THE U.S.-SOVIET LONG-TERM MILITARY COMPETITION VOLUME III- APPENDICES

J. Bengston, J. Fromm, J. J. Martin, J. Miller,
R. A. Montgomery, D. E. Smallwood, R.S. Soll
Science Applications International Corporation
10260 Campus Point Drive
San Diego, CA 92121

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J. Bengston, J. Fromm, J. J. Martin, J. Miller, R. A. Montgomery, D. E. Smallwood, R.S. Sol

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SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
10260 CAMPUS POINT DRIVE
SAN DIEGO, CALIFORNIA 92121

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This three-volume report examines the nature of the U.S.-Soviet long-term military competition and sets forth improved means for developing and implementing strategies for this competition. This research encompasses broad national strategy as well as specific military missions and is directed at planning concepts and methods, rather than at devising specific strategies. Volume III consists of background papers and case studies that supplement volumes I and II.

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SUMMARY

This volume consists of a series of appendices containing background studies of various aspects of the U.S.-Soviet long-term military competition. These papers supplement the research and conclusions contained in volumes I and II.

The following is a summary of each of the appendices.

Appendix A, "A Guide for Competition Planning," by Dr. J. J. Martin.

This appendix outlines a set of questions as a heuristic guide to military competition planning. These questions can be used by DoD staffs to evaluate U.S. programs from a competition perspective and to identify program modifications or other actions to compete more effectively with the Soviet Union.

Appendix B, "B-52: A Case Study for Military Competition with the Soviet Union," by Dr. R. A. Montgomery.

In this appendix Dr. Montgomery examines the B-52 program to determine which factors have been most influential in deploying a cost-effective weapon system with high competitive leverage and in extending its useful life many decades beyond the initial projections and design goals. These factors include those external to the B-52 design and those related to the design and program plan for the bomber.

The principal external factors are as follows: first, strong user interest, involvement, and feedback; and second, large-scale exploitation of a technological advantage in a critical area of military capabilities to establish a long-lasting competitive advantage. Other external factors are the competence, dedication, and continuity of the lead personnel, both in government and in industry; a clear mission and role for the weapon system; willingness to accept and resolve the inevitable technical and operational problems; willingness to take a major first step in the prototype development; and public and congressional support.

The principal internal factors are: inherent design flexibility to accommodate growth in performance and robustness to enemy counters; rapid development and fielding to obtain early service operational experience to reduce overall risk while providing important early capability; and a vigorous product improvement program with extensive model changes effected without breaks in production or delays in deployment.

Appendix C, "The Technological Level of Soviet Industry", by Dr. Dennis E. Smallwood.

Dr. Smallwood summarizes the contents of a book by a group of British specialists on technology and the Soviet Union (The Technological Level of Soviet Industry (1977)). This book evaluates the state of Soviet technology in key civilian and military areas of the economy of the USSR. The basic conclusion of the authors of this book is that the Soviets have trailed the free world nations in the majority of the development and production-oriented technologies.

Appendix D, "Soviet Demographic Trends And The U.S.-Soviet Military Competition," by Dr. Richard S. Soll.

Dr. Soll reviews demographic trends in the Soviet Union and their potential impact on the military, economic, manufacturing, and political sectors of the USSR. He describes the increasing percentage of Muslims in the population and concludes that the impact of this population shift on the social, economic, political, and military dimensions of the Soviet Union could be major. Soviet demographic trends tend to place the USSR at a disadvantage in the competition with the United States. Dr. Soll identifies a number of demographic opportunities that the United States could exploit in the military competition.

Appendix E, "Historical Examples Of Military Competition," by Dr. J. J. Martin.

In this appendix, Dr. Martin briefly summarizes several case histories and identifies the lessons that can be gained that are applicable to today's competition with the Soviet Union. One of the major lessons is that there are no permanent advantages in military competition -- adroit management of innovation has been a key part of military competition since at least medieval times. Martin concludes that the state of a nation's technology is determined primarily by economic, political, and social conditions, not military investment. Military investment can, however, affect the speed and efficiency with which new technology is incorporated into the armed forces.

Appendix F, "Contemporary Lessons for the U.S.-Soviet Military Competition from NSC-68", by Mr. Joseph Fromm.

NSC-68 was written in 1950 by the State Department's Policy Planning Staff under the direction of Paul Nitze. purpose was to convince President Truman of the reality of the long-term Soviet threat and the necessity to take strong steps to counter this threat. In this appendix, Mr. Fromm reviews the more salient features of the NSC-68 document and points out that the policy of containment has been a major and successful U.S. strategy in the military competition with the USSR.

Appendix G, "The U.S.-Soviet ICBM Long-Term Competition," by Dr. Joel Bengston.

This appendix is a chronological review of the U.S. and Soviet development and deployment of intercontinental ballistic missiles (ICBMs) over the past three decades. Dr. Bengston finds a number of lessons in this chronology for the U.S.-Soviet military competition, notably that the Soviet Union, while lagging the United States in ICBM technologies, has been able to produce ICBM systems that meet Soviet warfighting requirements and that progressively have put the United States at a disadvantage in the strategic balance.

Appendix H, "U.S.-Soviet Ballistic Missile Defense Competition," by Dr. Joel Bengston.

This study concentrated on U.S. and Soviet ballistic missile defense (BMD) programs. Dr. Bengston finds that, through the 1970s, U.S. BMD programs were driven more by technology opportunities and problems than by actual Soviet threats; the technologies of Soviet BMD programs lagged behind those of the United States until the signing of the ABM Treaty in 1972. Thereafter, until the start of the Strategic Defense Initiative (SDI) program, the United States reduced work on BMD technology, while the USSR sought to catch up with the United States in this area.

Appendix I, "Soviet ICBM and BMD Developments in the U.S.-Soviet Military Competition," by Dr. Richard Soll.

Dr. Soll traces the development of Soviet ICBMs and antiballistic missile (ABM) systems. He includes a discussion of Soviet military planning factors and weapon system procurement decision processes related to ICBM and ABM systems. He concludes that the Soviets study systematically the status of the long-term military competition and initiate the actions necessary to satisfy their offensive and defensive warfighting requirements.

PREFACE

The term "competition" is commonly used to characterize the relation between the United States and the Soviet Union. Despite the recognition that the two superpowers compete in all the major dimensions of international relations -- political, military, economic, technological, and ideological -- there has been relatively little research on the nature of this competition and on systematic ways for the United States to improve its competitive position in this complex vying for power and influence.

There are many examples of effective U.S. competitive actions, but little attention has been given to explicit planning processes and strategies to help the U.S. Government compete more effectively with the USSR over a long period. In the late 1940s and early 1950s there were discussions of broad national strategies for the competition, especially at the RAND Corporation. But this line of questioning gradually died out by the mid-1950s. In 1969-1070, Andrew Marshall worked on a framework for analyzing the U.S.-Soviet long-term competition, concentrating on strategic forces. Under Marshall's leadership, the Department of Defense began in the mid-1970s to carry out studies of more general strategies for the military competition, drawing on business concepts for strategic planning. In 1986, the Secretary of Defense established the Competitive Strategies Initiative, which addresses specific military missions or tasks.

As part of the DoD examination of how to compete more effectively with the Soviet Union, Science Applications International Corporation (SAIC) has been under contract since 1985 to carry out research on the nature of the U.S.-Soviet long-term military competition and on improved means for developing and implementing strategies for this competition. While the focus of our research is on the military dimension of the competition, it also takes into account the political, economic, technological, and ideological dimensions, Moreover, our effort encompasses broad national strategy as well as specific military missions or tasks and is directed at planning concepts and methods, rather than at devising specific strategies. Thus, the SAIC work has sought to improve the context and methods for DoD competitive strategies development, but does not duplicate planning efforts being carried out by the Department of Defense.

SAIC's research on the U.S.-Soviet long-term military competition was funded and guided by the Director of Net Assessment in the Office of the Secretary of Defense. The contract was administered by the Defense Nuclear Agency.

The results of SAIC's research are contained in three volumes.

- Volume I describes the general nature of the U.S.-Soviet long-term military competition, including concepts useful for understanding what is important in this competition and for developing strategies to compete effectively.
- Volume II describes a structured process for devising and implementing strategies for the long-term military competition, evaluates current analysis tools in terms of their adequacy to support competitive strategy development, and recommends improvements.
- Volume III contains case studies and other background papers that supplement volumes I and II.

Although these three volumes collectively describe the SAIC research, each is designed to be read independently of the other.

Dr. J. J. Martin was the Principal Investigator for SAIC's research on the U.S.-Soviet long-term military competition and is the author of two of the appendices in this volume. Authors of the other appendices include Joel Bengston, Joseph Fromm, Richard Montgomery, Dennis Smallwood, and Richard Soll. James Miller edited this volume.

Conversion factors for U.S. Customary to metric (SI) units of measurement

MULTIPLY ——————→ BY ——————→ TO GET
TO GET ←—————— BY ←—————— DIVIDE

MULTIPLY / TO GET	BY	TO GET / DIVIDE
angstrom	1.000 000 X E -10	meters (m)
atmosphere (normal)	1.013 25 X E +2	kilo pascal (kPa)
bar	1.000 000 X E +2	kilo pascal (kPa)
barn	1.000 000 X E -28	meter² (m²)
British thermal unit (thermochemical)	1.054 350 X E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical)/cm²	4.184 000 X E -2	mega joule/m² (MJ/m²)
curie	3.700 000 X E +1	giga becquerel (GBq)*
degree (angle)	1.745 329 X E -2	radian (rad)
degree Fahrenheit	$t_K = (t°f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 X E -19	joule (J)
erg	1.000 000 X E -7	joule (J)
erg/second	1.000 000 X E -7	watt (W)
foot	3.048 000 X E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 X E -3	meter³ (m³)
inch	2.540 000 X E -2	meter (m)
jerk	1.000 000 X E +9	joule (J)
joule/kilogram (J/kg) (radiation dose absorbed)	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 X E +3	newton (N)
kip/inch² (ksi)	6.894 757 X E +3	kilo pascal (kPa)
ktap	1.000 000 X E +2	newton-second/m² (N-s/m²)
micron	1.000 000 X E -6	meter (m)
mil	2.540 000 X E -5	meter (m)
mile (international)	1.609 344 X E +3	meter (m)
ounce	2.834 952 X E -2	kilogram (kg)
pound-force (lbf avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 X E -1	newton-meter (N·m)
pound-force/inch	1.751 268 X E +2	newton/meter (N/m)
pound-force/foot²	4.788 026 X E -2	kilo pascal (kPa)
pound-force/inch² (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 X E -1	kilogram (kg)
pound-mass-foot² (moment of inertia)	4.214 011 X E -2	kilogram-meter² (kg·m²)
pound-mass/foot³	1.601 846 X E +1	kilogram-meter³ (kg/m³)
rad (radiation dose absorbed)	1.000 000 X E -2	Gray (Gy)**
roentgen	2.579 760 X E -4	coulomb/kilogram (C/kg)
shake	1.000 000 X E -8	second (s)
slug	1.459 390 X E +1	kilogram (kg)
torr (mm Hg, 0° C)	1.333 22 X E -1	kilo pascal (kPa)

* The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.

** The Gray (Gy) is the SI unit of absorbed radiation.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

APPENDIX A

A GUIDE FOR COMPETITION PLANNING

J. J. Martin

This appendix outlines a set of questions as a heuristic guide to military competition planning.[1] It is consistent with the procedures of the more extensive layered planning process described in volume II. This guide has, however, the advantage that it can be used now, whereas decisions about resources and organizational structure must be made in order to implement the layered planning process in the Department of Defense. The guide can also be used as an aid in the layered planning process, especially in layer 2 (high-level strategic plan) and layer 3 (subarea goals and strategies).[2]

Following is a set of questions to be explored by DoD staffs as a means of evaluating current U.S. programs from a competition perspective and of suggesting modifications to these programs or other actions to compete more effectively with the USSR.

1. What enduring U.S. and Soviet strengths and weaknesses are relevant to the long-term military competition?
   - Enduring refers to attributes that are not likely to change for at least twenty years, if ever.
2. What temporary U.S. and Soviet strengths and weaknesses are relevant to the long-term military competition?
   - Temporary refers to attributes that are not likely to change over the period of a weapons development cycle (e.g., ten years), but could change over a longer period.
3. In each subarea of the competition, what are the critical success variables to which each side must respond?

- Critical success variables relate to the inherent demands of a particular subarea of the military competition. These may include, for example, mastery of basic technologies, responses to geographic constraints, possession of requisite management skills, or the ability to deal with alliance requirements.

4. What U.S. actions (e.g., technology applications or new operational concepts) should be set in motion to take better advantage of U.S. strengths and Soviet weaknesses in the long-term military competition? Such actions might have one or more of the following competition objectives:

   - Make Soviet military investments obsolete.

   - Impose costs on the USSR.

   - Cause the Soviet Union to sustain expenditures on obsolete weapon systems.

   - Otherwise divert Soviet resources from more threatening to less threatening areas or from areas where they are more competitive to areas where they are less competitive.

5. What actions (e.g., technology applications or new operational concepts) are the Soviets pursuing or might they pursue to take better advantage of Soviet strengths and U.S. weaknesses in the long-term military competition? Soviet competition goals might include one or more of the following:

   - Make U.S. military investments obsolete.

   - Impose costs on the United States.

   - Cause the United States to sustain expenditures on obsolete weapon systems.

   - Otherwise divert U.S. resources from areas of primary relevance to U.S. security to areas of secondary relevance or from areas where the United States is more competitive to areas where it is less competitive.

6. What actions should the United States take that will improve its future ability to compete with the Soviet Union (long-term U.S. investments to improve its competitive position)? What actions is the Soviet Union likely to take to try to improve its competitive position?

   - Technology developments.

- Weapon system deployments.
- Operational concepts.
- Political, economic, or arms control actions.

7. Are there different uses of current U.S. military assets (e.g., deployed weapon systems) that will:

   - Make Soviet military investments obsolete?
   - Impose costs on the USSR?
   - Cause the Soviet Union to sustain expenditures on obsolete weapon systems?
   - Otherwise divert Soviet resources from more threatening to less threatening areas or from areas where they are more competitive to areas where they are less competitive?

8. What are notable past successes and failures in the long-term competition? What lessons can be learned from these successes and failures?

   - U.S. successes and failures.
   - Soviet successes and failures

9. How competitive are current U.S. programs in light of answers to the above?

   - Weapons development and procurement programs.
   - Technology developments.
   - Operational concepts, doctrine, and campaign plans.
   - Arms control objectives and positions.

ENDNOTES TO APPENDIX A

1. This set of questions was developed by Graham Allison, Joseph Fromm, and J. J. Martin in a meeting on July 1, 1986.

2. See discussion of the layered planning process in volume II, chapter 1.

APPENDIX B

B-52
A CASE STUDY FOR MILITARY COMPETITION WITH THE SOVIET UNION

R.A. Montgomery

B.1 INTRODUCTION

Success in the long-term military competition between the United States and the Soviet Union requires realistic selection and delineation of national security requirements and objectives; a long-range planning foundation for predicting military capabilities required vis-a-vis the Soviets at future times; determination of future military force design principles; and timely acquisition and introduction in quantity of major new weapons systems essential to maintain a competitive advantage for execution of critical missions.

The B-52 program has been examined in an effort to determine which factors were, or have been, most influential in initially deploying a cost-effective weapon system with high competitive leverage and in extending its useful life many decades beyond the initial projections and design goals.

Current formal U.S. acquisition principles, policies, and procedures, as contained in DoD Directive 5000-1 and DoD Directive 5000-2, do not sufficiently evidence the long-term perspective needed to assure that major weapon systems approved for development and production will make both a significant contribution to our military capability and have a long, militarily-useful life.[1] The Packard Commission report recognized this in 1986 and recommended actions to improve the acquisition process, including rapid prototyping.[2] The early stages of the B-52 program provide an excellent example of the soundness of the Packard Commission's recommendations about rapid prototyping as a means to reduce acquisition lead-time.

The factors affecting program success and related competitive advantage fall into two groups: those external to the program, relating to the decision process and overall program environment, and those internal to the program, relating to design and program plans.

The principal external factors are as follows: first, strong user interest, involvement, and feedback; and second, large-scale exploitation of a technological advantage in a critical area of military capabilities to establish a long-lasting competitive advantage. Other external factors are the competence, dedication, and continuity of the lead personnel, both in government and in industry; a clear mission and role for the weapon system; willingness to accept and resolve the inevitable technical and operational problems; willingness to take a major first step in the prototype development; and public and congressional support.

The principal internal factors are: inherent design flexibility to accommodate growth in performance and robustness to enemy counters; rapid development and fielding to obtain early service operational experience to reduce overall risk while providing important early capability; and a vigorous product improvement program with extensive model changes effected without breaks in production or delays in deployment.

Other examples could be selected -- such as the HAWK air defense system, the M-60 tank, and the F-4 aircraft -- where a fundamentally sound initial design, major commitment and support at all levels of government, and strong user inputs have provided long-life weapon systems.

This appendix is based in part on an excellent history of the B-52 prepared by Mr. Walter J. Boyne in 1981.[3] The factual material in Boyne's book is supplemented by additional material from personal involvement of the author while in government service and from interviews. The assistance and cooperation of Mr. Boyne is greatly appreciated, as is his permission to draw heavily from his book.

B.2 GENESIS OF B-52 PROGRAM

Walter Boyne traces the origin of the B-52 back to the Atlantic Charter meeting between President Roosevelt and Prime Minister Churchill in August 1941. At this meeting, the need was identified for an intercontinental bomber capable of carrying a 10,000 pound payload a distance of 10,000 miles. Development of the B-36, initiated during World War II, was the first-generation response to this need; the B-52 was the second-generation response. The B-36 was operational by 1949 and was replaced by the B-52 starting in 1955.

An intercontinental bombing capability was envisaged in 1941 as required to fight effectively against Hitler's Germany if Great Britain were to fall to Nazi invasion forces. Later, with the onset of the cold war between the United States and the Soviet Union, this desired military capability was viewed as potentially providing a decisive military advantage to the United States using nuclear weapon payloads.

The U.S. Air Force initiated design studies for the B-36 replacement in 1946, even before the B-36 was operational. A large aircraft was envisaged with turbo-propeller propulsion. Boeing won the initial design competition in September 1947, but had little hope of major funding until sufficiently powerful turboprops were available and a significant performance margin over the B-36 could be assured.

The B-47 development had been initiated in mid-1946, and in 1948 production of this medium all-jet bomber was ordered. Early B-47 flight tests proved out the aerodynamics of high subsonic speed flight, giving confidence about the feasibility of a pure-jet heavy bomber. In any event, Boeing and the air force agreed on an all-jet design by default as soon as it was recognized that an adequate turboprop engine would not be available early enough. The Boeing proposal, prepared over a single weekend in October 1948, was thirty-three pages long and defined the B-52 as it initially was built. The program received immediate support from the air force's Research and Development Command and the Strategic Air Command (SAC). Development was initiated in early 1949.

Later in 1949, detonation of the first Soviet nuclear device shocked the U.S. intelligence community, the Defense Department, the administration, the Congress, and the public. Additional priority for B-52 development was one of the consequences. The onset of the Korean War in 1950, following several years of continuing European crises after the Berlin blockade in 1948, further reinforced the perception of the need to maintain and strengthen U.S. strategic superiority over the Soviet Union.

Since the B-52 payload objectives were about 10 percent of the gross takeoff weight for useful ranges, small variations in weight, thrust, drag, or fuel consumption could impact significantly the overall performance. The air force leadership recognized that the performance potential of the B-52 justified the development risks and to some degree overruled their own laboratories in accepting the novel and unproven design approaches necessary to achieve the overall flight performance goals.

