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Bomber Flexibility Study

A Progress Report

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PREFACE

The Bomber Flexibility Study is a 2-year effort aimed at providing the Air Force with the analytical underpinnings for future bomber modernization decisions. This briefing provides a description of research in progress after 8 months and highlights selected methodological and analytical issues to stimulate discussion with members of the Air Force operational, planning, and development communities.

The Bomber Flexibility Study is being sponsored by the Directorate of Requirements, Air Combat Command, as a part of a larger project examining force modernization issues for the Air Force within the Force Modernization and Employment Program of Project AIR FORCE, a federally funded research and development center.

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SUMMARY

This briefing is an 8-month progress report on a 2-year study of modernization options for the heavy bomber force. In addition to reporting on the study's progress, it is intended to stimulate discussion about our approach to the problem, as well as about system-related details.

The objective of the RAND Bomber Flexibility Study is to provide the U.S. Air Force with guidance for the long-term improvement of the bomber force as an integral element of U.S. conventional military strategy. The analysis will

- focus on integrating the heavy bomber force within a consistent joint military doctrine that exploits the unique capabilities of the bomber force while capitalizing on the existence of other friendly forces
- identify the effective operational concepts for employing the bombers
- place bomber modernization plans within a realistic set of budgetary constraints.

In the Bomber Flexibility Study, we are performing a set of trade-off analyses with the assumption that money is fungible across the entire range of bomber modernization options, including survivability, avionics, information systems, weapon type, and integration, as well as carriage, repair, and maintenance. The two driving factors are (1) relative performance of offensive missions by bombers and (2) maintenance of the heavy bomber forces over several major conflicts.

To perform these analyses, we adopted a generalized approach that selects appropriate sets of potential technologies based on their applicability to a variety of missions and then performs detailed effectiveness and cost analysis. Ultimately, we will produce a listing of the assessments of the contributions of various technologies and operational concepts that will help decisionmakers to better understand the benefits and costs of different approaches.

We are conducting trade-off analyses within a range of potential bomber missions. Decreases in the number of aircraft available for early power projection provide an incentive for shifting bombers to missions previously associated with fighter aircraft. However, the bomber force originally was designed and equipped to perform very different kinds of

missions than currently being envisioned. Traditionally, bombers have been intended for missions involving long planning times and relatively immobile targets. These missions required limited in-flight communications and no onboard systems to assist with mission planning. Bombers are now being considered for many operations that are characterized by mobile targets and rapid revision of mission plans to adapt to changing circumstances. These more dynamic operations will require substantially improved capabilities for communications, onboard sensing, and computing.

Four missions that cover much of the range of bomber operations have been selected for analysis: (1) suppression of infrastructure, (2) halting of invading armies, (3) defeat of enemy air defenses, and (4) attack on critical mobile targets. Only *suppression of infrastructure* falls into the less dynamic range of operations. The critical characteristics of such missions are penetration into an integrated air defense system (IADS) consisting of area and terminal defenses, target acquisition and identification, and the ability to retarget based on late-arriving intelligence data. Suppression of infrastructure can be performed by the B-52, the B-1B, or the B-2. The other three missions are more dynamic. Missions to *halt invading armies,* which can be performed by the B-1B or the B-2, stress target acquisition, dynamic planning, cooperative tactics, and operation independent of theater support. Since such missions involve only limited penetration of a national IADS, the tactical defenses of the maneuver forces, as well as of fighter forces tasked for peripheral and point defenses, form the basic defense environment. Missions to *defeat enemy air defenses* involve B-52s armed with standoff weapons attacking fixed installations while B-2s attack mobile long-range surface-to-air missiles (SAMs). These missions are emerging as an important driver of a number of qualities of onboard sensors. Finally, missions to *attack critical mobile targets* such as theater ballistic missile launchers and high-value command assets stress target acquisition, identification, ability to search for a target, and operation and communication with other forces and intelligence-gathering assets. The B-2 is suited to these operations in denied areas, while the B-52 and B-1B might also contribute to that mission.

