRV). In the nose cone of the Minuteman III there were three Mark 12 MIRVs, programmed to separate from the post-boost vehicle and follow separate trajectories to three different previously selected targets. Each of the three Mark 12 MIRVs in Minuteman III had less explosive energy yield than did the larger single warhead of Minuteman II, but each could be delivered with better accuracy. A further improvement took place in 1981, when the Mark 12A twice the yield and 60% of the CEP of the Mark 12, began to replace the latter[30].

After much development and debate over mobile missiles, the USA finally deployed a new ICBM called MX (or "Peacekeeper"), placing it in silos vacated by Minuteman III[31]. MX carries ten 300 KT MIRVs, and has the extraordinary accuracy of a 100 m CEP[32].

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29 This was outlined in President Bush's unilateral announcement of 27 September 1991. START allows the number of accountable MIRVs to be reduced if every member of the category is fitted with no more than the new number of warheads. The maximum total number of reentry vehicles that can be "downloaded" is 1250, which cannot include any on heavy ICBMs or new types of missile. Thus, 500 Minutemen III could each be downloaded from three to one warhead, reducing the accountable number to 500.

30 Minuteman II carried one warhead with a yield of 1.2 Megatons (MT), delivered with a CEP of about 550 metres. The Minuteman III deployed in 1970 carried three Mark 12 MIRVs, each with a yield of 170 KT, delivered with a CEP of about 370 m. Aimed against individual hard targets (such as missile silos), under most circumstances no one of the smaller MIRV warheads would have as high a probability of destroying its target as would the single larger warhead, but the three would have a higher probability of destroying at least one of the targets, and might destroy two or even three. The yield of the Mark 12A warhead was 340 KT, and its delivery system has a CEP of 220 m.

31 With 550 MIRVed Minutemen III, compliance with SALT II obliged the USA to limit the total number of MIRVed SLBMs to 650, and the total number of MIRVed SLBMs plus ALCM-equipped bomber aircraft to 770. In 1986 they came within ten SLBMs of the former limit, and exceeded the latter limit. If the MIRVed MX ICBMs had replaced single-headed Minutemen II instead of MIRVed Minutemen III, this would have caused a further violation of the SALT II limits.

The history of the deployment of American ICBM warheads is illustrated on Figure 4 and Table 4. It should be compared with Figure 2B, which plots the number of launchers. The number of warheads is a better measure of offensive capability than the number of launchers, but offensive capability also depends on the accuracy and the energy yield of the warheads. It is the combination of number of warheads on Minuteman III and MX with their considerable yield and small CEP which gives the US ICBM force a great counterforce potency, all built up without breaching the numerical restrictions of the SALT treaties.

The Multiple Independently Targeted Reentry Vehicles, combined with greatly improved accuracy, is the outstanding example of modernization producing enormous increases in offensive capability, while complying with numerical arms control limitations.

Modernization and Replacement in the ICBM Program of the Soviet Union[33]

Although the United States expected the Soviets to deploy a large number of ICBMs soon after the launching of Sputnik, and engineered as a matter of urgency the programs for Atlas and Titan, it is now known that the Soviet buildup was considerably slower than the American. Only four of the first type of Soviet ICBM, the SS-4, were deployed, and these were withdrawn in 1962. The SS-7 and SS-8 improved on the poor accuracy of SS-6. SS-7 and SS-8 were liquid-fuelled, about the same size as the American Atlas, and in the first years were mounted on soft launchers. One could conclude that SS-7 was the first satisfactory missile, as eight times as many of these as for SS-8 were deployed, and some were provided with harder launchers.

A major change came with the SS-9. Liquid-fuelled, housed in a hard underground silo, and considerably larger that the American Titan II, SS-9 carried a very heavy warhead with the enormous energy yield of 25 megatons[34], the largest that has ever been deployed on any single weapon. A modification allowed a smaller warhead to be delivered on a "fractional orbital" trajectory, going more than half way around the earth and striking the target from the direction opposite to that for the direct trajectory[35].

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32 The design of MX was complicated by the intention (not so far realized) to deploy it in a mobile mode (with multiple shelters). To observe the SALT II prohibition on new heavy ICBMs it was also necessary that the launch weight and throw-weight not exceed those of the Soviet SS-19.

33 *Soviet Nuclear Weapons*, by Thomas Cochran, William Arkin, Robert Norris & Jeffrey Sands, Volume IV of Nuclear Weapons Databook, Harper & Row, New York, 1989.

34 SS-9 had a launch weight of 200,000 kg. and a throw-weight of 6,100 kg. The other "heavy ICBM" of the time was Titan II, weighing 150,000 kg., with a throw-weight of 3,800 kg., and a warhead with an energy yield of 9 MT.

35 An advantage of this trajectory would be that it would not be detected by warning systems placed across the direct path. But it sacrifices considerable throw-weight and accuracy in comparison with the direct trajectory.

The most durable of the Soviet ICBMs has been the SS-11, somewhat larger than Minuteman and with a slightly larger throw-weight, which could deliver a single 1 MT warhead or three separate (but not individually-targeted) warheads of 350 KT yield[36]. Figure 3B shows the numerical preponderance of SS-11s in the Soviet inventory.

SS-13 was the first Soviet ICBM to use solid fuel, but only 60 of these missiles were deployed, all in fixed underground silos.

Another radically improved generation of Soviet ICBMs appeared in force in 1975, with three new types, much larger than SS-11 or SS-13, each equipped with MIRV, and each with a CEP roughly three times better than that of SS-11 or SS-13. The most formidable was the heavy SS-18, a direct descendant of the SS-9, which it replaced on a one-for-one basis in order to honour the SALT limit on heavy ICBMs, but this time with ten MIRVs instead of one huge warhead. SS-17 had four, and SS-19 six MIRVs. Every MIRV had a yield of half a megaton or more.

Compare Figure 3B, or Table 3, showing the number of Soviet ICBM launchers, with Figure 5, or Table 5, which show the number of independently targeted warheads. Enough SS-11s were withdrawn to compensate for the new missiles as regards the overall SALT II limit of 2250 strategic nuclear delivery vehicles, but when the number of SS-19s reached 360 the USSR was within two of the SALT limit of 820 MIRVed ICBMs. It is evident that the introduction of MIRV allowed a dramatic increase in offensive capability, without breaching the numerical limits of SALT.

The MIRVed SS-17, -18, and -19 all used liquid fuel and were housed in hardened silos. Ten years later came SS-25, a mobile single-headed ICBM.

The latest new arrival was SS-24, the permitted new ICBM. Although its launch weight and throw-weight is about the same as those of SS-19[37], SS-24 carries ten extremely accurate MIRVs. With solid fuel, SS-24 is rail-mobile, although most of the missiles are mounted in static silos.

The Soviet history has been similar to that of the United States, with the changes towards solid fuel and multiple warheads coming some years later, but the Soviets were the initiators of mobile deployment.

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36 A "Multiple Reentry Vehicle" (MRV) simply scatters its warheads about the point at which the nose cone would have impacted. This would probably do more damage to an area target (such as a large city) than a single larger warhead, but would be unsuitable for use against separated targets. In Table 5 and Figure 5 each SS-11 is counted as contributing one warhead.

37 Any missile with a launch weight or throw-weight greater than those of the "heaviest light ICBM", namely SS-19, would be considered as "heavy". The SS-18s are heavy, and the numbers already deployed use up all of the agreed quota, which was reduced from 308 to 154 by START.

The START limits of 1600 strategic nuclear delivery vehicles, and of 4900 warheads of ICBMs and SLBMs, will clearly force the USSR to cut the number of their ICBM launchers and warheads drastically. Half of the heavy SS-18s must go, and it is probable that all of the SS-11, -13, -17, and SS-19s will be eliminated.

Arms Control Restraints on Improving the Survivability of Land-Based Missiles

The theory of mutual and stable strategic deterrence requires that most of the forces that could retaliate for an attack should be able to survive that attack, even if it should be concentrated against the retaliatory weapons and achieve surprise. Submarine-based retaliatory forces can reduce their vulnerability by keeping a significant proportion of their boats at sea. Air bases can place some of their bombers on short-notice alert, able to save themselves by taking off, provided that they receive a few minutes of warning. The location of land-based missiles on fixed sites will be known, but protection can be given by encasing the missile launcher in an armoured underground silo with a heavy (but quickly movable) lid. However, no practical amount of physical hardening will suffice to save the missile from destruction by a direct hit (or a very near miss) by a large-yield ground or underground burst of a thermonuclear bomb. The probability of destruction depends on the energy yield and CEP of the attacking bomb and the hardness of the silo, but if the CEP comes down below a few hundred metres, it will be difficult and expensive, or perhaps even physically impossible, to make the missile highly survivable[38].

In the early days of Minuteman I there were schemes to mount the missiles on railroad cars, and to move them frequently enough that they could not be targeted from the USSR. However, instead of this they have always been based in underground silos.

While making land-based missiles mobile would improve their survivability, thus enhancing deterrence, it would greatly impede the capability to verify the total number of launchers that were deployed. The Americans wanted to ban mobile ICBMs in SALT I, but the Soviets would not agree. The SALT I treaty made no reference to mobile ICBMs, but in a unilateral statement the USA declared that they would consider deployment of operational land-mobile launchers during the period of the Interim Agreement (1972-1977) to be inconsistent with its objectives. The mobile SS-25s were not deployed until 1985.

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38 For example, a single Minuteman III warhead with a yield of 335 KT and a CEP of 280 metres would have a 27% probability (Pk) of destroying a silo hardened to 3000 psi. Doubling the yield of the warhead would increase Pk to 40%, halving the CEP would increase it to 72%. Doubling the hardness of the silo would decrease Pk to 18%. Against a 3000 psi silo one MX warhead with a yield of 300 KT and a CEP of 100 m would have a Pk of 90%.

SALT II contained an undertaking not to develop, test, or deploy mobile launchers of heavy ICBMs, and a protocol to the treaty forbade deployment or flight testing of mobile ICBMs of any size prior to 1982. Testing and deployment of new types of ICBM were limited to one new type of light ICBM, which could carry no more than ten MIRVs. This could, however, be mobile.

The Soviet SS-24, which appeared in 1987, took full advantage of the provisions of SALT II, being rail-mobile, with ten MIRV, and close to the maximum launch weight for a "light ICBM". SS-25 is road-mobile. The Soviets claim it to be a modernized SS-13, a type which had been based in fixed silos since first observed in 1969. They may, however, have originally intended SS-13 to be mobile.

In mid-1991 the USSR had 36 SS-24s (each with 10 MIRV) deployed in railway trains, in addition to another 60 immobile in former SS-19 silos, and about 300 SS-25s on the road. Thus they are already more than half way to the START limit of 1100 warheads on mobile ICBMs.

The United States has gone through extraordinary gyrations with its one new permitted ICBM[39]. Now known as the MX (alias "Peacekeeper"), it also presses to the limits of SALT II, with ten MIRVs and a launch weight close to that of the heaviest "light ICBM". The gyrations have revolved around the desire to make MX survivable against an attack that could be directed against fixed targets with great accuracy, but which could not follow the movements of mobile missiles closely enough for targeting. However, in order to guarantee that they would be able to negotiate conditions that would enable them to verify the number of mobile missiles deployed by the USSR, the USA was prepared to expend great efforts to ensure that the Soviets *would* be able to verify that no unauthorized US missiles were being deployed. Various schemes were devised which would provide a number of hardened protective shelters, far greater than the number of MX missiles, among which the missiles would be moved. For verification of numbers, the tops of selected shelters would be opened, allowing satellites to detect the presence or absence of a missile in the exposed shelters.

Other schemes intended to reduce vulnerability included rapid launching under attack, basing in ships or small submarines, lifting to safety by aircraft, and concealment in deep caves. In the end, MX was sited in silos formerly occupied by Minutemen III. Because of the possibility that a significant number of mobile ICBM launchers and mobile ICBMs could be concealed and then rapidly deployed, START contains provisions to limit the number of mobile launchers and mobile ICBMs which can be manufactured but not deployed[40]. The unilateral statements of Presidents Bush and Gorbachev indicated a desire to terminate development of mobile land-based systems.

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39 See, for example, *MX Missile Basing*, Office of Technology Assessment, US Congress, Washington, 1981.

ICBMs which can be manufactured but not deployed[40]. The unilateral statements of Presidents Bush and Gorbachev indicated a desire to terminate development of mobile land-based systems.

The difficulty of verifying the numbers of mobile land-based missiles was also a very important factor in the INF Treaty, but was solved by the drastic method of banning *all* of the intermediate range missiles.

The Program of Modernization and Replacement of SSBNs[41]

The programs of the Soviet Union and of the United States towards acquisition of effective strategic Sea-Launched Ballistic Missiles were very different. The design and construction programs, and the effectiveness of the resulting product, depends on both the missiles and the submarine which carries and launches them. The discussion will concentrate first on the submarines, and follow with a more detailed discussion of the missiles.

The USSR proceeded in systematic graduated steps, beginning with the Golf series of conventionally-powered submarines, each carrying three SS-N-4 ballistic missiles. Before it could qualify as an effective intercontinental strategic system this combination had to overcome four fundamental limitations. The Golf submarine was diesel-electric powered, it carried only three missiles, it had to come to the surface to launch them, and the range of the SS-N-4 was only 560 km. One by one these limitations were surmounted. The Hotel and all subsequent Soviet ballistic missile submarines were nuclear-powered. The SS-N-5 and SS-N-6 missiles had ranges of 1400 and up to 3000 km. respectively, and, like all subsequent SLBMs, were launched submerged. The Yankee SSBN, of which 34 were built, armed with 16 SS-N-6 missiles, was a fully-fledged strategic weapon system[42]. Ten years elapsed between the commissioning of Golf I and Yankee I. See Tables 6 and 7, and Figures 6A, 6B, and 7. Figure 7 shows the steady buildup in the number of SSBNs, from 1960 to 1976, followed by a slight decrease. Figures 6A and 6B illustrate the increase in tonnage and missile load of each successive class. As the number of missiles in the submarine increased from 3 to 6 to 16 to 20, the boat had to be built much larger.

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40 A maximum of 18 rail-mobile launchers and 125 rail-mobile missiles can be produced but not deployed. For all types of mobile ICBM systems a maximum number of 110 launchers and 250 missiles can be stored.

41 *The Ships and Aircraft of the US Fleet*, Norman Polmar (ed), (11th edition), Naval Institute Press, Annapolis, 1978.
Soviet Naval Developments, Norman Polmar (ed), Nautical & Aviation Publishing Co., Annapolis, 1979.
US Nuclear Forces & Capabilities, op.cit.
Soviet Nuclear Weapons, op.cit.

42 Even with a missile range of 3,000 km., the Yankee boats based in the Kola Peninsula had to make their way down through the GIUK gap and into the North Atlantic before they could threaten the major strategic targets in the United States.

The United States Navy had pioneered the use of nuclear propulsion for submarines with the Nautilus in 1955, and undertaken the building of a series of nuclear-propelled attack submarines (SSNs). Once the technology of thermonuclear warheads and of solid fuel rocket propulsion made it possible to design the Polaris missile, small enough to put in a submarine, a cylindrical section housing 16 Polaris missiles was inserted into the mid-section of a nuclear-powered submarine initially designed as an attack boat, and the resulting George Washington, commissioned in 1959, was the first true strategic submarine, and was in service nine years earlier than the Soviet Yankee.

After the remarkable success of the George Washington/ Polaris combination, of which five were built, the United States followed with a rapid progression of successively larger SSBNs; five Ethan Allens, nine Lafayettes, ten Madisons, and twelve Franklins[43]. The range of Polaris was extended, and a successor SLBM, the Poseidon, with MIRV, designed, with the submarines being refitted to take the improved missiles. See Table 6.

The 34 Soviet Yankee and first 41 American SSBNs provided major elements of mutual and stable strategic deterrence for a considerable period of time. The SALT I interim agreement set an upper limit of 62 and 44 modern ballistic missile submarines for the two parties, which reflected Soviet plans for substantial further additions. These appeared in due course with four classes of Delta SSBNs and with Typhoon, all larger[44] than the Yankees and armed with missiles of very much longer range. These 49 very capable Delta and Typhoon SSBNs are able to patrol in bastions of shallow water, close to the Soviet coastline, with the benefit of protection from antisubmarine defences provided from nearby land bases, and at the same time to threaten most of the important strategic targets anywhere in the world.

Eighteen years after commissioning the first of the Lafayette SSBNs, the United States began to deploy the Ohio class, very large submarines carrying 24 Trident missiles. The Trident I SLBM, with much greater range than Polaris or Poseidon, was first put to sea in some of the later Lafayette boats. Only the Ohio boats can accommodate Trident II, the range of which is effectively worldwide.

As was the case for the Soviet boats, each new class of American SSBN was successively larger. Ohio, with twenty-four missiles, displaced over twice the tonnage of any of its predecessors (which carried sixteen). Quieting of the radiated noise, crucially important for SSBNs, also demands increased tonnage.

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43 The hulls of the Lafayettes, Madisons, and Franklins were similar, and all three groups are often lumped together as "the Lafayette class".

44 The Typhoons, displacing 25,000 metric tons submerged, are the largest submarines ever built.

Modernization and Replacement in the SLBM Program of the United States[45]

The United States Navy was unwilling to place large liquid-fuelled ballistic missiles into its submarines, or even its surface ships, and had experimented with nuclear-armed cruise missiles[46] carried external to the pressure hull and launched on the surface with a solid booster rocket. Substantial improvement to the yield-to-weight ratio of nuclear warheads, and the development of controllable solid-fuel rocket propulsion resulted in the design of the Polaris A1 SLBM, able to deliver a 500 KT warhead to a range of 2200 km. This was followed by Polaris A2 and Polaris A3, with ranges of 2,800 and 4,600 km. respectively. Polaris A3 carried three 200 KT warheads, but these were not independently targeted (i.e. they were MRVs rather than MIRVs). A3 was significantly more accurate than A1 or A2. For the number of American SLBMs see Table 8 and Figure 8. The replacements of Polaris missiles were scheduled to keep the total number of SLBM launchers at 656 for fourteen consecutive years. Figure 8 is a particularly good illustration of modernization, with capability being increased without surpassing numerical limitations.

The most important escalation in the number of sea-based nuclear *warheads* came with the Poseidon SLBM. Although longer and fatter than Polaris, and nearly twice as heavy, it was possible to fit Poseidons into the Lafayette submarines[47]. With twice the throw-weight of Polaris, Poseidon could deliver as many as fourteen MIRVs to the same range as Polaris A3, or a smaller number to a longer range[48]. Poseidon was twice as accurate as Polaris A3.

Ten years later Poseidon was followed by Trident I (C4), sized to fit into the same launch tubes. With three rocket stages instead of the two of Poseidon and Polaris, Trident I carries eight 100 KT MIRV to a much longer range than Poseidon, with about the same accuracy. Once 24

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45 *The Ships and Aircraft of the US Fleet, op.cit.*
US Nuclear Weapons: the Secret History, op.cit.
US Nuclear Forces and Capabilities, op.cit.

46 Regulus was a subsonic cruise missile able to carry a 3.8 MT nuclear warhead to a range of 925 km. It was mounted on submarines, cruisers, and aircraft carriers between 1955 and 1964. Regulus II, a supersonic successor, was cancelled in favour of Polaris. See *The Evolution of the Cruise Missile*, by Kenneth P. Werrell, Air University Press, Maxwell, 1985, pp.113-119.

47 All of the Lafayette, Madison, and Franklin SSBNs were commissioned with Polaris missiles, but later refitted with Poseidons. In its later years the entire group was sometimes described as "Poseidon submarines" (although the later models were later fitted for Trident I).

48 Each Poseidon warhead had a yield of 40 to 50 KT. Able to carry as few as six or as many as fourteen MIRV, the average number of ten is normally used for estimates of total warheads, as in Table 9.

submarines were deployed with 384 Trident I missiles, the US total of MIRVed ICBMs and SLBMs had risen to 1190, almost at the SALT II limit of 1200. See Table 9.

The latest American SLBM is Trident II (C5), much larger and heavier than Trident I, designed to carry several combinations of reentry vehicles to the remarkable range of 12,000 km[49], and with the even more remarkable CEP of only 120 metres. Although the first eight Ohio SSBNs went into service with Trident I missiles, all the Ohios will be able to accommodate Trident II.

The deployment of MIRV on the Poseidon and Trident missiles has allowed the total number of American sea-based strategic warheads to increase by a factor more than eight, without breaching the SALT limit on the number of SLBM launchers. Contrast Table 9 with Table 8, and Figure 9 with Figure 8. Figure 9 demonstrates the way in which the Poseidon made a dominant contribution since 1972, only recently overtaken by the Trident family.

An interesting feature of the American programs was the repeated rematching of submarine construction and refits to improvements in missiles. Polaris improved faster than the pace of the SSBN building program, so that the first five SSBNs began operational life with Polaris A1, the next fourteen with A2, and the next twenty-two with A3. But the first ten of the 41 were refitted for Polaris A3, the last 31 for Poseidon, and then the last twelve refitted again for Trident I.

The START limit of 4900 warheads on ICBMs and SLBMs will oblige the USA to withdraw a substantial proportion of their 5376 SLBM warheads. All of the Poseidon SLBMs are likely to be eliminated[50].

Modernization and Replacement in the SLBM Program of the Soviet Union[51]

The short 560 km. range of the first Soviet SLBM, the SS-N-4, together with the fact that the submarine had to come to the surface to launch it, limited the combination to a theatre, rather than an intercontinental capability. SS-N-4 was, nevertheless, retained in service for twenty years, primarily deployed on diesel submarines for service in European waters. SS-N-5, and all subsequent

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49 Eight MIRVs of 300 to 475 KT are carried by the first operational Trident II missiles. Up to fourteen MIRV, or seven manoeuvrable reentry vehicles could be loaded instead. START will charge each Trident II as having eight accountable warheads. However, the production of W-88 warheads is being terminated at 400, and President Bush has suggested "downloading" of Trident II.

50 Part of President Bush's unilateral undertaking announced on 27 September 1991 was to stand down all of the remaining Poseidon-carrying SSBNs from their patrols.

51 *Soviet Nuclear Weapons, op.cit.*
Soviet Naval Developments, op.cit.

SLBMs, were launched submerged. The 1400 km. range of SS-N-5 also restricted it to a theatre role, and its withdrawal from operations is now complete.

It was SS-N-6, with a 2,500 km. range, which gave the USSR a true sea-based strategic capability. As shown on Table 10, and Figure 10, over 500 of these missiles were deployed, on 34 Yankee I submarines. SS-N-6 appeared in three versions, the last of which carried two 350 KT MRV warheads.

SS-N-8 brought a revolutionary increase in range over previous Soviet SLBMs. The first version, Mod 1, could reach 7,800 km., allowing a Delta I or II submarine to threaten many major strategic targets on another continent from one of the coastal bastions off the Soviet coast. Mod 2, appearing four years later, had a range of 9,100 km., which made nearly all strategic targets in NATO territory reachable from a coastal bastion[52]. Nearly 300 SS-N-8s have been deployed on 22 Delta submarines.

SS-N-17 was the first Soviet SLBM to use solid fuel, and had a range on only 3,900 km. It probably had a more significant role in development of technology than in strategic deterrence, since only twelve missiles on one Yankee II submarine were deployed, and the submarine has now been deactivated.

The introduction of MIRV into the Soviet sea-launched strategic force came in 1977, with SS-N-18. This missile used liquid propellant. Mods 1 and 3 could carry three and seven MIRVs respectively[53], to a range of 6,500 km, Mod 2 a single warhead to 8,000 km. 224 SS-N-18s are deployed in fourteen Delta III submarines.

Each of the huge Typhoon submarines carries twenty SS-N-20 missiles, which use solid fuel to propel at least six 100 KT MIRVs to a range of 8,300 km. The Delta IV SSBNs each have sixteen SS-N-23 SLBMs, each missile probably able to deliver ten 100 KT MIRVs to a range of 8300 km. Both of these two types of Soviet SLBM are more accurate than any of their predecessors. The accumulation of SS-N-20 and SS-N-23 SLBMs took the USSR to the SALT II limit of 1200 MIRVed ICBMs and SLBMs, necessitating removal of some SS-17 ICBMs. START charges each SS-N-20 with ten accountable warheads, which are likely to be downloaded, but each SS-N-23 with only four.

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52 See *Strategic Stability in the Arctic*, by G.R.Lindsey, Adelphi Paper 241, IISS, London, 1989.

53 START charges SS-N-18 with three warheads. The warhead totals on Table 11 and Figure 11 assume five.

Table 10 shows regular introduction of a new Soviet SLBM every four or five years[54]. Illustrated by Table 11 and Figure 11, and as already seen for ICBMs and American SLBMs, the appearance of MIRV causes the warhead contribution of the latest missiles to dominate that of the earlier types. However, comparing Table 11[55] with Table 9, it is seen that the number of American SLBM warheads has exceeded by far the corresponding Soviet total.

The START limit of 1600 delivery vehicles and 4900 warheads on ICBMs and SLBMs will clearly force the USSR, who have traditionally favoured land-based missiles over sea-based, to cut the number of SLBM launchers and warheads quite deeply. They will probably eliminate all of the Hotel, Yankee, and Delta I and II submarines, and the SS-N-5, -6, -8, and -17 missiles, and download the number of warheads on the SS-N-18 and -20 missiles.

An interesting difference between the Soviet and American programs is that if we group Delta I and II together (same IOC, size, and type of missile), every class of SSBN produced in quantity came with a new type of SLBM. In contrast, the USN tended to refit older submarines to accept newer missiles.This is an example of two general types of modernization: completely new systems or upgrading of key components only.