A rare coincidence of influences probably contributed to the decision to start the B-52 program and to its eventual success. These were:

- Strong leadership and support in the using command.
- Recognition of international danger at the time of the Berlin blockade in 1948, the subsequent initial Soviet nuclear detonation in 1949, and the Korean War of 1950-53.
- The newness of the U.S. Air Force as a separate service and its relative lack of bureaucracy at the time.
- The spirit of cooperation and mutual trust between industry and government.
- The competence, experience, and self-confidence of the prime contractor.
- The continuity of assignments of key personnel in both government and industry.
- Minimal interference and second-guessing by Congress or DoD staffs.
- Public support for aviation projects.

B.3 DEVELOPMENT AND PRODUCTION

Although the B-52 aircraft was an entirely new design the first flight of a prototype took place in mid-1952, approximately three and a half years after the start of development. Many design innovations necessary to obtain the desired performance were incorporated into the B-52 design. These included a large-area flexible swept wing designed for fuel storage; a pneumatic system for auxiliary power; a steerable eight-wheel bicycle landing gear; new bombing and navigation systems; and a new high-thrust turbojet engine.

Aerodynamic calculations and wind tunnel tests showed that a wing root relatively thicker than that of the B-47 could be used without significantly impacting drag. This permitted a lighter-weight wing with provision for fuel storage in the wing, thus adding to the potential range and providing fuel storage space without using the fuselage. The relatively large wing area contributed to the high lift over drag ratio essential for long range. The pneumatic system was selected for weight savings and was eventually replaced by a hydraulic system. The novel landing gear contributed to stability and a small turning radius on the ground, as well as ease of taxiing in cross winds. The new bombing and navigation systems were needed for long over-water flights and accurate bombing without visual target acquisition. The new-design Pratt and Whitney JT3A jet engines each provided approximately double the thrust of the General Electric engines used on the B-47.

Taken together, these features provided a relatively low empty aircraft operating weight. The speed, altitude, payload, internal volume, and unrefueled range of the B-52 gave it a major advance in performance over all previous heavy bombers and provided a significant competitive advantage over any bomber aircraft or air defenses the Soviets would be capable of producing for many years. These features contributed to the robustness of the system in the following ways: the long range allowed flexibility in target attack flight paths and altitudes; the large payload and internal volume provided room for defensive armaments, electronic warfare equipment, and defense suppression weapons, as well as flexibility in primary payload carriage.

Initial production was ordered more than a year before first flight of the experimental aircraft. Initial production models from the Seattle Boeing plant flew in mid-1954. By the end of 1954 full production was ordered, using Boeing assembly lines in both Seattle and Wichita, Kansas. The first aircraft were delivered to the Strategic Air Command in 1955 and the initial wing of B-52B aircraft was fully operational in 1956. In today's procurement there would be significant delays between each phase of the program, greatly delaying the fielding of the system and increasing its costs.

The average unit production costs (including engines, electronics, and armaments) were as follows, in current or then-year dollars:[4]

Model	Number Produced	First Delivery	Average Unit Cost
B-52A	3	1954	$29.5M
B-52B	50	1955	14.5
B-52C	35	1956	7.0
B-52D	170	1956	6.5
B-52E	100	1957	6.0
B-52F	89	1958	6.5
B-52G	193	1959	7.5
B-52H	102	1961	9.5

Production started at the Boeing Seattle plant, with a second production line later established at the Boeing Wichita plant. Of the total of 744 air frames, 467 were built in Wichita. Production was split both to establish a second production source and to reduce vulnerability to potential Soviet air attack. The B-52D, E, and F models were produced at both plants. The B-52G and H models were produced only at the Wichita plant. B-52s were produced at a maximum rate of approximately eight aircraft per month.

An important characteristic of the B-52 program was the series of changes to increase performance, adapt to new missions, fix problems, and extend the useful life of the aircraft. The last

B-52 aircraft was delivered in 1962, over a quarter century ago. But this statistic is misleading to some degree, as all models now in service have seen extensive modification. Without these modifications the aircraft would long ago have been obsolete or unsafe to fly.

In retrospect, the pace of the program was really remarkable by current standards. Seven major models were fielded in as many years after initial deployment, each in major production quantities. The G and H models, comprising approximately one-half the total production, incorporated major design changes. The changes in the G model included a new wing, which eliminated the fuel bladders; hard points for external missile carriage; and significant crew-friendly minor changes. The H model introduced the fan-jet engine, whose fuel consumption was markedly lower that of earlier B-52 engines, providing the final increment of range-payload performance. The H model was also the first to be equipped with a terrain-avoidance radar for low-level flight.

These aircraft design changes resulted in significant growth in flight performance as measured by range, payload, and low-altitude flight capability.[5]

Model	**Gross Weight (lbs.)**	**Payload (lb.)**	**(MIL-C-5011A) Unrefueled Radius (nm)**
B-52A	420,000	14,000	3100
B-52B	420,000	63,000	3100
B-52C-F	450,000	64,000	3300
B-52G	488,000	105,000	3800
B-52H	488,000	105,000	4500

MIL-C-5011A is a military specification defining procedures for calculating the flight performance of aircraft on a standardized basis. Basically, the radius cited is for unrefuelled high-altitude flight with a specified reserve fuel amount. Radius at low altitude is reduced and radius with refuelling is greatly increased as compared with the data shown in the table. The increase in payload for a fixed range between the A and B models was due to thrust increases in the engines for the B models, as well as to some weight reductions. Only three B-52As were completed; others were converted during production to the B design.

B.4 OPERATIONS

The Strategic Air Command had matured with the deployment and operation of the B-36 and B-47 aircraft. General Curtis Le May, SAC commander during 1948-1957, raised the SAC force to standards of training, efficiency, and combat readiness previously unknown in peacetime by any U.S. forces. The Strategic Air Command tripled in manpower and equipment between 1950 and 1960 with the build-up of the B-47 force to a total of approximately 1500 aircraft, the large B-36 deployment, and the overlapping B-52 deployment.

The high standards of training and close relationship between the service developer, the service user, and supporting industry minimized the feedback time for necessary safety or mission changes. A service operational test organization could not have achieved the same results. Fundamentally, an operational test organization has a mission to discover all possible problems and to send equipment back to the developer for modification. The user wants necessary modifications incorporated while maintaining service utility. His priorities are significantly different. Delaying the fielding of production hardware simply delays the discovery of critical operational problems or needs that are not otherwise reasonably possible to anticipate, and delays the realization of operational benefits.

The Strategic Air Command was, however, much more than B-47s or B-52s. It had efficient and demanding officers in command positions who in today's service environment might be judged as too deficient in interpersonal attributes to be selected for promotion. The Strategic Air Command, almost uniquely, operates under near-wartime alert and training conditions. It demands much of its people and equipment, and drives the rest of the air force system to provide support.

Initially, a large fraction of the SAC force was based overseas, at bases in North Africa, for example. The introduction of reliable in-flight refueling, the procurement of large numbers of KC-135 tanker aircraft, and the development of the longer-range B-52 aircraft permitted consolidation of most SAC resources in the United States. Overall, the pace of the B-52 program was probably due more to "pull" from the user, rather than "push" from the developer. Necessary fixes were worked out and implemented under extreme time pressure, to maintain operational capability.

Surprise operational-readiness inspections served to check combat readiness as well as to eliminate from the chain of command officers unwilling or incapable of meeting the high operational standards of the Strategic Air Command.

The B-52Ds were extensively used in the Vietnam War and were augmented by the B-52Gs for the major raids on Hanoi and other key targets immediately preceding the end of the war.

The size of the B-52 fleet was reduced in the 1970s for a number of reasons, including costs and arms control restrictions. Only the B-52D, G, and H models were retained. The B-52D became primarily a conventional weapon carrier, and the B-52G and H models were equipped to carry up to twenty Short-Range Attack Missiles (SRAMs) each. When the Air-Launched Cruise Missile (ALCM) became operational in 1982 all the B-52H aircraft and approximately half of the G aircraft were fitted to carry it. The remaining B-52G aircraft replaced the D aircraft as conventional weapons carriers.

B.5. MAJOR PROBLEMS AND SOLUTIONS

It is difficult to make a clear distinction between problems inherent in the basic design as related to the initial missions and concepts of operations and problems that were exacerbated or resulted from changes in operational use or life extension. In any event, solutions were developed with minimal recrimination, giving priority to mission effectiveness and flight safety. Some of the major problems and solutions are discussed in the following paragraphs.

B.5.1 Structural and Flight Control

The original structural design requirement was for 5000 hours of high-altitude flight. Actual usage is estimated to have averaged about 600 hours per year, much at low-altitude flight, which consumes fatigue life at a much higher rate than high-altitude flight. As a consequence, all models have undergone a series of changes that resulted in major redesign or renewal of a large fraction of the skin. In addition, specific problems surfaced.

The initial design of the B-52H wing used an advanced aluminum alloy that turned out to be fatigue-sensitive, and those wings were replaced using a more conventional alloy. Moreover, the primary rear bulkhead of the fuselage was redesigned after flight failures under both high- and low-altitude clear-air turbulence (CAT) conditions.

Low-level penetration flight to avoid air defenses became normal doctrine starting about 1960. Auto-pilot changes were needed to ameliorate the rough ride, not just for crew comfort, but also for crew effectiveness. Low-level flight is much more stressing on the air frame than high-level flight, in terms of using up fatigue life.

The U.S. Air Force initially planned to phase out the B-52 starting in 1969 and to complete the process by 1974, replacing it with one of the many potential successors (the B-70, RS-70, or the Advanced Manned Strategic Aircraft) visualized in 1962-1964. Major changes were, however, initiated in 1964 to provide a comprehensive long-term fix to the control and structures problems recognized at that time, as well as to permit service-life extension through at least 1976. A committee appointed by the Office of the Secretary of Defense reviewed the investigations and analyses of the air force and Boeing, recommending a comprehensive redesign of the flight-control system to provide greater load alleviation and to meet fully the diverse demands of high-level flight, response to CAT conditions during refueling maneuvers, low-level flight, take-offs, and landings. A modernized flight-control system was developed and incorporated.

In the early 1970s, extending the range of the B-52Ds for usee in Vietnam led to the need for additional modifications for a portion of the B-52D fleet. Eight aircraft were selected for further life extension in a $220M program called Pacer Plank that involved the rebuilding of major portions of the wings and large portions of the fuselage.

B.5.2 Other Problems

The pneumatic system used for primary power on the early models was unsatisfactory and was replaced. The original concept was to bleed air from each jet engine to drive air turbine power packs. This system was replaced early in the program.

The most important feature of all of these B-52 modification programs was the willingness of the air force to recognize and to correct problems on a continuous basis, sustaining the confidence of the flight crews in the basic integrity of their aircraft.

B.6 MODERNIZATION

B.6.1 Evolution of the Air Defense Threat

Recognizing that the initial design of the B-52 predated the deployment of the first-generation Soviet surface-to-air (SAM) systems (principally the SA-2 and SA-3) and the first demonstration of a nuclear weapon capability by the Soviets, the threat environment has changed dramatically since the initial deployment of the B-52. The generations of air defense threat change basically were as follows:

- Transition from guns to SAMs.
- Netting of air defense systems.
- Advanced fighter-interceptors and air-to-air missiles.
- Airborne radar warning and control with low-altitude tracking capabilities.
- Look-down/shoot-down fighter-interceptors.

Air defense interceptors, SAM systems, and radars have all grown in capability as modern technology was incorporated. Radars have become more capable of operating in an electronic countermeasures (ECM) environment, as well as better able to handle high traffic rates.

As air defense threats grew in capability and density, B-52 modifications made it possible to retain the competitive advantages of this bomber. Penetration was enhanced by a combination of route selection, flight profile, defense suppression, and electronic countermeasures. ECM capabilities, in particular, have gone through a series of generation improvements, details of which are classified.

As Soviet air defenses were extended over an increasingly large fraction of the USSR, U.S. bombers had to cover greater distances at low altitude or to carry long-range stand-off missiles. Both approaches have been pursued in the B-52 program. Longer ranges at low-altitude imply heavier reliance on both pre- and post-attack refueling. The large payload, range, and internal fuselage volume of the B-52 made it highly adaptable to varying missions and weapon loads.

In short, the B-52 established early superiority over Soviet air defenses and over a thirty year period largely retained that superiority through an aggressive program of modernization of the air frame, the avionics suites, the weapons carried, and the concepts of operations.

One may ask why the Soviets did not develop and field a bomber force comparable to the U.S. B-52 force, particularly in the period before technical feasibility and operational utility of either land-or sea-based strategic ballistic missiles was assured. The United States was ahead of the Soviets in the technologies critical to a heavy-bomber force, including in-flight refueling. The Soviet response in the 1950s was the Bison and Bear bombers. The Bison was a pure jet, large subsonic aircraft, the Bear a similarly large turbo-propeller-powered aircraft. Relatively few of the Bisons were built. Arguably, however, the large-scale application of advanced technology to air defenses by the United

States in the 1950s anticipated, pre-empted, and discouraged the Soviets from the production of the major long-range bomber force predicted by contemporary intelligence sources.

U.S. air defenses had initially developed along lines similar to those of the Soviet Union. The Nike Ajax and Hercules SAM systems were roughly comparable to the Soviet SA-1 and SA-2. In 1951, however, the U.S. Air Force initiated development of long-range netted air defenses, applying much more advanced technology in anticipation of a Soviet response in developing and producing a B-52-like force of their own. The major elements of the system, partially deployed by 1960, were the Semi-Automatic Ground Environment (SAGE) netted air defense, using digital communications and large main-frame digital computers, advanced manned all-weather supersonic interceptors, very long-range pilotless interceptors with active radar homers, and modern ground-based long-range radars. For example, the BOMARC B unmanned interceptor had a range of over 400 miles and incorporated the first operational pulse-Doppler radar for interception of low-flying targets and a small nuclear warhead. Remote launching and in-flight vectoring of BOMARC at Cape Kennedy by a SAGE facility in Kingston, New York, was demonstrated in 1958.

Deployment of these advanced U.S. air defenses was never completed, as the Soviet bomber threat did not fully materialize and the development of intercontinental ballistic missiles (ICBMs) posed new threats. U.S. continental air defenses were largely dismantled in the 1960s.

Nevertheless, the U.S. developmental investments in advanced air defenses helped to anticipate and understand Soviet air defense developments, thus contributing to wise choices in the modernization and operational employment of the B-52 force.

B.6.2. Ballistic Missile Threats

The design and operation of the B-52 force were significantly affected by the threat of surprise attack by ballistic missiles. This threat was not envisaged when the B-52 initially was developed, but was accepted as realistic with the deployment of Soviet ICBMs in the early 1960s. One response was to maintain a fraction of the aircraft continuously airborne and carrying nuclear weapons. This airborne alert procedure was adopted in the early 1960s, with the capability to increase the fraction of the fleet airborne during a crisis period. These operations were expensive to sustain, as well as politically unpalatable, and were halted after the Palomares incident in which a nuclear-loaded B-52 crashed, dispersing radioactive material.

The other principal response was to maintain a fraction of the B-52 force always ready to take off and fly to a safe distance within the warning time available after detection of the launch of hostile ballistic missiles. This ground-alert procedure required crews to be present in ready huts near the aircraft. Base-escape times have shortened with the Soviet deployment of submarine-launched ballistic missiles (SLBMs) on submarines that can operate relatively close to U.S. coastlines. On-board and support equipment have evolved to permit sustained ground-alert readiness.

Some protection against thermal and blast loads was necessary to reduce the lethal radius of a nuclear weapon attacking the B-52's base, thus allowing a larger fraction of the alert force to survive a short-warning attack. Modifications to the B-52s to enhance survivability under CAT conditions also reduced their vulnerability to blast from nuclear detonations.

B.6.3 Evolution of B-52 Weapon Suites

The B-52 was designed initially with a bomb bay capable of carrying the nuclear weapons envisaged for the 1948-1950 time period, which were large, heavy devices. Weapon evolution due to changes in threats, missions, and technology was as follows.

Hound Dog. The Hound Dog was a high-altitude, subsonic missile with approximately 500 miles range that was carried on B-52s during 1958-1964. About 400 of these missiles were deployed. It was planned to replace these missiles with the Sky Bolt missile starting in the mid-1960s, until the Sky Bolt program was cancelled. The Hound Dog was a relatively large weapon, requiring external carriage under the wing.

Sky Bolt. Sky Bolt was an air-launched ballistic missile with a range of 1500 miles that was designed to carry a megaton-size warhead. Development of Sky Bolt was cancelled in 1962 because it was redundant with the accelerated deployment of Minuteman and Polaris. Four Sky Bolts were planned to be carried externally on each B-52 equipped for the purpose. The air force considered the Sky Bolt as primarily a defense-suppression weapon.

Short-Range Attack Missile. SRAM was a post-Sky Bolt initiative backed by the Office of the Secretary of Defense. The concept was to provide the B-52s with a capability to stand off from terminal SAM defenses. SRAM had a thirty-mile range at low altitudes and approximately double that range in a semi-ballistic trajectory. SRAM development was initiated in 1966, with initial deployment in 1972. Large numbers of SRAMs could be carried internally to the B-52 in a rotary launcher. External carriage was also possible, but at considerable range penalty for the bomber. The SRAM had a supersonic speed and a low radar cross-section, making it difficult for defenses to intercept after launch. Of approximately 1400 SRAMs built, 1020 were deployed on B-52G and H models.

Air-Launched Cruise Missile. The concept of providing bombers with a multiple warhead, long-range stand-off attack capability originated with a Defense Science Board panel in 1967. Initially accepted by the air force and Strategic Air Command only as a bomber decoy, the ALCM program was kept alive as a bargaining chip for arms control reasons.

Eventual acceptance of the concept by the air force and Strategic Air Command led to deployment of the Air-Launched Cruise Missile as a low-altitude subsonic missile with a range of over 1000 miles, permitting stand off from area defenses as well as terminal defenses. The Carter administration cited the potential of cruise missiles on the B-52 and other aircraft as a major rationale for cancelling the B-1 bomber program in 1977. Both ALCM and SRAM were considerably smaller and lighter than earlier U.S. stand-off missiles or contemporary Soviet designs, enhancing their competitive advantage in performance and numbers carried.

Conventional Weapons. B-52Ds were equipped to carry a 54,000 pound payload of 500-pound conventional bombs for use in Vietnam, a total of eighty-four bombs plus retaining racks. More recently some B-52Gs have been fitted to carry HARPOON air-to-surface missiles for maritime patrol.

B.6.4 Avionics

B-52 penetration was enhanced by a combination of route selection, flight profile, defense suppression, and electronic countermeasures. As air defense threats grew in capability and density, changes were made as possible to retain B-52 penetration capabilities. The avionics, in particular, have gone through a series of generational improvements, details of which are classified.

B.6.5 Modernization Costs

The total initial production cost of the B-52 force, in current or then-year dollars, was approximately $6.0 billion. In 1981, planned or expended B-52 modification costs were projected to be:[6]

Accomplished through FY1979	$0.34 billion
On-going in FY 1981 (FY1980-FY1990)	$0.33 billion
Future (FY1983-FY1990)	$4.40 billion

More recent procurement expenditures for B-52 modifications are as follows:[7]

FY 1986	$393 million (Actual)
FY 1987	$397 million (Planned)
FY 1988	$270 million (Planned)
FY 1989	$195 million (Planned)

These costs exclude procurement of ALCM missiles.

B.7 LESSONS LEARNED FOR COMPETITION STRATEGIES

B.7.1 Major Competitive Payoffs From Technological Breakthroughs

The first lesson learned is that establishing a significant lead in one major area of military capabilities can force the opponent to make major expenditures in order to catch up over a protracted period of time, assuming continuing investments to sustain the competitive margin. In the B-52 example, the lead was effected through a combination of clear mission concept, advanced vehicle design and technology application, rapid development and testing, early deployment in operationally-significant numbers, and a vigorous product improvement program.

The B-52 pioneered in the application of high subsonic speed aerodynamics and controls, the largest design turbo-jet engines at the time, and high-speed aerial refueling techniques to a long-range bomber system. This combination of enabling technologies made feasible an advanced system concept that even in its initial deployment represented a large step forward.