Current plans for modernizing bomber technology continue to focus on capabilities needed for less dynamic operations. The Bomber Roadmap, as articulated early in 1993, contributes significantly to the conventional warfighting capability of the bomber force. It adds the ability to carry and control a variety of effective weapons, improves tactical voice communications, addresses long-standing supportability issues, and attempts to correct system deficiencies on the B-1B to allow the aircraft to survive close approach to enemy defenses. However, the roadmap

focuses on defensive improvements. We believe that the bomber's offensive capabilities need to be addressed first. Thus, the ability to find and attack targets on demand and to use sensors and air crews to adapt to tactical needs must be improved significantly.

To determine what technical capabilities the bombers need, we began by analyzing a concept of operations. In this analysis, we broke down bomber operations by task and then examined the demands these tasks make on the bombers' subsystems. We then drew from a broad pool of possible technical approaches to address each demand. After consultation with experts in the analytic, operational, and laboratory communities and some quantitative analysis, we eliminated those approaches that are not technically feasible within the time frame of reference or that cannot be integrated into bombers.

Next, for each bomber/mission combination, we rated the technologies as necessary for the performance of the mission, of significant benefit, of marginal benefit, or of little interest. We then selected those technologies that were applicable to multiple missions. Table S-1 shows the resulting list.

The number of modernization options associated with each bomber reflects differences in the mission areas. For instance, the B-52 is associated with relatively few modifications, because its primary mission—suppressing infrastructure—closely resembles its original mission. The B-2 lies at the other extreme: this highly capable aircraft might be adapted to a variety of very different missions; therefore, we flag a number of applicable technologies.

This basic set of technologies is serving as the initial input to our cost and effectiveness analyses. The effectiveness analysis consists of a mission analysis and a technical analysis. In the latter, we examine the use of each technology in stressing cases, then make detailed performance estimates. These estimates are the input for the mission analysis.

To illustrate our approach to the technical analysis, we identified a variety of radar technologies that are of interest, then examined how synthetic aperture radar (SAR) could be used in defeating enemy air defenses. Examination of this operational concept reveals that the need to process data from a large radar footprint requires signal processing and bus upgrades.

Table S-1

Heavy Bombers Modernization Options of Interest

Technology	B-52	B-1B	B-2
Advanced countermeasures/1122 antenna fix		x[a]	
Addition of system operator			x
Automatic target recognition			x
Relative global positioning system (GPS) with antijam capability		x	x
Display enhancements		x	x
Ground-moving target indication (GMTI) mode in the radar		x	
Improved situational awareness (onboard electronic order of battle [EOB] that can update from external sources)			x
Medium data-rate satellite communications	x		x
New weapons suspension/1760/ weapon integration	x[a]	x[a]	x[a]
Onboard planning system for the missiles	x	x	x
Synthetic aperture radar footprint extension			x
Substantial information systems improvements	x	x	x
Terrestrial data link	x	x	x
Ultrahigh resolution synthetic aperture radar (UHR SAR)		x	x

[a]Partially addressed in Bomber Roadmap.

We are now in the heart of the analysis. We are examining bomber-modernization options in three major steps built on our initial identification of high-leverage technologies to support the four bomber missions. First, we have begun the cost analysis, which includes both initial and lifetime costs. Second, we are now conducting the effectiveness analysis, to examine both the technical and operational implications of various technologies. The technical analysis is focusing on identifying system breakpoints; the mission analysis is examining the effects of the technologies, as well as operational responses, such as operating with friendly forces, to assess the impact of these systems in militarily significant terms. Third, we will combine these to assess the effectiveness of force modernization versus cost.