Measures of Effectiveness of Ballistic Missiles

Among the various characteristics that determine the effectiveness of a ballistic missile weapon system are:

- the number of missiles of the type being assessed
- the range to which the missile can reach
- the throw-weight, determining the mass of reentry vehicles, dispensing devices, and penetration aids that can be delivered
- the numbers of warheads each missile can deliver
- and, if it carries multiple warheads, whether they are independently targeted
- the accuracy with which the warheads can be delivered
- the energy yield of the nuclear warheads
- the reliability with which the missile can be launched and boosted into its intended trajectory
- the vulnerability of the missile or its reentry vehicles to defensive countermeasures

54 Possibly related to the five-year government planning cycle ?

55 The numbers of Soviet warheads in Table 11 are calculated on the basis that the two MRV on SS-N-8 count as one independently-targeted warhead, and that the average numbers of MIRVs on SS-N-18, -20, and -23 are 5, 6, and 10 respectively.

- the vulnerability of the launchers to enemy attack
- the launch weight of each missile, which provides the potential which is convertible into range and/or throw-weight

These characteristics are not independent. Maximum range and throw-weight can be traded off under the constraint of launch weight. Accuracy is likely to decrease when range is increased[56]. Increasing the number of warheads usually implies that each be smaller, with a reduced energy yield. Penetration aids can be substituted for warheads.

The SALT agreements placed limits on numbers of missiles, and on the launch weight and throw-weight of "light" ICBMs. SALT II limited the number of missiles fitted with MIRV, and on the number of MIRVs on each missile. START limits the number of missiles, the number which can be mobile, and the number of warheads, with some restrictions on how these can be distributed. Total throw-weight is limited to 3,600 metric tons. But no restrictions have been applied to range, energy yield, or accuracy.

Maximum range posed some constraints on the strategic targets that could be threatened by the earliest land-based ICBMs, but once a large number were able to reach to 10,000 km, additional range conferred little marginal value. But for many years it was different for submarine-launched missiles. The restricted dimensions of the earlier submarines placed a limit on the size of the missiles, which in turn bounded the amount of rocket fuel that could be loaded, and therefore the maximum range attainable. This meant that the submarine was obliged to patrol fairly close to the adversary's coast, especially when the targets were located well inland. Increasing the range of the missile not only allowed more targets to be threatened, but also gave the SSBN a greater ocean area in which to station itself, thus increasing flexibility and decreasing vulnerability.

The steady increase in the range of American SLBMs is shown in Table 6 and on Figure 6C. With the range of 12,000 km. achieved by Trident II, there would be little advantage in any further increase.

Once there is launch weight adequate to allow delivery of a useful payload to a sufficient range, additional launch weight would be employed to increase throw-weight. With the earlier missiles, throw-weight was needed to deliver a warhead with an energy yield large enough to compensate for poor accuracy. When accuracy was improved, throw-weight was used to provide multiple warheads. Table 12 and Figure 12 show the throw-weights of Soviet ICBMs. Table 12 also

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56 If guidance is only applied during the boost phase, as is the case for most ballistic missiles, CEP will increase with range. However, mid-course stellar guidance or any form of terminal guidance could make the accuracy independent of range.

indicates whether the fuel of the main booster rockets was liquid or solid. Liquid fuel is more energy efficient, and it can be seen that prior to 1987 the two solid fuelled missiles had throw-weights considerably less than their liquid-fuelled contemporaries.

Figure 12 separates the two "heavy ICBMs", SS-9 and SS-18 from the others. SS-9 caused great concern to the United States, who were ahead of the Soviets in MIRV technology, but recognized the potential capability for MIRV afforded by the large throw-weight of SS-9[57]. SS-18 did exploit its large throw-weight by having ten 500 KT MIRVs. Twelve years later SS-24 was designed to be rail-mobile. Like the American MX, SS-24 has a throw-weight about the same as that of SS-17 and SS-19, and carries ten MIRVs. Both MX and SS-24 press close to the limits of the SALT II definition of a "new heavy ICBM". The other recent Soviet ICBM, SS-25, is road mobile, and therefore much smaller than any of its fixed predecessors. With its small throw-weight (a tenth of that of SS-18) it has a single 750 KT warhead.

Once the range, number and size of warheads, and the survivability of the systems reached the level needed to be able to deliver assured massive retaliation against cities, the performance characteristic of ballistic missiles that had the greatest strategic significance was the accuracy with which the warheads would strike close to their intended targets. High accuracy was not necessary for assured destruction of population targets. But with inaccurate weapons, military point targets such as the opponent's airfields, naval docks, and especially his hardened missile silos, could not be dealt a mortal blow. However, if the missiles could achieve great accuracy, the possibility arose of a counterforce first strike being sufficiently successful that the victim would be almost disarmed, and consequently unable to retaliate with unbearable destruction. In this case the fundamental condition for mutual stable deterrence would be undermined.

Table 13 shows the accuracy of the ICBMs and SLBMs of both superpowers, with the same data appearing in graphical form on Figures 13A and 13B. The first thing on Figure 13A that strikes one is the rapid improvement made to the American missiles during the first five years of their program. Figure 13B shows a more gradual progress in the Soviet program. In both cases the land-based ICBMs were more accurate than their sea-based contemporaries, even though the ranges of the SLBMs were shorter. One reason for this is that the position of the submarine could never be known as accurately as the position of a fixed land launcher.

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57 In addition to warheads of large energy yield, or multiple warheads, large throw-weight can be employed to provide countermeasures against a ballistic missile defence system. These could take the form of penetration aids, such as decoys, or of a capability for reentry vehicles to manoeuvre rather than simply following a predictable ballistic trajectory (i.e. MaRV).

The Use of Withdrawn Equipment in Other Roles

The usual objective of modernization of a weapon system is to replace it with another, better, system. However, some or all of the system that is replaced may continue in use, perhaps by conversion to another role or transfer to another country (which may represent a modernization of the equipment of the recipient).

In the case of strategic ballistic missiles, the SALT agreements made no stipulation regarding destruction of missiles or disposal of warheads. Some of the rockets (such as Atlas and Titan) have been used for space launches and other research[58]. START explicitly permits the presence of up to twenty ICBM or SLBM launchers or missiles to be located at space launch facilities. It does, however, describe the procedures necessary to have a weapon removed from "accountable status" by conversion or destruction. While the number of nuclear warheads has been increasing, because of MIRV, the total megatonnage has been decreasing as the single large-yield warheads are withdrawn[59]. The nuclear material can be used again, for weapons or possibly for power reactors.

While START places a number of restrictions on silos and launchers for ICBMs, and on nuclear-capable bomber aircraft, including provisions for their destruction, the limitations of SLBMs is not accompanied by requirements to limit the number of submarines which carry them. There are instructions regarding the elimination of the SLBM launching tubes, but the submarine need not be destroyed. However, the statement made by President Gorbachev on 5 October 1991 included a plan to decommission six Yankee SSBNs.

SSBNs withdrawn from the role of launching SLBMs can be converted into SSGNs (armed with strategic or anti-ship cruise missiles) or SSNs (armed with torpedoes). Or they can serve as test beds for the development of new submarine-launched weapons[60].

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58 The American programme basing space launches on the space shuttle instead of expendable boosters has suffered serious delays, and therefore increased the desirability of using booster rockets withdrawn from the ballistic missile role for space launches.

59 To quote from *Discriminate Deterrence* (Report of the Commission on Integrated Long-Term Strategy, by Fred Iklé and Albert Wohlstetter, US Department of Defense, January 1988), in which the discussion included tactical as well as strategic nuclear weapons, "The total explosive power of US nuclear weapons today is only one quarter of the peak reached in 1960. The average warhead yield of US nuclear weapons today is only one-fifteenth its 1957 peak. Even on the Soviet side, while the number of nuclear weapons has been steadily increasing, the total explosive power and average warhead yield have both been declining since the mid-1970s."

60 Two Soviet Yankees now carry SS-N-21 SLCMs instead of their former SS-N-6 SLBMs. Another is being used for trials of the experimental SS-NX-24 SLCM, and a fourth has been converted to the SSN role. The only use for American SSBNs withdrawn from operations appears to have been for training.

American Polaris and Trident SLBMs have been sold to the Royal Navy, although their nuclear warheads were designed and constructed by the British. However there has been very little evidence of international transfer of strategic weapons technology. There has been much more transfer of armaments and technology with non-nuclear systems, such as tactical aircraft and tanks, as will be discussed in Chapter V.

III THE MODERNIZATION OF COMBAT AIRCRAFT

The Modernization of American Strategic Bombers

The end of World War II left the United States with several thousand B-29 "Superfortress" bombers, powered by four piston engines, and well able to deliver large tonnages of conventional bombs.[61] But each of the three nuclear explosive devices that had been built had been detonated (one test at Alamogordo and the two dropped on Hiroshima and Nagasaki).

The US Strategic Air Command, created in 1946, inherited 148 B-29s, a number that rose to nearly 500 during the next two years. See Table 14 and Figure 14. Before a B-29 was qualified to deliver a nuclear weapon, considerable expensive modification (known as "silver plating") was necessary.[62] However, the real constraint on fielding a sizeable nuclear capability in these early years was the slow production rate of nuclear weapons. Only a small proportion of the B-29s were silver plated. The majority of the force continued to serve as conventional bombers, a number being used in the Korean War.

The B-50 bomber was an improved version of the B-29, with greater range, weapon load, and speed, and a better capability for in-flight refuelling. But to be able to conduct operations against strategic targets in Eurasia it was necessary to operate the B-29 and B-50 bombers from forward bases.

The first truly intercontinental bombing capability was achieved with the B-36. The largest (though no longer the heaviest) bomber ever built, the B-36 had an unrefuelled combat radius of 6,300 km, and the enormous weapon load of 32,000 kg. The early model B-36B was propelled by six piston engines (with pusher airscrews), and was slower than either B-29 or B-50. Four turbojet engines were added, making B-36D faster than the other two. Performance figures for these and other bomber aircraft are listed in Table 15.

The new interceptor aircraft of the 1950s had jet propulsion, giving them a decisive advantage over propeller-driven bombers. The next American bomber was the all-jet B-47, with high speed, small size, a high ceiling, and good manoeuvrability, but its combat radius and weapon

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61 3960 B-29s were manufactured as bombers, of which more than 3800 were operationally deployed in 1945. They had an unrefuelled combat radius of 2400 km, and could carry 9160 kg of bombs.

62 The early nuclear bombs were too large for the standard bomb bays of the B-29. To increase the range and speed of the aircraft, the armour and most of the defensive guns (important features for which the B-29 was renowned) were removed. High speed and altitude were needed for survival, not only against enemy fighter aircraft and antiaircraft guns, but also to escape the effects of the nuclear explosion. See *The History of the US Nuclear Arsenal*, by James N. Gibson, Bison Books, London, 1989, pp.100-101.

load were less than those of the B-50. It was therefore essential to deploy the B-47 at forward bases, with a large tanker fleet for in-flight refuelling. Over 2,000 B-47s were manufactured.

The testing and production of nuclear bombs for these aircraft proceeded through a series of rapidly changing designs.[63] The early bombs weighed about 5,000 kg, beyond the carrying capacity of any aircraft except the B-29, B-50, and B-36. But the Mark 5 fission bomb, produced in 1952, yielding 40-50 KT, weighed only 1,500 kg, enabling smaller air force and navy aircraft, and also the cruise missiles Matador and Regulus, to carry it. The Mark 7 warhead, weighing less than 750 kg, was light enough for short-range surface-to-surface ballistic missiles, and Mark 9 was designed for a 280 mm artillery shell weighing less than 300 kg, but with an energy yield of 15 KT. Consequently, from 1952 onwards the production of nuclear weapons was no longer directed exclusively towards strategic bombers.

The first thermonuclear (hydrogen, fusion) device was detonated in 1952, by the United States, and two types of bombs (Mark 14 and Mark 17) were available for operational deployment in 1954. These were enormous crude weapons, weighing 13,600 kg and 18,800 kg, and could only be lifted by a B-36. But in 1955 the Mark 15 thermonuclear bomb was ready, with a weight of 3,500 kg, light enough for B-47s and navy bombers.[64]

The history of the buildup of SAC bombers and of the total stockpile of American nuclear weapons during the first ten years is illustrated on Figure 14. Remembering that all of these weapons were for strategic bombers up to (but not after) 1952, it can be seen that it was only after 1948 that the USA possessed a really sizeable strategic nuclear capability. With the deployments of the B-36 and then the B-47, and the weaponization of thermonuclear explosives in 1954, the capability had become truly formidable.

The annual inventory of bombers for the entire history of the US Strategic Air Command is listed on Table 16, and illustrated on Figure 16. As the B-29, B-50, and then the B-36 aircraft were phased out, the number of B-47s rose to a maximum (reached in 1958) of over 1350.

The B-36 had overcome the range and payload limitations of the B-29 and B-50, but even with its ten engines it was too slow. The B-47 had overcome the speed limitation of the B-36, but its restricted range and payload obliged widespread deployment to forward bases. The next step

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63 See *U.S. Nuclear Weapons: The Secret History*, by Chuck Hansen, Orion Books, New York, 1988, and *The History of the US Nuclear Arsenal*, *op.cit.*

64 The yields of Marks 14, 17, and 15, all fusion weapons, were approximately 7 MT, 15 MT, and 1 to 2 MT respectively. Contrast these with the upper limit of 50 KT of the earlier fission bombs.

was to design a larger all-jet bomber, with greater range and weapon load. The first models of the B-52 had nearly twice the combat radius and 3.5 times the weapon load of the B-47. With aerial refuelling over friendly territory or the sea, a B-52 could start in the United States and reach almost anywhere in the world on a direct flight at economical altitude. However, the range was still too short to permit evasive routing or penetration at low altitude in hostile airspace, which was becoming increasingly necessary as air defences against bombers flying at medium and high altitude were improved. Consequently, extensive modifications were made with the B-52 G and H models, to produce significantly increased range, as well as a capability for penetration at low altitude. The B-52H achieved approximately twice the range of the earliest B-52s.

Other changes equipped the B-52G and H to carry air-launched cruise missiles. Some B-52Gs have been given non-nuclear maritime roles. The B-52H can fly long missions at low altitude, and can suppress defences with short-range nuclear air-to-surface missiles (SRAMs).

Because of these important differences between the B-52 G and H and the earlier models, the data in Table 16 for B-52s is divided into two columns, and shown by two curves on Figure 16. Starting in 1965 some of the models up to B-52F were sent to Vietnam for conventional bombing, and all were phased out several years ago. But B-52Gs and Hs are still in the inventory. Some were used in 1991 in the Persian Gulf for conventional bombing.

By 1955 the Soviets were beginning to deploy supersonic interceptor aircraft. The American B-58 was the first supersonic strategic bomber. Smaller than the B-47, and much smaller than the B-52, it had twice the maximum speed of the B-52 and a higher ceiling. But its combat radius and weapon load were much inferior to those of the B-52. For survival in the face of enemy defences, however, the value of high speed and ceiling were being reduced by the deployment of Soviet surface-to-air missiles, whose speed and ceiling can exceed those of any bomber. Only 116 B-58s were built, of which over twenty were lost in crashes. By 1970 all had been withdrawn from the inventory.

Survival against medium or long-range surface-to-air missiles lay in flying fast and low, not high. With the subsonic B-52s being reduced and the B-58 eliminated, the USAF adapted the variable geometry dual-capable F-111 fighter-bomber for use as a medium-range strategic bomber.[65] The FB-111A is capable of supersonic speed, and is specialized for fast low-level penetration.

65 "Variable Geometry" signifies that the sweep of the wings can be altered in flight, allowing economic cruising at altitude, reasonably low takeoff and landing speeds, and also fast but steady flight at low-altitude. The term "Dual-capable" indicates that the weapon system is designed to deliver either nuclear or conventional ordnance. (However, although the B-52 was designed as a nuclear bomber, its only service in war has been to deliver conventional bombs).

Once the B-52 G and H were able to remain outside hostile airspace and launch long-range ALCMs, the need (which had been addressed in their day by the B-58 and FB-111A) was for a "penetrating bomber" able to reach deep into territory heavily defended by both interceptors and missiles.

After a very long period of planning and development, with many delays, interruptions and cancellations[66], the USAF eventually deployed the B-1B. The first operational B-1B appeared in 1984, thirty-two years after the first B-52. One hundred B-1Bs were built. Although the B-1B is nearly as large as the B-52, it reflects a much smaller radar echo. B-1B has a shorter combat radius but nearly double the weapon load of the B-52. With variable geometry, it can fly fast and low, or more economically at high altitude.

The latest American strategic bomber is the B-2, designed to exploit the new "stealth" technology which makes aircraft almost invisible to radar[67]. The B-2 is smaller and slower than the B-1B, and is extraordinarily expensive[68]. However, its proponents are encouraged by the success during the Gulf War of the much smaller (and also subsonic) F-117 stealth fighter-bomber.

The START accounting rules for nuclear warheads provides substantial incentives for the retention or acquisition of heavy bombers, and especially for those not equipped with ALCMs, in preference to MIRVed ballistic missiles. A bomber not equipped to carry ALCMs is only charged as one warhead. But a B-1B, with a 60,000 kg payload capability, is said to be able to carry twenty-four nuclear bombs internally, and another fourteen on external racks. A B52 can take at least twelve internally. It seems probable that the small force of B-2s, ideally designed as penetrating bombers, will not be equipped for ALCMs.

Soviet Strategic Bomber Aircraft

The histories of the Soviet and American airborne legs of their strategic nuclear triads are sharply different. They start in a similar fashion, in that both entered the nuclear age with a large

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66 Before the decision to produce the B-1B was finally made, there had been extensive planning and development of other contending designs, two prominent ones being named "Advanced Manned Strategic Aircraft" (AMSA), and B-70. See *Unguided Missiles*, by Fen Hampson, W.W. Norton, New York, 1989.

67 "Stealth" technology reduces the echoes reflected back towards a searching radar from the skin of the aircraft. Special non-conducting materials are used which absorb rather than reflecting electromagnetic energy, and the shape of the aircraft is carefully designed to minimize flat surfaces likely to return echoes back in the direction from which the radar pulses are coming. Other forms of stealth technology reduce the probability of detection by optical or infrared sensors. See *The Tactical and Strategic Significance of Stealth Technology*, by G.R.Lindsey, Centre québécois de relations internationales, Université Laval, Québec, 1989.

68 The total cost of the program to produce 24 B-2 bombers is estimated at $45 billion.

inventory of B-29 type bombers[69]. However, the first nuclear weapon released to the Soviet operational forces did not appear until late in 1953, by which time the USA had over a thousand deployed, deliverable by B-36 and B-47 as well as B-29 type bombers. It seems probable that the USSR recognized the limitations of their Tu-4, decided to employ it in a theatre role only, until it could be replaced by the jet-propelled Tu-16 Badger, and waited for two new types of heavy bomber to give them an intercontinental nuclear capability.

The Mya-4 Bison was a large bomber with turbojet engines, able to lift 9,000 kg, but with somewhat less than intercontinental range. The Tu-95 Bear A, with turboprop propulsion, had better range and payload, though it was slower. Both aircraft have given long service, the Bisons being converted to reconnaissance and as tankers. The inventory of Bear bombers was built up contemporaneously with the American B-52, although in much smaller numbers. Later, the Bear B and C models were equipped with air-to-surface missiles, as alternatives to bombs. Other models (D, E, and F) were used in maritime roles. Then in the 1980s Bears appeared in new forms, with strategic roles.

Bear G, converted from B and C, carries four nuclear bombs and two AS-4 cruise missiles, which can be used against land targets or ships. Bear H, first appearing twenty-seven years after Bear A, is a newly-built aircraft carrying up to eight long-range AS-15 ALCMs.

The history of the Soviet Bear has a certain resemblance to that of the American B-52, in that both have been in operation for thirty-five years, and have been produced in a number of variants, for use as bombers and missile carriers fulfilling strategic, nuclear, conventional, maritime, and reconnaissance roles. Bear would not be able to penetrate heavy modern air defences without risking heavy losses. The numbers are listed on Table 17, and illustrated on Figure 17. They are markedly lower than those for the US Strategic Air Command.

The latest Soviet strategic bomber is the Tu-160 Blackjack, a counterpart to the American B-1B. Blackjack is thought to carry twelve AS-15 ALCMs. Blackjack is probably less stealthy than B-1B, but, with variable geometry wings and supersonic dash would have a penetrating as well as a standoff capability against air defences. Only fifteen Blackjacks are thought to be operational in 1992.

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69 The US built their huge force of B-29s for long-range conventional bombing in the last years of World War II. Three American B-29s landed in Vladivostok in 1944, following bombing raids against Japan. The Soviets used these as models for the construction of the Tu-4 Bull, built in large numbers after the war. Although it may well have been the first carrier of a Soviet operational nuclear weapon, the Tu-4 should be considered as a conventional bomber, operating from bases in the USSR for use in Europe and Asia.

Arms Control Restrictions on Heavy Bombers and Cruise Missiles

SALT I placed no restrictions on aircraft or air-launched missiles. However, in the seven year interval between the signing of SALT I and SALT II the US reduced its inventory of strategic bombers by 18% (due to the withdrawal of earlier model B-52s), while the Soviets remained exactly the same, at about one-third of the American level.

The USSR have been consistent advocates of cruise missiles for air and naval roles, ever since World War II.Their shipborne cruise missiles brought about the eclipse of the large naval gun as the primary anti-surface ship weapon. Launched from surface ships, submarines, and aircraft, cruise missiles permitted nuclear attack on surface ships at very long ranges. And, for both tactical and strategic aircraft, air-to-surface cruise missiles allowed delivery of a large warhead (whether nuclear or conventional) against a heavily defended target at a standoff distance, greatly reducing the vulnerability of the aircraft. First deployed in 1958, AS-1 (Kennel), with a conventional warhead, was carried by medium-range Badger bombers for use against shipping, to be followed in 1961 by the nuclear-armed AS-2 (Kipper). But by 1960 the AS-3 (Kangaroo), more like a full-sized fighter aircraft than a missile, and able to carry a megaton warhead to a range of 500 km, was deployed in Bear A strategic bombers. Other nuclear-armed Air Launched Cruise Missiles followed, beginning with AS-4 (Kitchen) in 1962, primarily for theatre-range bombers but later deployed on Bear G.

The United States had deployed nuclear-armed strategic cruise missiles in the forms of the ship-launched Regulus, between 1955 and 1964, and the land-launched Snark for a brief period in 1961. With the success of ballistic missiles these were abandoned, and a long hiatus followed for American cruise missiles. However, in the 1970s work was undertaken on Harpoon, an antiship cruise missile to be launched from surface ships, submarines, and aircraft. Although a nuclear warhead was considered, none has ever been fitted to Harpoon. Somewhat later the Tomahawk programmewas initiated, beginning as a long-range sea-launched cruise missile for the attack of land targets. Three critical advances in technology becoming available in the 1970s promised very substantial improvements in the capabilities of strategic cruise missiles. One was the ability to package a large-yield nuclear warhead into a lightweight payload[70]. Another was advances in the design of lightweight turbofan propulsion units, producing high thrust with low fuel consumption. The third was the development of terrain-following guidance, by which the missile steers itself along a programmed course by comparing the readings of its radar altimeter with height contours recorded form previous map surveys (often carried out by satellites).

70 The W80 warhead used in Tomahawk and ALCM missiles has a yield of 200 KT, but weighs only 130 kg.

Attracted by these technological possibilities, both the USA and USSR were developing new cruise missiles for the 1980s, including air-launched, sea-launched, and ground-launched versions with long ranges and nuclear warheads.

As the negotiations proceeded towards SALT II, a demand arose to place some limitations on the airborne leg of the strategic nuclear triad, since the land-based and sea-based components were to be constrained. It was evident that cruise missiles would soon become a significant element in the strategic balance, and would add to the capability of bomber aircraft, quite possibly extending the useful life of types of bomber no longer able to penetrate modern defences. Another factor which concerned the United States was the appearance in 1974 of the Soviet Tu-26 Backfire bomber. Supersonic and with variable geometry, and twice the weight of the FB-111A, it was feared that Backfire would be capable of intercontinental range, and that a programmefor rapid manufacture of Backfires would give the USSR a significant advantage as compared to the reducing strength of SAC. American intelligence agencies developed differing estimates of the unrefuelled combat radius of the Backfire, and of the direct threat which it posed to North America.

In the end, SALT II did not deal with Backfire in the text of the treaty. The limitations were to be on "heavy bombers". To facilitate verification, aircraft that could be mistaken for heavy bombers, but were not (e.g. Bisons converted to tankers, or Bear maritime patrol aircraft) were to be given "Functionally Related Observable Differences" that would be recognizable by National Technical Means (normally these would be reconnaissance satellites). "FRODs"[71] were to distinguish aircraft configured to carry cruise missiles, or fitted for air-to-air refuelling.

Backfire was armed with the nuclear AS-4 (Kitchen) ALCM, whose range is believed to be less than 600 km. Just prior to the signing of SALT II in 1979 President Brezhnev wrote a letter to President Carter, stating that the Backfire was a medium-range bomber and that the USSR did not intend to give it the capability to operate at intercontinental distances, to enable it to strike targets in the territory of the USA, or to give it in-flight refuelling. He pledged to keep the production rate no higher than thirty per year[72]. As a result, neither Backfire nor the American FB-111A are "SALT accountable". At the time of signing START the USSR declared that the Tu-22M Backfire will not be given intercontinental capability, and that no more than 300 air force and 200 naval Backfires

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71 This acronym has an unfortunate suggestion for confidence building, when pronounced in English!

72 This letter falls into the category of "a unilateral political statement" rather than "a negotiated and legally binding obligation". "Political Statements" are not generally considered to offer as much assurance as negotiated undertakings integral to treaties, but may offer an escape from the failure to reach formal mutual agreement on some contentious point.

will ever be operational at any one time. The American FB-111s have been withdrawn from their nuclear role.

SALT II identified B-52, B-1, Bear, and Bison to be "heavy bombers", and added "future types of bombers which can carry out the mission of a heavy bomber in a manner similar or superior to that of bombers listed above", as well as bombers equipped to carry cruise missiles with a range of over 600 km, or air-to-surface ballistic missiles (ASBMs).