The large-scale, rapid deployment of the B-52 during 1956-1962 gave the United States a major competitive advantage over the Soviet Union in strategic offensive forces, while greatly reducing U.S. dependence on foreign air bases. This advantage has driven major Soviet expenditures on air defenses, including SAM systems, manned fighter-interceptors, radars, and C^3 systems, over a period of thirty years in an effort to catch up or make obsolete the initial U.S. investment. The United States, in turn, has been able to capitalize on and maintain its initial lead through continuing modernization of both offensive and defensive avionics suites and the adoption of new tactics such as low-level penetration. The B-52 fleet still carries approximately 25 percent of the warheads and a larger fraction of the total megatonnage of the U.S. strategic force.

B.7.2 System Design Flexibility

The second lesson learned is that any new major weapon system design should include as principal objectives adaptability, flexibility, and robustness in the face of efforts by the adversary to counter the system. Adaptability has multiple dimensions. First, we expect the threat to evolve in intensity and quality, and not always in a predictable manner. It is essential that the weapon system be designed to accommodate necessary new capabilities to maintain its competitive advantage over an improved threat with time. Second, our own technological advances create opportunities for product improvement for either increased capabilities or lower support costs. Third, operational concepts change due to policy changes, target system changes, or introduction of complementary U.S. weapon systems. The B-52 was adapted successively to low-altitude penetration missions, conventional bombing missions, and carriage of stand-off missiles, among other changes.

As its long service life has demonstrated, the basic design of the B-52 had these characteristics. To what degree the flexibility and growth potential were preplanned is arguable and perhaps irrelevant. On the one hand, the service requirements were not specified in anything like the detail now imposed. This fact, and Boeing's design philosophy derived from earlier pioneering aircraft designs (B-17, B-29, B-47), led in the B-52 example to a very large jet aircraft with ample interior room and payload capacity. The design lift to drag ratio was approximately twenty, providing an airframe efficiency that could, even today, only marginally be improved.

On the other hand, the air force never expected to retain the B-52 for such a long service life. The RS-70, the B-70, and later the B-1 were developed as replacements for the B-52 in its strategic bombing mission. In 1964, air force plans called for phasing out the B-52 starting in 1969 and completing the phase-out by the mid-1970s. Service life limits and mission obsolescence were foreseen, but were averted through extensive modernization programs.

Current DoD procurement regulations and practices dictate design solutions that are optimized on a cost-effectiveness basis against specific threat estimates, initial fielded capabilities, and specific concepts of use. All three of these boundary conditions can and do inevitably change, and flexibility to adapt to such changes is an important determinant of useful program life.

B.7.3 Rapid Development and Fielding

There are powerful arguments for rapid development and fielding, as was done with the B-52 in approximately six years. Operational capabilities that yielded major competitive advantages would have been delayed for at least a decade if the Department of Defense had insisted at that time on basing the B-52 design on mature technology or subsystems to avoid risk. With such a delay, the United States might have been trying to overtake the Soviets in manned bombers rather than dictating the competition.

Any new weapon system will have a projected useful life, depending on its operational use, the threat, and the technology used. While the useful life of a weapon system can only be estimated, it can be limited by changes in military plans, threat changes, or technical obsolescence long before the hardware wears out. Once the system design is selected and initial technical choices made, the clock starts running on the useful life. The longer the time spent in developing and fielding a weapon, the shorter the useful operational life and, consequently, the acquisition cost must be amortized over a shorter period. Modifications and improvements can, however, extend the operational life if the basic technical concept remains current, as in the HAWK SAM system or the B-52.

One lesson of the B-52 program is that the initial capabilities of systems can be applied effectively while corrections or improvements are made. Also, many problems are detected only in actual service use and would not necessarily ever be discovered by a test organization before production.

Most defense analysts consider the risks of rapid development and fielding and do not balance these risks against the potential payoffs. In the B-52 example there was a clear payoff. For instance, all the B-52B through F models, a total of 447 aircraft or approximately two-thirds of the total production, were operational within ten years after initiation of development.

The principal lesson is that rapid development and fielding for force-wide utilization was a key element in the B-52 program success.

B.7.4 Affordability

The B-52 was purchased in large quantities for heavy bomber aircraft, with the total fleet delivered in approximately eight years. Although the production line learning curve savings were significant, they were to a large degree balanced out by the costs of changing models during production. Nevertheless, the total system was affordable in quantity buys for SAC force-wide usage, replacing the prior mix of B-36 and B-47 aircraft. With a large deployment, modernization, problem correction, or life-extension costs can be spread over a wider base, making changes more affordable per unit than for a small fleet of aircraft.

The lessons are that a continuing, high-rate production program can be efficient and that modernization developments are more flexible and cheaper per unit for a large fleet.

B.7.5 Strong User Involvement

Strong user involvement and personnel continuity were key aspects of the overall management approach to B-52 development and deployment. User involvement implies high-level support for program authorization and funding; a continuous voice in and presence during the development test program; early fielding and expedited problem-correction programs; and demand and support for meaningful capability improvements to exploit fully the concept and technology potential. Synthetic users, such as the U.S. Army Training and Doctrine Command (TRADOC) or operational test organizations, are not a satisfactory substitute for involvement of the actual operational users. Their motivation, incentives, charters, and responsibilities substantially differ. Recent moves to involve the unified commanders in the acquisition process reflect this need.

The B-52 system design concept was backed from the beginning with an equally solid concept for operational use. The Strategic Air Command was thus able to bring B-52 wings to full operational readiness in a relatively short time.

The program satisfied a valid operational need and had strong user interest, involvement, and support in the development, test, and production phases. "Need" does not have the same meaning as "requirement," which implies a formal, specific, requirement statement. In the B-52 example, the Strategic Air Command had a clear need for a large, high-speed, long-range bomber with as much capability as the state-of-the-art would permit.

B.7.6 Continuity of Senior Personnel

In most successful programs a few capable, dedicated managers and key personnel have played a major role in assuring success. They are needed on both the government and contractor teams for a considerable period of time, if not for the life of the development program. Specifically, rotation of key personnel on a milestone, rather than on a calendar, basis can be helpful in fixing responsibility and minimizing disruptions at critical times.

The B-52 program was no exception. The Boeing team also evidenced remarkable continuity, even with the shift from Seattle to Wichita. The successful Polaris/Poseidon/Trident SLBM program is a parallel example of personnel continuity.

B.8 RELEVANCE OF LESSONS LEARNED TO LONG-TERM MILITARY COMPETITION

In the long-term military competition between the United States and the Soviet Union, each side's prevailing image of future wars strongly affects its selection of competition strategies and military applications of technologies. The two patterns of technological innovation are evolutionary force improvements and technical breakthroughs that open opportunities for major shifts in competitive position. The B-52 program is a good example of the latter. Full response to the B-52 required evolution of Soviet air defenses from point defense to netted broad area defense systems and from sole dependence on ground-based radars to a combination of ground-based and airborne radars. This total response cycle required twenty to forty years as contrasted to eight to fifteen years required for B-52 development and fielding. Thus, the B-52 program is an excellent example of a U.S. initiative that forced the Soviets into a responsive mode and huge expenditures to maintain an overall competitive posture. The Soviets historically have historically spent about three times as much on their air defenses as the United States spent on its bomber force.[8]

Increasing formality in the weapons systems acquisition process has eroded the U.S. ability to effect such technical breakthroughs in systems to be widely deployed. The Packard Commission recognized this problem and recommended a number of corrective actions.[9] One consequence of the management environment, as viewed by the Packard Commission in 1986, was unreasonably long acquisition times for major weapons systems and obsolete technology in fielded equipment. In addition to streamlined acquisition procedures, the commission recommended high priority for building prototypes and the utilization of prototypes in initial operational testing in order better to assess their military potential and estimate their full-scale development cost.

If one considers the three B-52A aircraft as operational prototypes, then the B-52 program reflects the wisdom of this approach, since operational feedback significantly improved the design of each subsequent model. The B-52 program, however, demonstrates the practicality and wisdom of going further than the Packard Commission recommendations in committing to initial quantity production (B-52B) prior to operational prototype testing (B-52A). Such a policy is warranted when the system either can provide a major and enduring U.S. advantage in the long-term military competition or is needed to counter an actual or potential Soviet decisive advantage. Both the Minuteman and Polaris/Poseidon programs are other examples of successful, rapid development and fielding of major weapons systems incorporating new technology applications. To carry the parallel further, both the Minuteman I and the Polaris A-1 were in operational use for a limited time period, but served as realistic operational prototypes for subsequent models of the weapon system.

The Packard Commission recommended the streamlining of acquisition organization and procedures as a major step in shortening the acquisition cycle. The B-52 program is a good example of the feasibility of shortening the acquisition cycle if such streamlining were accomplished both in form and in spirit.

The Packard Commission also stressed the importance of applying new technology to improve military capability and using prototype hardware to begin operational testing. The B-52 example is relevant to the recommendations.

Another recommendation of the Packard Commission dealt with the balance between cost and performance, implying the need for an early determination whether a sufficient quantity can be afforded in order to influence the military balance. Again, the B-52 program is a good example of technology-cost balance.

Further, the Packard Commission endorsed the congressional establishment of a minimum four-year tenure for program managers. This is consistent with the lessons learned on personnel continuity in the B-52 program.

The principles and objectives for acquisition management contained in DoD Directive 5000-1 are:

- Obtain effective design and price competition.
- Apply equal emphasis to operations suitability as to operational effectiveness.
- Ensure reasonable program stability (includes evolutionary approach and preplanned product improvements).
- Delegate authority to the lowest level, with overall program oversight.
- Develop maximum international cooperation.
- Preserve a strong industrial base, however arms-length the relationship may be with government.

In particular, the arms-length relationship is deemed to better maintain fairness in the acquisition process. While this approach is essential before contractor selection, arms-length relationships during development and production can be detrimental to the establishment of the mutual candor, respect, and trust essential to the execution of a vigorous program.

While these appear to be desirable guidelines to the acquisition process, they are silent on some of the criteria derived from the foregoing case study of the B-52.

B.8.1 Strong User Involvement

Birth-to-death user involvement is critical to program success. The recent trend to provide to the unified commanders a greater voice in acquisition decisions is a step in the right direction. Trade-offs to balance cost and performance, as recommended by the Packard Commission, need strong user inputs if realistic decisions to drop gold-plating requirements are to be made and later supported. Further, test organizations cannot substitute for direct user experience in identifying and correcting problems during testing, whether technical or operational. Placing prototypes in the hands of the users, as suggested by the Packard Commission, helps assure that subsequent production will better suit users' needs. In effect, the three B-52As were production prototypes following the B-52 design; and the fifty B-52Bs could be considered as operational prototypes, not retained in service for an extended period.

B.8.2 Technology Breakthroughs

The current policy of using proven technology, combined with long lead times, can only produce near-obsolete hardware. Major investments in weapons systems that significantly impact the military balance must incorporate new concepts and technology if they are to provide a significant increment in capability or reduction in cost. While this is particularly true for combat weapons systems, it is also frequently true for support systems where technology innovation is essential if lower acquisition and maintenance costs are to be achieved, as discussed in the Packard Commission report.

Preplanned product improvement is a concept for reducing costs and risks in weapon systems development by incorporating proven subsystems or equipments in the initial design, with the objective of later replacing these equipments or subsystems with more advanced designs. The merits of this approach should be reassessed as the cost of later technology insertion, re-integration, test, and validation in some cases will more than outweigh any initial savings or costs to pursue alternate technical backup paths in risky areas. Furthermore, risk areas are not easy to predict -- their major common feature is unpredictability. If the improvement is understood well enough at the outset to preplan its incorporation, why defer it? Retaining flexibility for incorporation of unforeseen product improvements is important, but deferring application of known technology capabilities reduces initial operational capabilities and usually will increase overall costs.

B.8.3 Design Flexibility for Growth

For major systems with long anticipated service lives, major threat and mission changes are virtually certain. Built-in flexibility for growth is critical, both in the system architecture and in physical characteristics such as size, power and payload. This subject is not specifically addressed in DoD Directive 5000-1. Costs associated with such growth can be anticipated and budgeted in long-range plans, thus helping to establish more realistic total program budgets. The B-52 was initially designed for anticipated growth, particularly as many of the enabling technologies such as jet engines were in a relative early stage of development.

B.9 CONCLUSIONS

The B-52 program demonstrates that a combination of enabling technologies can be capitalized on to create a major new military capability that contributes significantly to implementing a competition strategy. This program also demonstrates that a sound design and commitment to product improvements generated largely by the user can provide weapons or other systems with extraordinarily long service lives. Accelerated development, prototypes, service testing, and deployment strongly impact the competitive payoff. Such actions can force the adversary into a reactive or responsive mode, deflecting his energies from pursuing force initiatives that are more essential to implementation of his own strategic goals.

The Department of Defense should utilize the lessons learned from the B-52 program to ensure that adequate consideration is given to the factors that will help ensure a maximum initial contribution to U.S. goals in the military competition and continuing impact over a long-term period in planning the acquisition of new major weapons systems.

ENDNOTES TO APPENDIX B

1. See Department of Defense Directive 5000-1, "Major Systems Acquisitions" (March 29, 1982) and Department of Defense Directive 5000-2, "Major Systems Acquisitions Procedures" (March 8, 1983).

2. President's Blue Ribbon Commission on Defense Management, A Quest for Excellence, Final Report to the President (Washington: U.S. Government Printing Office, June 1986).

3. Walter J. Boyne, Boeing B-52: A Documentary History (Washington: Smithsonian Institution Press, 1981).

4. Ibid., p. 93.

5. Ibid., p. 145.

6. Nuclear Weapons Databook, vol. I (Cambridge, Mass.: Ballinger, 1982).

7. Caspar W. Weinberger, Secretary of Defense, Annual Report to the Congress: Fiscal Year 1988 (Washington: U.S. Department of Defense, January 12, 1987), p. 212.

8. Ibid., p. 66.

9. Blue Ribbon Commission on Defense Management, Quest for Excellence.

APPENDIX C

THE TECHNOLOGICAL LEVEL OF SOVIET INDUSTRY

Dennis Smallwood

C.1. INTRODUCTION

This appendix contains assessments of the state of Soviet technology in a number of key industries by British authors who are experts on the individual industries.[1] The assessments are ldetailed and highly technical at many points; the volume has over 1,000 pages. This study appears to be the most thorough attempt available to evaluate the strengths and weaknesses of Soviet industrial technology while still attempting to derive general characterizations.

Not surprisingly, the collection of assessments do not support any simple generalizations that are robust across different industries and different levels of analysis (such as research and development, innovation, diffusion, and production). Although R. W. Davies provides an overview of the volume in chapter 2, even this lengthy overview fails to portray the varieties of characterizations and lessons apparent in the individual assessments. The following pages therefore contain, first, the volume's table of contents, which includes, for most chapters, the specific questions and areas of technology addressed, and second, selective synopses of most of the chapters in the volume. The synopses are constructed primarily from direct quotations in order to maximize fidelity with the authors' intended conclusions. But they are also selective, focussing only on those areas that are most relevant to the U.S.-Soviet military competition, and thus do not represent summaries of the full content of the volume.

Unfortunately the assessments are dated, covering only the period up to 1973. Indeed, Soviet technology appears to have made major strides in some military areas in the intervening years. In general, however, glasnost has made clear the sorry state of Soviet technology and belies even the few notes of optimism found in the 1973 study. In fact, The Technological Level of Soviet Industry and the following summary make clear that the roots of the current problems of the Soviet economy have been there since the end of World War II -- the lack incentives for innovation and the rapid diffusion of technology, the strong dependence of many sectors of the economy on Western technological innovation, the organizational and bureaucratic impediments to innovation and diffusion of technology, and the deplorable state of the electronics and computer sectors of the civilian economy, with deleterious impacts its on other sectors.[2] For this reason, the following summary of the state of Soviet technology through 1973 contributes to understanding an important historical dimension of the U.S.-Soviet competition that is relevant to today's goals and strategies.

Chapter 1 provides background material; its author examines methodological questions that arise in making technological comparisons, particularly the issue of whether all-inclusive measures are valid. Chapters 3 and 11, on the iron and steel industry and the on the technological level and quality of machine tools and passenger cars, respectively, are omitted, although a brief summary of the conclusions of chapter 3 are contained in the synopsis of the chapter 2 overview. Relatively more complete synopses are provided for chapter 4 on machine tools, chapter 8 on computer technology, chapter 9 on military technology, and chapter 10 on rocketry.

C.2 VOLUME TABLE OF CONTENTS

<u>The Technological Level of Soviet Industry</u>, edited by Ronald Amann, Julian Cooper, and R. W. Davies (New Haven: Yale University Press, 1977).

Steelmaking

Continuous casting of steel

Alloy and quality steel

Rolled metal products

Automation of processes in the iron and steel industry

Conclusion

Chapter 4. "Machine Tools," by M. J. Berry and Julian Cooper.

Machine tools: stock and production

Soviet imports and exports of metalcutting machine tools as an indicator of technological level

Numerically controlled (NC) machine tools

The NC machine tool stock

Machining centres

Control systems

Some new paths of development of numerical control

Some aspects of the use of NC machine tools

The problem of technological level

Conclusion

Chapter 5. "High Voltage Electric Power Transmission," by W. G. Allinson.

Introduction

Power systems and their development in the USSR, 1917-mid 1950s

Basic features of HVAC and HVDC

Summary and conclusions

Chapter 6. "The Chemical Industry: Its Level of Modernity and Technological Sophistication," by Ronald Amann.

Some distinctive features of the chemical industry in industrialised societies

The diffusion of technology

The pattern of output of the Soviet chemical industry

The pattern of Soviet foreign trade in chemicals and chemical plant

Technological development

Patents

The first commercial production of synthetic materials

The level of research

Outstanding contributions to chemical science

Citation of Soviet chemical research

Conclusions

Chapter 7. "Industrial Process Control," by Z. A. Siemaszko.

Introduction

Analogue control up to 1970

Equipment for the 1970s and 1980s (GSP and "all-regime" RP2)

Computer control

Critical review of the technology

Chapter 8. "Computer Technology," by Martin Cave

Introduction

Soviet computer systems since 1968

The diffusion of computers

Summary and conclusions

Chapter 9. "Military Technology," by David Holloway

Introduction

Medium tanks

Intercontinental ballistic missiles

Soviet and United States ICBM programmes, 1957-75

Assessment of the level of technology

Conclusion

Final Conclusions

Chapter 10. "Rocketry: Level of Technology in Launch Vehicles and Manned Space Capsules," by Milan Kocourek

Introduction

Comparative history of Soviet rocketry

Soviet space policy

Soviet space technology

Launch vehicle building

Spacecraft building

Conclusions

Chapter 11. "Technological Level and Quality of Machine Tools and Passenger Cars," by M. J. Berry and M. R. Hill

Introduction

Western and Soviet assessments of the technological level of Soviet machine tools with special reference to quality

The quality and reliability of Soviet general-purpose machine tools

Passenger cars

Appendix 11A: Assessments of the accuracy of Soviet-made horizontal knee and column milling machines and centre lathes

Appendix 11B: Assessment of the accuracy of the major design elements of the 6M82 milling machine

Appendix 11C: Soviet-built machine tools in use in Britain

C.3. CHAPTER 2: "THE TECHNOLOGICAL LEVEL OF SOVIET INDUSTRY: AN OVERVIEW" (R. W. DAVIES)

In this chapter R. W. Davies comments on the the particular case studies that were chosen, provides an overview of their content, and discusses the problems of generalizing about Soviet technology.

Davies cites two major objectives: "to improve our knowledge of the comparative international position of the Soviet economy" and "to find out the particular respects in which Soviet technology was advanced or backward as compared with that of Western countries." (p. 35) Rather than trying to characterize Soviet technology generally, the method used is "to establish, wherever possible, the Soviet comparative position for each industry or group of products at each of the main stages of what is known in the USSR as the 'research-production cycle'" (p. 36)

The authors attempted to compare the Soviet Union with five major industrialised countries: the USA, UK, France, FRG, and Japan. Most comparisons focus on Soviet and U.S. technological levels, although many comparisons of Soviet and British technologies are also made.