SALT II placed two types of limits on "heavy bombers". One was the overall limit in strategic nuclear delivery vehicles, which include both ballistic missiles and heavy bombers, to be 2250 after 1981. The other was a limit of 1320 on the total number of launchers of MIRVed ballistic missiles and heavy bombers with long-range cruise missiles. This allowed heavy bombers *without* ALCMs to be traded one-for-one against ICBMs and SLBMs (whether MIRVed or not), under the limit of 2250 delivery vehicles, and heavy bombers *with* ALCMs, to be traded for *MIRVed* ICBMs and SLBMs under the 1320 multiple warhead limit. Thus, bombers equipped with ALCMs (presumably several ALCMs that would be directed against separate targets) were grouped with ICBMs and SLBMs equipped with MIRV[73]. While bombers not equipped with ALCMs could carry any number of free-fall gravity bombs, or short-range air-to-surface missiles, and therefore a considerable number of nuclear warheads, they were accounted the same as single warhead missiles. A (rather large) cap was placed on the number of ALCMs to be carried by any one bomber: twenty for the existing B-52, B-1, Bear. and Bison bombers, and for any future fleet the average number of ALCMs to be carried by any one bomber was not to exceed twenty-eight[74].

START added B-2 and Blackjack to the list of heavy bombers, and removed Bison. It defined a heavy bomber as an aircraft with a combat range in excess of 8000 km and/or equipped to carry long-range nuclear-armed cruise missiles. If the integrated planform area of an aircraft exceeded 310 square metres, it would be considered to be a heavy bomber unless an agreement to the contrary were reached.

73 In 1986 the USA had 550 MIRVed ICBMs and 640 MIRVed SLBMs, bringing them within 130 of the SALT II limit for MIRVed ballistic missiles plus ALCM-equipped bombers. That year the program to convert B-52G and H bombers to SLCM carriers passed 131, exceeding the limit. SALT II was never ratified, and would have expired at the end of 1985, so that the limit had no legal status. Nevertheless, the non-compliance generated considerable concern in the United States.

74 Subsequent modifications to the B-52G allow it to carry 12 ALCMs on external pylons, while the B-52H can carry eight internally as well as twelve on pylons. B-1B can carry twenty-two, Bear H probably ten, and Blackjack twelve.

START treated bombers in the same fashion as SALT II. There is freedom to mix the number of aircraft with the number of ICBM and SLBM launchers under the 1600 ceiling. Under the ceiling of 6000 nuclear warheads, a bomber with any number of nuclear gravity bombs or short-range missiles, but not able to carry long-range missiles, counts as one warhead. But up to 150 American bombers equipped for ALCMs will be accountable for ten warheads each, and up to 180 Soviet ALCM capable bombers for eight each[75]. Counting rules apart, American bombers were not to be equipped to carry more than twenty ALCMs, Soviet bombers more than sixteen.

SALT II devoted considerable attention to limitation of air-to-surface ballistic missiles (ASBMs), with a range of more than 600 km. Some of the provisions resembled those for ICBMs (eg MIRVs, prohibition of "heavy" missiles), others were parallel to the ALCM limitations (the number to be mounted on one heavy bomber, and provisions for testing). However, the protocol accompanying SALT II stated that "Each Party undertakes not to flight-test or deploy ASBMs", and the Memorandum of Understanding listed an inventory of 0 ASBMs, with or without MIRVs, for each side.

An article in START contains the statement that "Each Party undertakes not to produce, test, or deploy ASBMs", but the frequent references to ASBMs of SALT II were not repeated.

An American project to produce an ASBM known as "Skybolt", which would have projected a nuclear warhead to a range of nearly 2000 km, figured in plans to extend the life of British as well as US bombers. But Skybolt was cancelled in 1963. It seems probable that it has been the technical problems of ASBMs, and the relative advantages of ALCMs, rather than arms control, which has removed the motivation for the acquisition of long-range ASBMs.

Measures of Effectiveness of Combat Aircraft

As was discussed in the previous chapter for ballistic missiles, capabilities and modernization of combat aircraft are associated with a number of characteristics which can be measured and compared. However, even more than for missiles, most of the measures of effectiveness are interdependent. The designers, and in many cases the operators, can improve one at the expense of another.

75 150 US bombers are permitted to carry twenty ALCMs each (although accountable for only ten), and 180 Soviet bombers sixteen ALCMs (although accountable for only eight). Beyond these limits bombers will be accountable for the number of ALCMs they actually can carry.

Some of the relevant characteristics are:

- the engine power, or thrust (and whether there is an afterburner)
- the maximum weapon load (and how it is distributed between internal and external mounting)
- the unrefuelled combat radius (and to what extent it is dependent on externally mounted fuel, and also whether air-to-air refuelling is possible)
- the maximum speed (at several altitudes and loadings)
- the operational ceiling (with different loads)
- the performance of the aircraft's radar system
- the echoing area offered to a searching or tracking radar.
- the rate of climb (important for interceptors)

Key design figures which constrain these performance characteristics include:

- the maximum takeoff weight
- the wing area (and whether there is variable geometry)

To an increasing extent modern aircraft can be fitted with many types of avionics and other equipment (such as extra fuel tanks or cameras), and to carry a wide variety of weapons. Changes may require modifications to the aircraft, but often components are easily and quickly interchangeable. The extent to which this can be done depends on the dimensions and load carrying capacity of the airframe, and may require the mounting of fixtures such as wing pylons. Every addition will have some effect on the performance, especially when externally mounted equipment alters the aerodynamics. There have been a number of cases of good basic airframes serving for many years, during which they have been re-equipped with a succession of new avionics and weapons, and perhaps engines, with consequent very substantial increase in capability.

Whenever new batches of an existing type are programmed, some changes describable as "modernization" are likely to be introduced. If these are substantial, the aircraft may be given a new model number. Or, if the changes bring a really significantly different capability or change in role, the new batch of aircraft may receive a new type name. In general, a long production run or a long service life of one model will see some modernization, while a change in model label is associated with more clearly distinct modernization or change in role.

Vital measures of combat effectiveness for a bomber aircraft are the weight of bombs or other weapons that it can carry, the radius of action to which it can deliver its weapons, and the speed with which it can penetrate defended air space. Representative values of these parameters are given on Table 15. However, any single one of these numbers is only valid under particular circumstances. The combat radius depends on the weight of payload carried, whether weapons and fuel are mounted externally, whether there is in-flight refuelling, and the speeds and altitudes flown. The maximum speed depends on the fuel and weapons loading and the altitude. Maximum weapons load is less dependent on other factors, and some for heavy bombers are listed in Table 18, and illustrated on Figure 18. These show the large increase in payload achieved by the B-36, the last of the US propeller-driven heavy bombers, followed by a sharp drop with the first all-jet bomber (the B-47), recouped by the B-52. The first supersonic bomber, the B-58, had a small payload, while the B-1B, which became operational twenty-six years later, can barely exceed Mach 1, and normally operates at subsonic speeds. The payloads of Soviet bombers have risen much more gradually, with Backfire and Blackjack having supersonic capability.

For many years it was an important asset for both bombers and reconnaissance aircraft to be able to climb to a high altitude. This increased their survivability against both propeller-driven interceptor aircraft, which took many minutes to climb to high altitude, and antiaircraft guns, which were extremely inaccurate at high altitude. It was not uncommon to convert bombers or fighters into reconnaissance aircraft, by removing their armament and adding cameras. Table 19 lists the operational ceilings of a number of American reconnaissance aircraft. The same data is also plotted in Figure 19, on which it can be seen that while adapted bombers achieved slightly higher ceilings between 1946 and 1953, and adapted fighters between 1960 and 1965[76], by far the highest ceilings were reached by aircraft specifically designed for reconnaissance, the most famous being the U-2, SR-71, and TR-1. The U-2 and TR-1 were subsonic, whereas the SR-71 could attain a speed above Mach 3, believed to be the fastest of any operational aircraft. Height alone is not enough to escape high-altitude surface-to-air missiles, or "snap-up" air-to-air missiles[77]. Although aircraft will continue to be valuable for reconnaissance, many such functions are being taken over by satellites, for strategic reconnaissance, and by drones ("unmanned airborne vehicles", "remotely piloted vehicles") for tactical reconnaissance.

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76 Fighter aircraft adapted for tactical reconnaissance often choose to conduct their mission at low altitude, both to survive defences and to obtain high resolution photographs showing detailed information.

77 An unguided antiaircraft shell follows the ballistic trajectory determined at the moment of firing, based on a prediction of where the target will be after the shell has risen to its estimated height. When the aircraft is at high altitude, it will travel a considerable distance while the shell is climbing towards it. If it is travelling fast, and elects to take evasive action, the target aircraft will not be very close to the predicted position when the shell passes its altitude. A guided missile, on the other hand, will make constant corrections to its trajectory according to the motions of the target.

For any combat aircraft, high speed is an asset. Table 15 shows how the maximum speeds of bombers rose gradually toward the speed of sound[78], and then, in the early 1960s, suddenly exceeded it by a considerable margin, but tended to stay in the neighbourhood of Mach 2 thereafter.

Speed is even more important for fighters than for bombers, and particularly so for air superiority fighters. Table 20 lists the maximum speed of Soviet fighter type aircraft over a period beginning in the 1930s, when all aircraft were propelled by low-powered piston engines and airscrews[79]. The data is shown in graphical form on Figure 20.

Steady progress (mainly due to the increasing power-to-weight ratios available in piston engines) is evident, from less than a quarter of the speed of sound to nearly 60%, achieved in 1944. The advent of jet propulsion allowed the post-war MiG-15 to reach Mach 0.92, but further progress was delayed by the problems of "breaking the sound barrier". Many of the aerodynamic performance characteristics of airframes change drastically at transsonic and supersonic speeds. Overcoming these problems occupied much of the attention of aeronautical engineers in the years following World War II. But once they had been solved (due in large part to the development of turbojet engines producing a very high thrust, although at the cost of heavy fuel consumption), there was very rapid progress from Mach 1 towards Mach 2. The MiG-17, operational in 1953, had barely supersonic maximum speed, but two years later MiG-19 achieved Mach 1.3, and in 1958 the highly capable MiG-21 (Fishbed) reached M 2.1. But thereafter, with one exception, new Soviet maximum fighter speeds remained less than M 2.5.

There are two primary reasons not to press maximum speeds beyond M 2.5. One is technical, and is based on the problems of aerodynamic stress, in the forms of both temperature and pressure. Around M 3.0 the energy required to overcome air friction and wave drag begin to heat surfaces to the extent that aluminum alloys are softened. It is possible to use more refractory materials or to apply cooling, but at high cost. The other reason to limit maximum speed of a fighter to around M 2.5 is that its manoeuvrability is lost at high speed[80]. In a close-range dogfight between two fighters both of whom want to fight, the advantage lies with the more agile one[81].

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78 The speed of sound depends on air temperature, and tends to be lower at higher altitudes. In the "standard atmosphere" it is 1224 km/hr at sea level, but only 1076 km/hr at an altitude of 10km.

79 The maximum speed of a subsonic aircraft is usually quoted in km/hr, and is achieved at a particular altitude. In order to have a single scale for comparing subsonic and supersonic speeds, the maximum speeds of these early aircraft have been converted into the Mach number for what is estimated to be the altitude at which they could attain their maximum speed.

80 A heavy object moving in a straight line at high speed has great inertia, and to change its direction requires

The Soviet aircraft that could exceed M 2.5 was the MiG-25 ("Foxbat") interceptor. Designed at the time when the US was planning the B-70 fast high-altitude bomber, the MiG-25 had a powerful radar, and was armed with a long-range air-to-air missile (the AA-6 Acrid, the largest of the Soviet AAMs). To intercept and engage a bomber moving at high speed and at high altitude, the Foxbat needed a rapid rate of climb, and high speed at high altitude, but should not have to engage in high acceleration manoeuvreing.

The other recent Soviet fighter whose speed is not in the M 1.75 to M 2.4 range is the Yak-38 Forger. This is a vertical and short takeoff and landing (VSTOL) aircraft with directed jet thrust, and, like its Western counterpart the Harrier, achieves its agility at the expense of high maximum speed. The first Forgers were subsonic, and capable of vertical takeoff and landing (VTOL) only. Later versions, now deployed on aircraft carriers, can lift greater payloads by using STOL, but can achieve barely supersonic speed.

Table 21 lists the maximum speeds for Western jet-propelled fighters. The associated graph on Figure 21 shows the sharp discontinuity, occurring in the mid-1950s, between the series of high-subsonic fighters and the subsequent series with maximum speeds of about M 2.0. Three exceptions to the general trend are identified in Figure 21. The Gnat and the F-5, with maximum speeds well below the trend line, were both lightweight fighters, designed for economy rather than for air-to-air combat against the world's most capable fighters. The F-15 Eagle, the only Western fighter with a maximum speed above M 2.5, was, and probably still is, the most effective air superiority fighter in the sky. Although not able to reach the high maximum speed of the MiG-25, the F-15 has a lower wing loading, and can use the high thrust of its engines for agile manoeuvreing. As was the case with the F-4 Phantom, the highly successful airframe of the F-15 has been adapted for a strike/interdiction role, in the form of the two-place F-15E Strike Eagle, with advanced avionics for ground attack, and a maximum weapon load greater than 11,000 kg[82].

Thus, while speed is an important indicator, other characteristics must be taken into account in assessing combat capability for various roles. No one parameter (we have discussed weapon load,

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correspondingly great force, applied in a direction lateral to the line of flight. For an aircraft to be able to reach high speed, it is necessary to design it with a small wing area (and consequent high wing-loading), which puts a limit to the lateral force that can be applied by aerodynamic control. Moreover, rapid manoeuvre at high speed would place a very heavy stress on the airframe and on the pilot ("high g").

81 If one of the aircraft does not want to fight, he would be glad to have superior speed!

82 To demonstrate the remarkable capability of the F-15E, note that while it is an extremely agile fighter, its weapon load of 11,113 kg is more than that of the B-29, B-50, or B-47 bombers. The thrust-to-weight ratio of the F-15E is about four times that of the B-47.

ceiling, and maximum speed, and there are many others) should be taken as a single comprehensive measure of effectiveness.

Air Defence

The only aircraft designed to combat others of their own type are fighters intended to establish and keep air superiority. While a fighter can be destroyed by ground fire, or on its base by missiles or bombs, its effectiveness depends on its ability to defeat its own kind in air-to-air combat. This capability must be measured relative to that of the opponent, so that modernization by the (prospective or actual) enemy is as important as by one's own force.

All other types of aircraft can be threatened by enemy fighters and by weapons fired from the ground, as well as by attacks on their base.

Few types of aircraft can match the aerodynamic performance of a modern fighter. An exception is the American SR-71 reconnaissance "Blackbird", which can fly higher and faster than a fighter. Helicopters and light aircraft are more manoeuvrable than a fighter, but this alone is unlikely to save them in a sustained attack. The usual means of defence against fighters is to avoid detection (by flying low, or using stealth technology), to operate with an escort of friendly fighters, or to use electronic countermeasures against the fighter's radar and air-to-air missiles. Against ground defences it is possible to use low-altitude evasive routing, especially effective over hilly terrain, stealth, and electronic countermeasures. At higher altitudes it may be possible to escape a surface-to-air missile by properly timed manoeuvreing, cued by a warning device. An operation over enemy territory may commence with attacks on the ground defences. A target that is surrounded by heavy ground-based air defences may be attacked by standoff air-to-ground weapons.

It can be seen that the effectiveness of combat aircraft other than air superiority fighters is dependent on their ability to survive the attentions of air defences, but that this ability is more dependent on their avionics, weapons, and operational procedures than on the aerodynamic characteristics of the aircraft.

Modernization of Air Forces by International Transfers

So far in this paper, modernization has been discussed in terms of the indigenous construction programs of a few major industrial countries. But, for countries other than these, the main means of building and maintaining an air force is to purchase or otherwise acquire equipment, either new or used, from one of the major suppliers. The acquisition may not, but usually does, represent a modernization of the forces of the recipient.

Arms transfers may be made for strategic, political, or financial reasons. Except for nuclear weapons, there are few formal internationally recognized barriers to arms transfers. The Non-Proliferation Treaty explicitly forbids transfer of nuclear weapons or their associated technology from any nuclear weapons state to a non-nuclear weapons state. The ABM Treaty prohibits transfer to other states or deployment outside of national territory of ABM systems or their components. SALT II and START include an agreement not to circumvent their provisions through any other state. The text of the draft Chemical Weapons Convention bans transfers or assistance to other countries, the Missile Technology Control Regime places restrictions on export of certain technologies associated with guided missiles, and COCOM controls diversion of strategic goods and technologies[83]. None of these agreements specifically limit transfers of combat aircraft.

The US Congress has passed laws to place strict control on the export of American nuclear technology, and many nations have laws or policies restricting the exports of selected military technology or equipment to specific countries[84]. Restraints such as these are likely to be strengthened when potential recipients are actively engaged in a war, and military aircraft are certainly one of the important types of equipment involved. On the other hand, there are a number of joint production programs in which several countries share in the manufacture of sophisticated weapons systems, and other arrangements by which a country is licensed to manufacture a system using a foreign design.

To examine the process of the modernization of air forces by international transfer, five of the most versatile and widely distributed types of fighter aircraft have been selected, three designed in the USA and two in the USSR.

First available in 1961, the F-4 Phantom deserves to be described as the most versatile combat aircraft ever built. Over 5,000 have been produced, in many models. Roles successfully

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83 Up to the time of the disintegration of the Soviet Union in 1991, 141 of the 159 member states of the United Nations had signed the Non-Proliferation Treaty. 149 countries participated in the 1989 Paris Conference on the Prohibition of Chemical Weapons. The ABM Treaty, SALT, and START involved only the USA and USSR. COCOM (the Coordinating Committee for Multilateral Export Controls) includes most of the NATO countries, Japan, and Australia. As of April 1992 a total of nineteen states had joined the Missile Technology Control Regime.

84 See "Arms Trade Regulations", by Agnès Courales Allebeck, Chapter 8 in *SIPRI 1989: World Armaments and Disarmament*, Oxford University Press, New York, 1989.

filled include carrier-based and land-based interceptor, fighter-bomber, close support, reconnaissance, and electronic warfare[85].

The first foreign countries to receive F-4s were the United Kingdom and Iran, in 1968, and Germany and South Korea in 1970. By 1974 F-4s were in the air forces of Spain, Japan, Turkey, Greece, and Israel, and they were transferred to Egypt in 1984. All of the eleven countries just mentioned still have F-4s in their inventories.

The American fighter that has had the most widespread international distribution is the F-5. Lighter, cheaper, and easier to maintain than its top performance contemporaries, the F-5 was chosen by the United States for supply to its allies under the Military Assistance Program. Since its first appearance in 1964, a number of models of F-5s have been produced in several countries, and it is in use in the roles of interdiction, close support, air defence, armed reconnaissance, and training. The F-5E version, first operational in 1973, incorporated important improvements, especially for the air-to-air role, with more powerful engines, better manoeuvrability, and a greater radius of action.

The F-16 is an extremely capable multirole fighter and reconnaissance aircraft, whose export began almost as soon as its entry into the USAF in 1980.

Table 22 shows the forty countries which have (or have had) F-4s, F-5s, and F-16s in their air forces, and also the dates of acquisition (and termination, when applicable. An uncompleted hyphen indicates that the aircraft was still in the operational inventory in 1992). It is evident that the F-5 has been joining very many air forces during the years since 1964. The list of countries in Table 22 includes nearly all of the security treaty partners of the United States[86].

The Eastern aircraft chosen for a similar examination were the MiG-17 (Fresco) and the MiG-21 (Fishbed). The MiG-17, which entered the Soviet Air Force in 1953, was a subsonic jet-propelled day fighter, and had later models designed for all-weather interception, for ground attack, and for reconnaissance. MiG-17s were exported to Warsaw Pact allies and beyond, with licensed manufacturing in Poland and in China (where the aircraft is known as the Shenyang J-5).

The MiG-21, which came five years later, began as a supersonic day interceptor, but saw many models and many roles, including all-weather interceptor, air superiority, ground attack, and

85 Perhaps the greatest tribute to the F-4's capabilities is that both the US Navy and the US Air Force have bought them in large numbers.

86 France, Italy, Portugal, and Australia are absent. France builds its own, and Italy and Portugal favour European-built aircraft. Australia uses American-built F-111s and F-18s.

reconnaissance. Different versions were equipped with several types of radar and missiles in its long and versatile life (which is by no means finished in 1992). MiG-21s have been manufactured in India, Czechoslovakia, and North Korea, and in the Xian plant in China with the designation J-7 or F-7.

Table 23 shows the distribution of MiG-17s, MiG-21s, and their Chinese models. Information regarding distribution prior to 1965 is scanty, and the dates in Table 23 are only from 1965 onward. The MiG-21 is the most widely deployed fighter aircraft in the world, and by 1980 the number exported by the Soviet Union exceeded the total of the NATO tactical aircraft in Northern and Central Europe. While the older and less capable MiG-17 has now been withdrawn from most of the better-equipped air forces,

MiG-21 continues to serve in over forty countries. The list traces the history of Soviet foreign relations, with the closest and longest being in the Warsaw Pact, followed by support for countries in Asia, the Middle East, and then Africa. Chinese-built J-5s and J-7s were exported to Africa, the Middle East, and Asia.

IV THE MODERNIZATION OF ARMOURED FORCES

The Principal Characteristics of Tanks

Designers of tanks must balance three primary objectives: hitting power, mobility, and vulnerability. These are highly interdependent. Good hitting power and good mobility reduce vulnerability. But a heavy gun, space for a lot of ammunition, and thick armour all reduce mobility.

The environment in which a tank must operate poses more constraints than those faced by the designers of missiles, aircraft, or ships. A tank should be light enough and small enough to be transportable by rail, and to be able to negotiate the bridges and tunnels in its theatre of operations. It must climb and descend slopes, and traverse rough and soft ground. It should be able to maintain a reasonable cruising speed on highways or smooth hard ground, and a highly desirable (though not absolutely essential) capability is to ford shallow water, or better, to swim across deep water.

The requirements of mobility set a practical limit to the size and weight of a tank, so that the designer is obliged to trade off his needs for a large and powerful engine, a gun with good range and hitting power, stowage space for adequate ammunition, and thick protective armour within strict limits of overall size and weight.[87]

As a consequence of these complicated interdependencies, it is difficult to isolate any one or two measures of effectiveness that would represent the overall combat capability of a particular tank.

The history of tank development has parallels with that of military aircraft, with rapid progress during World War I, little more until World War II, a tremendous series of replacements and modernizations during that war, and continuation at a slower but steady pace throughout the Cold War period. There are also parallels with the operational requirements. Both combat aircraft and tanks are threatened, not only by their own kind, but by other (antiaircraft and anti-tank) weapons, which may pose the greater danger. Combat aircraft have more varied roles to fill than do tanks, but tanks can be used to fight other tanks, to conduct operations on their own, or to support the operations of other arms of the service. The most successful operations involving tanks have been as part of a combined force, working with artillery, aircraft, and infantry. For this to be effective it is essential that the tanks be provided with good wireless communications.

87 If armour is minimal, the weapon becomes a self-propelled gun or a "tank destroyer".

The Development of Tank Technology to the End of World War II

The first tanks were designed for use against the trench and barbed-wire defences which had defeated infantry attacks in the first years of World War I. The primary requirement was to be able to move over wire and trenches in the face of machine-gun fire. The British armed their first tanks with two light naval guns and several machine-guns, the French used a single 75mm howitzer and machine-guns. The armour was good enough for protection against enemy machine-gun and small arms fire, though not against artillery, but the speed of the vehicle was only 6 to 8 km/hr. The German response was a large, very clumsy vehicle (A7V) with a crew of 18, more like a fortress than a tank.

In the period between the wars, several diverging lines of thought developed regarding the use of tanks. The Germans wanted to avoid trench stalemates, and designed the Blitzkrieg tactics, centered on fast-moving well-armed tanks working in combination with infantry, aircraft, and artillery. Two families of larger tanks were built, the PzKpfw III battle tanks, to fight against enemy tanks, and the PzKpfw IV medium tanks, to support friendly infantry. As the war progressed, the Panzer forces were faced with ever better opposing tank guns and anti-tank guns, and had to increase the thickness of their armour. To penetrate armour on opposing tanks, the calibre of the PzKpfw III gun was increased from 37mm to 50mm to 75mm, and the length of the 75mm gun on the PzKpfw IV increased[88]. Naturally, the weight of both tanks grew with these modernizations. Later the Tiger, heavier, with very thick frontal armour, and armed with an 88mm gun, became the war's most feared tank. The Soviet T-34, appearing in 1941, revealed a number of features of superiority over the PzKpfw IV, including sloped armour and high agility, prompting the Germans to design many of these characteristics into their Panther. The success of the Tiger motivated a Tiger II, the heaviest, best protected, and with its high-velocity 88mm gun the most powerfully armed tank produced during World War II.

Table 24A gives a list of main battle tanks, with their year of issue, calibre of main armament, and weight, up to the end of World War II.

In their planning after World War I the British favoured three classes of tank. Light tanks would be used for reconnaissance, cruiser tanks would be fast, and used to fight other tanks. The Infantry Tank would be heavily armoured and therefore slow, with its main weapon being machine guns. Disappointingly, the experience of war showed the light tanks and cruiser tanks to be

88 The muzzle velocity of the shell, and therefore the kinetic energy with which it strikes its target, can be very considerably increased by lengthening the barrel of the gun, thus allowing the expanding gas from the burning propellant to give it more acceleration.

extremely vulnerable, and none of the three British types of tank able to compete with German tanks, by which they were decisively out-gunned.

The Soviets never depended on small-calibre guns, and entered World War II with the heaviest tanks. The T-28 was given a longer 76mm gun and better armour, and used until T-34 was available. The 76mm gun on the heavy KV-1 was replaced by an 85mm weapon, and served until the arrival of the Josef Stalin series of heavy tanks. The T-34 represented a radical improvement in tank design, with its diesel engine[89], fast speed, sloping armour, and high velocity 76mm gun. It was extremely successful in battle, especially after being given an 85mm gun. The most successful Soviet heavy tank of world War II was the JS-2, with very heavy and cleverly shaped armour and a 122mm gun.

With their late entry into the war, the USA did not go through as many stages of modernization as the other participants. The first tank built by the Americans in large numbers was the M4 Sherman. Nearly 50,000 were built, with many minor variations in guns (mostly of 75mm calibre), engines, and hull construction. The M26 Pershing, with a 90mm gun, came just at the end of the war, but saw service in Korea, and with other armies.

In spite of the disadvantages of size already outlined, there were occasional projects to build enormous tanks. The German K tank, designed in 1918, but overtaken by the Armistice and the Treaty of Versailles, weighed 150 tons, accommodating four 77mm guns and 7 machine-guns, with a crew of 22. The French super-heavy Char 2C, also designed in 1918, and retained until 1940, weighed 70 tons, with an armament of one 75mm gun, four machine-guns, and a crew of 13. The second world war's giant was the German Maus, weighing an incredible 188 tons, with very heavy armour, and armed with coaxial 128mm and 75mm guns, but unable to move at more than 20 km/hr. None reached operational service.

Anti-tank Technology

Many of the most interesting and important technological developments related to armoured warfare have been in the field of anti-tank weaponry. Naturally, the appearance of an effective anti-tank technology motivates countermeasures on the part of the tank designers, with modernization begetting offsetting modernization. Therefore for this discussion we will divert temporarily from tank to anti-tank technology. They can hardly be separated in any case, since a major role of most tanks is to counter the tanks of the opponent.

89 Although it allowed tank engines to have a higher power-to-weight ratio, high-octane gasoline presented a terrible fire hazard.

Until part way through the Second World War, the only means of penetrating the armour of a tank was by firing a projectile that was heavy enough and travelling fast enough to smash its way through the armour. This required an accurate shot from a powerful gun, at fairly short range, and even then the shot could bounce off if it struck the armour at a glancing angle. Heavy man-carried rifles soon proved inadequate for this task, as did 40mm (2-pounder) guns. 57mm (6-pounder) guns had some success in the early years of the war, but it soon became necessary to move to calibres of 75mm or more, if the armour was to be defeated by kinetic energy.

There is another way to penetrate armour, which relies on chemical energy rather than kinetic energy. An ordinary high explosive shell is not very effective against thick armour, because the force of its explosion is not sufficiently concentrated against the resisting armour. But a cylindrical explosive charge with a cone hollowed out of the forward face, and lined with metal, will focus the energy of its explosion forward into a jet of molten metal able to penetrate a considerable thickness of armour. Such a "hollow charge" warhead can be placed in an artillery shell with a rod projecting forward, so that on contact with the armour it will detonate the charge at the proper distance to focus the blast most effectively. Or the warhead can be projected at low velocity, using a light mortar or rocket launcher instead of a heavy gun. Launchers such as those of the spigot mortar for the British PIAT, the rocket launcher for the American Bazooka, and the recoilless gun for the German Panzerfaust were carried and fired by infantry.

Several methods of increasing the penetrating power of gun-fired projectiles were discovered. One, initiated by the Germans in 1941, was to construct the projectile with a hard tungsten carbide core encased in a light metal jacket. This would attain a higher muzzle velocity than a homogeneous shell of heavier total mass, and therefore increase the penetration by the hard core. Other methods of increasing muzzle velocity were to use a tapered bore in the gun (done by Germany in 1941), or to embed a hard armour-piercing core in a full-calibre piston-like "sabot" which fell apart after leaving the muzzle of the gun. This "armour piercing discarding sabot" (APDS) ammunition was introduced by the British in 1944.

Instead of penetrating the armour with all or part of the projectile itself, or making a hole with the explosive force of a shaped charge, it is possible to use a "High Explosive Squash Head (HESH)" shell which spreads its plastic explosive on the surface of the armour before being detonated, thus transmitting the shock of the explosion into the armour and causing scabs and splinters to fly off from its inner surface. This method has the additional advantage that a shell striking the armour at an angle is less likely to bounce off.

For accurate long-range gunfire it is necessary that the projectile remain stable in its flight, rather than tumbling. The usual solution to this problem is to rifle[90] the bore of the gun barrel so that the shell rotates, which keeps its orientation steady in flight. For antitank gunnery this has two disadvantages. One is that the barrel of a high velocity rifled gun wears quickly, the other is that the penetrating power of a shaped charge is reduced if it is spinning, since this defocuses the directional effect of its explosion. As a consequence, many new tank guns are being designed with a smooth bore. Their non-rotating projectiles are given "arrowhead stability" by fins.

During the second war fixed-wing aircraft had some success in attacking tanks with bombs and light cannon fire, but the best results were achieved with high velocity unguided rockets. Aircraft giving close support to ground troops must be able to engage tanks, and do so in the face of antiaircraft fire. The modern aircraft most highly developed for anti-tank warfare is the American A-10, operational since 1975, armed with air-to-surface guided missiles and a large high velocity rapid fire rotary cannon able to fire armour-piercing incendiary 30mm shells. A-10s had good success against Iraqi tanks and other vehicles in the Persian gulf war.

While the powerful gun with the right ammunition is probably the best antitank weapon, its size and weight require a large and heavy mounting, with consequent problems for mobility. A "tank destroyer" sacrifices mobility and protection, siting itself to get in the first shot from a concealed position. Its gun may have a limited traverse, and dispense with an armoured turret.

The alternative to the gun is the anti-tank guided missile (ATGM). Several very effective ATGMs have been designed which depend on visual selection and tracking of the target by a gunner, who transmits guidance commands to the missile through thin wires, or by radio, while it is in flight. The usual scheme is to accelerate the missile by rocket propulsion, after which it coasts under aerodynamic control. There can be different degrees of sophistication in the control. The simplest is to have the gunner steer the missile (which may be launched from a site displaced from his own), usually by keeping it on the line of sight between himself and the target. In "Semi-Automatic Command to Line of Sight (SACLOS) the gunner establishes the line-of-sight to the target and the missile (which must be launched from a location close to the gunner) flies along it. In both of these cases the gunner must keep the target under continuous observation throughout the entire flight of the missile.

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90 Rifling consists of the cutting of spiral grooves into the inner surface of the gun barrel. The projectile is given a "driving band" in the form of a soft metal ring, with an outer diameter slightly larger than the inner diameter of the grooves in the barrel. As the projectile is forced along the barrel the helical grooves cut into the driving band, and force the projectile to rotate.

With semi-active laser guidance the target can be designated by an observer located on the ground or in the air, and the missile fired from a completely different location. Or, with passive homing guidance, and once launched in the right direction, the missile can direct itself towards the heat of the tank, or towards its distinctive shape as projected in an optical image.

ATGMs using any of these forms of guidance have allowed helicopters to become extremely effective anti-tank vehicles. Also field artillery has reentered the anti-tank role, firing shells able to alter their trajectory by small steering vanes, in order to home onto a laser spot directed at the tank by a forward observer. And, finally, small homing weapons can be projected by rocket, howitzer, or helicopter over an area containing tanks, after which the small munitions will slowly descend while using infrared or millimetre wave radar to locate the tanks and steer towards them for attack from above[91]. In the Gulf war the greatest success against tanks came with aircraft and helicopters firing electro-optically guided ATGMs[92].

There are, of course, methods of combatting tanks other than by long-range guns or guided missiles. Anti-tank mines can be very effective, especially if sited in conjunction with obstacles and fields of fire. If infantry can get very close to tanks, they may be able to disable the running gear with grenades, or to attach explosive charges to the hull. At slightly greater ranges they can use unguided missiles fired from light recoilless guns or rocket launchers. While these are unlikely to defeat the turret or the thick frontal armour, they may be able to disable the tracks, or to penetrate or damage the hull through the more thinly armoured sides or bottom.

Naturally, with all these anti-tank devices and tactics appearing, both for opposing tanks and for other natural enemies of tanks, the designers and operators of the tanks have produced countermeasures.

Modernization and Replacement of Tanks During the Cold War

The Soviet Union has continued to produce a new type of tank every few years. The JS-2 heavy tank of World War II was the progenitor of a series ending with the T-10, which appeared in 1957. Successive models had improvements such as a more powerful gun (still 122mm calibre, which was not exceeded by any tank for many years), better armour, antiaircraft machine guns, infrared illumination, and a snorkel apparatus for fording rivers. The T-54/55 main battle tank, with

91 The heavy armour able to defeat a modern anti-tank weapon is concentrated in the revolving turret containing the tank's gun, which must be exposed to the return fire from any targets within line-of-sight, and on the front of the hull. Comparable armour protection to the sides, top, or bottom of the hull would entail unacceptable weight.

92 See, for example, *Desert Victory: The War for Kuwait*, by Norman Friedman, Naval Institute Press, Annapolis, 1991.

a 100mm gun, was extremely successful, with as many as 70,000 being manufactured. Later models had a system of controlled air circulation for protection against nuclear, biological, and chemical warfare[93]. Auxiliary fittings allowed variants of the T-54 to clear mines or lay bridges. Its successor was the T-62, armed with a 115mm smooth-bore gun, followed by T-64, with a 125mm smooth bore gun and much faster than T-62. The two latest, T-72 and T-80, have the same gun as T-64, but with an automatic loader, and employ the latest improvements in armour protection and integrated fire control.

China, which had been supplied with Soviet-built tanks through the 1950s, began to manufacture copies in the 1960s, and by 1968 had home-built versions of the T-54 in the PLA, under the designations T-59 or T-69. Subsequent Chinese-built tanks, both heavy and light, have been of indigenous design.

The British Centurion came just too late to fight in World War II, but was the ancestor of a long line of successful tanks. Twenty-five separate "Marks" were produced. The 76mm gun of Centurion I was replaced by an 83mm, and eventually by a 105mm stabilized gun. Many other army vehicles were built around the Centurion hull, including bridgelayers, armoured recovery vehicles, and self-propelled guns. The weaknesses of the Centurions were slow speed and short cruising range. Conqueror, with a 120mm gun, was heavy, no faster, and with cruising range even shorter than Centurion. Chieftain was lighter and faster than Conqueror, had a much longer cruising range, and a very high-powered rifled 120mm gun, using separate ammunition[94], and with a stabilization system allowing it to fire on the move. Challenger uses the same gun as Chieftain, but is faster and has a new type of composite laminated armour. Challenger has laser range-finding, thermal imaging, and computerized fire control.

The United States entered the cold war with a large inventory of M-4 Sherman medium and M-26 Pershing heavy tanks. With new engines and transmissions the Pershings became M-46 Pattons. Two slightly improved Pattons followed, M-47 and M-48, still with 90mm guns (except for the final model M-48 A5), and finally M-60 with a 105mm gun and a better shaped turret. M-60s

93 The filtered air prevents inhalation of most gases and biological agents, and of radioactive dust from fallout. It will not help against the intense prompt gamma and neutron radiation emitted when the nuclear weapon explodes. The thick walls of the tank will provide considerable protection against the gamma radiation, but less against neutrons. The "Enhanced Radiation Weapon" or "neutron bomb", much discussed in the late 1970s but never deployed, was intended as an anti-tank (or, more correctly, an anti tank crew) weapon.

94 The standard ammunition for tank guns and smaller calibre artillery has a metal cartridge, containing the propellant charge, attached ("fixed") to the projectile. For the larger calibres this makes a large round to be stowed, and a heavy object for the gun loader. "Separate" ammunition provides the propellant charge in the form of a separate bag, easier to store and to load, and without the need to dispose of the metal casing.

were produced over a long period in a number of models. The most unusual was M-60 A2, with a new turret mounting a gun/launcher able to fire a 152mm shell or a Shillelagh anti-tank missile[95]. The M-60 A3 had a more powerful stabilized 105mm gun, a laser rangefinder, computerized fire control, and equipment for night vision.

After a long and ultimately unsuccessful programmeto design "Main Battle Tank 1970" the United States settled on the M-1 Abrams. This tank has well-shaped composite armour, a powerful gas turbine engine, advanced electronic vision and sighting devices, and a fully stabilized gun. The first model used a rifled 105mm gun, but the M-1 A1 has a 120mm smooth-bore gun.

Germany recommenced the manufacture of main battle tanks with the very successful Leopard I. Armed with a 105mm gun, it has gone through a series of updatings, including stabilization of the gun and spaced armour. The Leopard I chassis has been used for the Gepard self-propelled antiaircraft system (with twin 35mm cannons), an armoured recovery vehicle, an armoured engineer vehicle, and a bridgelayer. Heavier than Leopard I, Leopard II has a 120mm smoothbore gun, composite armour, and good road speed.

The principal French tank is the AMX-30, in service since 1967. Rather lighter than most other main battle tanks, it has a 105mm rifled gun[96], an infrared searchlight, ability to ford shallow streams, and filtering of contaminated air. The chassis serves for other applications such as bridgelaying, carriage of tactical nuclear missiles, and antiaircraft defence.

Table 24B summarizes the list of major main battle tanks appearing after World War II, together with the calibre of their main gun and the total weight of the vehicle. The history of the gun calibres and vehicle weights throughout the entire period from 1916 is shown in graphical form on Figures 24A and 24B.

Figure 24A demonstrates that the designs of World War I and the lessons deduced from it produced calibres of between 47mm and 75mm, generally satisfactory for use against infantry and lightly armoured vehicles. Prior to World War II some designers were content with 37mm or 40mm calibres, but the early experience of combat showed these to be totally inadequate. 75mm became the absolute minimum, and post-war tank guns have had calibres of 90mm to 125mm[97]. Certainly

95 Shillelagh was rocket propelled, and guided by the gunner via an infrared command link.

96 The rifled gun fires a round with an anti-armour warhead mounted in ball bearings inside the outer casing. This reduces the rotation of the shaped charge, thus preserving its focusing effect.

97 The larger calibre ammunition makes manual loading difficult, but this problem can be solved with automatic loading mechanisms. There are plans to use 140mm calibres in future tank guns.

the CFE definition of a battle tank as having a gun of at least 75mm calibre will include all current main battle tanks.

Figure 24B shows a sharp increase in the weight of tanks during World War II, but no noticeable further trend upwards thereafter. Except for the French Char C of 1923 and the Soviet T-35 of 1933, no tank has exceeded 35 tons before 1940, and no new tank since 1944 has weighed less than 35 tons or more than 66 tons. The CFE definition setting 16.5 tons as the lower limit should certainly encompass all current main battle tanks.

Although remarkable degrees of increase in combat capability have been accomplished during the period between 1945 and 1991, they have not been accompanied by a consistent tendency to increase either the calibre of the guns or the weight of the tanks.

Summary of the Modernizations in Tank and Anti-tank Technology

The purpose of this chapter has been to describe the continuing development of the technology of tank and anti-tank weapons. Nothing has remained static for any length of time since 1939.

The firepower of tank guns has been strengthened by increasing the muzzle velocity and weight of the shot, and by the design of various different types of anti-armour projectiles. Automatic loading speeds up the rate of fire, and dispenses with a crew member. Combustible cartridge casings contribute to firepower without posing problems of disposal of the spent casings. Laser rangefinders, night vision devices, and computerized fire control allow accurate gunfire to be delivered by day or night, and stabilization permits fire on the move.

Mobility has been improved by the progression from gasoline to diesel piston engines, and then to gas turbines. Better suspensions have allowed higher cross-country speed. Wading and Snorkel devices have made it possible to ford or swim across water obstacles. Bridgelaying tanks expedite crossings by other vehicles and men as well as tanks, mine-clearing tanks can prepare safe passage for others, and armoured tank recovery vehicles can repair immobilized tanks.

Many steps have been taken to reduce the vulnerability of tanks, necessitated by ever better anti-tank weaponry. Prevention against fire include replacement of gasoline by diesel oil fuel, compartmenting of ammunition and provision of halon fire extinguishers. Lower silhouettes make concealment easier. And a host of measures have been taken to make armour more effective. Sloping surfaces deflect projectiles, or oblige them to attempt their penetration at an oblique angle. Layers of armour with space between them cause a shaped charge to dissipate the energy of its penetrating jet before it can breach the inner layer. Special materials such as depleted uranium or certain ceramics can reinforce the resistance of steel armour. Reactive armour detonates a small explosion just outside the surface of the main armour, which defocuses the penetrating jet of a shaped charge. Weak spots not covered by the main armour can be covered by add-on patches of "appliqué" armour. And, in partial answer to the threat of aircraft (especially anti-tank helicopters), ordinary tanks carry antiaircraft guns, and can be accompanied by special antiaircraft tanks.

Many of the improvements in anti-tank technology can be employed by tanks themselves, since their major enemy is the opponent's tanks. However, guided missiles and mines have become very serious threats to tanks, with which they are not able to deal on a reciprocal basis. The anti-tank gunner (hidden on the ground, or in a helicopter hovering behind cover) will probably see the tank first, and the first indication of his presence is likely to be the approach of one of his guided missiles. However, the missiles travel very much slower than the shells of a tank gun, and the tank may be able to fire back in time to prevent the gunner from completing the guidance of the missile. Or, if the time of flight of the missile is long enough and the tank acts quickly enough, it may be possible to use smoke grenades to obscure the tank from sight and from the designation by a laser spot, or to use a flare to decoy an infrared homing missile.

Anti-tank mines are becoming much harder to combat by the older techniques of hunting and probing by human sappers. Mines can be actuated by various sensors, and may project themselves from a concealed position before detonating. They can be dispensed by guns, rockets, or helicopters, as well as land vehicles and sappers. Plastic mines cannot be detected by the usual form of metal-sensitive mine-hunting sensors. But in addition to the ploughs and flails attached to tanks, it is now possible to detonate a buried minefield by projecting a tube of liquid explosive over it, or exploding a layer of fuel-air explosive vapour above it.

In short, tank and anti-tank technology has exhibited a consistent story of steady modernization, too complicated in nature to allow adequate description by a few numerical measures of effectiveness.

Modernization of Heavy Armoured Forces by Arms Transfer

The spread of technology via international distribution of a few selected US and Soviet fighter aircraft was illustrated on Tables 21 and 22, which show the years during which recipients operated the aircraft. A tabulation for tanks is given in Table 25, in slightly different form. Sixteen different tanks from six countries are listed, together with the number of countries operating tanks of the specified type during 1970, 1980, and 1990.

It is evident that the most widely distributed types (as measured by the number of different armies using them) were the Soviet T-34 and T-54/55. First appearing in 1941, and giving an excellent account of itself in World War II, the T-34 had its widest distribution forty years later, but was beginning to disappear fifty years later. The T-54/55, a very successful post-war design, was being used by 45 countries in 1990 (57 if one includes the Chinese-built version Type 59/69).

One might conclude from Table 25 that the USSR was pleased to supply its allies and clients with older technology, but was more selective with newer tanks. But it may well be that for many of the recipients a T-34 or a T-54 was (is) quite adequate for their purposes. Tanks are very durable objects as long as they do not get into combat with more modern tanks or anti-tank forces.

For both aircraft and tanks, it should be noted that transfer of the weapon system is usually accompanied by training in the donor (selling) country, and subsequent supply of spare parts and often of maintenance personnel from the manufacturing agency. This creates a dependency lasting long after the original acquisition.

V SUMMARY AND CONCLUSIONS

The Various Degrees and Types of Modernization

Quite a variety of changes to weapon systems have been considered in this paper as constituting "modernization".

While excluding routine maintenance, or straight repair of broken equipment, or replacement of "lifed" or worn out items such as batteries or tires, "modernization" does include:

- periodic overhauls (refits) in which components are replaced by new and different models, or control-software by later versions
- addition of completely new capabilities, through alterations to equipment or addition of new components
- complete replacement of old by new and substantially different equipment similar enough to be considered to be still of the same general type or category.

At this stage there can be disagreement as to whether the outgoing weapon is being replaced by a "modernized" version of its own type, or by a "new and different" type.

Sometimes there are legal or political reasons to have a new system considered as a modification of one already accepted, even though its characteristics are substantially different. One example is the highly accurate and mobile Soviet missile known in the West as SS-25, first deployed in 1987. The Soviets claimed that it was a modernized version of the inaccurate SS-13, which had been deployed in fixed silos since 1969. The Soviets called the two missiles RS-12 and RS-12M. Since SS-24 was clearly a new ICBM, and SALT II had allowed only one new type to be deployed, another new missile would have represented a transgression.

Another example is the replacement by the US of Pershing I with Pershing II, as part of the "INF modernization program". Pershing II was a radically different missile, but it was thought that there would be less political opposition if it were seen as "only a modernization".

A few agreed statements have been appended to treaties stating criteria such as percentage changes in dimensions which would signal a change in type.

Modernization may be conducted by altering the equipment in national workshops, may come about through procurement from national suppliers, or come by transfer from one nation to another. In the case of transfer, the term "new" signifies new for the receiving country, but not necessarily previously unused by the donor country.

The Qualitative Arms Race

The "arms race", the object of so much criticism and opposition from those describing themselves as "the Peace Movement", has often been portrayed as a contest to acquire larger and larger numbers of offensive weapons. In fact, there have been periods (mostly some years in the past) when the numbers of strategic nuclear delivery vehicles deployed by NATO and the Warsaw Pact were increasing, but longer periods during which numbers were stable or decreasing. The total megatonnage has decreased very significantly. And a considerable proportion of the new weapons have been designed for defensive rather than offensive use. However, in terms of capabilities, as opposed to numbers, there have been continuing substantial advances in most of the major weapon systems deployed by the industrialized countries and also transferred to other countries.

These characteristics of the Cold War have been illustrated in the case of strategic weapon systems, in Chapters II (for ballistic missiles) and III (for combat aircraft). With the end of the Cold War, the signing of significant agreements for arms reductions, and announced national plans for decreased defence budgets, we can expect the inventories of both nuclear and conventional armaments to be very considerably diminished, at least for many of the most powerful countries. However, the "quantitative arms race" (which had the racers standing still or running slowly backwards for much of its existence) can fade away, only to be replaced by a qualitative arms race. This would cost less than a quantitative race, and would probably produce mixed results as regards strategic stability in the world.

Strategic deterrence requires a sufficient number of nuclear weapons to be able to answer nuclear aggression with unbearable nuclear retaliation. For this deterrence to be stable, the number of retaliatory weapons must be sufficiently large, and their vulnerability to a first nuclear strike sufficiently low, that the survivors of the worst conceivable surprise first strike would still be capable of delivering unbearable retaliation. Therefore, once the numbers come down the survivability of those that remain becomes ever more important. Mutual numerical reductions will diminish the threat, modernization of the offensive weapons may increase it. Modernization may make the retaliatory force more survivable. Construction of an ABM system able to protect a retaliatory force could preserve deterrence, but if it were able to protect population and industry it could eliminate deterrence.

Numbers will always matter, but quality may be even more important.

Ballistic Missiles

During the 1960s there was a large numerical buildup in the inventory of ICBM launchers, but it started from zero, and levelled out about the time that the SALT I agreement was signed. American SLBM launchers reached their numerical peak in 1967, the Soviets fourteen years later. The US strategic bomber force had passed its numerical zenith by 1960, and since then has decreased steadily, while the Soviet capability for delivery of attack by long-range bomber aircraft has been modest, but steady, for about thirty years. If the "arms race" is measured in terms of the *number* of strategic *launchers*, then it ceased about twenty years ago. If *total megatonnage* of nuclear explosive energy is the index, then the race ended in the 1970s.

If one chooses to keep score with *warheads*, which is probably a better index of striking power than launchers or total megatonnage, then the "race" lasted up to the signing of START in 1991, with the major accelerations for ICBMs in the 1970s. Cruise missiles, both air and sea launched, are still being deployed today.

The earliest ICBMs were slow to fire and dangerously vulnerable to a disarming first strike. Modernization rectified this unstable situation by putting the missiles into hardened underground silos, and shortening the reaction time, and later on by making some of them mobile.

The SALT agreements may have had some influence in the stabilization of numbers of launchers, the number of SSBNs, and the throw-weight of new ICBMs, but it would probably be more realistic to describe SALT as a tacit mutual recognition that nether side wanted the number of launchers to increase above the levels planned at that time, but wished to preserve the right to proceed with modernization (including the deployment of MIRVs), albeit at a measured pace and with some general constraints.

If the establishment and maintenance of mutual and stable strategic deterrence is taken to be the prime objective of the strategic weapons programs, then most of the qualitative developments should be regarded as beneficial. The steps to reduce the vulnerability of the early ICBMs and their need for a long preparation prior to launching, as well as the placing of a substantial proportion of the weapons in submarines, removed the incentive for a surprise counterforce first strike. The provision of reliable early warning of the launch of foreign missiles, and of the approach of missiles or bombers, made important contributions towards crisis stability. The increase in the range of the American bombers and the Soviet SLBMs removed the need for forward air bases around the periphery of the USSR, and for submarine patrols close to the North American coast. Making ICBMs mobile was another means of reducing vulnerability.

The strategic consequences of increasing accuracy and of the deployment of multiple warheads have less favourable aspects. Increasing accuracy raises the threat that ICBMs and SLBMs can pose to fixed military targets. On the other hand, the increased accuracy has motivated the designers to reduce the yield of the nuclear warheads, so that, if the weapons were ever detonated, less collateral damage would be caused, and the contribution to worldwide fallout would be reduced. The Multiple Independently Targeted Reentry Vehicle is a destabilizing factor, since it permits one launcher to threaten several fixed launchers such as silo-based ICBMs[98]. The combination of MIRVs with high accuracy allows SLBMs to add to the threat against fixed ICBMs.

START recognized the significance of limiting the number of independent warheads as well as launch vehicles, and made specific restrictions on the number of warheads on ballistic missiles (with a sub-limit for warheads on mobile ICBMs). START halved the number of (Soviet) heavy ICBMs, set a limit on total throw-weight, and allowed credit for accountable warheads by downloading of MIRVs from deployed missiles. In his later unilateral announcement President Bush suggested the possibility of eliminating all ICBMs with multiple warheads. Plans to reduce the number of mobile ICBMs, indicated in START, the unilateral announcements, and budgets, are motivated more by the desire to have reliable verification of numbers of weapons than by considerations of stability[99].