Davies notes that while "most assessments ... have concluded that the Soviet contribution to knowledge is less substantial than that of the United States" it is nevertheless true that "in some important fields ... Soviet research is reported to be in advance of the West: thus the Soviet research effort on high current electron beams is 'more intensive ... than in the West', and has made a 'number of significant advances.' In one field directly relevant to our own project, chemical fibres, several foreign specialists have praised the quality of Soviet research." (p. 38) Thus one is limited to the "very general conclusion that Soviet scientific research tends to be smaller in quantity (in terms of equivalent populations) and lower in quality than in the United States and some other Western countries." (p. 39)

The iron and steel industry is examined in chapter 3, which is not included among our chapter synopses. We omit it because, as Davies notes, the industry is "correctly described as 'traditional,' both because it is a long established industry and because the cost of research and development is a relatively small proportion of total costs." (p. 40)

The iron and steel industry has played a major role in Soviet industrialization, however, and the findings from chapter 3 are briefly summarized here. Davies notes the long tradition of native iron and steel research and development in the USSR and the high priority the industry has always received. "This, then, is an industry which might be expected to be in the forefront of world technology." Indeed, "although the Soviet industry has lagged in scrap production methods, it has remained generally in a leading position in traditional methods of production" in steelmaking. (p. 40) Davies concludes with the observation that ever since the 1940s, the USSR "has been generally in a leading position in scaling-up traditional large-scale iron and steel processes; and it developed the new processes at approximately the same time as the United States, West Germany and Japan, though later than the Austrians.... The Soviet record has been much less impressive in the other major branches of steelmaking." (p. 40)

The machine tool industry, discussed in chapter 4, "offers a second example of a more traditional industry in which the introduction of new technology has been given high priority by the Soviet authorities over a long period.... Sufficient information has been available to show a continuing lag behind the United States and the other major countries, which grew in the 1960s and has been somewhat diminished only in 1971-73.... Soviet failure to keep up with some recent major developments appears to have been due primarily to the weakness of the control systems; this in turn was a result of the backwardness not of the machine tool industry itself, but of the science-based electronics industry." (p. 41)

"The electric power industry (chapter 5) provides our third example of a traditional high priority industry in which the Soviet Union has a long research and production experience.... The Soviet Union has been notably successful in developing high-voltage alternating current (HVAC) and moved into a leading position in world technology in the middle and late 1950s.... In two major recent developments the Soviet Union has also on the whole retained a leading position" (high-voltage direct current, and ultra-high-voltage alternating current). (p. 42)

"In the chemical industry (chapter 6), an intermediate industry in the sense that it has a high proportion of R and D in total costs than in the traditional industries, but less than in the high technology industries, a substantial effort has long been devoted to research, but the industry itself was, according to all Soviet accounts, relatively neglected until about 1958: since then it has been afforded a much higher priority. The evidence assembled in chapter 6 below about pilot plants and first commercial production reveals no diminution whatsoever in the lag behind the more advanced countries in the last 20 years." (p. 42)

"The Soviet Union alone in this entire group of countries has never been the original innovator of a major plastic material or chemical fibre." (p. 43)

In commenting on chapters 7 and 8 which deal with industrial process control and computer technology, respectively, Davies notes that "our findings for the science-based industries which have been established since the Second World War were similar" to those for the chemical industry. In general, "the lag of the USSR has not been reduced since the 1950s in respect of computer hardware ... though a substantial improvement has occurred in software, from a previous low level." For industrial process control instruments, where Davies notes the priority is lower, the lag is even greater, although: "One original Soviet innovation was the USEPPA pneumatic system, in 1964 the most advanced pneumatic system in the world. This provides an interesting example of an innovation resulting from industrial demand in circumstances of technical backwardness.... The continuing lag in both computers and control instruments is in turn largely due to the backwardness of the Soviet electronics industry." (p. 45)

Military technology and rocketry (chapters 9 and 10). As examples of high technology industries -- those in which research and development amounts to 10 percent or more of the total cost of production -- on which the USSR places very high priority, the authors choose space rockets and ballistic missiles. In the case of space rockets, "thrust power has (with some qualifications) been taken as an indicator of the technological level of the launch vehicle. The USSR was clearly in the lead from the launching of Vostok in 1957, followed by Proton, until 1967 when the United States launched Saturn V.... Lead has given way to lag. In manned spacecraft, too, the Soviet Union has lost the leading position which it temporarily obtained in 1961." (p. 45)

Noting that Soviet weapons development is an ultra-high-priority area and that it is commonly assumed that the Soviet Union has been uniformly successful by international standards in the experimental development of weapons, while being less successful in technology which is not directly military, Davies observes that interestingly "the studies undertaken in chapter 9 below have, with some exceptions, unexpectedly revealed a pattern not dissimilar to that in civilian industry." (p. 46)

Regarding tanks, it appears that Soviet tank technology "lost its wartime lead by 1950, regained it between 1950 and 1960, and then 'between 1960 and 1970 lost its marked superiority to a new generation of Western tanks.'" (p. 46)

"The position was in some respects similar in the case of Intercontinental Ballistic Missiles. In the 1950s several striking examples occurred of Soviet 'firsts'.... In the 1960s, however, on available evidence the Soviet rate of innovation lagged behind that of the United States.... The Soviet lag has ... been compensated by the massive use of simpler technologies." (p. 47)

Similar patterns have been observed in other studies, as in a RAND Corporation analysis of twenty-eight Soviet turbine engines, which concluded "that after a period, up to about 1955, in which Soviet engines were on the whole technically more advanced (though with a shorter endurance) than those of the United States, American engines have been consistently superior to those of the USSR, and that the gap gradually widened between 1955 and 1971, the concluding date of the analysis." (p. 47)

On the other hand, the situation in naval warfare "appears to vary considerably from technology to technology." (p. 47)

Overall, Davies concludes that "the comparative level of Soviet experimental development and innovation thus varies considerably between the different technologies we have studied." Davies maintains that in the traditional industries, the Soviet Union generally occupied a leading position by the middle 1950s "and that position has on the whole not been lost in the 20 years covered by our study." But in the science-based industries, including both the long-established such as chemicals and the newly established, "the considerable Soviet lag in the middle 1950s ... has not been reduced in the past 20 years: in the chemical and control instruments industries it may even have increased. There is also some evidence of a relative decline in the Soviet technological level in high priority high technologies: for instance, in launch vehicles, spacecraft and even certain weapons, such as military turbine engines." (p. 47)

Turning to questions of the diffusion of new technology, Davies discusses Boretsky's study of comparative changes in Soviet and U.S. technologies for the years 1940-1962. Although citing a conclusion that Boretsky's assessments were generally unsuccessful, Davies states that "a number of his individual indicators ... provide very useful pointers to comparative changes," and generally accepts "Boretsky's general conclusion" that "'the rate of technological change' was faster in the United States than in the USSR during this period." (p. 48)

The Soviet post-war reconstruction -- during which the devastated Soviet economy grew at rates comparable to that of the United States -- was based "to a considerable extent on pre-war technology." Davies notes this "dichotomy between technological development and industrial growth when considered in relation to the United States." But starting in the middle 1950s, "in terms of Boretsky-type indicators we begin to enter a new era. In the last seven years of Boretsky's study, 1955-62 ... a definite if small improvement took place.... We have extended our calculation of Boretsky-type indicators to 1973, and ... the relatively more rapid Soviet technological advance on the whole continued." (p. 48)

These indicators of technological change are measures such as the rate of growth of:

- Consumption of electric power per production worker
- Maximum capacity of steam turbines for electricity production
- Length of HVAC transmission lines (over 400 kV)
- Proportion of aluminum and magnesium in total basic metal consumption
- Percentage of steel output by electric arc or oxygen process
- Percentage of metalforming machine tools in total stock of metal working machine tools
- Output of NC machine tools
- Output of synthetic resins and plastics
- Output of chemical fibers
- Number of telephones in the economy

"These relative improvements in technology coincided with a decline in the rate of growth of Soviet industrial production.... In general it might be argued on this basis that the relative growth rate has produced a certain convergence in the economic behavior of the Soviet Union and other countries. Notable exceptions are Japan, which has outpaced the Soviet Union and all other countries ... and the United Kingdom, which has lagged badly." (p. 52)

"In spite of this 'convergence,' the Soviet pattern of diffusion of new products and processes is substantially different from that in the industrial capitalist countries.... This reflects a more conservative pattern of industrial production in the Soviet Union." (p. 52)

"A similar pattern has appeared within each of the industries we have studied.... While there are some exceptions,... this slower pattern of diffusion is characteristic of the chemical industry generally.... A similar pattern with some variations appears in some of the sub-branches of industry examined in this volume.... Certain exceptions may be found to the general conservative pattern. The production of numerically controlled machine tools, which lagged behind that of other industrialized nations in the 1960s, has risen extremely rapidly since 1970." (p. 54)

"Space rockets are also in part an exception to the general rule.... In the pattern of distribution of launches between rockets of different generations and thrust powers, the normal differences in diffusion of new technology between the United States and Soviet Union are not quite so marked.... The Soviet pattern was more conservative than that of the United States.... The conservative pattern of production also predominates in the examples of weapons production studied ... below." (p. 57)

"It may safely be concluded that the rate of diffusion of new products and processes in terms of their share in total output is lower in the USSR than in the other industrialized countries. This is evidently partly because existing production capacity is withdrawn from use much more slowly than in the West.... This low rate of capital retirement in Soviet industry generally might be economically defensible in certain cases in view of the continued availability throughout this period of adequate supplies of fresh labour.... But technological conservatism may often be a result of the economic mechanism, which provides little encouragement to the diffusion of new technology." (p. 58)

"Western studies of Soviet technological development ... have commonly assumed that research is more advanced than experimental development, that development is more advanced than innovation, and that the Soviet economy is least advanced in the diffusion of new technology.... Our studies of the traditional industries, including high priority civilian industries, have on the whole confirmed this generally accepted stereotype." (p. 59)

"In the traditional industries the diffusion of new technology in the Soviet Union is slower than experimental development and innovation, in comparison with major capitalist countries. In the science-based industries, the situation is more varied, but in some important cases, such as nuclear power, diffusion has certainly been slow.... Evidently the transition from experimental to genuine full-scale production (i.e., from development to innovation) may often be as difficult for the Soviet economy as the transition from innovation to diffusion." (p.61)

"In some cases ... the lower technological level appeared to be due to insufficiently flexible attention to alternative or more recent processes at the R and D stages.... In iron and steel, as in many other major industries, research and development are concentrated into national units under ministerial control, a common technological policy is enforced at a national level, and complaints are frequently found that experimentation is restricted by the monopoly position of the major R and D organizations." (p.62)

"A further conclusion of several of our studies has been that at all stages of the research-production cycle Soviet industry display a particular aptitude for improving and scaling up existing processes, rather than for bringing basically new processes and products into full-scale production.... A RAND study of aircraft design procedures ... commends the efficiency of these and related Soviet R and D arrangements, which enable more aircraft to be taken to the test and production stages than in the United States, with smaller teams of designers. Whether or not the economical conservatism of the Soviet approach should be preferred to the expensive innovationary dynamism of the United States must remain an open question. The RAND study agrees that the propulsion and avionics systems in Soviet aircraft are inferior to those of the United States; and our chapter on the Soviet space programme similarly concluded that the Soviet pattern of innovation and philosophy of design were responsible for the loss of tempo and of technological lead in relation to the United States.... It is interesting to note that an 'add-on' approach is seen by several studies to be a characteristic of Soviet technological development as distinct from the 'jumpiness' of the United States development." (p. 63)

"In the case of computers, Richard Judy concluded in the late 1960s that: 'technology in the Soviet Union is virtually entirely imported from the West'.... According to Judy virtually all innovations have first occurred in the West and been transferred to the USSR either through examination of the Western technical literature or through importing foreign computers." (p.65)

"The chemical industry is the outstanding example of Soviet dependence on foreign technology.... Plant for all the major plastics and synthetic fibers has been imported, largely from Western countries." (p. 65)

"Soviet reliance on foreign technology has on the whole tended to increase in the course of the past 20 years." (p. 65)

"In most of the technologies we have studied there is not evidence of a substantial diminution of the technological gap between the USSR and the West in the past 15-20 years, either at the prototype/commercial application stages or in the diffusion of advanced technology.... There is some evidence that the position has improved in the past four or five years in certain respects: NC machine tools provide an important recent example of rapid diffusion, and quality of production in a number ofindustries has recently begun to improve. Finally, the recent depression in capitalist countries may well be inhibiting diffusion of new technology in the West and thus providing the Soviet Union with a better opportunity to catch up." (p. 66)

C.4 CHAPTER 4. "MACHINE TOOLS" (M. J. Berry and Julian Cooper)

In comparing the Soviet and American stocks of machine tools, Berry and Cooper note the striking fact that "the Soviet Union has over one million more metalcutting machines than the United States overall, and in the case of those under 10 years old has almost 1,300,000 more, or two and a half times as many." Furthermore, "the American stock is likely to include a significant proportion of machine tools smaller and simpler in design than those in the Soviet stock." (p. 139)

Yet even with its huge stock of machine tools, "the bulk of the substantial and increasing production of machine tools goes to increase the size of the stock" and "demand far exceeds supply" in the Soviet Union. The discrepancy with the United States is attributed to "the low general level of utilisation." (p. 143).

Barry and Cooper note that in the Soviet Union, "demand is high for 'non-progressive' universal machines with a wide range of speeds, feeds, etc., which can be used for a variety of tasks.... 'Progressive' demand is represented by those factories and industries which want advanced machine tools -- the ballbearing industry and the motor industry are two good examples. These machines are less popular with the machine tool industry and where possible it often tends to try to avoid producing them." (p. 144)

Apparently the central authorities, operating through Gosplan, attempt to counter "the technological conservatism of industry" and impose their own policy regarding the composition of the machine tool stock, "largely guided, it would seem, by the experience of capitalist countries." (p. 144)

But attempts to modernize are difficult: "Palterovich cites unsuccessful attempts to change the technological structure of machine tool output by a sharp reduction in the number of lathes produced and an increase in the number of grinding and boring machines. The change in output failed to alter the demand structure: a shortage of lathes resulted, while there was no increase in demand for the more progressive machines." (p. 145) Some writers argue that "the size and shape of the machine tool stock are essentially a symptom of the technological level of industry as a whole, rather than a cause. Thus, in the Soviet context, because of low quality casings it would probably be unwise to reduce the output of equipment used for machining these and increase the proportion of finishing machines." (p. 145)

Berry and Cooper note that the machine tool industries of Western countries have tended to specialize to some degree, but "in the case of the Soviet Union the situation is rather different, since self-sufficiency was from the beginning a major element of Soviet policy." But "from the mid-1950s ... Soviet imports of machine tools began to expand.... Soviet purchases in the West have increased dramatically in value terms and in 1973 accounted for almost 50 percent of imports (by value)." (p. 147)

Correspondingly, "the Soviet Union has a long way to go before establishing itself as a major seller of sophisticated machine tools, although it has had some success with its universal machines. Surprisingly, it has failed to emerge as a major supplier to the developing countries." (p. 159)

Berry and Cooper examine at length the adoption of numerical control, which permits small and medium batch production to be automated. Numerical control of machine tools requires interaction between machine tool makers and the electronics industry, and Soviet lags in electronics appear to have critically slowed their adoption of numerical control.

While the U.S. Air Force, seeking methods of machining intricate aircraft components, initiated research on numerical control in 1947, "the Soviet Union was relatively well advanced in the initial stages of development of NC. The technical level of its NC machines was certainly well below the level attained in the USA by 1958, however," and "during the mid-1960s, progress in the USSR was relatively slow compared with other leading machine tool building countries and official concern was evident by 1968 when the government intervened to accelerate the rate of development." (p. 163)

Whereas "in capitalist countries a very prominent role in the development of NC has been played by the electronics industry itself ... in the USSR, at least in the early years, the situation appears to have been much less satisfactory; poor cooperation between control systems production and the machine tool industry was frequently reported." (p. 164)

Berry and Cooper argue that "the relative backwardness of the Soviet electronics industry itself, in particular those sectors concerned with computing technology" slowed progress in NC, but also that in the late 1950s and early 1960s, a "campaign ... for highly adaptable unit-construction machine tools" which would allow automation using traditional methods, reduced pressures for the spread of NC. (pp. 164-5)

"A major turning point in the development of NC machine tools in the Soviet Union was a government decision of April 1968. This called on the Ministry of the Machine Tool and Tooling Industry and the Ministry of the Aviation Industry to try to significantly increase the output of NC machine tools in the years 1969-70.... During these years the foundation for future growth were laid, and the subsequent increase in the output of NC machines is impressive.... In terms of units built per year the Soviet Union now occupies first place in the world, having overtaken the USA in 1971. (pp. 167-68)

"Since 1968 the policy of the Soviet industry has been more outward-looking. Cooperation agreements have been entered into with French, German and Japanese firms in the field of control systems." (p. 170)

While in 1970 the Soviet NC machine stock was one tenth that of the USA, and also smaller than those of the United Kingdom, Japan, and West Germany "estimates suggest that the Soviet stock is now over twice those of Japan, West Germany, and Britain." (p. 176)

"In view of the role of the aviation industry in the production of NC machine tools in the Soviet Union, it seems highly probably that the aerospace sector possesses a large proportion of the total NC stock." (p. 177)

"Even since the 1968 decision there is evidence that in the Soviet Union the development of control systems has not kept pace with the demands of the machine tool industry and that in the creation of new systems there has been inadequate coordination between systems builders and machine tool builders.... The multiplicity of organisations in NC development in the USSR in the early years, the inadequate control from the centre and the policy of independent design work in isolation from foreign practice, all resulted in a proliferation of programming media and coding systems.... Efforts are now being made to achieve compatibility with Western systems.... In developing NC control systems, the Soviet Union has designed and built its own systems rather than resorting to the use of existing designs. In recent years, however, there has been an increased willingness to cooperate with foreign control systems firms and agreements have been reached between Soviet industry and firms in a number of countries." (p. 184)

"There are two types of control systems, point-to-point (or positioning) and contouring. The more complex contouring systems are used for the control of milling, turning, or grinding operations.... Soviet technical policy has been one of giving priority to the relatively more complex contouring systems, but at the same time emphasis has been placed on a simpler form of this type of control, less complex from the point of view of electronics, and suitable for use with batch produced general-purpose basic models. It is therefore probable that the average level of accuracy of Soviet NC machine tools is somewhat lower than that typical for British or American machines." (p. 186)

"The programming of NC machine tools is a difficult and time-consuming operation.... On average it takes about 30 hours to prepare the input tape for one-hour's machining.... Computerised programming for NC requires suitable programming languages and considerable research has been undertaken in the West.... The USSR appears to be more backward in this area." (p. 188)

"In the future machine tools will be looked at as the output elements for computers.... CNC (computerised numerical control) originated in the United States in the late 1960s and was quickly taken up by the Japanese industry.... In the Soviet Union CNC appears to be still at the experimental stage, but suitable small computers for use with machine tools are now in production.... It seems unlikely that CNC will be widely adopted until the production of mini-computers has been mastered on an industrial scale and at a cost competitive with that of conventional control systems.... CNC is a possible future area of CMEA (Comecon) collaboration." (p. 190)

"Some Soviet writers consider that the high prices of NC machines compared with the basic machines they replace hinder their diffusion.... Given their high initial price, the organisation of multi-shift work for NC machines is particularly important. In the USA shift work for NC machines is widespread.... In the USSR desirability of multi-shift operation is acknowledged, but it is frequently not achieved; about 80 per cent of NC machines in the USSR are used only in a single shift. A major reason for this poor utilisation is the lack of sufficient trained NC machine operators and specialists. According to Miroshnikov the provision of training for NC personnel is inadequate." (p. 193)