As the number of strategic nuclear delivery vehicles is reduced, stable deterrence depends more and more on keeping them survivable against a counterforce strike. In this regard, the reversal of the quantitative arms race calls for an increase in the qualitative race to reduce vulnerability.

Cruise Missiles

Long range cruise missiles have brought a new combination of characteristics. They are probably even more accurate than ballistic missiles. Air and sea-launched cruise missiles act in the capacity of MIRVs, with the mother aircraft, submarine, or surface ship as the carrier. But they differ from MIRVs in two important respects. They approach much more slowly, giving the opponents time to detect the attack, and perhaps to intercept the attacking missiles, as well as to initiate nuclear

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98 If both sides had ICBMs with ten MIRVs each, one launcher could threaten ten, and have the potential to reduce the retaliation by a hundred warheads.

99 Mobile ICBMs are more survivable than those in known fixed locations, which is a stabilizing factor. Satellites can detect and identify fixed ICBM silos, and can use observations accumulated over an extended period to make an accurate estimate of the number in fixed sites. They can probably also detect mobile ICBMs which are exposed to overhead observation. But in any one day they can only make high-resolution observations of a small fraction of the territory of a large country, and would therefore see only a small sample of the number of mobile missiles that were out in the open on that day. They could observe other samples on successive days, but since, the missiles may move from day to day, it would not be possible to establish an accurate count of the total number.

retaliation, if that is their intention. The other important difference is that cruise missiles are cheap enough and accurate enough to be cost-effective carriers of conventional warheads (as was well demonstrated in the Persian Gulf in 1991). In fact, shorter range conventionally-armed cruise missiles have practically displaced guns as the antiship armament for surface warships. It is, therefore, likely that an increasing number of nations will equip themselves with cruise missiles, and those who own nuclear weapons will be able to arm their missiles with either conventional or nuclear warheads. If conventionally-armed versions are unrestricted, this creates a difficult problem for verification of the absence or the number of nuclear-armed missiles.

The START rules for warhead accountability gave encouragement to proliferation of ALCMs. But the United States is curtailing the production of the advanced cruise missile. START was accompanied by declarations that the number of nuclear-armed sea-launched cruise missiles with a range exceeding 600 km would be limited to 880.

Combat Aircraft

The definitions of "heavy bombers" and "combat aircraft", and the constraints on their characteristics and performance specified in SALT II, START, and CFE[100] are not likely to place any significant limitations on modernization. But the SALT counting rules for nuclear warheads favour heavy bombers over missiles, and heavy bombers not equipped for ALCMs most of all.

Except for a lull between 1918 and 1939, the history of combat aircraft is one of constant modernization, which could well be described as a qualitative arms race. Piston-engined bombers were given progressively greater payloads, ranges, speeds, and ceilings. The arrival of jet propulsion began a new sequence, which produced immediate dramatic increases in speed and ceiling, but took some time to be followed by payloads and ranges surpassing those of the last piston-engine bombers.

Fighter aircraft prize speed and manoeuvrability above all other aerodynamic characteristics, and again these rose gradually but steadily up to the jet age. Jet propulsion took speeds into the transsonic region, and once the techniques of supersonic flight had been solved, very quickly from Mach 1 past Mach 2. Beyond that, manoeuvrability decreased to the point that higher speeds were of little value for air-to-air combat.

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100 CFE defined a "combat aircraft" to be a fixed-wing or variable-geometry wing aircraft armed and equipped to engage targets by employing guided missiles, unguided rockets, bombs, guns, cannons, or other weapons of destruction, as well as any model or version of such an aircraft which performs other military functions such as reconnaissance or electronic warfare.

The increasing power-to-weight ratio of gas turbine engines has given comparatively small fighter-type aircraft the payload capacity of earlier medium bombers. This can be exploited by providing a large radar and long-range air-to-air missiles for interceptors; radar, guided air-to-surface missiles, and devices for electronic warfare, for interdiction and ground attack; or a large cannon and a heavy bomb load for close support of ground operations. The technology of aircraft engines, sensors and armament has developed even faster than that of the basic airframes, and the history of a good airframe is likely to include several modernizations, changes of armament, perhaps of engines, and extensions of roles.

Antiaircraft technology has also moved through a series of constant modernizations, many of them featured by ever more capable guided missiles. Visual, electro-optical, radar, and infrared guidance are used. The general result has been to drive aircraft to low altitudes, at which the best AA weapon is the rapid-fire radar-controlled multi-barrel gun. The aircraft's capability for sustained fast low-level flight is greatly enhanced by variable geometry wings. But the most effective defence against antiaircraft missiles is likely to be found in electronic countermeasures, such as warning receivers, radar jamming and deception, decoys, chaff, and infrared flares, and in stealth technology, which reduces the signals reflected to radars and radiated to IR sensors.

To deliver weapons effectively against defended ground targets, to combat other aircraft, and to survive antiaircraft defences, modern aircraft have had to undergo continual modernization and replacement, without which their air force becomes obsolete for combat against an opponent who has kept up in the current technology.

Airframes have a finite lifetime for safe flying, due to metal fatigue, and many of the parts require periodic replacement simply to keep the aircraft able to fly. But against an ill-equipped opponent, anything that flies , whether ancient or modern, can be used as a weapon.

Tanks and Anti-tank Weapons

There are parallels between the histories of the qualitative arms races in the air and of armoured forces on the ground. Both had their origins in World War I, followed by a lull until the beginning of an unremitting series of modernizations from World War II to the present day. Like aircraft, tanks must cope not only with opposing tanks, but with other dangerous enemies specialized for their destruction and exploiting all the opportunities of modern technology. And, also like aircraft, in addition to opposing their own counterparts they have a role to assist in the operations of friendly ground forces.

The progress of tank technology has been steady, rather than being characterized by spectacular breakthroughs (like jet propulsion or supersonic speed for aircraft). The most important single innovation was probably the use of shaped charges as a means of penetrating armour, which was a great boost to anti-tank warfare. Guided missiles, combined with shaped charge warheads, have given advantages to anti-tank weapons, which have been partially offset by the substantial improvements to tank armour. Tank guns have been given steadily improved hitting power, through progress in the design of their fire-control equipment and ammunition as well as the guns themselves. Tank mobility has been increased, by more powerful engines, better suspensions, and by keeping the total weight down. The history is one of continual modernization. However, tanks are very durable articles, (more so than aircraft), and an old tank that would be obsolete in combat against modern opposition would still pose a formidable threat to a force without tanks or modern anti-tank weapons. A few of them could be an important factor in the control of armed uprisings.

The Problems of Qualitative Arms Control

In order to establish or to stabilize a satisfactory balance between forces, it may be mutually agreeable to set numerical limits (probably, but not necessarily, equal) on the numbers within certain categories of weapons, without adding stipulations regarding the quality or characteristics of the weapons that will be retained (other than the definition of the categories). Replacement and modernization would be unrestricted, as long as the total number within each category remained within the agreed limit. This would legitimize a qualitative arms race.

Such an arrangement could lead to an unsatisfactory situation a few years after the implementation of the agreement, if one side improved their equipment to the extent that the balance of combat capability was destabilized. Or, new technology might allow one side to design weapons which escaped the categories specified in the agreement but were able to discharge an equivalent role, or make some of the opponent's weapons unacceptably vulnerable. With the advance of technology it may be impossible to define categories for limitation in terms that will continue to be satisfactory over a long period of time. One protection against either of these possible developments is to set a finite duration for the agreement, or at least to make provision for periodic review or renegotiation.[101]

We have described some attempts made in existing agreements to limit modernization. Existing types of ICBMs were not to be converted into different types. Light ICBMs could not be

101 This is a fairly common practice in international treaties, and allows for adjustment to other circumstances as well as for technological change. However in some areas it is possible to foresee continuing rapid technological change, likely to move faster than the political background against which the treaty was negotiated.

converted into heavy ICBMs, and changes in dimensions of more than a certain percentage would be considered as representing a "new" missile. The numbers of MIRVs were limited, for both ICBMs and SLBMs, as well as the number of ALCMs for bombers. The INF Treaty removes the incentive to modernize ground-launched ballistic and cruise missiles with ranges between 500 and 5500 km.[102]

Modernization of nuclear weapons has probably been impeded to some extent by the partial test ban and the limited test ban.But it has continued, aided by ingenious use of underground testing, and probably could go on, though with difficulty, even under the terms of a comprehensive test ban. It should be noted that the safety of nuclear weapons has often been improved as a result of both modernization and of testing, and probably does not require a large number of tests, or high energy yields. The ABM Treaty sets limits to radar design, and discourages the development and testing that is necessary to improve BMD technology. However, for most types of weapons, whether or not they are subject to numerical limitations, there have been no restrictions at all on qualitative improvement.

If an agreement were reached that permitted a limited number of weapons of a certain category to be retained but not modernized, difficult problems of verification would be created. The monitoring of the development of ballistic missiles has been greatly aided by the need for full-range testing, which can be observed at long distance by radar, and is accompanied by extensive use of telemetry, which can be intercepted at long distance by satellites, aircraft, or suitably located ground stations. For most other weapon systems these measures cannot be used, and information revealing modernizations would have to await detection of external features by reconnaissance satellite, observation of exercises, and opportunities to inspect the weapons at close range. If they were to be adequate for verifying non-modernization, on-site inspections would need to be far more intrusive than if their sole purpose had been to verify numbers.

Finally, there is the other form of arms control, whether numerical or qualitative, over the process which is described in the context of nuclear weapons as "horizontal proliferation". The dissemination of modern weapons to allies, clients, and commercial customers has been a powerful arm of international relations, with economic as well as strategic aspects. It has been extremely carefully controlled for nuclear weapons and strategic nuclear delivery vehicles, somewhat less so for combat aircraft, and less still for main battle tanks. But it should be noted that control over distribution of the avionics and weapons for the aircraft, and the corresponding equipment in the tanks, could be a means to limit the degree of modernization.

102 But this does not stop an ICBM, SLBM, ALCM, SLCM, or air-dropped nuclear bombs from being targeted on Europe.

The reductions in armaments negotiated under CFE, and also those being planned by most major countries as a consequence of diminished perceptions of military threat, as well as for reasons of economy, can lead to a "quality cascade". Except for those systems which must be destroyed in order to comply with the treaty, the reductions will be made with the least capable weapons in the relevant inventory of each country. And, (again except for those which must be destroyed) the best of the items which must be removed may be transferred to other countries, for whom they are likely to represent a modernization. Thus after the reductions in the inventories of the best-equipped nations, and the transfers, the average weapon in both the donor states and their clients will be more modern than before.

To summarize, while numbers of weapons are certainly an important measure of combat capability, it is essential to take into account quality, and to recognize the role of modernization in the constant upgrading of quality. If it is to be effective in the future, arms control will need to pay more attention to characteristics, and to the freedom to modernize, as well as negotiating the numbers of weapons to be controlled.

[illegible]

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APPENDIX I - TABLES AND FIGURES

1. DEPLOYED MILITARY SYSTEMS WITH HIGH TECHNOLOGY

STRATEGIC SYSTEMS

ICBMs
SSBNs
SLBMs
Bombers
SAMs
Ballistic Missile Defence
Antisatellite
Cruise Missiles

TACTICAL SYSTEMS

Land Forces

SAMs (including Naval)
Tanks
Artillery
Infantry Combat Vehicles
Antitank Guided Missiles
Attack Helicopters
Chemical Warfare
Biological Warfare

Air Forces

Fighter\Attack and Interceptor Aircraft
Air-to-Air Missiles
Air-to-Surface Munitions
Airlift Aircraft

Naval Forces

SSNs
Torpedoes
Sea-Based Aircraft
Surface Combatants
Naval Cruise Missiles
Mines

COMMAND, CONTROL, COMMUNICATIONS, and INTELLIGENCE

Communications
Electronic Measures and Countermeasures
Early Warning
Surveillance and Reconnaissance

Training Simulators

2. NUMBER OF UNITED STATES ICBM LAUNCHERS

YEAR	ATLAS			TITAN		MINUTEMAN			MX	TOTAL
	D	E	F	I	II	I	II	III		
1959	6									6
1960	6	0								9
1961	30	0	0	0		0				71
1962	30	27	0	18	0	100				222
1963	28	27	72	54	54	180				409
1964	13	27	72	54	54	600				811
1965	0	0	0	0	54	800	0			854
1966					54	800	50			904
1967					54	750	250			1054
1968					54	650	350			1054
1969					54	550	450	0		1054
1970					54	490	500	10		1054
1971					54	400	500	100		1054
1972					54	300	500	200		1054
1973					54	140	510	350		1054
1974					54	21	450	529		1054
1975					54	0	450	550		1054
1976					54		450	550		1054
1977					54		450	550		1054
1978					54		450	550		1054
1979					54		450	550		1054
1980					54		450	550		1054
1981					52		450	550		1052
1982					52		450	550		1052
1983					43		450	550		1043
1984					34		450	550		1034
1985					23		450	550		1023
1986					11		450	550	0	1011
1987					0		450	527	23	1000
1988							450	511	39	1000
1989							450	500	50	1000
1990							450	500	50	1000
1991							450	500	50	1000

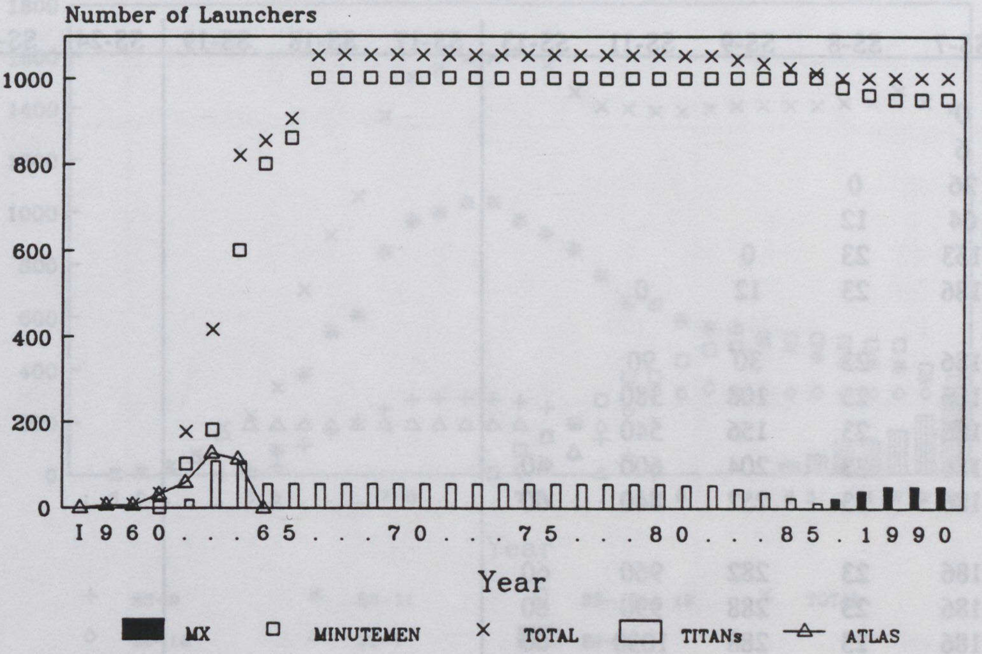

Figure 2A. Total Numbers of US ICBM Launchers

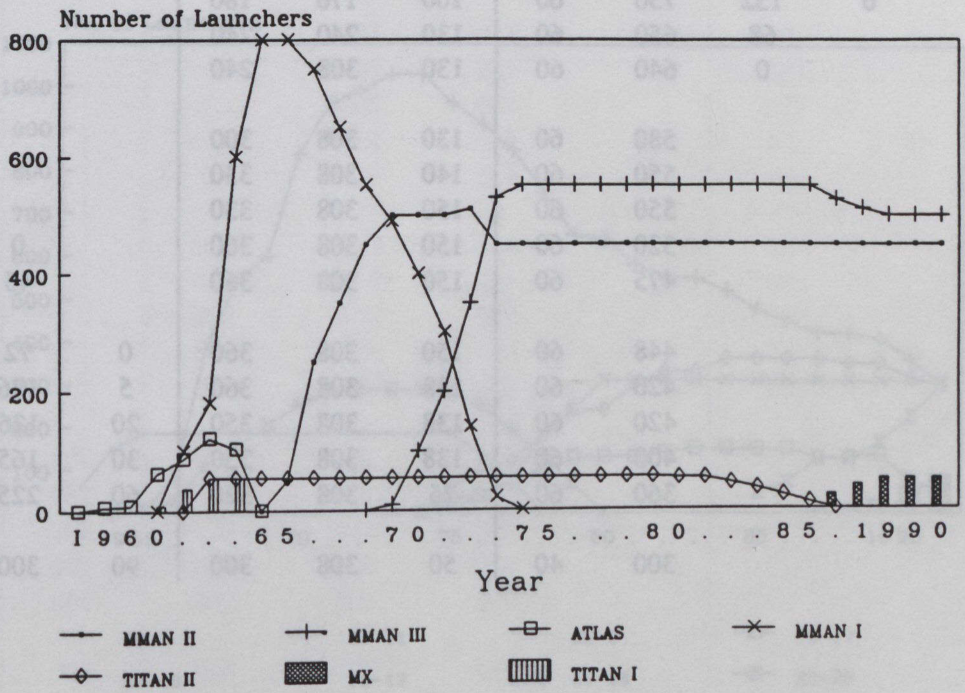

Figure 2B. Numbers of Various Types of US ICBM Launchers

3. NUMBER OF SOVIET ICBM LAUNCHERS

YEAR	SS-7	SS-8	SS-9	SS-11	SS-13	SS-17	SS-18	SS-19	SS-24	SS-25	TOTAL
1960	0										0
1961	6										6
1962	26	0									26
1963	64	12									76
1964	153	23	0								176
1965	186	23	12	0							221
1966	186	23	30	90							329
1967	186	23	108	380							647
1968	186	23	156	540							905
1969	186	23	204	600	40						1053
1970	186	23	252	840	60						1361
1971	186	23	282	960	60						1511
1972	186	23	288	990	60						1547
1973	186	23	288	1030	60						1587
1974	186	23	288	1030	60	0	0	0			1587
1975	186	23	278	960	60	30	10	60			1607
1976	138	23	252	910	60	40	36	100			1559
1977	78	9	190	850	60	70	76	120			1453
1978	0	0	132	750	60	100	176	180			1398
1979			68	650	60	130	240	240			1388
1980			0	640	60	130	308	240			1378
1981				580	60	130	308	300			1378
1982				550	60	140	308	330			1388
1983				550	60	150	308	330			1398
1984				520	60	150	308	360		0	1398
1985				475	60	150	308	360		45	1398
1986				448	60	150	308	360	0	72	1398
1987				420	60	138	308	360	5	126	1409
1988				420	60	138	308	350	20	126	1414
1989				400	60	138	308	350	30	165	1451
1990				360	60	75	308	320	60	225	1408
1991				300	40	50	308	300	90	300	1388

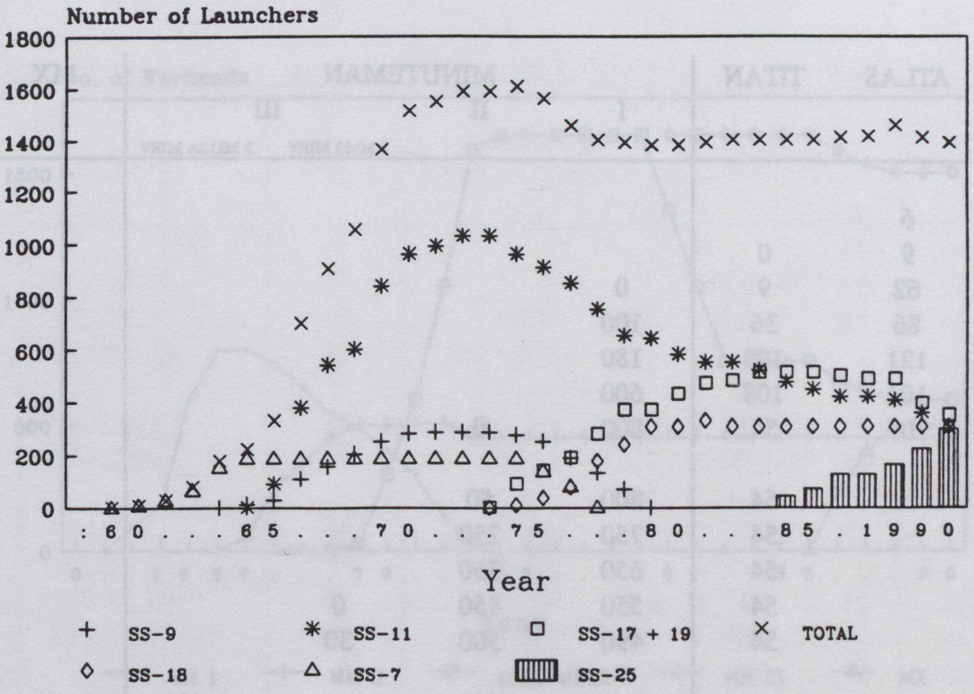

Figure 3A. Total Numbers of Soviet ICBM Launchers

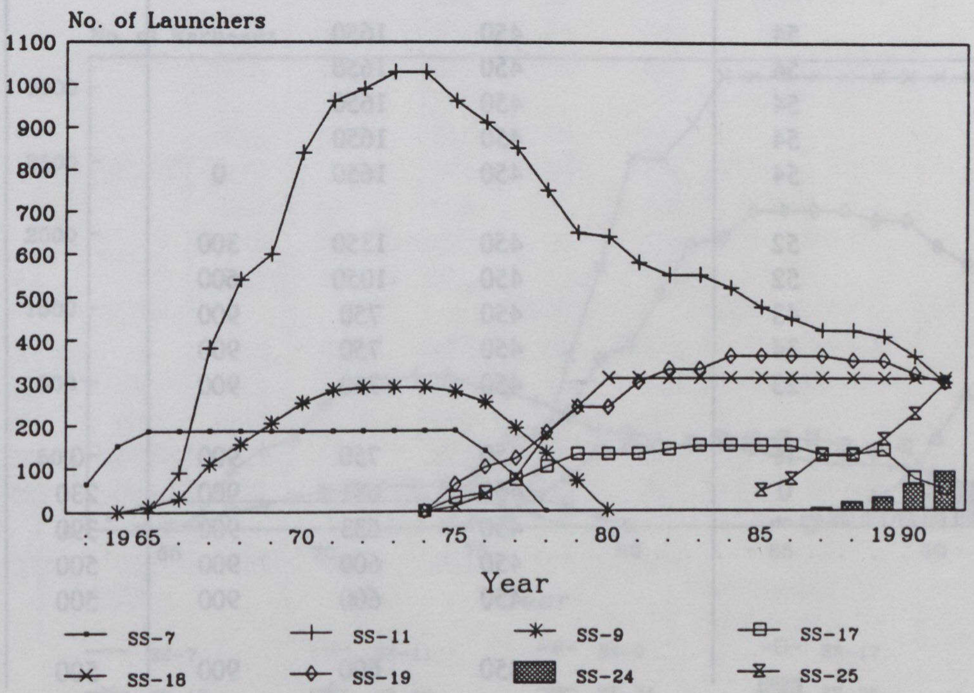

Figure 3B. Numbers of Various Types of Soviet ICBM Launchers

4. NUMBER OF UNITED STATES ICBM WARHEADS

YEAR	ATLAS	TITAN	MINUTEMAN I	MINUTEMAN II	MINUTEMAN III 3 Mk12 MIRV	MINUTEMAN III 3 Mk12A MIRV	MX	TOTAL
1959	6							6
1960	9	0						9
1961	62	9	0					71
1962	86	36	100					222
1963	121	108	180					409
1964	103	108	600					811
1965	0	54	800	0				854
1966		54	800	50				904
1967		54	750	250				1054
1968		54	650	350				1054
1969		54	550	450	0			1054
1970		54	490	500	30			1074
1971		54	400	500	300			1254
1972		54	300	500	600			1454
1973		54	140	510	1050			1754
1974		54	21	450	1587			2112
1975		54	0	450	1650			2154
1976		54		450	1650			2154
1977		54		450	1650			2154
1978		54		450	1650			2154
1979		54		450	1650			2154
1980		54		450	1650	0		2154
1981		52		450	1350	300		2152
1982		52		450	1050	600		2152
1983		43		450	750	900		2143
1984		34		450	750	900		2134
1985		23		450	750	900		2123
1986		11		450	750	900	0	2111
1987		0		450	681	900	230	2261
1988				450	633	900	390	2373
1989				450	600	900	500	2450
1990				450	600	900	500	2450
1991				450	600	900	500	2450

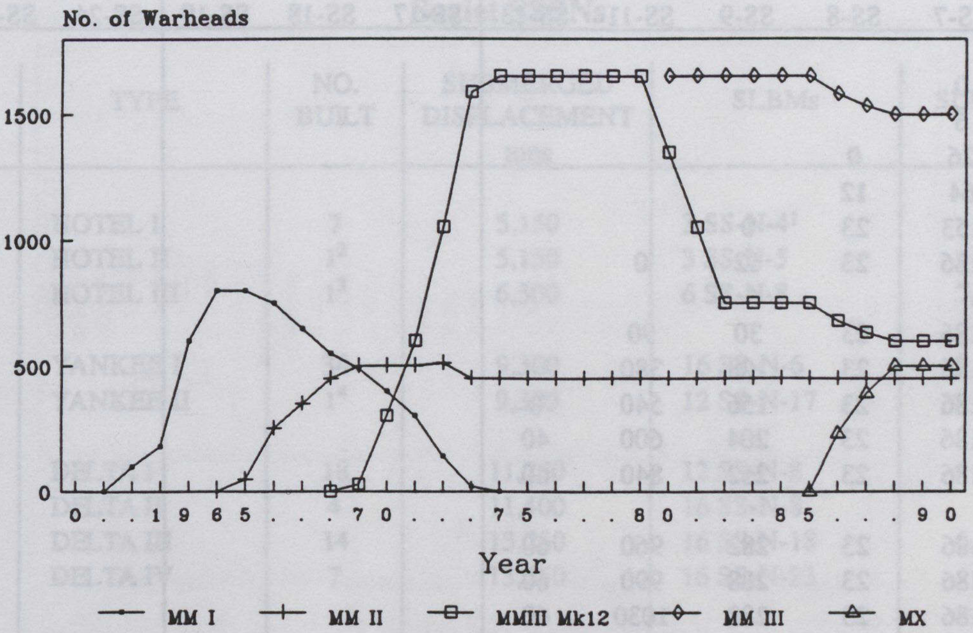

Figure 4. Numbers of US ICBM Warheads (Minuteman and MX)

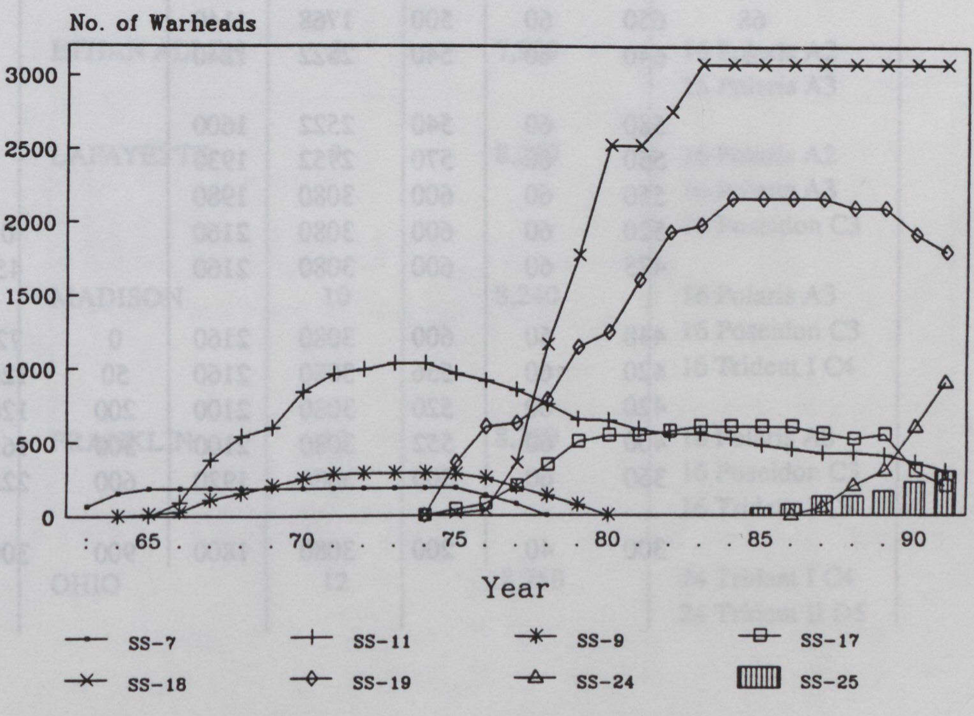

Figure 5. Numbers of Soviet ICBM Warheads

5. NUMBER OF SOVIET ICBM WARHEADS

YEAR	SS-7	SS-8	SS-9	SS-11	SS-13	SS-17	SS-18	SS-19	SS-24	SS-25	TOTAL
1960	0										0
1961	6										6
1962	26	0									26
1963	64	12									76
1964	153	23	0								176
1965	186	23	12	0							221
1966	186	23	30	90							329
1967	186	23	108	380							647
1968	186	23	156	540	0						905
1969	186	23	204	600	40						1053
1970	186	23	252	840	60						1361
1971	186	23	282	960	60						1511
1972	186	23	288	990	60						1547
1973	186	23	288	1030	60						1587
1974	186	23	288	1030	60	0	0	0			1587
1975	186	23	278	960	60	40	10	360			1917
1976	138	23	252	910	60	80	36	600			2099
1977	78	9	190	850	60	200	356	620			2363
1978	0	0	132	750	60	340	1156	700			3138
1979			68	650	60	500	1768	1140			4186
1980			0	640	60	540	2522	1240			5002
1981				580	60	540	2522	1600			5302
1982				550	60	570	2752	1930			5862
1983				550	60	600	3080	1980			6270
1984				520	60	600	3080	2160		0	6420
1985				475	60	600	3080	2160		45	6420
1986				448	60	600	3080	2160	0	72	6420
1987				420	60	556	3080	2160	50	126	6452
1988				420	60	520	3080	2100	200	126	6506
1989				400	60	552	3080	2100	300	165	6657
1990				360	60	300	3080	1920	600	225	6545
1991				300	40	200	3080	1800	900	300	6620

6. SUBMERGED DISPLACEMENT TONNAGE AND MISSILES OF SSBNs

Soviet SSBNs

IOC YEAR	TYPE	NO. BUILT	SUBMERGED DISPLACEMENT tons	SLBMs	SLBM RANGE km
1959	HOTEL I	7	5,150	3 SS-N-4[1]	560
1963	HOTEL II	1[2]	5,150	3 SS-N-5	1,400
1969	HOTEL III	1[3]	6,500	6 SS-N-8	7,800-9,100
1968	YANKEE I	34	9,300	16 SS-N-6	2,400-3,000
1977	YANKEE II	1[4]	9,300	12 SS-N-17	3,900
1973	DELTA I	18	11,750	12 SS-N-8	
1973	DELTA II	4	11,400	16 SS-N-8	
1977	DELTA III	14	13,250	16 SS-N-18	6,500-8,000
1985	DELTA IV	7	13,550	16 SS-N-23	8,300
1981	TYPHOON	6	25,000	20 SS-N-20	8,300

American SSBNs

1959	WASHINGTON	5	6,700	16 Polaris A1	2,200
1966				16 Polaris A3	4,600
1961	ETHAN ALLEN	5	7,900	16 Polaris A2	2,800
1974				16 Polaris A3	
1963	LAFAYETTE	9	8,260	16 Polaris A2	
1970				16 Polaris A3	
1977				16 Poseidon C3	4,600
1964	MADISON	10	8,240	16 Polaris A3	
1971				16 Poseidon C3	
1980				16 Trident I C4	7,400
1965	FRANKLIN	12	8,250	16 Polaris A3	
1972				16 Poseidon C3	
1979				16 Trident I C4	
1981	OHIO	12	18,750	24 Trident I C4	
1989				24 Trident II D5	12,000

1 Missile had to be launched from surface.
2 7 Hotel Is were converted to Hotel IIs.
3 Converted from Hotel II.
4 Converted from Yankee I.

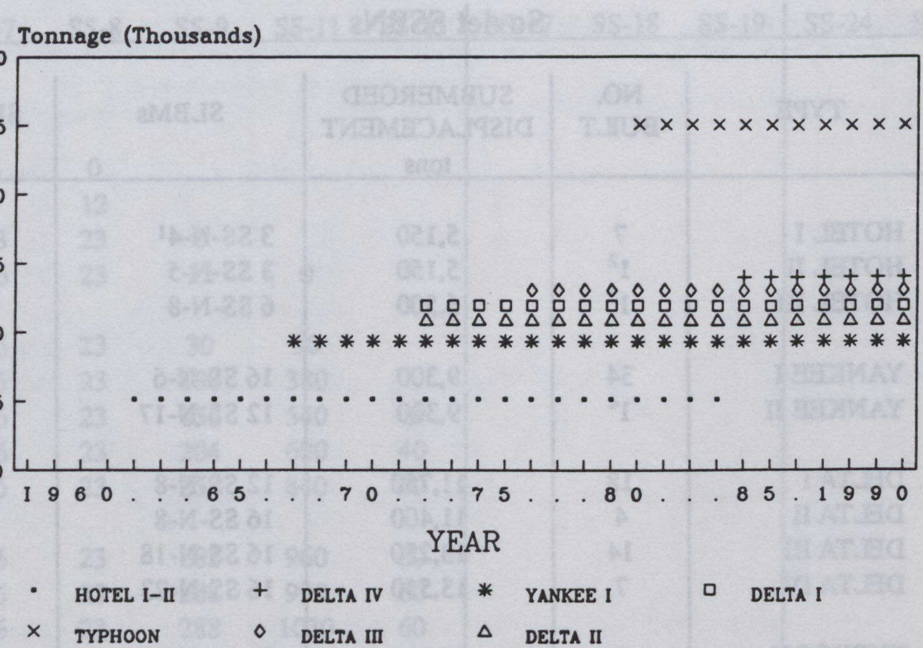

Figure 6A. Soviet SSBNs - Submerged Tonnage

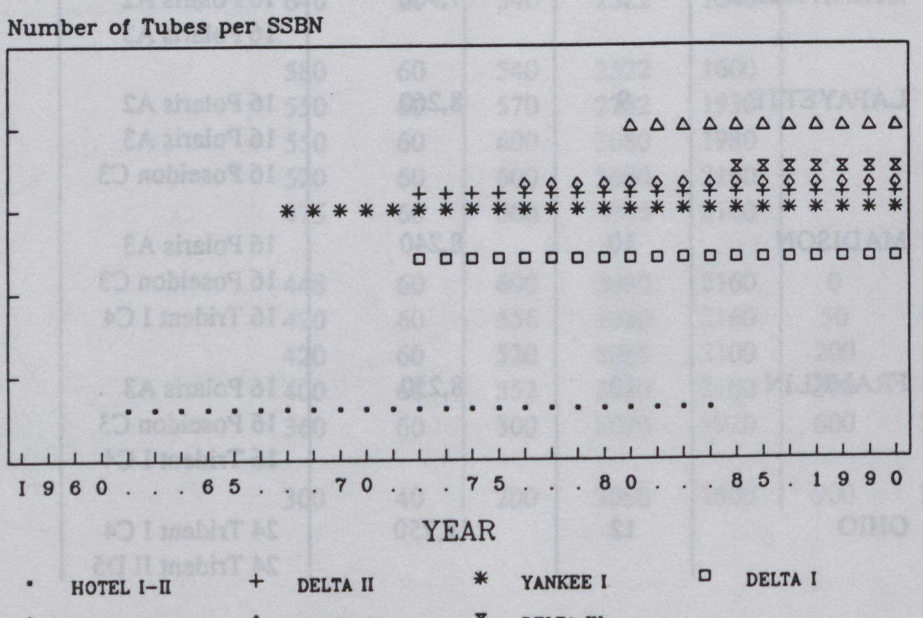

Figure 6B. Soviet SSBNs - Number of Launch Tubes

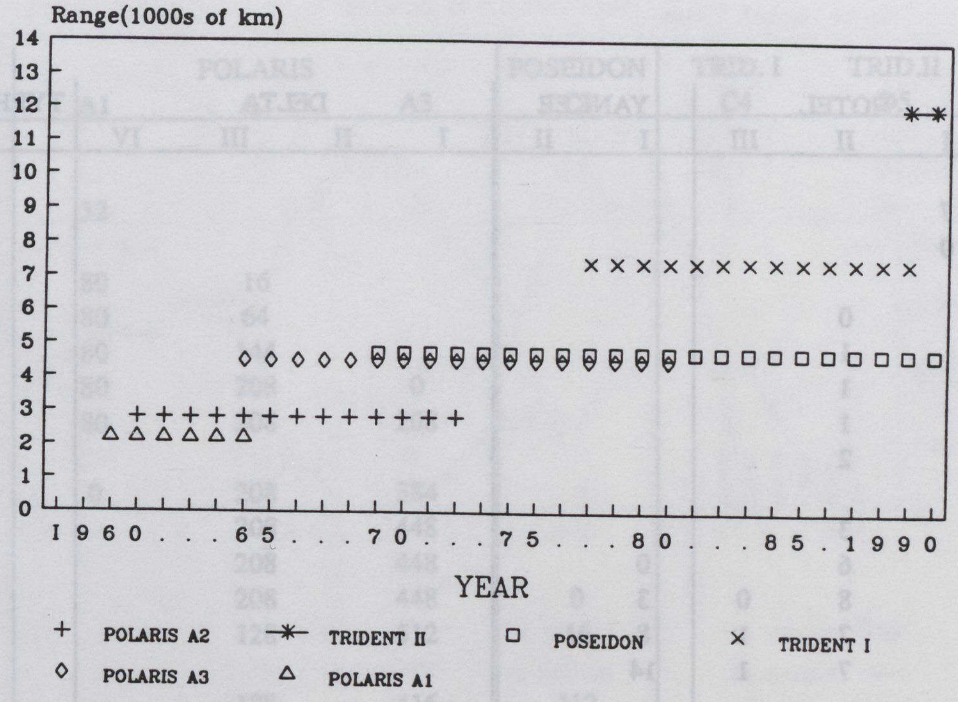

Figure 6C. US SLBM Ranges

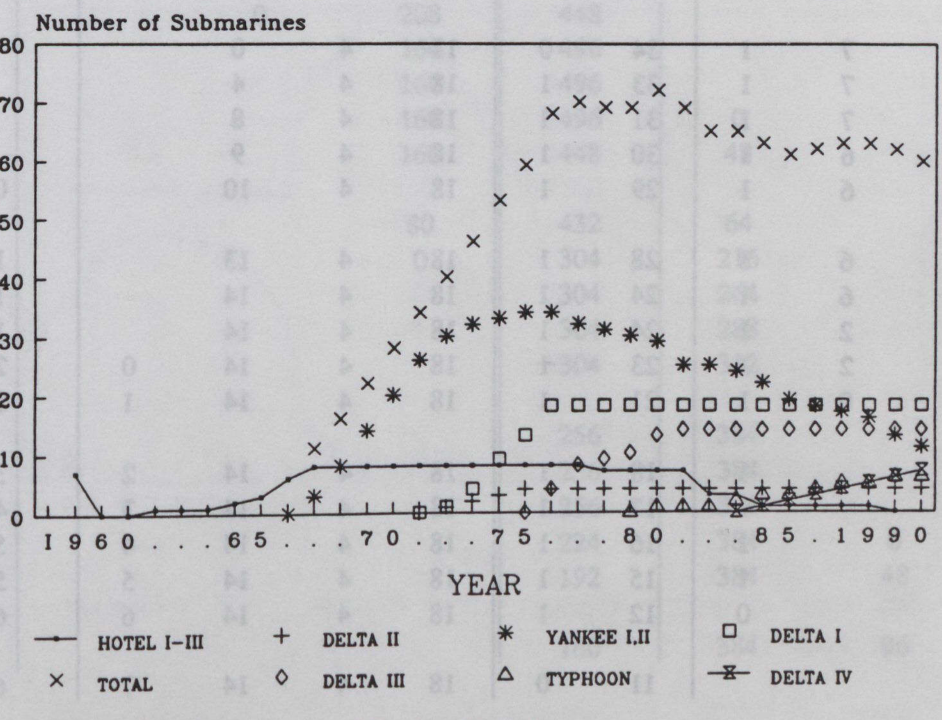

Figure 7. Numbers of Soviet SSBNs

7. NUMBER OF SOVIET SSBNs

YEAR	HOTEL I	HOTEL II	HOTEL III	YANKEE I	YANKEE II	DELTA I	DELTA II	DELTA III	DELTA IV	TYPHOON	TOTAL
1959	7										7
1960	0										0
1961		0									0
1962		1									1
1963		1									1
1964		1									1
1965		2									2
1966		3									3
1967		6		0							6
1968		8	0	3							11
1969		7	1	8							16
1970		7	1	14							22
1971		7	1	20							28
1972		7	1	26		0	0				34
1973		7	1	30		1	1				40
1974		7	1	32		4	2				46
1975		7	1	33		9	3				53
1976		7	1	34	0	13	4	0			59
1977		7	1	33	1	18	4	4			68
1978		7	1	31	1	18	4	8			70
1979		6	1	30	1	18	4	9			69
1980		6	1	29	1	18	4	10		0	69
1981		6	1	28	1	18	4	13		1	72
1982		6	1	24	1	18	4	14		1	69
1983		2	1	24	1	18	4	14		1	65
1984		2	1	23	1	18	4	14	0	2	65
1985		0	1	21	1	18	4	14	1	3	63
1986			1	18	1	18	4	14	2	3	61
1987			1	17	1	18	4	14	3	4	62
1988			1	16	1	18	4	14	4	5	63
1989			1	15	1	18	4	14	5	5	63
1990			0	12	1	18	4	14	6	6	62
1991				11	0	18	4	14	7	6	60

8. NUMBER OF AMERICAN SLBM LAUNCH TUBES

YEAR	POLARIS A1	POLARIS A2	POLARIS A3	POSEIDON C3	TRID. I C4	TRID.II D5	TOTAL
1959							0
1960	32						32
1961	80	16					96
1962	80	64					144
1963	80	144					224
1964	80	208	0				288
1965	80	208	208				496
1966	0	208	384				592
1967		208	448				656
1968		208	448				656
1969		208	448	0			656
1970		128	512	16			656
1971		128	416	112			656
1972		128	336	192			656
1973		128	208	320			656
1974		96	208	352			656
1975		48	208	400			656
1976		0	208	448			656
1977			160	496			656
1978			160	496			656
1979			160	496	0		656
1980			160	448	48		656
1981			80	432	64		576
1982			0	304	216		520
1983				304	264		568
1984				304	288		592
1985				304	312		616
1986				256	384		640
1987				256	384		640
1988				256	384		640
1989				224	384	0	608
1990				192	384	48	624
1991				160	384	96	640

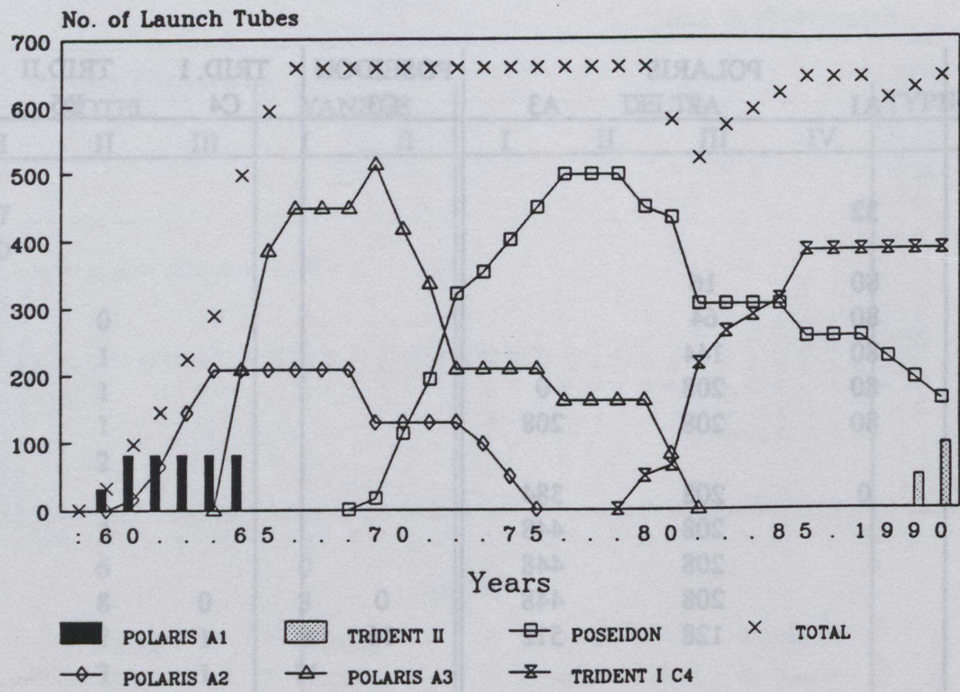

Figure 8. Numbers of US SLBM Launch Tubes

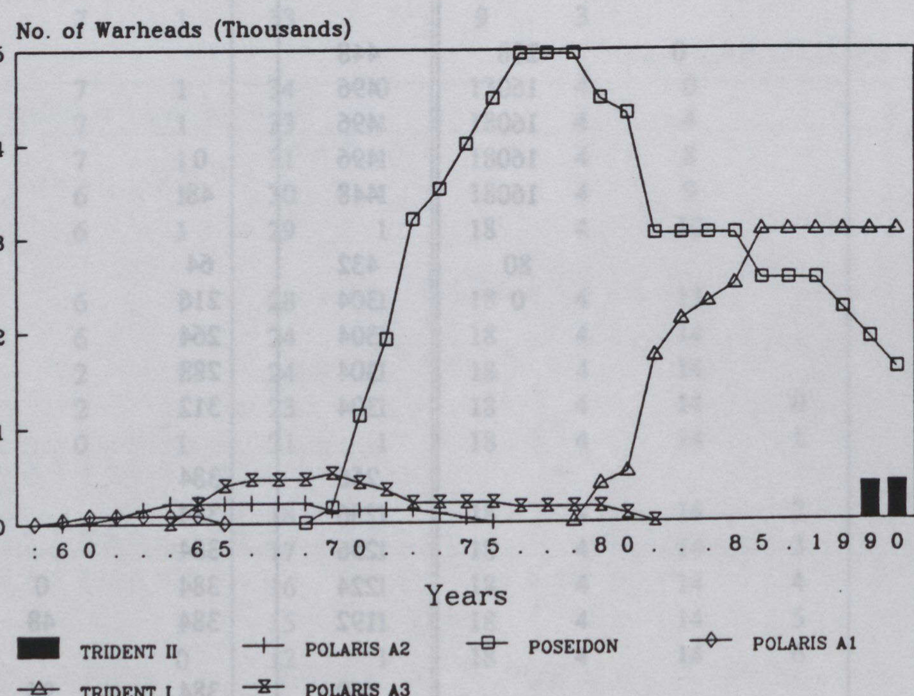

Figure 9. Numbers of US SLBM Warheads

9. NUMBER OF AMERICAN INDEPENDENTLY-TARGETED SLBM WARHEADS

RVs:	POLARIS			POSEIDON	TRID. I	TRID.II	TOTAL
YEAR	A1	A2	A3	C3	C4	D5	
	1	1	1	(10)	8	(8)	
1959	0						0
1960	32	0					32
1961	80	16					96
1962	80	64					144
1963	80	144					224
1964	80	208	0				288
1965	80	208	208				496
1966	0	208	384				592
1967		208	448				656
1968		208	448				656
1969		208	448	0			656
1970		128	512	160			800
1971		128	416	1120			1664
1972		128	336	1920			2384
1973		128	208	3200			3536
1974		96	208	3520			3824
1975		48	208	4000			4256
1976		0	208	4480			4688
1977			160	4960			5120
1978			160	4960			5120
1979			160	4960	0		5120
1980			160	4480	384		5024
1981			80	4320	512		4912
1982			0	3040	1728		4768
1983				3040	2112		5152
1984				3040	2304		5344
1985				3040	2496		5536
1986				2560	3072		5632
1987				2560	3072		5632
1988				2560	3072		5632
1989				2240	3072	0	5312
1990				1920	3072	384	5376
1991				1600	3072	(768)	(5440)

10. NUMBER OF SOVIET SLBM LAUNCH TUBES

YEAR	SS-N-4	SS-N-5	SS-N-6	SS-N-8	SS-N-17	SS-N-18	SS-N-20	SS-N-23	TOTAL
1958	6								6
1959	33								33
1960	30								30
1961	57	0							57
1962	66	6							72
1963	66	6							72
1964	66	6							72
1965	66	9							75
1966	66	12							78
1967	54	33	0						87
1968	48	42	48						138
1969	45	42	128						215
1970	42	45	224						311
1971	21	60	320						401
1972	21	60	416	0					497
1973	21	60	480	34					595
1974	21	60	512	86					679
1975	21	60	528	162					771
1976	15	60	548	226	0	0			849
1977	12	60	532	286	12	64			966
1978	9	60	500	292	12	128			1001
1979	3	57	484	292	12	144			992
1980	0	57	468	292	12	160	0		989
1981		57	448	292	12	208	20		1037
1982		57	384	292	12	224	20		989
1983		45	384	292	12	224	20		977
1984		45	368	292	12	224	40	0	981
1985		39	336	292	12	224	60	16	979
1986		39	288	292	12	224	60	32	947
1987		39	272	286	12	224	80	48	961
1988		36	256	286	12	224	100	64	978
1989		18	240	286	12	224	100	80	960
1990		6	192	286	12	224	120	96	936
1991		0	176	280	0	224	120	112	912