"In examining the development of NC machine tools in a number of countries, one is struck by the existence of distinct paths of technical development, shaped both by social and economic circumstances, and by more directly technical factors. Thus in the United States and Britain the initial development of NC was promoted by the need to satisfy certain specific requirements of production for military purposes.... In Japan a very different path has been followed, with the building of NC machines for the general engineering user.... The Soviet path of development appears to have combined elements of both the US-British and the Japanese approaches. An advanced sector has developed complex, high precision machines to meet the needs of the aviation industry and other high priority users, but at the same time a major emphasis has been placed on the batch production of simpler, general-purpose models.... It is not possible to make meaningful assessments of the 'level' of different countries in terms of the path of development followed.... In the case of the USSR in the early years the bias towards relative technical simplicity may have been due to the limitations of the electronics industry." (p. 194)

"Our evidence strongly suggests that until recently [the control system] has been the major weakness of Soviet NC technology.... Soviet industry was slow compared with other countries in making the transition from valves to semi-conductors, and from the latter to integrated circuits.... The fact that the Soviet industry has found it necessary to conclude a number of agreements with Western firms indicates the existence of a lag which the industry is anxious to overcome.... The well attested unsuitability of some systems for use under industrial conditions and the complaints of poor reliability point to design and construction weaknesses. Problems are now being overcome.... The Soviet industry was rather slow compared with the USA and Japan in developing third-generation computers for CNC and DNC. While such equipment is now in production, its cost is probably high and the volume of production inadequate. Nevertheless, the Soviet industry is undertaking interesting work in the creation of automated machining systems." (p. 197)

"During the 1960s at least, Soviet industry was evidently not very successful in handling the organisational problems associated with NC machine tools, in particular those of securing skilled workers and specialists and ensuring multi-shift use of the machines.... Today the machine tool industry itself appears to be playing a much more active role in promoting effective use of NC machines throughout industry and with the wider availability of NC equipment it is probable that utilisation is in fact gradually improving. The programming of NC machines also appears to have been backward. The reliance on manual programming methods indicates shortcomings in computer utilisation; these are now being overcome with the development of computing centres with time-sharing capability." (p. 198)

Berry and Cooper summarize their conclusions as follows: "In the initial period when control systems were based on an established radio-electronic technology, Soviet performance compared quite well with that of Germany and Japan, but lagged behind Britain and also, to quite a considerable degree, behind the USA, the pioneer of NC technology. During the 1960s the rate of diffusion and the technology lagged behind the achievements of the other main NC producing countries and the Soviet industry generally fell behind. This lag appears to have been associated with problems of developing suitable control systems, based at first on semi-conductor technology and later on integrated circuits. This widening gap gave rise to official concern and prompted government measures in 1968. Since 1968 intensive activity has substantially changed the situation. In terms of diffusion the Soviet industry has overtaken the other main producing countries, although this achievement was facilitated by a downturn in the rate of growth of output in capitalist countries.... The general state of the Soviet computer industry has imposed some constraints on progress in this field, but suitable computers have now been created and with intensified CMEA cooperation, in particular with the GDR, it seems likely that the Soviet machine tool industry will not only keep abreast of developments, but may move ahead in such areas as the creation of large automated production systems. This case study indicates that in the conditions of the Soviet economy technological lags can be very quickly narrowed and overcome once their existence has been acknowledged and priority granted to their elimination." (p. 198)

C.5. CHAPTER 5: "HIGH VOLTAGE ELECTRIC POWER TRANSMISSION" (W. G. ALLINSON)

Allinson notes that while the USSR had been a technological follower in high voltage (HV) power transmission before the fifties, by the early sixties it ranked "roughly equal with ... the leading countries." Allinson attributes this progress to "geographical and economic conditions prevalent in the USSR as compared with some other countries." But this progress has slowed; by the later 1960s, the USSR has "tended to be overtaken in certain respects by some Western countries." (p. 199)

The technological leader in this area has not been the United States, but Sweden: "By 1959, the diffusion of higher voltages in Soviet power systems was measurably greater than in American systems. Furthermore, the USSR was in second place, "both as regards the diffusion of higher voltages, and as regards the balance between network lengths at HV and station capacity." Regarding innovation in HVAC, the Soviet Union also emerged as a leader by the sixties and was the first to introduce 500 kV: "The little available evidence would seem to indicate that the USSR was largely self-sufficient in its development of the equipment for both 400 and 500 kV.... It must be presumed that the USSR was able to manufacture the necessary equipment of its own accord. This conclusion is strengthened by the Soviet Union's own insistence that it had the facilities to do this." (pp. 222-23)

Sweden and the USSR also emerged as leaders in the field of HVDC: "In the Soviet Union its introduction stemmed from a need to gain experience with a view to its possible application in helping to solve energy and population distribution problems.... In the area of convertor equipment development, essential to HVDC, what evidence there is indicates that the USSR was able to develop the necessary HVDC equipment of its own accord." (p. 223) Allinson summarizes: "Thus, the USSR moved by 1960 from a position in which it was a follower of technological trends in the HV field to one in which it ranks among the leaders, both in AC and DC fields. This is not surprising to the extent that HV technology is one area in which a country's performance as an innovator is to a large degree a function of its geographical and economic problems. Given the Soviet goal of, and effort put into, electrification, and given the country's size and energy distribution problems, the pressure was greater than in most countries to adopt higher HVAC voltages and to move to HVDC. In the 1960s, however, the Soviet Union has in several respects lost its leading position in the development and diffusion of HV technology." (p. 224)

C.6. CHAPTER 6: "THE CHEMICAL INDUSTRY: ITS LEVEL OF MODERNITY AND TECHNOLOGICAL SOPHISTICATION" (RONALD AMANN)

Amann argues that the chemical industry is a particularly interesting case study because its "economic and organisational characteristics" are "fundamentally different from those of manufacturing industry as a whole and constituted the hallmark of a high technology sector. The chemical industry is extremely heterogeneous in its range of products and technologies, it is capital intensive and wages form a relatively low proportion of running costs, white-collar workers are a relatively large component in total employment, the industry is research intensive (in terms of R and D manpower and expenditures), its product assortment is subject to rapid renewal and the rate of growth of the chemical industry tends to outstrip the overall rate of industrial growth." (p. 239)

Because of these factors, Amann asserts that the chemical industry is of central importance in the economies of advanced countries, and that "the Soviet chemical industry follows this general pattern fairly closely, though less emphatically in terms of some indices than others.... It would be difficult to form any general impression about the technological level of a nation which purported to be highly developed, without taking the contribution of the chemical industry into consideration.... How Soviet chemical technology stands in relation to that of these other countries is an important element in the broader study of innovation." (p. 239)

"In the years following the Second World War the USSR has emerged as a major producer of chemicals and chemical products and it now possesses the second largest chemical industry in the world.... The growth profile of the Soviet chemical industry during the 1960s resembles that of chemical industries in Western countries.... In absolute terms the Soviet Union has made rapid progress in the more traditional sectors of the chemical industry but its performance in the more sophisticated sectors has been less impressive. A rough impression of the overall level of sophistication in various countries ... does suggest ... how far the Japanese and West Germans have depended on the most advanced areas of chemical technology for the course of their development during the 1960s and the extent to which the Soviet chemical industry is still rooted in traditional technologies despite its large overall size." (p. 257)

Amann asserts not only that the USSR lagged behind Western chemical technology, applying the criteria used earlier in the paper, but that "its chemical industry is situated at a wholly different stage of development.... The output profile of the Soviet chemical industry as a whole is slanted towards relatively simple technologies.... Large quantities of uncomplicated end-products, such as fertilisers, are produced in the USSR. The Soviet Union also produces large quantities of basic organic and inorganic chemicals (particularly the latter), but the quality, range and quantity of these is not sufficient to prevent large imports of basic chemical reagents, in addition to more sophisticated products such as plastics and manmade fabrics. The pattern of trade is quite unlike that of the most advanced Western countries, which are all net exporters of chemical products, especially of those requiring complex technological processes. In the key sectors of organic chemicals and macromolecular compounds, the Soviet level of significant inventive activity appears to be far lower than that of Western countries. Moreover, the USSR tends to lag behind these countries in bringing important synthetic materials to commercial production and, in some cases, Western assistance has been decisive in bringing this production about. However, irrespective of whether these achievements could be credited to the USSR or not, the typical pattern has been for initial production to be followed by substantial purchases of process plant from Western countries. Indeed, during the 1960s, the Soviet Union has supplied only about two thirds of its own process plant for the chemical industry as a whole." (p. 297)

Amann also comments on the quality of Soviet research and development, and concludes that "compared with most Western countries, the Soviet research effort and total output of scientific papers are probably considerable, but the overall quality is such that it does not appear to have made a proportionate impact on world science. Also, the Soviet research effort does not seem to have generated any really important and original innovations, which could be successfully scaled up to mass production. Thus, there is a consistent pattern of backwardness highlighted by all the criteria adopted in this study." (p. 297-98)

C.7 CHAPTER 7. "INDUSTRIAL PROCESS CONTROL" (S. A. Siemaszko)

While the control and instrumentation industry might appear insignificant as a fraction of the Soviet national economy, its actual significance is recognized. Brezhnev declared at the XXIV Party Congress that instrumentation and electronics together formed the basis for development by other industries. Siemaszko notes that "control is also closely related to management and cybernetics which are playing a vital role in the current attempt to modernise Soviet economic organisation.... As is appropriate for a leading industry, the control and instrumentation industry has always held a high, if not the highest, position in the main success indicators: growth of output, plan fulfilment and growth of labour productivity." (p. 328)

Siemaszko points out that even though the advanced economies had already turned away from pneumatic control systems in favor of electronics, in 1959-1960 "the Soviet Union embarked on a large project for a novel pneumatic control system which became known as USEPPA.... Professor Rosenbrock commented:

> 'The effort being devoted in the USSR to the theoretical and experimental investigation of pneumatic elements was surprising. It was taken by some to indicate that Russian solid-state electronic devices are not yet freely available (or perhaps not yet very reliable).'

Indeed, it is hard to find any other raison d'etre for USEPPA, except that it was meant as a second-best alternative, enforced by the non-availability of semiconductors." (p. 347-48)

Even though the USSR has a planned economy, Siemaszko notes that it has "five major systems (two electronic, one mixed and two pneumatic) and at least six minor ones ... in current production" which, he asserts, "reflects the well-known Soviet tendency to dissipate resources. If there was a market economy in the USSR, quite probably the number of control equipment systems would have been no higher. Moreover all the equipment in current production is of old design, and no new system has been launched since 1964. None of the electronic systems in current production is fully transistorised. Equipment used for the power industry (the largest user) is particularly antiquated." (p. 350-51)

Siemaszko concludes that the situation in 1970 was most unsatisfactory from the Soviet point of view, in that:

> "1. The control and instrumentation industry failed to adjust itself to the transistor age, and has been unable to reap the full benefit from the revolutionary technological breakthrough.
>
> 2. The State System of Instruments (GSP), which 10 years earlier carried high hopes of ending the technical backwardness, proved a failure.
>
> 3. No new system had been launched since 1964.
>
> 4. The largest user -- the power industry -- remained firmly 'hooked' to an obsolete range of equipment, belonging to the 1950s.
>
> 5. Most control systems in production (pneumatic and electronic without a unified signal) were incompatible with computer management and therefore could not be incorporated into ASU [automated management systems] schemes." (pp. 351-52)

Although Soviet reviews and statistics at the beginning of the 1970s depicted satisfaction and confidence, Siemaszko believes that "the realisation of the true situation must have been there, because positive measures were taken to remedy it, by launching a far-reaching plan for the development of a new stage of the State System of Instruments, subsequently referred to in the present work as GSP3.... Unfortunately it appears ... that this plan for radical innovation has been upset by the power industry opting out of it, to seek a slower road to modernisation." (p. 352)

Siemaszko argues that this program was well conceived, and correctly identified "the areas where innovation is of paramount importance.... A speedy assimilation of all these principles in production, coupled with phasing-out the obsolete systems, could have wiped out the traditional lag of the Soviet control and instrumentation industry." (p. 353)

The refusal by the power industry, the largest user of process control equipment in the USSR, to participate in the program seriously undermined it. Its refusal may have been because the industry "achieved complete standardisation in the range of control equipment known as VTI or MZTA, which is largely a product of the immediate post-war years, and therefore highly obsolete. There has been evident unwillingness to depart from this splendid position of complete standardisation. All innovation was effectively blocked" (p. 357)

"The first digital computing devices entered industrial service in about 1960 as processors and loggers of data mainly for continuous process, particularly in the chemical industry. This development was parallel to the West, but while in the West the data logger quickly disappeared as a separate 'breed' (except for a few small machines) ... in the Soviet Union it still survives.... Such a computer cannot really be regarded as a technological asset, since it is incompatible with nearly all other digital equipment.... On the whole, therefore, there was disillusionment with the application of computers to the direct control of industrial processes, and cybernetics pointed the way to ASU." (p. 359-62)

Siemaszko cites case studies comparing Soviet and British systems which illustrate that on selected projects the Soviet Union can achieve comparable rates of development and assimilation. But Siemaszko still concludes that "the general rate is close to that of the GSP, i.e., slower than the UK by a factor of approximately 2.5." (pp. 364-65) Furthermore "the UK lags behind West Germany and USA in the control and instrumentation industry, although the lag is not very pronounced. This means, however, that in general the Soviet lag with respect to these two countries is greater than with respect to the UK." (p. 366)

Siemaszko proceeds to examine Soviet lags with respect to the U.K. Concerning analog control in then current production, Siemaszko states: "Despite continuous exhortations for at least two decades, the overall level of automation in process control in the USSR appears to be quite low, at least in the power industry.... That the level of automation in general in the USSR is hardly rising at all, is shown by the fact that the percentage of workers engaged on non-automated manual operations decreases only very slowly, and the absolute numbers of such workers actually increase." (p. 366)

Continuing to compare the USSR with the UK, Siemaszko's primary conclusions include:

> "Slow Innovation. In control systems innovation is extremely slow, almost nonexistent."
>
> "Standardization. Apart from the power industry, the Soviet level of standardisation is extremely low, and far too many mutually incompatible, obsolescent and downright antiquated systems are in production." (p. 368)
>
> "Reliability. The current Soviet standard calls for a mean time between failures (MTBF) of six years per 'instrument'.... In British practice an MTBF of 50 years is quite normal." (p. 368)

"Environmental conditions. Soviet instruments are designed to meet less stringent environmental conditions." (p. 368)

"Amplifying elements. In the Soviet equipment, thermionic valves and magnetic amplifiers are still in full use; there are some transistors, but no fully transistorised system; as far as it is known, there are no integrated circuits in use in any of the standard production equipment." (p. 369)

"Electrical equipment for hazardous atmospheres. The Soviet Union still relies mainly on explosion-proof enclosures and purging; there are very few intrinsically-safe designs. (p. 369-70)

Siemaszko summarizes by concluding that "there is very little that the British control and instrumentation industry could learn from the Soviet side." While the Soviets led the United Kingdom in a few minor aspects, "it must therefore be concluded that in this industry Soviet lags far exceed the leads.... The members of Study Group 5 were probably correct in 1970, when they assessed that in analogue equipment the Soviet Union lagged behind the UK by some 10 years. Similarly a well informed article in the Economist assessed that Soviet computers were 10 to 15 years behind in quality and design.... There is no indication that the gap has been diminishing since the early 1950s; on the contrary, it may well be increasing.... It would appear that in approximately two-and-a-half decades the Soviet lag increased by 13 years." (pp. 371-72)

C.8. CHAPTER 8: "COMPUTER TECHNOLOGY" (MARTIN CAVE)

Cave's comparisons concentrate largely on the performance of the central processing unit, taking as a measure the maximum number of operations per second of which a computer is capable. But Cave admits that "unfortunately, this measure does not have the satisfying properties of objectivity or even of accuracy that it may appear to have." (p. 379)

Cave notes that "it can be argued that the USSR and Western countries are in two different stages in the development of computer systems. In the USSR, hardware is still of primary importance, while in Western countries customers' software needs largely determine the shape of the hardware in a system." (p. 381)

In the Soviet Union "the most important series of third generation computers, known variously as the Edinaya Sistema (Unified System) or Ryad series, is the result of a programme of cooperation within CMEA (Council of Mutual Economic Assistance).... One of the objectives of the scheme has been to increase the level of specialisation of the member countries in computer production.... While there is specialisation between models, there is little within the peripheral equipment of each model taken separately." (p. 385) Cave asserts that "the Edinaya Systema series is one of those cases, discussed in the last part of this chapter, where the range is very similar to an earlier American range, in this case the IBM 360 series, which first appeared in 1965.... The ES series has come in for some harsh criticism. Some of this concerns shortage of peripherals and the software lag, but Zhimerin ... noted early in 1974 that the core storage of the ES series was inadequate, and must at a minimum be doubled, or even trebled or quadrupled." (p. 386)

Discussing peripherals, Cave states that "since 1968 the main development in this field has been the appearance of disc storage units.... A disc unit was first displayed in 1970, seven years after the announcement of the IBM 1302 disc unit." (p. 386)

Cave cites a RAND study which argues that time-sharing would be particularly advantageous in Soviet conditions, since the small computer centers in the USSR are "notorious for their primitive methods and inefficient use of machines." Time-sharing appeared in the United States in the early sixties, but had not appeared in the USSR at the time that Cave wrote. Cave argues by "inverting the argument of this chapter, that it is consistent with the lag between Soviet and American technology for a similar dissemination to take place in the USSR over the next few years." (p. 388)

Cave asserts that "software has always been one of the major weaknesses of Soviet computer development.... In spite of planning and coordination, the ES series has fallen victim to the same delays and shortcomings in software which have diminished the operational efficiency of virtually all other Soviet computers." (pp. 388-90)

A major question is the extent of diffusion of computers in the USSR. According to Cave, "Information on the size of the Soviet computer stock is scanty.... There may be some ambiguity in the definition of a computer; for example, how large does a machine have to be to qualify as a computer? It is also important to distinguish between estimates of the total stock of computers and the stock in civilian uses only.... According to Soviet Cybernetics Review, the generally accepted Western estimate of the size of the Soviet computer stock in 1970 is 5,000-6,000" (compared to 70,000 in the USA). "However, these figures tell only part of the story, for they count each computer as one unit and ignore the enormous disparity in computing power between different models of computers.... In 1974 93 per cent of computers in the Ukraine were second generation models, and of the remainder, the majority were probably first generation. In the USA a second generation computer had become a rarity. The Soviet lag was compounded by two factors. Output has grown at a slower pace in the USSR than in the USA, so that, even with the same lifespan of a computer, the Soviet Union would have a higher proportion of machines of earlier years. Second, the comparative scarcity of computers in the USSR has meant that they have been kept in service longer than elsewhere." (p. 391-95)

Given the relative scarcity of computers in the Soviet Union, one might expect that they would be intensively utilized. But Cave notes that rates of utilization are actually low, and that "when asked by Pravda to explain the low rate of utilization, Zhimerin mentioned several factors, including the inadequacy of software and peripherals and the lack of preparedness of enterprises receiving computers. Another factor to which Zhimerin has drawn attention is the lack of a centralised system for servicing and repair of computers.... The rate of computer utilization reported in 1972 was 10.3 hours per day (only 5.7 for the Minsk 32); in 1973 the overall figure had increased to 10.7 hours, according to TsSU estimates. These low rates undoubtably exacerbate the computer shortage." (p. 395-96)

In the next section, Cave examines evidence on the supply of peripherals, and concludes that "although there is not definite statistical evidence it is clear that the inadequacy of the supply acts as a limiting factor in computer use. Two problems are perceived, the first relating to the production of peripherals, the second to the arrangements for their distribution." (p. 396)

Cave notes that his study follows the same general method as that of Richard Judy, which covered the period up to 1968. Judy had concluded that:

> "Soviet computer technology started in the early fifties with a modest qualitative lag behind Western equipment. This lag lengthened into a serious gap by 1964, when Soviet technology was greatly inferior in all respects.