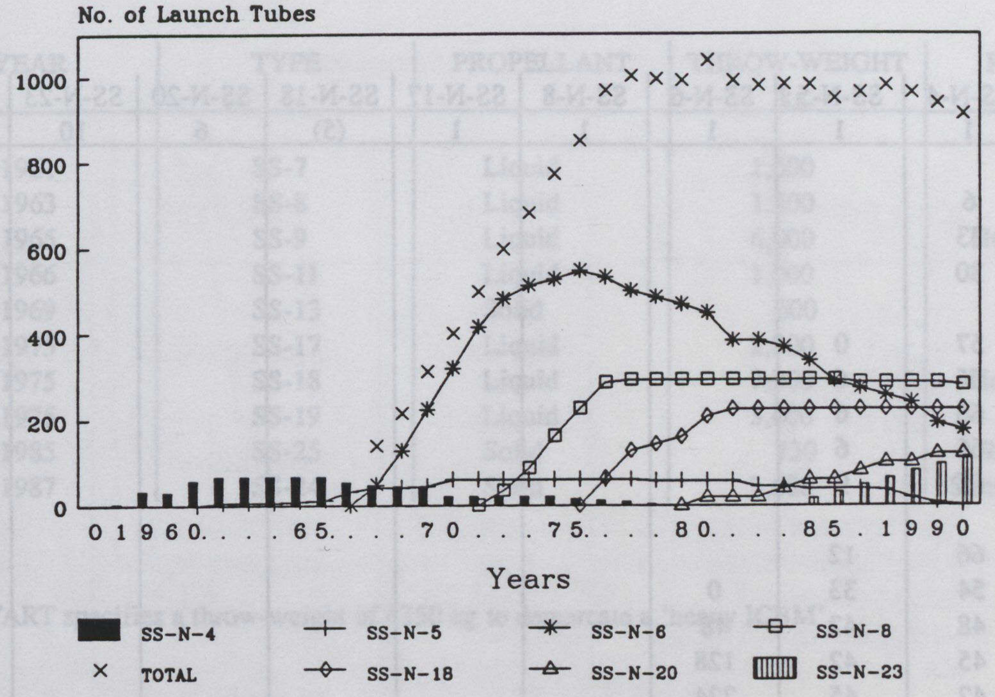

Figure 10. Numbers of Soviet SLBM Launch Tubes

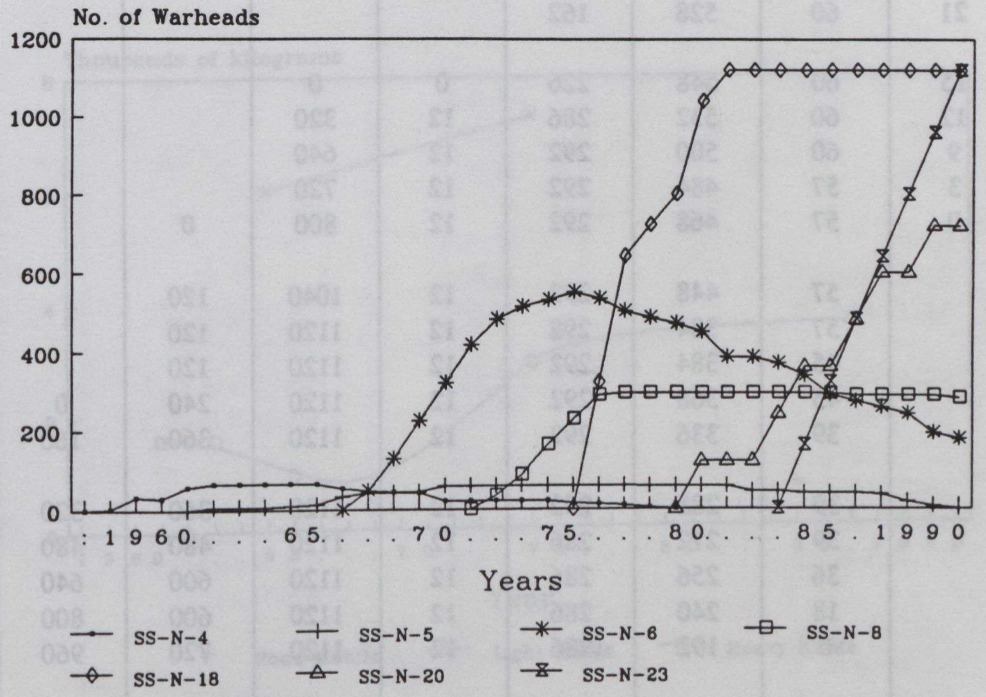

Figure 11. Numbers of Soviet SLBM Warheads

11. NUMBER OF SOVIET INDEPENDENTLY-TARGETED SLBM WARHEADS

RVs*: YEAR	SS-N-4 1	SS-N-5 1	SS-N-6 1	SS-N-8 1	SS-N-17 1	SS-N-18 (5)	SS-N-20 6	SS-N-23 10	TOTAL
1958	6								6
1959	33								33
1960	30								30
1961	57	0							57
1962	66	6							72
1963	66	6							72
1964	66	6							72
1965	66	9							75
1966	66	12							78
1967	54	33	0						87
1968	48	42	48						138
1969	45	42	128						215
1970	42	45	224						311
1971	21	60	320						401
1972	21	60	416	0					497
1973	21	60	480	34					595
1974	21	60	512	86					679
1975	21	60	528	162					771
1976	15	60	548	226	0	0			849
1977	12	60	532	286	12	320			1222
1978	9	60	500	292	12	640			1513
1979	3	57	484	292	12	720			1568
1980	0	57	468	292	12	800	0		1629
1981		57	448	292	12	1040	120		1969
1982		57	384	292	12	1120	120		1985
1983		45	384	292	12	1120	120		1973
1984		45	368	292	12	1120	240	0	2077
1985		39	336	292	12	1120	360	160	2319
1986		39	288	292	12	1120	360	320	2431
1987		39	272	286	12	1120	480	480	2689
1988		36	256	286	12	1120	600	640	2950
1989		18	240	286	12	1120	600	800	3076
1990		6	192	286	12	1120	720	960	3296
1991		0	176	280	0	1120	720	1120	3416

* Actual number of MRVs and MIRVs vary with different models.

12. SOVIET ICBM THROW-WEIGHT

YEAR	TYPE	PROPELLANT	THROW-WEIGHT kg.	REMARKS
1961	SS-7	Liquid	1,600	
1963	SS-8	Liquid	1,600	
1965	SS-9	Liquid	6,000	Heavy ICBM*
1966	SS-11	Liquid	1,000	
1969	SS-13	Solid	600	
1975	SS-17	Liquid	2,900	
1975	SS-18	Liquid	7,300	Heavy ICBM*
1975	SS-19	Liquid	3,400	
1985	SS-25	Solid	730	Road Mobile
1987	SS-24	Solid	3,600	Some Rail Mobile

* START specifies a throw-weight of 4350 kg to demarcate a 'heavy ICBM'.

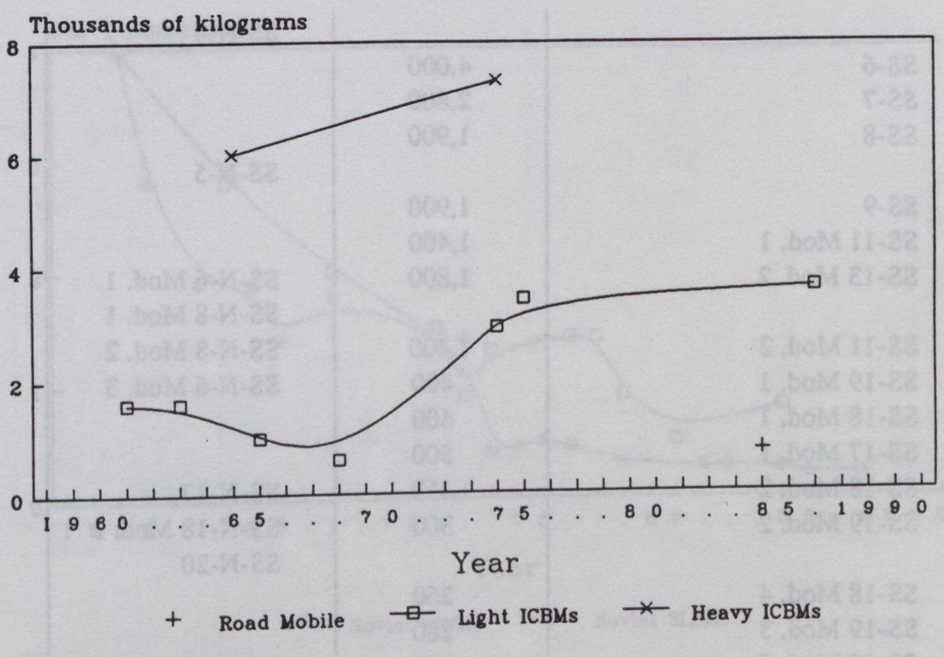

Figure 12. Missile Throw-Weight - Soviet ICBMs

13. THE ACCURACY OF STRATEGIC BALLISTIC MISSILES

American Ballistic Missiles

YEAR	ICBM TYPE	C.E.P. metres	SLBM TYPE	C.E.P. metres
1959	ATLAS	4,000		
1961	TITAN I	3,500	POLARIS A2	3,500
1962	MINUTEMAN I	900		
1963	TITAN II	1,300		
1965			POLARIS A3	900
1966	MINUTEMAN II	550		
1970	MINUTEMAN III (Mk12)	370	POSEIDON C3	450
1980	MINUTEMAN III (Mk12A)	220	TRIDENT I C4	450
1982	MINUTEMAN II	370		
1985	MINUTEMAN III (Mk12)	280		
1986	MX	100		
1989			TRIDENT II C5	120

Soviet Ballistic Missiles

1960			SS-N-4	4,000
1961	SS-6	4,000		
1961	SS-7	2,800		
1963	SS-8	1,900		
1964			SS-N-5	2,800
1965	SS-9	1,900		
1966	SS-11 Mod. 1	1,400		
1968	SS-13 Mod. 2	1,800	SS-N-6 Mod. 1	2,000
1972			SS-N-8 Mod. 1	1,500
1973	SS-11 Mod. 2	1,400	SS-N-8 Mod. 2	900
1974	SS-19 Mod. 1	400	SS-N-6 Mod. 3	1,300
1975	SS-18 Mod. 1	400		
1976	SS-17 Mod. 1	500		
1977	SS-18 Mod. 2	450	SS-N-17	1,400
1979	SS-19 Mod. 2	300	SS-N-18 Mod. 2	900
1981			SS-N-20	500
1982	SS-18 Mod. 4	260		
1983	SS-19 Mod. 3	280		
1985	SS-18 Mod. 5	250	SS-N-23	800
1986	SS-25	200		
1988	SS-24	200		

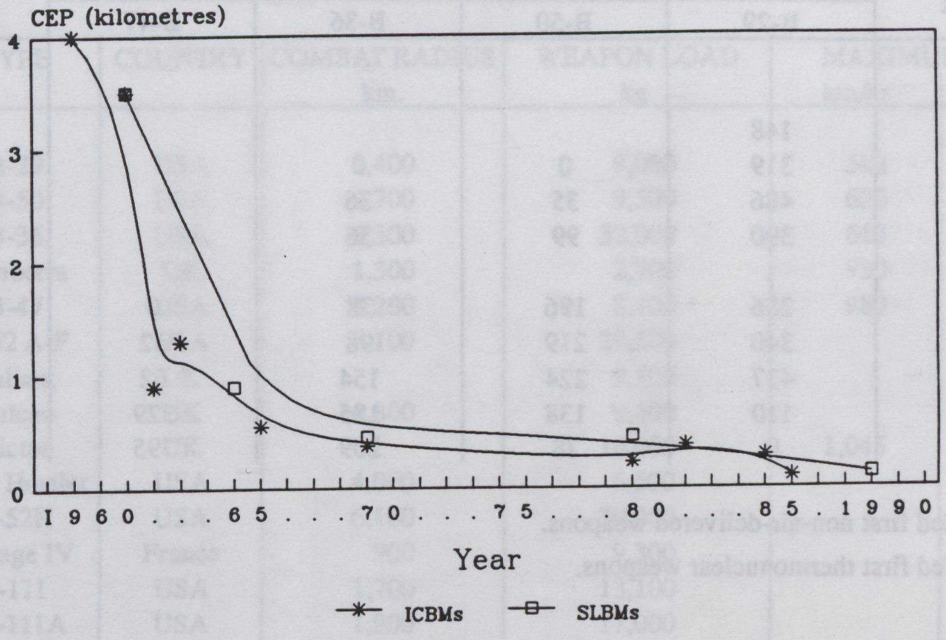

Figure 13A. Ballistic Missile Accuracies - American ICBMs and SLBMs

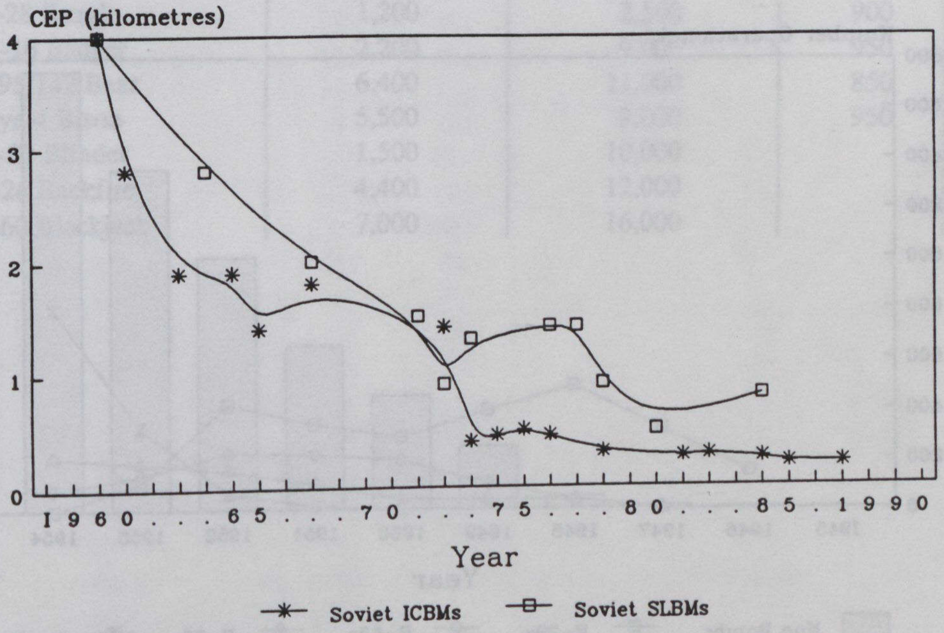

Figure 13B. Ballistic Missile Accuracies - Soviet ICBMs and SLBMs

14. EARLY AMERICAN NUCLEAR CAPABILITY

YEAR	NUMBER of BOMBERS in SAC				TOTAL NUCLEAR STOCKPILE
	B-29	B-50	B-36	B-47	
1945					2
1946	148				9
1947	319	0	0		13
1948	486	35	36		50
1949	390	99	36		250
1950	286	196	38	0	450
1951	340	219	98	12	650
1952	417	224	154	62	1000[1]
1953	110	138	185	329	1350
1954	0	78	209	795	1750[2]

[1] Included first non-air-delivered weapons.

[2] Included first thermonuclear weapons.

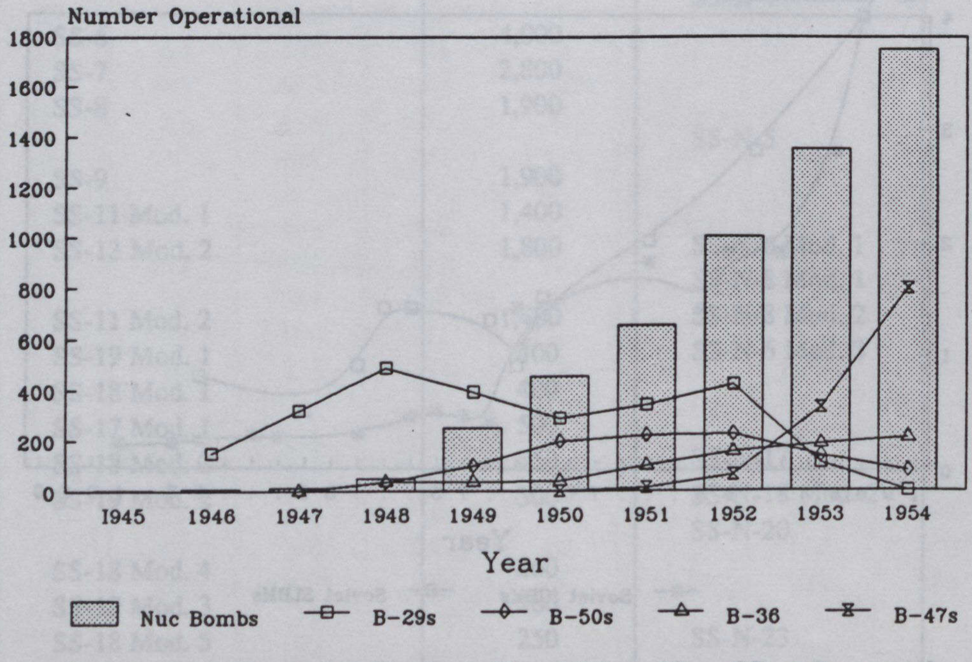

Figure 14. Early US Nuclear Capability - No. of Bombers and Nuclear Weapons

15. BOMBER AIRCRAFT

Western Aircraft

YEAR	TYPE	COUNTRY	COMBAT RADIUS km.	WEAPON LOAD kg.	MAXIMUM SPEED km/hr	Mach
1944	B-29	USA	2,400	9,080	588	
1947	B-50	USA	3,700	9,500	620	
1947	B-36	USA	6,300	32,000	662	
1950	Canberra	UK	1,300	2,700	930	
1952	B-47	USA	3,200	8,100	980	
1955	B-52 A-F	USA	6,100	29,500		0.95
1955	Valiant	UK		9,500		0.84
1957	Vulcan	UK	4,800	9,500		0.97
1958	Victor	UK		16,000	1,045	
1960	B-58 Hustler	USA	4,000	5,500		2.0
1961	B-52H	USA	6,100	30,000		0.95
1964	Mirage IV	France	900	9,300		2.2
1967	F-111	USA	1,700	13,100		2.5
1969	FB-111A	USA	1,900	17,000		2.2
1986	B-1B	USA	4,600	61,000		1.25

Soviet Aircraft

1948	Tu-4 Bull	2,600	6,800	600	
1950	Il-28 Beagle	1,200	2,500	900	
1955	Tu-16 Badger	2,200	9,000	950	
1956	Tu-95/142 Bear	6,400	11,000	850	
1956	Mya-4 Bison	5,500	9,000	950	
1963	Tu-22 Blinder	1,500	10,000		1.4
1975	Tu-26 Backfire	4,400	12,000		1.92
1988	Tu-160 Blackjack	7,000	16,000		2.0

16. NUMBER OF AMERICAN STRATEGIC BOMBER AIRCRAFT

YEAR	B-29	B-50	B-36	B-47	B-52		B-58	FB-111A	B-1B	TOTAL
					C/D/E/F	G/H				
1946	148									148
1947	319	0	0							319
1948	486	35	36							557
1949	390	99	36							525
1950	286	196	38	0						520
1951	340	219	98	12						669
1952	417	224	154	62						857
1953	110	138	185	329						762
1954	0	78	209	795	0					1082
1955		0	205	1086	18					1309
1956			210	1306	97					1613
1957			120	1285	243					1648
1958			22	1367	380	0				1769
1959			0	1366	400	50	0			1816
1960				1178	350	103	12			1643
1961				889	347	224	35			1495
1962				880	347	283	76			1586
1963				613	347	283	80			1323
1964				391	347	283	80			1011
1965				114	317	283	80			794
1966				0	308	283	80			671
1967					305	283	25			613
1968					281	281	40	0		602
1969					223	281	40	3		547
1970					178	281	0	35		494
1971					131	281		60		472
1972					121	281		60		462
1973					141	281		71		493
1974					148	274		72		494
1975					150	270		66		486
1976					154	265		66		485
1977					83	265		66		414
1978					75	241		66		382
1979					75	241		65		381
1980					75	241		63		379
1981					75	241		60		376
1982					75	213		60		348
1983					31	180		56		267
1984					0	174		56		230
1985						180		56	0	236
1986						211		55	19	285
1987						233		56	54	343
1988						233		56	74	363
1989						173		48	90	311
1990						154		24	90	268
1991						172		0	97	269

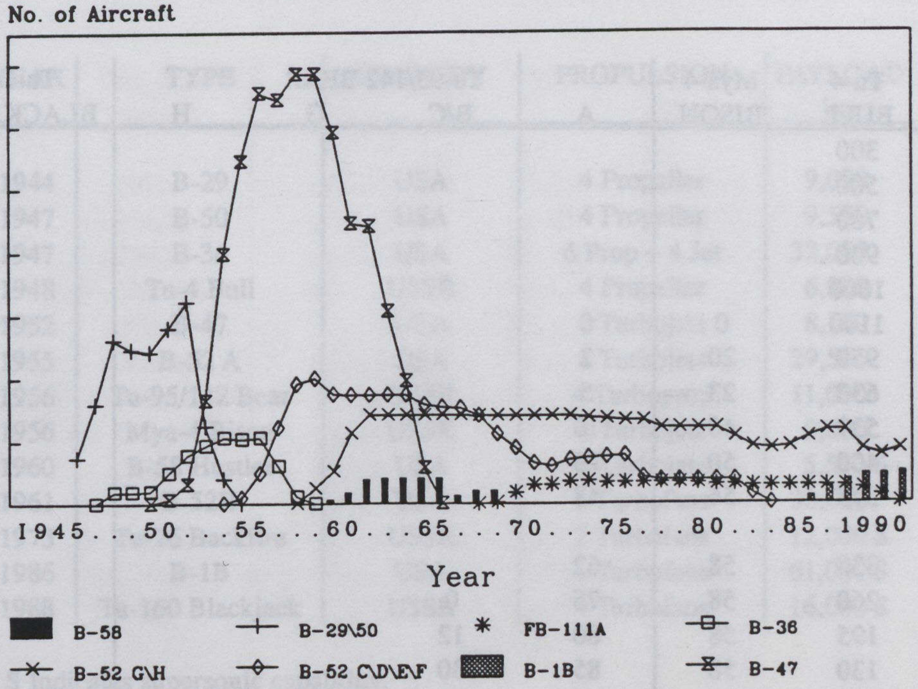

Figure 16. Numbers of US Strategic Bombers

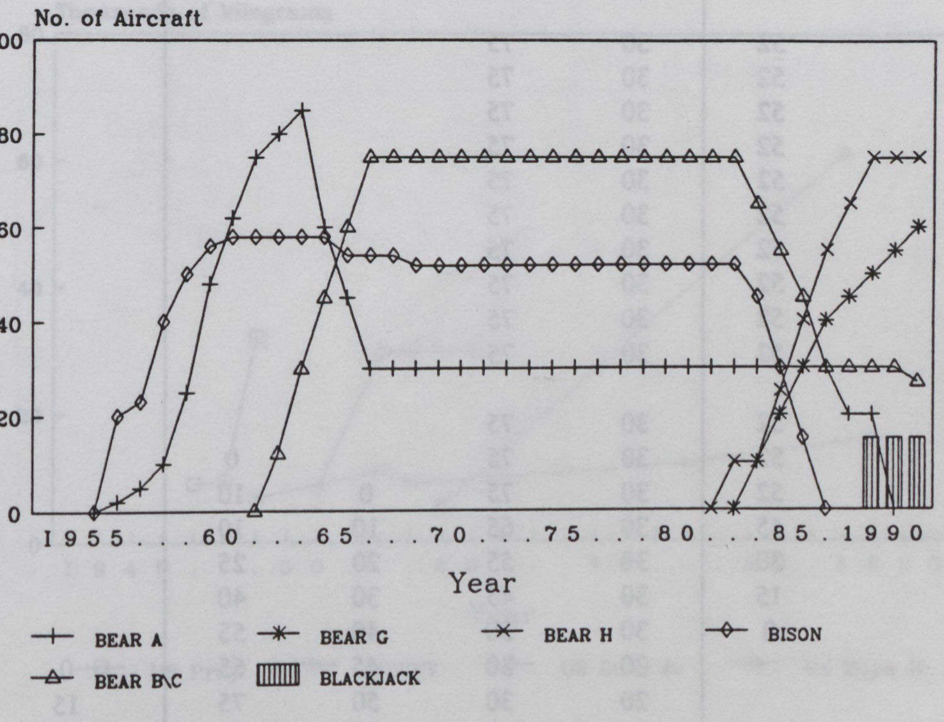

Figure 17. Numbers of Soviet Strategic Bombers

17. NUMBERS OF SOVIET LONG-RANGE BOMBER AIRCRAFT

YEAR	Tu-4 BULL	Mya-4 BISON	Tu-95/142 BEAR				Tu-160 BLACKJACK	TOTAL
			A	B/C	G	H		
1950	300							300
1951	500							500
1952	700							700
1953	900							900
1954	1000							1000
1955	1100	0	0					1100
1956	950	20	2					972
1957	630	23	5					658
1958	539	40	10					580
1959	400	50	25					475
1960	375	56	48					479
1961	330	58	62					450
1962	260	58	75	0				393
1963	195	58	80	12				345
1964	130	58	85	30				303
1965	50	58	60	45				213
1966	0	54	45	60				159
1967		54	30	75				159
1968		54	30	75				159
1969		52	30	75				157
1970		52	30	75				157
1971		52	30	75				157
1972		52	30	75				157
1973		52	30	75				157
1974		52	30	75				157
1975		52	30	75				157
1976		52	30	75				157
1977		52	30	75				157
1978		52	30	75				157
1979		52	30	75				157
1980		52	30	75				157
1981		52	30	75				157
1982		52	30	75		0		157
1983		52	30	75	0	10		167
1984		45	30	65	10	10		160
1985		30	30	55	20	25		160
1986		15	30	45	30	40		160
1987		0	30	30	40	55		155
1988			20	30	45	65	0	160
1989			20	30	50	75	15	190
1990			0	30	55	75	15	175
1991				27	60	75	15	177

18. HEAVY BOMBER PAYLOADS

YEAR	TYPE	COUNTRY	PROPULSION	PAYLOAD kg.
1944	B-29	USA	4 Propeller	9,080
1947	B-50	USA	4 Propeller	9,500
1947	B-36	USA	6 Prop + 4 Jet	32,000
1948	Tu-4 Bull	USSR	4 Propeller	6,800
1952	B-47	USA	6 Turbojets	8,100
1955	B-52 A	USA	8 Turbojets	29,500
1956	Tu-95/142 Bear	USSR	4 Turboprop	11,000
1956	Mya-4 Bison	USSR	4 Turbojets	9,000
1960	B-58 Hustler	USA	4 Turbojets	5,500 S
1961	B-52H	USA	8 Turbofans	30,000
1975	Tu-26 Backfire	USSR	2 Turbofans	12,000 S
1986	B-1B	USA	4 Turbofans	61,000 S
1988	Tu-160 Blackjack	USSR	4 Turbofans	16,000 S

S Indicates supersonic capability.