Since 1965, with the announcement of the new Ural and Minsk systems, and the BESM-6, the gap has narrowed somewhat. Soviet computer technology remains quite inferior to the best in the West. Quantitatively the US appears to have about 50 times as many computers installed as does the Soviet Union which lags behind the United Kingdom, France, Germany and Japan as well as the United States. The gap separating contemporary Western computer software and that employed in the Soviet Union is enormous."

"Writing in 1972, Judy noted that 'the Soviet lag in software has been even greater than in hardware. In recent years the software situation has improved somewhat.'" (pp. 397-98)

Cave provides charts that illustrate Judy's conclusion for the period up to 1968 that "the gap between Soviet and American technology widened throughout the fifties and sixties. In the second half of the sixties the lag was stabilised or even reduced, but since 1970 there is no sign of further reduction in the lag, which may even have increased.... The method of comparison illustrated the fact that a single computer tends to dominate whole sections of the curve covering a period of years.... The same general picture is corroborated by the lag of the USSR behind the United States in entering successive generations of digital computers." (p. 400-401)

"Of the lag between Soviet and American development in peripherals ... we have seen the first Soviet disc unit was available in 1970, seven years after the first American unit.... The other example is line printers.... These two examples suggest that the Soviet lag in development of peripherals in 1973 was about 8 or 10 years, at least as great in the lag in development of CPUs." (pp. 401-2)

At the time Cave wrote, it appeared that the software constraint may have been loosening: "There is further evidence to support Judy's view that software has recently improved.... The situation has greatly improved over the last five years as compilers for high-level languages have been prepared, and we can no longer with equal confidence identify the provision of software as a restraining factor in Soviet computer development." (p. 402)

Cave summarizes as follows: "The technological gap between the Soviet Union and the United States has continued since 1968.... This rather bleak account of the situation so far might, however, be misleading about the future. Before 1968 Soviet computer technology operated under conditions of rather low priority and suffered many of the disadvantages of a competitive situation without reaping any of the compensating advantages.... But since 1968 a higher priority has been given to computer production and more effort has been put into coordination. A far smaller range of machines is produced in far greater numbers and there has been much greater emphasis on ensuring compatibility between different models and series. This effort has, at the least, prevented Soviet computer technology from slipping further behind American and created a more favourable outlook for the future." (p. 403)

Cave considers last to what extent Soviet computer technology was developed independently or was copied from Western developments. Cave states that "Now it is virtually indisputable, as much now as in 1968, that all significant technological innovations have been made in the West, though the same is not true in the field of programming where the Soviet Union has made theoretical advances, even if they are not of great practical significance. But it is another question how far the Soviet Union has been able to copy particular Western developments rather than just follow their general orientation.... Without a more detailed comparison of Soviet computers and their alleged Western progenitors it is difficult to reach a firm conclusion on this issue." (p. 403)

C.9. CHAPTER 9: "MILITARY TECHNOLOGY" (DAVID HOLLOWAY)

Holloway notes the common presumption that the level of Soviet military technology is higher than that of their civilian technology. He quotes Sutton who, "at the end of his exhaustive study of Western technology and Soviet development," wrote:

> "Soviet innovation presents a paradox: an extraordinary lack of effective indigenous innovation in industrial sectors is offset -- so far as can be determined within the limits of open information -- by effective innovation in the weapons sectors." (p. 407)

Holloway notes that this assumption is found in much of the writing on Soviet research and development, sometimes explicitly but often implicitly, and is rarely challenged. But according to Holloway, there have been few efforts to systematically compare Soviet civilian and military technologies. The two case studies in Chapter 9 -- tanks and ICBMs -- are intended as a contribution to such an assessment.

Holloway cites the estimates made in 1972 by Dr. John Foster, then the U.S. director of Defense Research and Engineering, which concluded that the Soviet Union had technological superiority over the United States in eleven deployed weapons systems, had approximate parity with the United States in four systems, and lagged behind in seventeen systems. (p. 408) "In 1973 Dr. Foster declared that a recent study of the Soviet and American military-technological bases had shown that 'the technological superiority that the United States once possessed had been substantially reduced by the USSR'.... Among the conclusions drawn from this study were:

> "The Soviets have closed the 'technology gap' in several important respects.
>
> "Important U.S. leads are in computer technology, integrated circuits, telecommunications, ship and submarine quieting techniques, and some designs of very strong fiber-reinforced composite materials.
>
> "Important Soviet leads are in chemical warfare defense techniques, high-performance integral rockets and ramjets, capability of land vehicles to cope with arctic conditions and difficult terrain, and aircraft maintainability." (pp. 408-9)

Holloway mentions that the studies on which these conclusions are based have not been published, a serious drawback "for the categories of comparison are often so general as to be misleading if they are presented without further qualification." (p. 409)

In addition to general surveys, Holloway cites attempts to systematically assess particular military technologies: "A group at the RAND Corporation developed a methodology for quantifying technological trends, and applied this to a comparison of Soviet and American aircraft turbine engine technology between 1943 and 1971.... The results indicated that, apart from the earlier years, Soviet engines compared unfavourably with their American counterparts.... 'After 1967, all American engines are well in advance of the Soviet state-of-the-art trend in production hardware, sometimes by an indicated 4 to 6 years'.... This result has to be treated with caution, however, because in the early years

Soviet designers pursued objectives which were different from those of American designers or from those they themselves later adopted." (p. 410)

"An analysis of Soviet and Western naval capabilities has been made at the Canadian Forces Maritime Warfare School.... It was found that 'in the aggregate area of hull form design, steel technology, and (possibly) overall systems engineering' Western submarines were ahead, but the Soviet Union was closing the gap. In anti-submarine warfare too the Soviet Union lagged. The ability of Soviet ships, aircraft and submarines to detect and pinpoint a 'standard' submarine was found to be considerably less than that of Western forces. Their capability to attack, however, was only slightly less than that of Western forces.... The Soviet Union was found to have a clear superiority in naval electronic warfare and in mine warfare. Soviet warships were found to have superior surface-to-surface capabilities, while Western surface-to-air capabilities were judged to be greater. In air-to-surface warfare no clear conclusion could be reached: Soviet aircraft had a considerably greater air-to-surface missile range than Western aircraft, but the latter could engage twice as many targets at shorter range." (p. 412)

Holloway argues that both the RAND and Canadian studies raise important methodological issues. "The distinction between adversary-situation and side-by-side comparisons has already been noted. Another major distinction must now be drawn: that between military effectiveness and technological level.... A higher level of technology will not necessarily lead to a superior capability, while a better capability cannot be taken as evidence of a high level of technology." Holloway notes that in one of the RAND studies Robert Perry goes as far as to argue that "the Soviet military R and D system is in some respects more effective than the American system, and that one consequence of this is the Soviet 'ability to create total systems with operational effectiveness not inferior to comparable U.S. systems even though the Soviets are handicapped by inferior subsystems, such as engines and avionics'.... This argument can be extended from individual weapons systems to force structures: a more effective military force can be constructed from units that are individually less effective or embody a lower level of technology." (p. 413)

According to Holloway, the picture that emerges from these studies is complex. While the overall level of United States military technology may be judged to be higher than the Soviet level, the Soviet Union may still lead in particular areas.

Commenting on the Soviet design philosopy, Holloway states that "Most studies of Soviet military technology suggest that the design and development of Soviet weapons are marked by several striking features, all of which indicate a coherent design philosophy.... Soviet designers concentrate on evolutionary progress, and continuous growth in small steps, while in the United States the tendency is to reach for larger, but less frequent, technological advances.... Soviet military design stresses commonality.... Soviet military equipment ... is designed to 'minimum acceptable requirements'.... The emphasis on simplicity appears to be a matter of choice rather than of necessity, for where more sophisticated equipment is needed it can often be produced.... Economising design practices seem to enable the defence sector to design and develop more models than would otherwise be possible. Moreover, it should not be thought that technological progress comes through evolutionary change alone." (p. 415)

Holloway elaborates by quoting Arthur Alexander in another RAND report:

"The design philosophy of incremental change ... if followed rigidly, would eventually lead to technological stagnation.... Discontinuous changes must be sought through temporary deviations from the normal patterns in the form of crash programs, the establishment of problem-oriented ad hoc organizations and committees, temporary suspensions of the usual procedures, and high level political intervention." (p. 415)

Holloway asserts that a "similar picture emerges from McGwire's reconstruction of Soviet naval shipbuilding programmes. This suggests that decisions are handed down, and that inertia is the guiding principle until and unless the centre intervenes. As a result, a modification [of existing programmes] appears to encourage innovation in the sense of fitting together elements that were not originally designed for each other." (p. 415)

Holloway concludes his introduction to the two case studies by noting that while "a distinction can be drawn between military and civilian technology ... the distinction becomes more blurred the closer one moves towards the research end of the research-development-production cycle.... The more advances in military technology come to depend on a large R and D effort, the greater will be the overlap between civilian and military.... Military technology may depend on much the same research base and some of the same development effort as civilian technology." (p. 416)

C.9.1. Tanks

Holloway presents detailed discussions of tank and ICBM developments, from which we excerpt only the most salient points.

"In the 1930s Soviet tank production consisted primarily of the T-26 and BT light tanks, the T-28 medium tank, and the T-35 heavy tank.... In 1940 the T-34 appeared.... The T-34 was recognised as the best medium tank in the world; its 'combination of mobility, protection and gunpower placed it well ahead of other tanks.'" General Guderian wrote of "the marked superiority of the T-34 to our Panzar IV" after a battle in 1941. (pp. 418-20)

"There have been no revolutionary changes in tank design since the end of the Second World War. In this period the Soviet Union has produced four medium tanks.... All these tanks have used basically the same V-12 diesel engine with modifications to increase the horsepower when necessary; the T-54/55 and T-62 tanks have used the same torsion bar/flat track suspension system.... The latest Western tanks rely, as before, on steel armour, gun armament, piston engines, torsion suspension, mechanical and hydromechanical transmission. The two most innovative designs are the turretless Swedish 'S' tank ... and the US M60 A2, which is armed with the Shillelagh ... anti-tank missile." (p. 421-22)

Holloway asserts that the three major combat features of a tank are protection, firepower, and mobility. Protection includes both armor and nuclear, biological, chemical (NBC) protection, while firepower encompasses fire control, caliber, ammunition type, and ammunition load. Mobility depends upon speed, range, and amphibious capability.

Regarding armor, Holloway notes that the most recent U.S. and FRG battle tanks are much heavier than their predecessors, reflecting the development of composite forms of armor, but this change is not yet reflected in Soviet designs.

C.9.1.1 NBC Protection. "It seems clear that the Soviet Union has done more to protect its armour from nuclear effects than the

Western armies, which have not gone beyond providing their tanks with filter systems." (p. 427)

C.9.1.2 Firepower. "The size of projectile limits the number that can be stowed in the tank, while the firing of large calibre, high velocity projectiles involves very large reaction forces on the vehicle. As a result of these limitations on gun development, the search for greater firepower has since the mid-1950s concentrated on the development of different types of ammunition and the improvement of fire control." (p. 427)

"The Soviet Union was ... slow to introduce new types of ammunition into its tank design.... Soviet tank design appears to lag significantly in rangefinding equipment, although it has been reported that a laser rangefinder is being developed." (p. 434)

C.9.1.3 Mobility. "The development of a new engine is the most time-consuming part of tank development.... Soviet tanks have used a diesel engine since 1939; in fact, they have used only one type of engine, the V-2, a water-cooled, 38.8 litre V-12 diesel.... It was only in the mid-1950s that Western tank design turned to diesel engines, after recognising, rather late, the importance of fuel economy in tanks. The diesel gives the best combination of two basic indicators of engine performance: overall power, and specific effective fuel consumption." (p. 435)

Regarding mobility, Holloway concludes that "the design of Soviet tank engines has not advanced greatly since 1945. Although clearly superior to Western tanks in speed and range in the early post-war years, Soviet tanks have been overtaken in both respects in the 1960s." (p. 436)

Commenting on the general design philosophy reflected in Soviet tanks, Holloway argues that "the development of Soviet tanks fits very well into the general picture of Soviet design philosophy outlined in the introduction. Change has been evolutionary rather than revolutionary, and many features have been passed on from one generation to the next: the engine and transmission system are perhaps the clearest examples.... Commonality is also apparent in Soviet tank design.... A high priority is placed on rugged design, and reliability which is seen as more important than maintainability.... Little attention seems to have been paid to human engineering" (p. 438)

"The contrast between Soviet and Western design philosophies should not, perhaps, be overstressed. Western tanks have not seen revolutionary changes in the last 30 years.... There is some commonality to be found in Western designs.... Nevertheless, a clear difference exists in design philosophies.... Soviet tanks are, after all, rugged and simple by comparison with Western tanks.... Innovation has been more marked in Western tank development. In some cases this has meant the adoption of devices that Soviet tanks do not have, for example, optical rangefinders.... When Soviet tanks are compared with those of the U.S. or UK (countries which have produced more than one tank since the war) the difference in the degree of design inheritance diminishes: American tanks all have many features in common and show a strong evolutionary, rather than revolutionary, pattern of development" (p. 439)

C.9.1.4 Diffusion. "It seems that in the post-war period Soviet tanks have been produced at an average rate of between 2,000 and 3,000 a year.... The total NATO tank force in 1975 ... suggests an average annual production total of about 1,500 in the USA, UK, France and Federal Republic of Germany.... It seems to be characteristic of Soviet tank production that when a new model is introduced, production of the previous model does not cease.... In the West, as a general rule, a production of one model ceases when a new model is introduced.... It is possible that the Soviet Union keeps at least two models in production so that it will not have to supply its most modern equipment to politically unreliable clients." (p. 440-41)

In drawing overall conclusions, Holloway notes that Ogorkiewicz "has suggested that tank designs can be evaluated on the basis of their comparative effectiveness in performing the specific mission of destroying or 'killing' a hostile tank.... The dominant factor in determining kill probability is the estimation of range -- hence the importance of the fire control system, and in particular of the rangefinder; the performance of Soviet tanks must be seriously impaired by their lack of effective fire control equipment. The analysis shows also how important reliability is in attaining high availability and high hit probability; their rugged design may give Soviet tanks an advantage here." (p. 441)

Holloway acknowledges that overall "the picture which emerged from this exercise is not especially sharp. But it suggests that by 1950 the T-34 had been overtaken by U.S. tank design, although it was still superior to the best British tank; by 1960 the T-55 had given the Soviet Union a marked superiority over U.S. and British tanks; by 1970, however, the T-62 had been overtaken by the M60 A2, the AMX-30 and the Leopard; it was superior to the Chieftain on all counts of mobility, but inferior in firepower. Thus the 1960s saw a relative decline -- from a position of superiority -- in the level of Soviet tank technology." (p. 441-42)

"The change in the relative position of Soviet tanks in the 1960s can be assessed in terms of those features which Marshal Rotmistrov singled out as important in foreign tanks in the 1960s.

"1. Soviet tanks, like all Western tanks except the S-tank, have retained the classical layout.

"2. Soviet gun calibre is greater than that of all foreign tanks except the Chieftain and the M60 A2, but the T-62's 115 mm gun is not thought to be more effective than the standard NATO 105 nm gun; Fig 9.5 suggests that the superiority of individual Soviet tanks in firepower has been lost since about 1960.

"3. The Soviet Union lagged behind the Western tank-producing powers in introducing new types of AP and HE shells, although it now uses ammunition of both types.

"4. Western -- tanks in particular the Leopard and AMX-30 -- have overtaken Soviet tanks in speed and power-to-weight ratio (although the Chieftain lags behind). Soviet performance has changed little since 1945.

"5. Since the T-34, Soviet medium tanks have been low and relatively light; of all the foreign MBTs only the S-Tank is lower and only the AMX-30 is lighter than their Soviet counterparts.

"6. Figure 9.6 shows that Soviet tanks carry fewer rounds of ammunition than Western MBTs.

"7. Soviet tanks are better protected against nuclear weapon effects.

"8. Figure 9.2 shows that Soviet tanks have lost their lead in cruising range.

"9. The Soviet Union was the first country to provide its tanks with underwater driving equipment; the M60, AMX-30 and Leopard followed suit later.

"10. The Soviet Union was one of the first countries to provide its tanks with IR equipment for night combat.

"11. The reliability and maintainability of tanks is difficult to judge.

"12. The Soviet Union has lagged in the provision of rangefinding equipment, and this has affected first-round hit probabilities; Table 9.10 shows that while the T-55 has 0.5 hit probability at 1,000 meters, the Centurion Mk.9 and M60 A1 have .85 hit probability at 1,000 meters and .5 hit probability at 1,800 meters." (p. 442)

Holloway's assessment of Soviet tank technology concludes: "The data ... are sparse and and unsatisfactory....

Nevertheless, a general picture does emerge from the fragmentary evidence: between 1950 and 1960 the Soviet Union strengthened its position vis-a-vis Western tanks, but between 1960 and 1970 lost its marked superiority to a new generation of Western tanks." (p. 446)

C.9.2 Intercontinental Ballistic Missiles.

Holloway notes that American interest in ballistic missiles was erratic and uncoordinated until the mid-1950s, in contrast to the Soviet decision to give priority to missile development immediately after the war: "The Soviet Union began to develop MRBMs about five years before the United States, but work on an ICBM started only one year earlier. The priority given to missile development after the war helps to account for the Soviet lead in flight-testing MRBMs and ICBMs. In some areas of missile technology the Soviet Union seems to have established a lead; for example in rocket engines." Nevertheless, "once the U.S. programme gained momentum technical advances came very quickly in guidance systems, propellants, warheads and ground equipment." (p. 459)

Holloway characterizes the evolution from Atlas and Titan I to Titan II and Minuteman I and then to Minuteman III as clearly demarcated generations. The pattern of development was different in the Soviet Union; generations have succeeded each other more slowly. But Holloway asserts that "in spite of the larger number of models deployed (ten as opposed to six in the U.S.), a clear demarcation between generations can be discerned." (p. 461)

Holloway cites evidence that the Soviet Union encountered serious problems in catching up with the U.S. in two important areas: MIRV technology and accuracy. Regarding MIRVs, Holloway notes that: "Deployment of the SS-9 began in 1965 and continued until 1970.... Model 4 carried three warheads, although they are not independently targetable; it has not been deployed. The test programme for this model suggests that the Soviet Union faced considerable difficulties with multiple warhead technology." (pp. 461-64) Holloway later asserts that: "The United States has enjoyed a clear lead in the development of multiple warhead technology. It first tested MRV in 1963.... In 1968 testing of MIRV warheads began, and in 1970 the MIRVed Minuteman III became operational.... It has been suggested that the reasons for the Soviet lag in multiple warhead technology are the same as those which account for the lag in missile accuracy: backwardness in computers and electronics, and in precision grinding and cutting machinery." (p. 476-67)

Holloway also argues that the "scanty evidence" available suggests that the Soviet Union "has faced considerable difficulty" in developing highly accurate guidance systems: "The new Soviet ICBMs are the first to carry onboard computers, although U.S. ICBMs have done so since 1962; and it is hard to see how high accuracies could be achieved without such computers.... It has been argued also that the Soviet Union lacks the very accurate metalcutting equipment essential in the construction of gimballed gyroscopes and accelerometers.... Another report suggested in 1973 that the Soviet Union was finding it difficult to master the gas-bearing inertial guidance technology which is essential for highly accurate MIRVed warheads." (p. 472)

But the Soviet program had counterbalancing strengths: "Notwithstanding these reservations, Soviet missiles have a much greater throwweight than U.S. missiles. They are, in general, much larger, and some of the latest ICBMs can be 'cold launched', whereas no American ICBM uses this technique.... In 1956 the U.S. Atomic Energy Commission said that it could develop compact nuclear warheads with a high yield, and this influenced U.S. missile design in the direction of smaller missiles." (p. 475)

C.9.2.1 Propellants. "With the exception of the SS-13 and SS-16, all Soviet ICBMs have liquid-propellant rocket (LPR) engines. All the Minuteman ICBMs have solid-propellant rocket (SPR) engines.... The United States appears to have made more advances in the development of SPRs. These have some advantages and some disadvantages, when compared with LPRs; it is not clear that one type of engine is decisively superior to the other.... Soviet ICBM deployment may suggest that the Soviet Union is not happy with its own SPR technology; or it may suggest that the sacrifice in specific impulse is not thought worthwhile for the benefits gained." (p. 477-78)

C.9.2.2 Penetration Aids. "Minuteman II was the first ICBM to be equipped with such aids; the first Soviet ICBM to be so equipped was the SS-11 mod 2, which became operational in 1973, seven years after Minuteman II." (p. 478)

C.9.2.3 Countersilo Lethality. "The comparison so far gives an unclear picture: it shows a Soviet lead in megatonnage and throwweight, and a U.S. lead in missile accuracy and multiple warhead technology.... Before the present generation, Soviet ICBMs, with the sole exception of the SS-9, lagged behind their U.S. counterparts. Even the SS-9 does not have as great a K value as the Titan II or Minuteman III. With the introduction of the SS-18 and SS-19, however, the picture changes. The SS-19 appears to have a K value at least as great as -- and perhaps greater than -- that of the Minuteman III, while the SS-18 appears to be far more lethal than any US ICBM." (pp. 480-82)

C.9.2.4 Conclusions. Holloway ends by drawing five general conclusions. The first is that "although the Soviet Union has had a number of spectacular firsts, almost all of these were in the 1950s.... The Soviet ICBM lead was quickly lost, while the Soviet thermonuclear test of 1953 represented a step in the development programme that the United States bypassed. Further, the MRBM which the Soviet Union tested in 1954 and deployed in 1955 had a range less than half that of the U.S. IRBM tested in 1957 and deployed in 1958; the apparent Soviet lead of three years is illusory. It can be argued, however, that after the eclipse of the 1960s and early 1970s, the Soviet Union has caught up again: certainly the SS-18 seems (if the published data are correct) to have been a far more lethal combination of yield and accuracy than any other ICBM.... This apparent lead ... does suggest a fluctuating relationship between Soviet and United States ICBM technologies." (p. 486)

"Second, the available evidence suggests a rather slower rate of technological innovation in the Soviet Union than in the United States.... In guidance system and multiple warhead technologies the United States has enjoyed a clear lead which the Soviet Union has been trying to eliminate. The Soviet Union has led in megatonnage and throwweight but this has been a result of American design decisions, and not due to the United States lack of the relevant technological capability. This distinction is important, for it shows how design decisions may compensate for a relatively lower technological base. The Soviet Union has attempted ... to compensate for its backwardness in guidance and multiple warhead technologies by building very large missiles with a correspondingly large throwweight." (p. 486)

"Third, the design philosophy outlined in the introduction to this chapter emerges less clearly in Soviet ICBMs than in Soviet tanks.... In Soviet ICBM development ... the different generations are clearly marked off from one another, and each has seen improvements in the three main elements of the missile, as well as in ground equipment.... When a new generation of missiles is required the most advanced developments are incorporated. This is rather different from the pattern of evolutionary designs and development to be found in Soviet tanks. A very important feature of Soviet ICBM history has been the development and production of competing (and redundant) models in each of the last three generations." (p. 487)

"Fourth, there have been important differences between the Soviet and United States attitudes to the testing of missiles and their withdrawal from service.... By 1975 the United States had withdrawn about 1,000 ICBMs from service, while the Soviet Union had withdrawn no more than about 40." (p. 487-88)

"Fifth, the ICBM programmes have been organised and managed differently in the two countries. In the Soviet Union special bodies were set up in the Council of People's Commissars to ensure centralised control from the very beginning.... In the United States management and control have been more fragmented, and ICBMs and IRBMs came under the U.S. Air Force during the 1950s only after considerable inter-service rivalry and an initial lack of enthusiasm for ballistic missiles on the part of the Air Force. In the United States, as in the USSR, missile-carrying submarines come under the Navy." (p. 488)

C.9.3 Final Conclusions

In drawing overall lessons based on both the tank and ICBM comparisons, Holloway concludes that: "These studies do not show the Soviet Union gradually catching up or overtaking its foreign competitors: the relationship appears to fluctuate. In both cases the Soviet Union has first led the world and has then lost that lead." (p. 489)

Holloway also believes that the evidence in both case studies "points up the features of design philosophy referred to in the introduction: commonality, design inheritance and simplicity.... Development was evolutionary, though punctuated by central intervention to set a programme going, or to change its direction.... The strengths and weaknesses of Soviet technology as a whole are reflected in the defence sector: for example, strength in welding has affected tank technology; weakness in electronics and computer technology has influenced ICBM development. The defence sector cannot be seen as an isolated realm within the Soviet research and development system." (p. 489)

C.10 Chapter 10. "ROCKETRY: LEVEL OF TECHNOLOGY IN LAUNCH VEHICLES AND MANNED SPACE CAPSULES" (Milan Kocourek)

Kocourek notes the early Russian interest in rockets; the first Soviet R&D organization in rocketry was established in 1928, although its origins went back to 1921. During the 1930s, only three English language books on rocketry appeared, while several dozen came out in the Soviet Union. A German rocket expert regretted that "there is a much wider and more sensitive interest among the Russian intelligentsia for the rocket than among the German upper classes." (p. 493)

Stalin crippled these efforts during 1937-1938, when he executed both the chief supporter of liquid-fueled rockets in the leadership and nearly all of the rocket experts. Thus, no liquid-fueled rocket was introduced by the USSR during World War II, although Soviet researchers managed to develop solid-fueled rockets.

Kocourek argues that the contribution of captured German scientists to Soviet progress has been overstated: "It can be inferred that even in 1946-7 the Russians had their own parallel rocket R and D in which the Germans did not participate, and which was at least as good in quality and speed as the Russian-supervised efforts by the German prisoners." (p. 498)

"The main problem which has aroused a lot of controversy in the West throughout the 1960s, and which has not yet been conclusively solved is whether the Soviets intended to undertake manned flights to the moon.... What is the centerpiece of the Soviet space programme, if such a thing exists at all, has always been something of a puzzle, and different Soviet experts and commentators offered different accounts of the order of priorities in the Soviet space programme.... The evidence in fact appears to indicate that what has been delaying Soviet realization of a manned flight to the moon is the lack of a powerful enough rocket carrier." (p. 499)

C.10.1 Soviet Space Technology

Kocourek divides space technology into launch vehicle building, including rocket engines and boosters; spacecraft (capsule) building, including instrumentation; and ground/sea support systems, including launching, servicing, and tracking facilities.

C.10.1.1 Launch Vehicle Building. Kocourek first examines Soviet achievements in rocket thrust and their design philosophy. He notes that: "The Soviet lead in terms of thrust lasted over eight years, from 1957 to 1966.... But from 1967 onwards, since the launching of Saturn V, the Americans have been consistently ahead.... The Soviet experts had accumulated extensive experience in rocket engine building since the early 1930s and their knowledge was further enriched by their familiarity with German rocket technology.... The Soviet decision to concentrate on a high thrust for their launch vehicles had its origins in the initial Soviet handicap in nuclear technology.... Rather than accept this lag and wait for lighter warheads to come, the Soviet authorities committed themselves to building a powerful guided intercontinental missile capable of carrying a heavy nuclear payload.... The initial emphasis on high thrust was reflected in the Soviet design philosophy, which was quite different from the American.... The Atlas tankers were so thin that they always had to be kept pressurized in order to prevent their collapse, while the walls of Vostok tankers were so thick that Soviet workmen could walk along their entire length without damaging them." (p. 501)

Regarding the development of launch vehicles, Kocourek discusses the Vostok system, the Western name for the chief family of launch vehicles in the Soviet space program. The different versions of the Vostok system combined various rocket engines together: "It can safely be said that it was this 'cluster' idea, the most daring and progressive of its time, which secured the Soviet Union its initial advantage in terms of rocket thrust." (p. 501)

Kocourek ends his discussion of design philosophy with the observation that: "Whereas the Soviet rocket engine designers have adopted a comparatively conservative approach of building upon a well-tested standard piece of technology with modest results, the Americans have followed the path of longer, but more sophisticated, innovation which facilitated carrying out a stupendously ambitious and publicly declared space goal, namely, landing on the moon.... Whereas any interested person could follow the American successes and failures in the process of Saturn V development, the circumstances of development of Vostok were kept entirely secret until success was assured." (p. 507)

Kocourek notes the contrasting styles regarding the exploitation of launch vehicles: "Whereas the U.S. had a different type of launch vehicle for each manned flight programme (with the exception of Apollo and Skylab, both of which used Saturn), the Vostok-type launch vehicle was used for all three Soviet manned programmes.... The USA lost its lead in the annual number of space launchings in 1967 and the total number of launchings fell below that of the USSR in 1971.... The average intensity of use of carriers is thus considerably higher in the Soviet Union than in the USA." (p. 507) But Kocourek stresses the difficulty in drawing any clear lessons from these statistics: "The different objectives of the respective countries' space programmes make it extremely difficult, if not impossible, to compare the individual Soviet and American launchings meaningfully.... In orbital stations, the Soviet Union is the years ahead.... But total number of launchings by the respective countries over a period may mean very little.... While both the number of launchings and the weight sent into space do indicate the degree of space activity, they do not necessarily suggest very much about the quality of technological advances in space." (p. 510)

C.10.1.2 Spacecraft Building. Kocourek notes the rapid development from the primitive Sputnik to the sophisticated Soyuz: "The fleet of Soviet spacecraft from Sputnik to Polet and Soyuz is very impressive both in total number and the performance of the individual craft.... In spacecraft building as in the development of launch vehicles we can observe what observers like Stoiko have called the 'add-on' philosophy, which is technologically an important feature of the Soviet programme. Instead of building a new type of space-craft for each mission, the design, materials, apparatuses and other equipment are basically the same." (p. 510)

Kocourek points to fundamental differences in design priorities between the U.S. and USSR: "They built the Vostok capsule as well as Voskhod and Soyuz as a heavy solid shell which potentially ensured a higher degree of safety during spaceflight and re-entry.... Low-pressure oxygen was used in all the U.S.

spacecraft, including the prototype of Apollo, until the disaster in January 1967. The death of the three U.S. astronauts can be seen as a sad penalty paid for the initial lack of option in U.S. spacecraft design." (p. 513) "Another important aspect of Soviet design philosophy was the role of the cosmonaut on board a spaceship. Again it was the concern ... with safety of cosmonauts during the flight which led to the emphasis on automatic rather than manual control of the spacecraft. Accordingly, the Vostok capsule was designed to be guided automatically through signals from the earth and the cosmonaut was supposed to use the manual controls only in case of an emergency.... A Soviet cosmonaut is not so much a pilot of his spacecraft as a well-trained passenger.... A U.S. astronaut, on the other hand, is deliberately made a more integral part of the spacecraft control and guidance system." (p. 513-14)

C.10.1.3 Engineering. Kocourek asserts that American engineers drew heavily on experience with U.S. rocket planes during the 1950s and also collaborated with future astronauts, while Soviet designers did neither. "The simplicity of design of their spacecraft has always been stressed in the Soviet Union." (p. 514) "Vostok, the first manned spacecraft designed for 10-day operation, consisted of two modules.... Voskhod, a multi-seater spacecraft ... was somewhat more sophisticated than Vostok.... The differences in engineering between it and Vostok were negligible compared with those between Gemini and Mercury spacecraft in the USA.... Only the Soyuz spacecraft was considerably different from the Vostok and Voskhod capsules in sophistication.... There is no equivalent in Soyuz of the Apollo digital computer which permits the crew to communicate directly with all systems on board. The drum-type preprogrammed sequencers in Soyuz do not enable the crew to input any other commands than those already present in the drum.... It could be argued that the safety of a Soviet cosmonaut may not be ensured to the same extent as that of an American who can actually over-rule the computer and is free to do so whenever he deems it necessary." (p. 515-16)

Kocourek states: "The launching of Salyut, the Soviet and the world's first orbital station, has been seen as a practical step towards the realization of Tsiolkovsky's old dream of 'settlements in space.'" (p. 516)

The prestige value of space achievements has not been closely correlated with technical achievements, according to Kocourek. "With Salyut I and Soyuz 10 and 11 the Soviets scored another important space 'first' which was matched by the U.S. with Skylab only two years later.... Hardly anyone in the Soviet Union seemed to fully appreciate that Skylab in may respects, including weight and the sophistication of equipment, was superior to Salyut." (p. 517)

C.10.2 Conclusions

In concluding, Kocourek notes that Soviet research and development in rocketry has been sponsored by the military since its early stages; the launch vehicle that sent the Sputniks and Vostoks into orbit was a modified ICBM. "The military character of Soviet rocket research and development before and after the Second World War resulted in certain special features which are largely lacking in the U.S. space programme. There is no clear-cut division between the civilian and military parts of the Soviet space effort: all rockets have always been for both science and defence.... Military matters have always had a high priority in Soviet and Russian history and we believe that this partly explains both the high level of technology and the secrecy of the Soviet space programme.... Distinguished pioneers ... became chiefs of the Soviet space effort, giving ... a sense of long-term and purposeful dedication and continuity, features lacking in the U.S space programme.... The U.S. self-imposed challenge, in the shape of the ambitious Apollo programme and sudden cuts in the NASA budget and manpower once the moon was reached, is perhaps the most typical illustration of this point." (p. 519)

While the U.S. program may have suffered from the lack of an enduring commitment, Kocourek argues that a "challenge-driven approach" also has advantages, although economy is not one of them: "In terms of innovating technological advances in rocketry, the United States challenge-driven approach, supported with excellent engineering skils, has proved to work to the American advantage.... The Soviet reliance on well-tested hardware, illustrated above by the example of the Vostok launch vehicle, and the slow development of new, more powerful rocket carriers ... cost the Soviets their leading position in rocket thrust. On the other hand, the slow, heavy-going path the Soviet Union has followed in the development of their new launch vehicles has undoubtably some interesting implications. If a vehicle type is developed which proves to be highly successful and then an intensive use is made of it for many years, as has been the case with the Vostok carrier, vehicle standardization, its manufacture on a production-line basis and thus economies of scale are the comcomitant factors." (p. 519)

But Kocourek believes that Soviet incrementalism must eventually take its toll in a technological race: "Clearly, Soviet reliance on traditional hardware and efforts to standardize work in the long run to their disadvantage: the absence of a powerful Soviet launch vehicle of the Saturn V type restricts the choice of alternatives in realizing the most prominent of present declared Soviet intentions in space, placing large manned stations into earth's orbit." (p. 520)

Kocourek notes that the Soviet design philosophy is also quite different from the American style: "Its origins go back to the post-war years when military considerations were of primary importance, and it also stems from Soviet concerns with maximum safety for manned flight programmes and maximum economy in other programmes, aspects which led to Soviet emphasis on control from the earth. As far as maximum safety is concerned, the weaknesses of that line of thought have been discussed above.... The emphasis on simplicity has led to a lower degree of computerization on Soviet spaceships as compared with American." (p. 522)

Soviet technological limitations have significantly affected their space program, Kocourek concludes: "Owing to the lack of a suitable carrier rocket the Soviet Union has not yet tested a capsule for manned flight to the moon, although from numerous Soviet sources it is obvious that such a manned trip is indeed the Soviet intention in the long run.... In the course of the 1960s, at least in the fields of rocket technology and manned spacecraft, the bold and pioneering Soviet space programme gradually ceased to maintain its high initial tempo vis-a-vis the dynamic U.S. Gemini and Apollo programmes. The main reason for the loss of this tempo ... is the peculiar Soviet pattern of innovation and design philosophy, both of which are very different from the American counterparts." (p. 522)

ENDNOTES TO APPENDIX C

1. The Technological Level of Soviet Industry, ed. Ronald Amann, Julian Cooper, and R.W. Davies (New Haven: Yale University Press, 1977).

2. These conclusions are reinforced and illuminated by a companion volume that is not summarized in this appendix, Industrial Innovation in the Soviet Union, ed. Ronald Amann and Julian Cooper (New Haven: Yale University Press, 1982).

APPENDIX D

SOVIET DEMOGRAPHIC TRENDS AND THE U.S.-SOVIET MILITARY COMPETITION

Richard S. Soll

Demographic trends have a direct impact on the social, economic, political, and military dimensions of a nation. Examination of these trends is, therefore, essential in assessing a nation's strengths, vulnerabilities, limitations, and prospects. Current and projected trends in Soviet demographics, stemming principally from the country's geographic expanse, ethnic diversity, socio-economic structure, and recent history (i.e., World War II) appear to be particularly problematic to the leadership.

Even in a centralized, authoritarian system such as that which still exists in the Soviet Union the leaders can do little more than provide incentives to the population in attempting to reverse negative demographic trends. In addition, they can attempt to offset the impact of the negative trends by circumventing the systematic processes, mainly by means of conducting trade with the noncommunist world and by acquiring technology from it.

Given the nature of Soviet demographic trends and the scarcity and potential fragility of the corrective measures available to the Soviet leadership, U.S. strategies for competing with the Soviet Union should take demographic factors into account and attempt to exploit them. This appendix provides a brief description and assessment of the relevant trends in Soviet demographics; a discussion of the implications of these trends for the United States in competing with the Soviet Union; and a list of references used in preparing the appendix.

D.1 PERTINENT SOVIET DEMOGRAPHIC TRENDS

The areas that are pertinent to defining the Soviet demographic problem are ethnicity, fertility, mortality, and labor-force population. Although these areas are distinct subsets of demography, each with its own indicators and measures, they are so closely intertwined and constantly overlapping that precise delineations are not useful for the purposes of the present paper. For instance, comparative trends in fertility of Soviet Muslims and Slavs bear not only on the fertility dimension but also on ethnicity and labor-force population.[1] Suffice it to say that ethnicity, as a definable characteristic, pervades almost all aspects of the Soviet demographic problem, given the Great Russian, internationalist, and urban-industrial orientation of the Kremlin leadership and thus its political, military, and economic objectives and policies, compared with the Muslim, regional, and agrarian orientation of a growing segment of the Soviet population.

In its entirety, the area of Soviet ethnic relations and their demographic implications involves not only the Great Russian leadership and population vis-a-vis the Muslim peoples, but also non-Russian Slavs (Ukranians and Belorussians), the peoples of the Baltic region (Estonians, Latvians, and Lithuanians), and various other non-Muslim groups (e.g., Jews, Moldavians, and Germans) living in the Soviet Union. The statistical trends associated with these groups are not, however, as dramatic or profound as those of the Slavs and Muslims, and therefore this appendix does not focus on them. This does not mean that Soviet policies are not affected by relations with these other nationalities, as the Jewish emigration issue clearly demonstrates. The Muslim question, however, appears to have the farthest-reaching social, political, military, and economic implications for the Slavic leadership of the Soviet Union.

The growth rates for the eight southern tier Soviet Socialist Republics (SSRs) -- Uzbekistan, Tadzhikistan, Kirgiziya, Turkmenistan, Kazakhstan, Azerbaydzhan, Georgia, and Armenia -- have been two or three times higher than those for the Slavic republics (the Russian, Belorussian, and Ukranian SSRs). While the Slavic republics comprised 81.6 percent of the USSR population in 1950, the proportion dropped to 74.8 percent by 1979, the year of the most recent Soviet census. According to Murray Feshbach, this decline is expected to continue and by the year 2000 the Slavic republics are projected to constitute 69 percent of the population; the southern tier republics, which comprised 14 percent of the Soviet population in 1950, will comprise 27 percent by the year 2000.[2]

An analysis of the various nationalities' birth rates and of corresponding differentials in terms of age groups points out the major consequence of the nationalities problem for the rest of this century and beyond: a shrinking urban-industrial work-force. In the period 1970-1978 the Soviet Muslim birth rate was 38 to 42 births per 1000 population, while the Slavic birth rate was 13 to 16. In a Soviet national survey conducted in 1972 among women aged 18 to 59, Slavic women stated that they expected to bear about one-third the number of children that Muslim women gave in their response (roughly two per woman against six for the Muslims). Demographers project, for instance, that in the year 2000 the natural increase rate (births minus deaths) for Uzbekistan will be over 14 times that for the Russian republic. This number is driven even higher if one considers only the Europeans in the Russian republic.