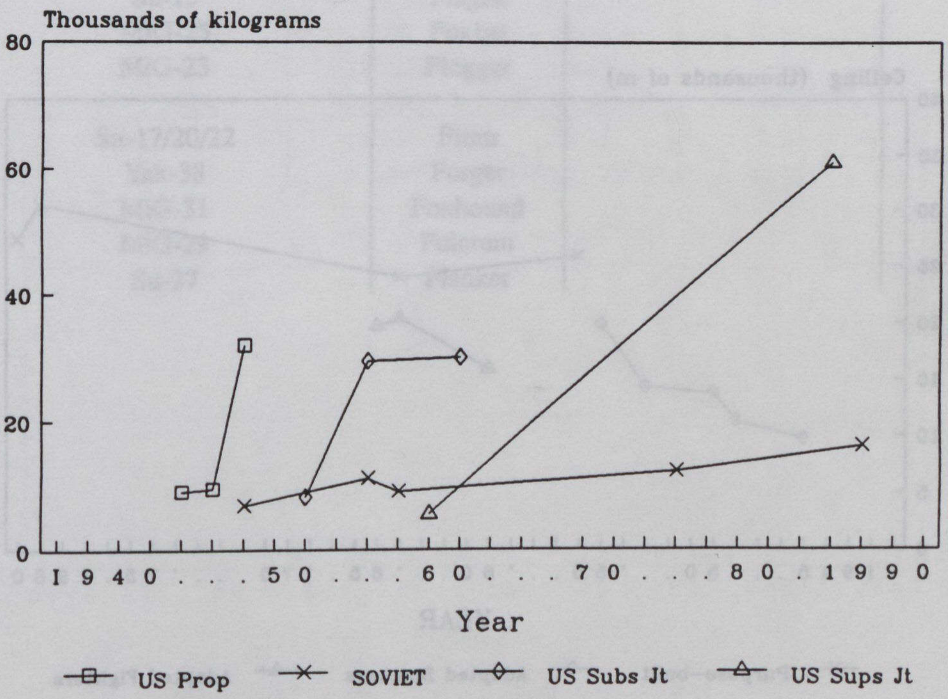

Figure 18. Heavy Bomber Payload

19. CEILINGS OF AMERICAN RECONNAISSANCE AIRCRAFT

YEAR	TYPE	ORIGIN	CEILING (metres)
1946	RB-29	Bomber	9,700
1949	RB-50	Bomber	11,300
1950	RB-36	Bomber	13,800
1953	RB-47	Bomber	14,300
1955	RB-57	Bomber	19,800
1956	U-2	Recce	25,900
1960	RF-101	Fighter	15,800
1964	RA-5C	Attack	20,400
1964	SR-71	Recce	24,000
1965	RF-4C	Fighter	19,900
1980	SR-71	Recce	30,500
1981	TR-1	Recce	27,400

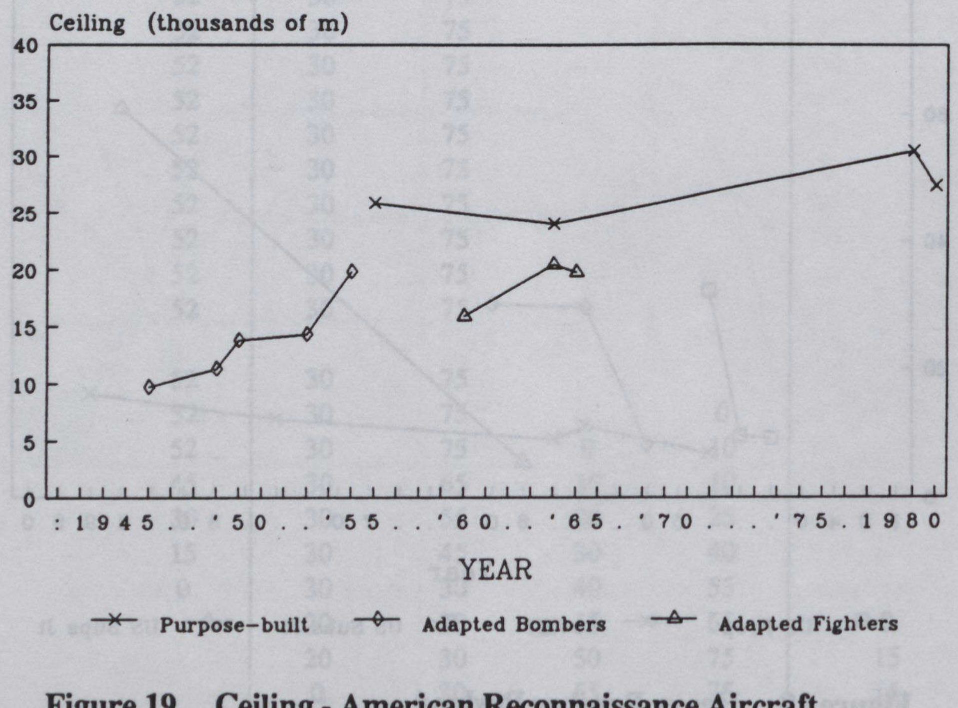

Figure 19. Ceiling - American Reconnaissance Aircraft

20. MAXIMUM SPEED OF SOVIET FIGHTER AIRCRAFT

YEAR	TYPE		PROPELLER-DRIVEN (Mach)	JET-PROPELLED Mach
1931	I-5		0.23	
1934	I-15, I-16		0.33	
1939	I-153		0.36	
1940	Yak-1, MiG 3		0.50	
1941	LaG		0.47	
1942	La-50, Yak-7B, Yak-9		0.51	
1944	Yak-3, La-7		0.59	
1948	MiG-15	Fagot		0.92
1953	MiG-17	Fresco		1.04
1955	MiG-19	Farmer		1.3
1956	Yak-25	Flashlight		0.90
1958	MiG-21	Fishbed		2.1
1961	Su-9	Fishpot		1.8
1964	Yak-28P	Firebar		1.13
1966	Su-11	Fishpot C.		1.75
1966	Tu-28P	Fiddler		1.75
1969	Su-15	Flagon		2.2
1970	MiG-25	Foxbat		3.2
1971	MiG-23	Flogger		2.25
1972	Su-17/20/22	Fitter		2.09
1976	Yak-38	Forger		1.1
1983	MiG-31	Foxhound		2.4
1984	MiG-29	Fulcrum		2.28
1985	Su-27	Flanker		2.3

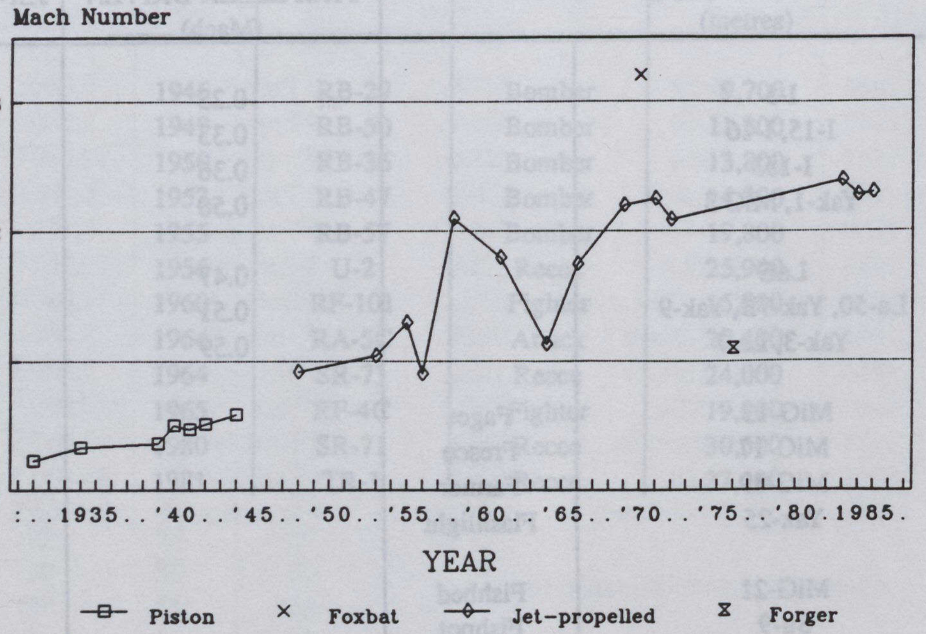

Figure 20. Maximum Speed - Soviet Fighter Aircraft

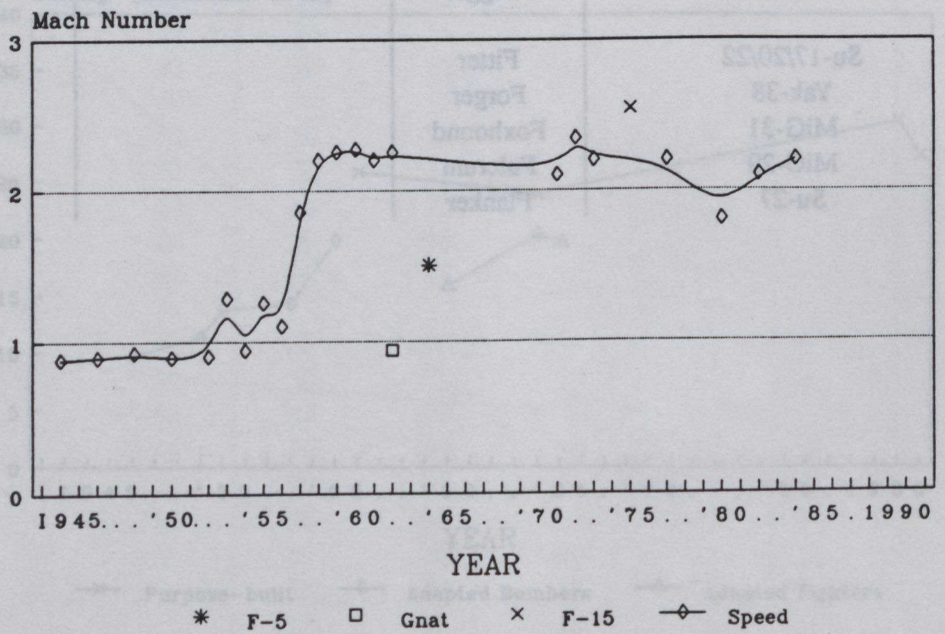

Figure 21. Maximum Speed - Western Jet-Propelled Fighter Aircraft

21. MAXIMUM SPEED OF WESTERN JET-PROPELLED FIGHTER AIRCRAFT

YEAR	COUNTRY	TYPE	MAX. SPEED (Mach)
1944	UK	Meteor	0.88
1946	UK	Vampire	0.89
1948	USA	F-86	0.92
1950	USA	F-84	0.89
1952	Canada	CF-100	0.90
1952	UK	Venom	0.90
1953	USA	F-100	1.28
1954	France	Mystère IVA	0.94
1955	USA	F-102	1.25
1957	USA	F-101	1.85
1957	France	Super Mystère	1.10
1958	USA	F-104	2.20
1959	USA	F-106	2.25
1960	UK	Lightning	2.27
1961	France	Mirage III	2.20
1962	UK	Gnat	0.94
1962	USA	F-4	2.25
1964	USA	F-5	1.50
1971	Sweden	Viggen	2.10
1972	USA	F-14	2.34
1973	France	Mirage F-1	2.20
1975	USA	F-15	2.54
1977	UK/FR/FRG	Tornado	2.00
1980	USA	F-18	1.80
1982	USA	F-16	2.10
1984	France	Mirage 2000	2.20

22. INTERNATIONAL DISTRIBUTION OF CERTAIN AMERICAN FIGHTER AIRCRAFT

COUNTRY	F-4 (RF-4, Phantom)	F-5 (CF-5, NF-5, RF-5, SF-5)	F-16
USA	1961-		1980-
Iran	1968-	1964-	
South Korea	1970-	1965-	1987-
Turkey	1974-	1965-	1989-
Greece	1974-	1965-	1989-
Norway		1966-	1981-
Taiwan		1966-	
Philippines		1966-	
(SO) Vietnam		1967-1974	
United Kingdom	1968-		
Thailand		1968-	1989-
Morocco		1968-	
Spain	1971-	1969-	
Canada		1969-1988	
(W) Germany	1970-		
Netherlands		1970-1990	1983-
Ethiopia		1970-1982	
Libya		1970-1973	
Venezuela		1973-	1985-
Japan	1973-		
Saudi Arabia		1974-	
Israel	1974-		1981-
Jordan		1974-	
Brazil		1976-	
Malaysia		1976-	
Chile		1977-	
Kenya		1977-	
(NO) Yemen		1978-	
Switzerland		1979-	
Singapore		1979-	1989-
Indonesia		1980-	1990-
Denmark			1981-
Egypt	1984-		1983-
Mexico		1984-	
Pakistan			1984-
Tunisia		1985-	
Bahrain		1986-	1991-
Belgium			1987-
Honduras		1988-	
Sudan		1988-	

23. INTERNATIONAL DISTRIBUTION OF CERTAIN EASTERN FIGHTER AIRCRAFT (From 1965 onwards)

COUNTRY	MiG-17	J-5	MiG-21	J-7,F-7
USSR	1965-1978		1965-	
GDR	1965-1985		1965-1991	
Poland	1965-1987		1965-	
Czechoslovakia	1965-1979		1965-	
Romania	1965-		1965-	
Hungary	1965-1977		1965-	
Bulgaria	1965-1990		1965-	
Yugoslavia			1965-	
Indonesia	1965-1974		1965-1974	
Egypt	1965-1989		1965-	1985-
Cuba	1965-1990		1965-	
PR. of China	1965-1979	1979-	1965-1979	1979-
India			1965-	
Cambodia/Kampuchea	1965-1970		1988	
North Korea	1965-1988	1989-	1966-	1989-
(NO) Vietnam	1965-1984		1966-	
Albania	1965-1987		1973-1990	1991
Syria	1967-1990		1967-	
Iraq	1967-1977		1967-	1991
Algeria	1968-		1968-	
Finland			1968-	
Somali Rep.	1970-		1974-	
Uganda	1970-		1975-	
Nigeria	1970-1981		1976-	
Sudan	1972-1980	1981-	1970-	
Guinea	1970-		1977-	
Morocco	1970			
Afghanistan	1971-1989		1971-	
Mali	1972-		1986-	
(SO) Yemen	1973-1990		1974-	
(NO) Yemen	1973-		1977-	1990
Bangladesh			1973-	1990
Tanzania		1975-1982		1977-
Angola	1976-		1976-	
Mozambique	1976-1989		1976-	
Ehtiopia	1979-1989		1976-	
Congo	1977-		1991	
Laos			1978-	
Madagascar/Malagasy	1981-		1979-	
Mongolia			1979-	
Libya			1980-	
Zambia			1981-	
Equatorial Guinea	1982-1986			
Burkina-Faso	1987		1988-	
Zimbabwe		1988-1990		1986-
Guinea Bissau	1989-			
Pakistan		1989-1990		1989-
Myanmar				1991

24A. MAIN BATTLE TANKS TO END OF WORLD WAR II

YEAR	COUNTRY	TYPE	CALIBRE (mm)	VEHICLE WEIGHT (metric tons)
1916	Britain	Mk I	2 x 57	28
1916	France	Schneider	75	14
1917	France	St. Chamond	75	25
1917	Britain	Mk IV	2 x 57	28
1918	Britain	Mk V	2 x 57	29
1918	Germany	A7V	57	32
1922	Britain	Vickers Medium II	47	13
1923	France	Char C	75	70*
1933	USSR	T-28	76	28
1933	USSR	T-35	76	50
1935	France	Somua S35	47	20
1936	France	Char B	75	32
1936	Germany	PzKpfw IIIA	37	15
1938	Britain	Cruiser MkI A9	40	13
1939	Germany	PzKpfw IVD	75	18
1939	Germany	PzKpfw IIIE	50	20
1939	Britain	Matilda I-Tank	40	27
1939	Britain	Crusader Cruiser	40	20
1939	Britain	Cruiser MkIV A13	40	15
1939	Italy	M13/40	47	14
1940	Britain	Valentine Mk I	40	16
1940	Britain	Churchill IV	57	39
1940	USSR	KV-1	76	44
1940	USSR	T-34/76	76	26
1941	Germany	PzKpfw VI Tiger	88	55
1942	Britain	Valentine Mk VIII	57	17
1942	Germany	PzKpfw IIIM	75	22
1942	Germany	PzKpfw V Panther	75	45
1943	USA	M-4 Sherman	75	32
1943	Britain	Churchill VI, VII	75	40
1943	Britain	Cromwell Cruiser	75	28
1944	USSR	JS-2 Josef Stalin	122	46
1944	Britain	Comet Cruiser	77	36
1944	Germany	PzKpfw IVJ	75	25
1944	USSR	T-34/85	84	32
1944	Germany	PzKpfw VI Tiger II	88	69
1944	Germany	Maus	128	188*
1945	USA	M26 Pershing	90	42

* Unsuccessful outsized tanks.

24B. MAIN BATTLE TANKS POST WORLD WAR II

YEAR	COUNTRY	TYPE	CALIBRE (mm)	VEHICLE WEIGHT (metric tons)
1945	USSR	JS-3 Josef Stalin	122	46
1946	Britain	Centurion I	76	43
1947	USA	M46	90	46
1948	Britain	Centurion 3	84	49
1950	USSR	T-54/55	100	36
1952	Britain	Centurion Mk13	105	52
1952	USA	M-46	90	50
1952	USA	M-47	90	46
1953	USA	M-48	90	47
1956	Britain	Conqueror	120	66
1957	USSR	T-10	122	50
1958	USA	M-103	120	57
1960	USA	M-60	105	49
1963	USSR	T-62	115 SB	37
1965	Germany	Leopard I	105	40
1965	Britain/India	Vickers Mks 1,2,3/Vijayanta	105	39
1966	Britain	Chieftain	120	56
1967	France	AMX-30	105	36
1968	PR China	Type 59/69	100	36
1974	USA	M-60 A2	152[1]	51
1974	USSR	T-64	125 SB	40
1976	USSR	T-72	125 SB	41
1978	Israel	Merkava	105	58
1979	Germany	Leopard II	120 SB	55
1980	USA	M-1 Abrams	105	55
1982	USSR	T-80	125 SB	42
1984	USA	M-60 A3	105	58
1985	Britain	Challenger	120	62
1985	USA	M-1 A1 Abrams	120 SB	63

SB Indicates smooth-bore gun.

[1] Combined launcher for gun and Shillelagh anti-tank missile.

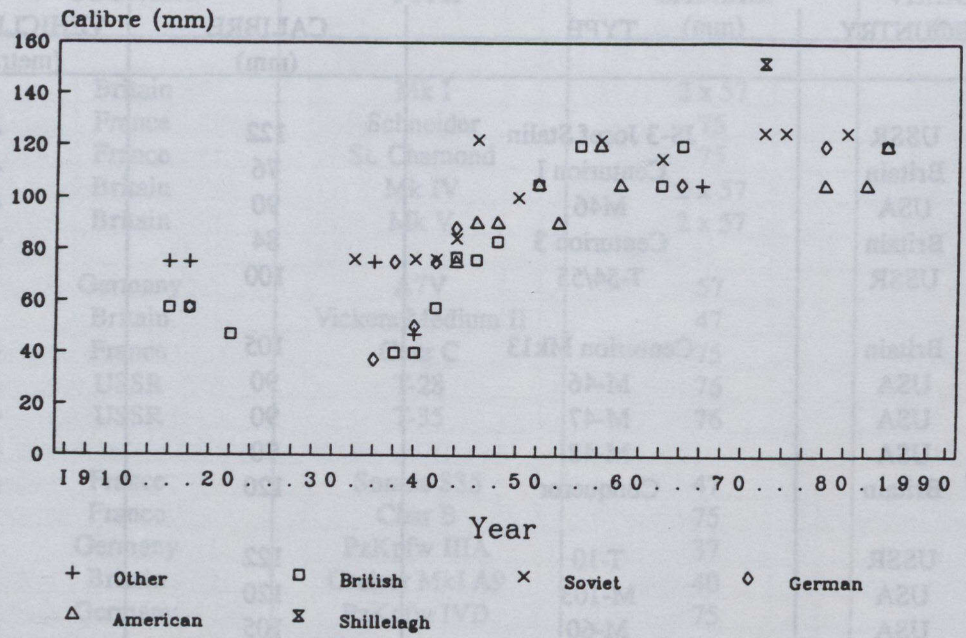

Figure 24A. Main Battle Tanks - Calibre of Main Gun

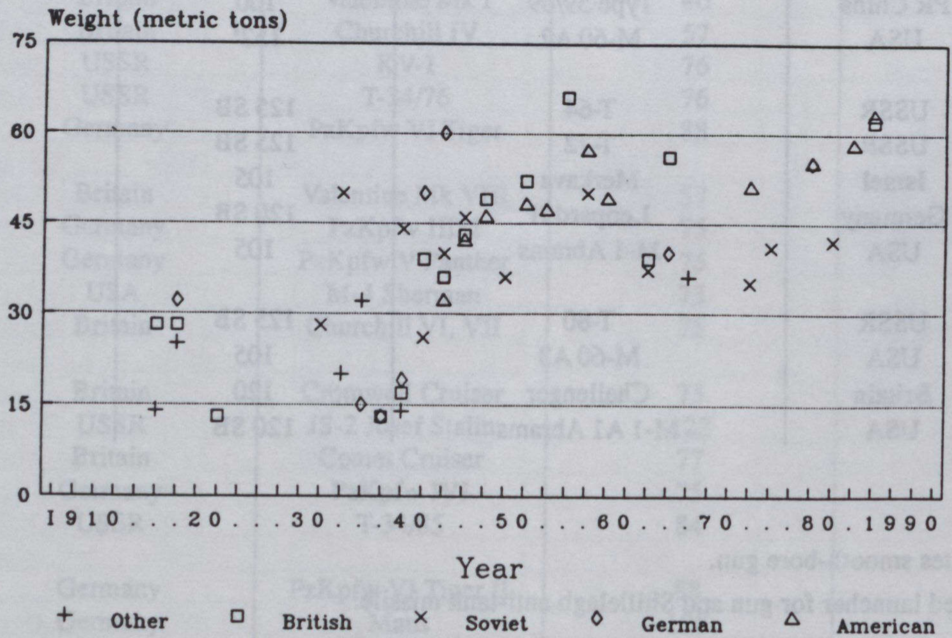

Figure 24B. Main Battle Tanks - Weight of Vehicle

25. INTERNATIONAL DISTRIBUTION OF TANKS

ORIGIN YEAR	COUNTRY	TYPE	NUMBER OF COUNTRIES OPERATING 1970	1980	1990
1941	USSR	T-34	16	23	16
1945	USSR	JS-3	7	1	0
1950	USSR	T-54/55	21	35	45
1957	USSR	T-10	8	1	0
1963	USSR	T-62	1	11	18
1968	PRC	Type 59/69*	2	7	12
1976	USSR	T-72		10	16
1943	USA	M-4	13	9	4
1952	USA	M-47	11	14	9
1953	USA	M-48	11	15	16
1960	USA	M-60	3	9	14
1946	UK	Centurion	14	9	9
1960	UK	Chieftain	1	3	6
1965	FRG	Leopard I	2	7	10
1979	FRG	Leopard II		1	3
1967	France	AMX-30	1	6	9

* Chinese-built version of Soviet T-54.

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Table 8 - American SLBM Launch Tubes

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Table 9 - Number of American Independently-Targeted SLBM Warheads

Sources as for Table 8.

Table 10 - Number of Soviet SLBM Launch Tubes

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Table 11 - Number of Soviet Independently-Targeted SLBM Warheads

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Table 17 - Numbers of Soviet Long-Range Bomber Aircraft

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Table 22 - International Distribution of Certain American Fighter Aircraft

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APPENDIX 2

EXTRACTS FROM A PROTOCOL TO THE TREATY ON CONVENTIONAL ARMED FORCES IN EUROPE (Paris, 19 November 1990)

PROTOCOL ON EXISTING TYPES OF CONVENTIONAL ARMAMENTS AND EQUIPMENT

I. Existing Types of Conventional Armaments and Equipment Limited by the Treaty

1. Existing types of battle tanks (21 types listed)

2. Existing types of armoured combat vehicles
   (A) Armoured Personnel Carriers (45 types listed)
   (B) Armoured Infantry Fighting Vehicles (14 types listed)
   (C) Heavy Armament Combat Vehicles (14 types listed)

3. Existing types of artillery
   (A) Guns, Howitzers and Artillery Pieces Combining the Characteristics of Guns and Howitzers (65 types listed, with calibres from 100 to 203 mm)
   (B) Mortars (13 types listed, with calibres from 107 to 240 mm)
   (C) Multiple Launch Rocket Systems (16 types listed, with calibres from 110 to 300 mm)

4. Existing types of combat aircraft (51 types listed)

5. Existing types of attack helicopters
   (A) Specialized Attack Helicopters (4 types listed)
   (B) Multi-Purpose Attack Helicopters (12 types listed)

II. Existing Types of Conventional Armaments and Equipment not Limited by the Treaty

1. Existing types of armoured personnel carrier look-alikes (33 types of APC listed, with various types of armament of calibres less than 20 mm)

2. Existing types of armoured infantry fighting vehicle look-alikes (2 types of AIFV listed, with various types of armament of calibres less than 20 mm)

3. Existing types of primary trainer aircraft which are designed and constructed for primary flying training and which may possess only limited armament capability necessary for basic training in weapon delivery techniques (16 types listed)

4. Existing types of combat support helicopters (24 types listed)

5. Existing types of unarmed transport helicopters which are not equipped for the employment of weapons (17 types listed)

6. Existing types of armoured vehicle launched bridges (13 types listed)

The protocol requires that all models and versions of the types listed in Section I are to be deemed to belong to that type, unless they are included in Section II.

III. Technical Data and Photographs

This requires a set of technical data and photographs of each item listed in Sections I and II to be supplied.

IV. Updates of Existing Types Lists and Obligations of the States Parties

The protocol constitutes agreement only for the existing types of armament and equipment listed in Sections I and II.

States are obligated to notify and provide technical data and photographs to all the other states upon entry into service of

(a) any new type of conventional armament or equipment which meets one of the definitions of Article II of the treaty proper, or which falls under a category listed in the protocol,

and (b) any new model or version of a type listed in the protocol.