Soviet authorities have attempted to resolve the differential in Muslim versus European population growth rates by encouraging Muslims to migrate out of the southern tier, hoping that they would thus become Sovietized. Muslims are not, however, moving out of their native regions in significant numbers. The 1979 Soviet census indicates, for example, that out of the approximately 12.5 million Uzbeks in the USSR, only 91 thousand, or 0.7 percent, live outside the southern tier republics.

The differential in fertility between the Muslim and non-Muslim portions of the Soviet population has resulted in a statistical aging of the Slavic and Baltic peoples relative to the Asiatics, and this trend is expected to continue. In the Slavic and Baltic republics in 1979 the youngest age group (0 to 15 years) accounted for 22 to 25 percent of the population, compared to 40 to 46 percent in the Muslim republics. Since this age group represents a good part of the parenting and work-force population for the next generation, it is apparent that the trends in Soviet fertility and, as discussed below, in Soviet labor productivity will only become accelerated. According to demographic projections, these trends could eventually result in a decline in population in the European republics of the USSR.

The proportion of working age (16 to 59 years) people in the Slavic republics declined from 82.7 percent of total USSR working age population in 1959 to 77.7 percent in 1979, while the share in the southern tier republics increased from 14 to 19 percent during the same period. This trend has a profound impact on labor supply, since Soviet labor needs are mainly for urban-industrial enterprises and the Muslim population generally shows little inclination to migrate to the industrial areas or participate in nonagrarian employment. The Soviet labor force was expected to grow throughout the 1980s at a rate that is less than half of the 1970s rate. About 90% of the growth will come from the southern tier and therefore will not benefit the industrialized regions of the USSR to any significant extent.

In order to spur economic development, the Soviet Union has traditionally tried to compensate for its lack of investment in production technology (brought about to a large extent by the magnitude of the Soviet military R&D and hardware effort) by relying on increases in the size of the labor force. Given the projections of sharply decelerating growth among that segment of the population, particularly the European, urban-industrial component, it is no longer possible for the leadership to employ this method for driving economic growth.

Concerned about this slowdown in the Soviet economy, the authorities began to institute measures for increasing the labor productivity of the existing work force in the late 1970s under Brezhnev. Successive regimes have reinforced the measures and continued to implement new ones. The measures include centralizing decisionmaking regarding labor issues under the State Committee for Labor (Goskomtrud); greater activism by the authorities in steering workers into particular industries; and taking tougher action against people who come to work drunk, are illegally absent, or avoid employment altogether. In addition, Soviet leaders have publicly committed themselves to long-term policies for investing in modern machinery in order to automate and mechanize what are now labor-intensive industries. The implementation of such policies may, however, require major shifts in longstanding resource allocation practices and an expanded work force -- both in terms of quantity and quality -- to build, install, and maintain the machinery.

The Soviet Union's emphasis on acquiring technology and equipment from the West constitutes an important means by which the leadership hopes to mitigate the consequences of the demographic trends. At the same time, Soviet interest in arms control is probably motivated partly by the prospect of a reduction in defense expenditures, thus allowing a shift of resources into capital investment.

In addition, the regional trends in Soviet population growth will have a major impact in the area of military manpower. It is estimated that by the year 2000 approximately one-third of all Soviet military recruits will come from the southern tier republics. Differences in language, education, and technical training between Soviet Muslims and non-Muslims, exacerbated by the racism that exists throughout Soviet society, will cause this to be a growing problem that the Soviet political and military authorities will have to confront. Furthermore, the inability of a growing percentage of the Soviet armed forces to operate and maintain the increasingly high-technology equipment being introduced into the operating forces is likely, given the language, educational, and training deficiencies of many conscripts of Muslim origin.

This trend in Soviet military manpower has important political dimensions. In the first place, the leading role of the Communist party in Soviet military affairs and the inculcation of all Soviet servicemen with party doctrine and values are considered by the Soviet leadership to be integral to the conduct of Soviet military organization and practice. However, Marxism-Leninism as an ideology and the concept of the Communist party as an organ of control are Western in origin and have never been embraced by the Muslim population of the Soviet Union. In fact, almost without exception, communists in the Arab world have been from Christian rather than Islamic backgrounds. Therefore, as the Muslim segment of the Soviet armed forces steadily increases in size, the leadership faces the prospect of an eroding mechanism of political control. This problem will become even more acute if the present and projected trends continue for an extended period so that the

Muslim contingent will have to be drawn upon to fill the ranks of the officer corps.

A second area in which the ethnic trend in Soviet military manpower threatens to affect the political dimension pertains to Soviet relations with Muslim countries, particularly those along the Soviet Union's southern tier (e.g., Iran, Afghanistan, Turkey). The prospect of a future Soviet leadership being able to commit Soviet forces into combat against a people with whom a major portion of Soviet soldiers shares linguistic, religious, and historical-cultural backgrounds may be in doubt.

Another area of Soviet demographics that is problematic to the leadership and might require a redirection of resources pertains to mortality, particularly infant and male mortality, the rates of which have both risen since the 1960s. Soviet infant mortality rate is the highest of any industrialized country -- double that of the United States -- and is higher than that of some third world countries such as Jamaica. Possible reasons include deficiencies in the Soviet health care system, alcoholism among mothers, repeated abortions (an average of 5 per woman during her child-bearing years), poor nutrition, inadequate infant formula, and poor water quality. Infant mortality tends to be more prevalent in rural areas than in urban, and therefore is more prevalent in Soviet Central Asia than in the western USSR. The rate in Tadzhikistan, for instance, is reported to be as high as 90 per 1000 births, compared to the Soviet average of 31 per 1000. Since the ethnic population projections discussed earlier took this into account, the relative growth of the Muslim versus European peoples would be even greater if the infant mortality problem were ameliorated. While this might pose a moral dilemma to Soviet leaders -- i.e., do they want to accelerate further the Muslim growth rate? -- nevertheless the overall problem will have to be redressed, since the infant mortality rate among Slavs is too high from their standpoint. Although evidence indicates that the rate continues to rise, it is not clear whether this is due to a worsening problem or to more accurate reporting.

The male mortality problem is, however, definitely worsening. The life expectancy at birth of Soviet males declined from 67 years of age in 1964 to 62 in 1980, which is lower than any European country; U.S. male life expectancy at birth in 1980 was 70 years of age. The distribution among Soviet republics is such that the trend does not favor Slavs or Muslims. The male life expectancy in the RSFSR was, however, lower than the national average of 62 in 1980, and that certainly is a source of worry to the national leadership, given the low rate of fertility in the Russian republic. The main reason for the rise in male mortality in the USSR is probably alcoholism, both its acute effects (such as toxicity and accidents) and long-term effects (e.g., heart disease, stroke, diabetes, liver disorders). One staggering statistic is that the number of deaths from acute alcohol poisoning in a given year in the Soviet Union is 88 times that in the United States. Adding to the concern is the fact that alcohol-related deaths in the Soviet Union are taking the greatest toll on males in the prime working and military service ages.

During the same period studied, 1964-1980, the Soviet female life expectancy at birth declined two years from 75 to 73 years of age. In the same period, U.S. life expectancy rose three years for males and five for females.

D.3 IMPLICATIONS OF SOVIET DEMOGRAPHIC TRENDS FOR THE UNITED STATES

The trends in Soviet demographics point to major problems that will confront the Soviet leadership well into the twenty-first century and suggest several areas that are potentially exploitable by the United States in the development and implementation of a political-military competition strategy. Competitive opportunities for the United States in accordance with these demographic trends might include the following:

1. The Soviet Union will need to compensate for continuing shortfalls in the qualified labor force by investing in production technology and equipment or by acquiring the necessary technology and equipment from the West. If Western technology and equipment are not available, the Soviets might be forced to shift additional resources from the defense sector into capital investment. Even if further reallocation does not occur, the defense sector is sure to feel the impact of the dwindling skilled labor force. Therefore, it might be in the best interests of the United States to further curtail the transfer of technology and equipment to the Soviet Union or to establish a Soviet dependency in return for concessions in certain areas, such as arms control.

2. In its propaganda line directed toward the Third World, the Soviet Union traditionally has used the "successes" of the Soviet ethnic relations experience as a model for the Third World in order to foster closer ties between the Soviet Union and the developing countries and to instill an anti-imperialist (i.e., anti-U.S.) orientation in them. According to the Soviet line, the Asiatic peoples of the USSR accepted socialist ideology and socialist principles of political economy without first having endured the capitalist stage of development, which Marx has claimed to be a precondition. The Soviet Union is presented as a unified collection of diverse peoples in which everyone works for the good of the whole state, according to standards established in and enforced by the Kremlin; U.S. race relations are publicized as a manifestation of the evils of traveling the capitalist route. Therefore, Third World countries are urged to adopt socialism and to accept the Kremlin's leadership of diverse peoples united against imperialism, just as Uzbeks, Kazakhs, Tatars, and others have done. The Soviet line appears to have contributed to some Third World leaders' (most notably Castro, Nasser, Sukarno, and Nkrumah) establishing bonds with the USSR in pursuit of shared anti-imperialist objectives and has in turn been used by Third World leaders in justifying their foreign and domestic policies. As a counter, the United States

should publicize the failures of the Soviet ethnic relations experience, highlighting Soviet racial antagonisms, asymmetries in infant death rates and assimilation into the labor force, and, in general, the failure of the Soviet leadership to sovietize a large and growing portion of the country's population.

3. Soviet nationalities bordering China, Mongolia, Afghanistan, Turkey, and Iran are ethnically (i.e., in terms of language, culture, religion, history, and physical features) closer to the peoples of these countries than they are to the Slavic leadership in Moscow. These centrifugal tendencies could have significant implications for Soviet domestic and foreign policies, based upon questionable national allegiance of the Soviet citizens in the southern regions. Given what is known concerning these ethnic groups' lack of adherence to the Soviet policy line in the past, it is doubtful that these peoples are more inclined to believe, for example, Soviet propaganda concerning the Afghanistan war or Sino-Soviet discord than U.S. propaganda on these same issues; ideological justifications are meaningless, since what is important to them is information on how their ethnic kin are being treated and the effect of the events on their immediate environs. Given an understanding of the local (not global) and ethnic interests and sensitivities of these peoples of the USSR, the United States, both in broadcasts (e.g., VOA, Radio Liberty, etc.) and in relations with the bordering countries, has an opportunity to exploit these centrifugal tendencies. In essence, a U.S. "active measures" program similar to the Soviet leadership's should be instituted vis-a-vis Soviet Asiatic minorities, with the trends in the ethnic composition of the Soviet military given special consideration.

4. Soviet demographic trends indicate that a growing proportion of the military service age population must come from the southern tier republics. Given the relative deficiencies of individuals from this region with regard to language, education, and training, a large proportion of the Soviet armed forces may be unable to use technologically sophisticated material without particularly extensive education and training. At the same time, the Soviet military leadership has traditionally exercised a policy of stationing minority soldiers outside of their home (or culturally similar) republics. If this policy is continued, an increasing proportion of Muslim servicemen might have to be sent into the forces opposing NATO. U.S.

decisionmakers should be aware of these developments affecting the Soviet armed forces and attempt to exploit them.

5. The Soviet crisis in health care, as suggested by the high rates of mortality and alcoholism (and more recently by the Soviet medical needs in the wake of the Chernobyl nuclear reactor disaster), might require the Soviet leadership to pursue transfers from the West of medical and psychiatric technology, equipment, and skills. Such potential dependencies on the West could be exploited in return for Soviet concessions in other areas (e.g., arms control, human rights, arms transfers).

ENDNOTES TO APPENDIX D

1. The term Muslim is used to describe people of Arabic, Turkish, and Persian origin and does not necessarily connote active religious affiliation or practice. The six republics that are predominantly Muslim are Uzbekistan, Tadzhikistan, Kirgiziya, Turkmenistan, Kazakhstan, and Azerbaydzhan. Although Kazakhstan is about half Muslim and half European, demographers nonetheless characterize it as Muslim. In addition, the Russian Soviet Federative Socialist Republic has a large number of Muslims, mainly Tatars and Bashkirs.

2. Murray Feshbach, "Trends in the Soviet Muslim Population -- Demographic Aspects," in Soviet Economy in the 1980s: Problems and Prospects, U.S. Congress, Joint Economic Committee, 1983, part 2, p. 317.

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APPENDIX E

HISTORICAL EXAMPLES OF MILITARY COMPETITION

J. J. Martin

Military competition is not a phenomenon unique to the late twentieth century. There are numerous examples of peacetime competitive behavior in national security affairs throughout history. Study of these examples can help understand today's U.S.-Soviet long-term military competition.

This appendix summarizes several historical cases and their lessons for today; the material is developed from William H. McNeill, The Pursuit of Power: Technology, Armed Force, and Society Since A.D. 1000 (Chicago: University of Chicago Press, 1982). Four cases are examined:

- The rapid rise of the armaments industry in medieval China and its subsequent decline.
- The close interaction between military establishments and private entrepreneurs that started in Europe during the period 1300-1600.
- The rapid spread of military innovation in Europe during 1600-1840.
- The intense interaction of commercial industry and military establishments in Western Europe during 1840-1914.

E.1 THE ERA OF CHINESE MILITARY PREDOMINANCE: 1000-1500

Around A.D. 1000, the political-economic system in China changed from a purely command system to one that permitted extensive market-regulated behavior. The result was a remarkable flourishing of industry and armaments that allowed China to dominate Asia for several centuries. But these new production patterns eventually broke up as remarkably as they had risen, due to changes in government policy and the social context that first fostered innovation, then subsequently resisted it. Consequently, by 1500 Japan and Europe had supplanted China as world military leaders.

Medieval China was governed as a command system, with centralized political and economic authority administered through career government bureaucrats. For reasons that are not fully understood because of gaps in the historical record, China's leaders allowed or fostered conditions that permitted an upsurge of market-related behavior. But the government command structure never lost control. When officials allowed it, technological advances and increases in the scale of production and trade occurred rapidly. When official policy changed, economic conditions shifted with the same rapidity.

During the period of strong market behavior after A.D. 1000 there was a quick rise in China's high technology iron, coal, and steel industries, cross-bow manufacture, development of large machines for defending walled cities, and naval shipbuilding. The ironworking industry of the eleventh century is probably representative. Major growth in iron production for weapons was made possible by a ready market (the government), an extensive network of canals that provided cheap transportation of raw materials and finished goods to and from family-run production centers, and market-determined prices that made it attractive for families to go into the ironworking business.

Chinese armament technology, government policy that permitted market behavior in the economy, and the command structure of government bureaucrats combined at this time to produce considerable innovation in armaments. External threats from barbarian hordes caused the government to reward innovation and to minimize obstacles to industrial growth. The city-based, defensive character of the Sung dynasty's strategy also encouraged experiment and innovation with large machines for fixed defenses. The market economy assured a flow of materials and incentives for skilled artisans to work in the armaments industry.

But the market economy never displaced the official bureaucratic command structure and eventually, as immediate external threats diminished, officials increased taxes, reimposed a command price structure, and increasingly extorted bribes from merchants and manufacturers, reducing incentives and causing the armaments industry to decline. The government was the sole market for weapons and used its monopolistic position to reduce the power of the merchants and manufacturers. The growing power of these classes probably was seen as threatening traditional Chinese values, which were opposed to both the professional pursuit of wealth and professionalized violence. Destruction of the canal transport system by floods in 1194 and the decision of the government not to restore the canals also contributed to the decline of the Chinese armaments industry.

One lesson for today's military competition between the United States and the Soviet Union is that market forces, if allowed free rein, can motivate technological innovation for military applications in a swift and powerful way under the right conditions. Among these conditions are a vigorous demand for armaments and the availability of appropriate skills and raw materials. This observation helps to explain why the more interesting technological innovations come from private industries that are not totally dependent on a single government customer, as contrasted with service arsenals and laboratories.

A second lesson is that, when technological innovations are available, a command political-economic system such as that of China in the eleventh century and the Soviet Union today can move these innovations rapidly into the military force structure. This helps to explain why the Soviet Union, which is technologically behind the West but has made a sustained effort to obtain Western technology, has military forces that in many areas are on a par technologically with those of the West.

E.2 COLLABORATION BETWEEN MILITARY ESTABLISHMENTS AND PRIVATE ENTREPRENEURS IN EUROPE: 1300-1600

Starting in the fourteenth century, market forces affected military actions in Europe in unprecedented ways. Through intense interactions between private entrepreneurs and European states, the art of war rose to new technological heights: ships capable of operating in most weather conditions, widespread use of gunpowder, and rapid advances in cannon artillery for both ships and armies.

The development of cannon artillery is an early example of obsolescing and cost-imposing actions. When cannon artillery was introduced in Europe in the fourteenth century, it made castle walls obsolete as a defense. Within a hundred years, however, Italian scientists and engineers (including Leonardo da Vinci and Michelangelo) were devising ways to make fortifications better able to withstand gunfire. By the 1520s the *trace italienne* -- a type of fortification composed of earthworks and ditches, with counterbattery artillery mounted in bastions and outworks -- was able to resist even the best-equipped attackers. But the cost was enormous. Only the most wealthy city-states could afford the large number of cannon and the construction labor required for the *trace italienne*. What originally was an obsolescing move -- the use of cannon artillery -- became over time a cost-imposing action as countermeasures were developed in Italy and spread to other parts of Europe.

The introduction of cannons aboard ships did, however, make permanently obsolete other forms of naval attacks such as ramming, boarding, and crossbows that were prevalent until the fifteenth century. From about 1500 until the widespread use of submarines in the twentieth century, heavy-gunned surface ships ruled the seas.

Two distinct competitive patterns emerged among private entrepreneurs and European states during the period 1300-1600, patterns that still characterize to some extent the military competition today:

- For a period of time there would be no technological breakthroughs. States that had distinctive advantages in the prevailing military technologies (e.g., natural resources, artisans trained in the requisite skills, basic manufacturing capabilities) could retain their competitive advantages by making evolutionary improvements in the dominant classes of weapon systems such as crossbows then or armor/anti-armor weapons today.

- Occasionally, however, there would be radical shifts in technologies with important military applications (e.g., gunpowder in the fourteenth century, steam ships in the nineteenth century, and computers in the twentieth century) in which other countries had distinctive advantages, resulting in shifts in the lead in the military competition. Countries with foresight positioned themselves to take advantage of these technological leaps forward; for example, Britain and America established worldwide coaling stations in the nineteenth century in order to take advantage of the steam revolution in naval vessels.

Inhibitions on the rapid transfer of technology among nations before the sixteenth century reinforced these patterns. By the seventeenth century, however, political and economic conditions in Europe encouraged the rapid spread of technology, with a resultant increase in the pace of military competition.

E.3 RAPID SPREAD OF NEW MILITARY TECHNOLOGIES IN EUROPE: 1600-1840

Military competition in Europe from the seventeenth century to the start of the industrial revolution was characterized by the rapid geographic spread of military innovations. There were no political barriers to the transfer of technologies among states and strong market incentives for private entrepreneurs to enter into commercial ventures that crossed national boundaries, rapidly spreading new technology. This process was facilitated by the efficient information exchange network that by then had come into being in Europe -- word of mouth, the widespread use of printed texts, state-sponsored espionage, and commercial intelligence-gathering for business purposes.

Not only did competition and the free exchange of information result in technological improvements to weapons -- ships, artillery, and small arms -- but this was also a time of rapid spread of innovation in military doctrine, organization, and command and control means. Town militias gave way to hired professionals in fourteenth century Italy, and a pattern of political management of standing armies evolved as city-states emerged as distinct political-economic entities. The Italian pattern was disrupted by wars with France and Spain in the fifteenth century, but reappeared on a larger territorial scale in France, England, and the Low Countries in the 1600s. The northern European countries expanded on the Italian pattern in two ways -- systematic drill of troops and a clear chain of command from king to the lowest noncommissioned officer.

Russia was as isolated from Western Europe in the seventeenth and eighteenth centuries as it is today and as