GLOSSARY

ACC/DRV	Air Combat Command, B-1B Systems Management Office
ACC/DRY	Air Combat Command, B-2 Systems Management Office
AFWAL	Air Force Wright Aeronautical Laboratories
AJ	antijam
AOA	Angle Of Arrival
ATO	Air Tasking Order
BDA	Bomb Damage Assessment
CAP	Combat Air Patrol
CMT	Critical Mobile Target
DF	Direction Finding
DPCA	Displaced Phase Center Antenna
ELINT	Electronic Intelligence
EOB	Electronic Order of Battle
ESM	Electronic Support Measures
FEBA	Forward Edge of Battle Area
GMTI	Ground-Moving Target Indication
GPS	Global Positioning System
HPA	High-Power Attenuator
IADS	Integrated Air Defense System
IFSAR	Interferometric Synthetic Aperture Radar
INS	Inertial Navigation System
JDAM	Joint Direct Attack Munition
JSOW	Joint Standoff Weapon
JSTARS	Joint Surveillance Target Attack Radar System
LPI	low probability of intercept
MMN	Multiple Monopulse Nulling
MTI	Moving Target Indication
PRC	Phase Rate of Change
RBM	Real Beam Mapping
RCS	Radar Cross Section
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SCSI	Small Computer System Interface
SEAD	Suppression of Enemy Air Defenses
SGMTI	Slow Ground-Moving Target Indication
SIGINT	Signals Intelligence
SIOP	Single Integrated Operations Plan
SMO	Systems Management Organization
SRAM	Short Range Attack Missile

TA	Terrain Avoidance
TBM	Theater Ballistic Missile
TDOA	Time Difference of Arrival
TEL	Transporter Erector Launcher
TF	Terrain Following
TMD	Tactical Munitions Dispensers
UHR	Ultra-High Resolution
TSSAM	Tri-Service Standoff Attack Missile
URR	Universal Release Rack
WRSK	War Readiness Spares Kits

Bomber Flexibility Study: A Progress Report

Dave Frelinger

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This briefing was presented on July 8, 1993, to our study's primary points of contact in Air Combat Command. We briefed Air Combat Command, B-2 Systems Management Office (ACC/DRY) and the Air Combat Command, B-1B Systems Management Office (ACC/DRV). This briefing is unclassified in this format. All references to the B-2 reflect the requirements we have identified for particular missions and do not reflect the actual capabilities of the aircraft. Detailed discussions are available at a higher level of classification.

Outline

- **Objectives and Approach**
- Background
- Concept of Operations
- Selection of Technology Options
- Assessment of Modernization Options
- Remaining Tasks

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This briefing is organized around the following structure:

- An introduction covering the purpose of the briefing and the objectives and approach of this study
- A discussion of the background and approaches being used in this study
- A discussion of concepts of operations for employing the bomber force
- Our approach to selecting candidate technologies for future investigation
- An example of our approach in performing technical analysis
- A summary of the remaining tasks in the analysis.

Purpose of Briefing

- Provide a progress report
- Encourage discussion

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The purpose of this briefing is to provide an 8-month progress report on a 2-year study of modernization options for the heavy bomber force and to encourage discussion on matters related to bomber modernization. We are interested in feedback on our approach to the problem, as well as on system-related details.

Discussion Questions

- **Have we selected the appropriate spectrum of missions?**
- **How does our grouping of technology appear to you?**
- **Are there any USAF cost and technical analyses we can build upon?**
- **Are there any programs that we need to know about?**

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Keeping in mind that this briefing is on work in progress, we would like you to think about a number of questions:

- Have we selected the appropriate spectrum of cases?
- How do our groupings of technology appear to you?
- Are there any USAF technical or cost analyses we can build upon?
- Are there any programs we need to know about?

Any comments on the strengths and weaknesses of our analytic approach, as well as help in ensuring that we can take into account relevant analysis, will be appreciated.

Study Objective

Provide the analytic basis for an improved future bomber force based on:

- **Consistent joint doctrine**
- **Appropriate technologies**
- **Effective operational concepts**
- **Realistic budgetary constraints**

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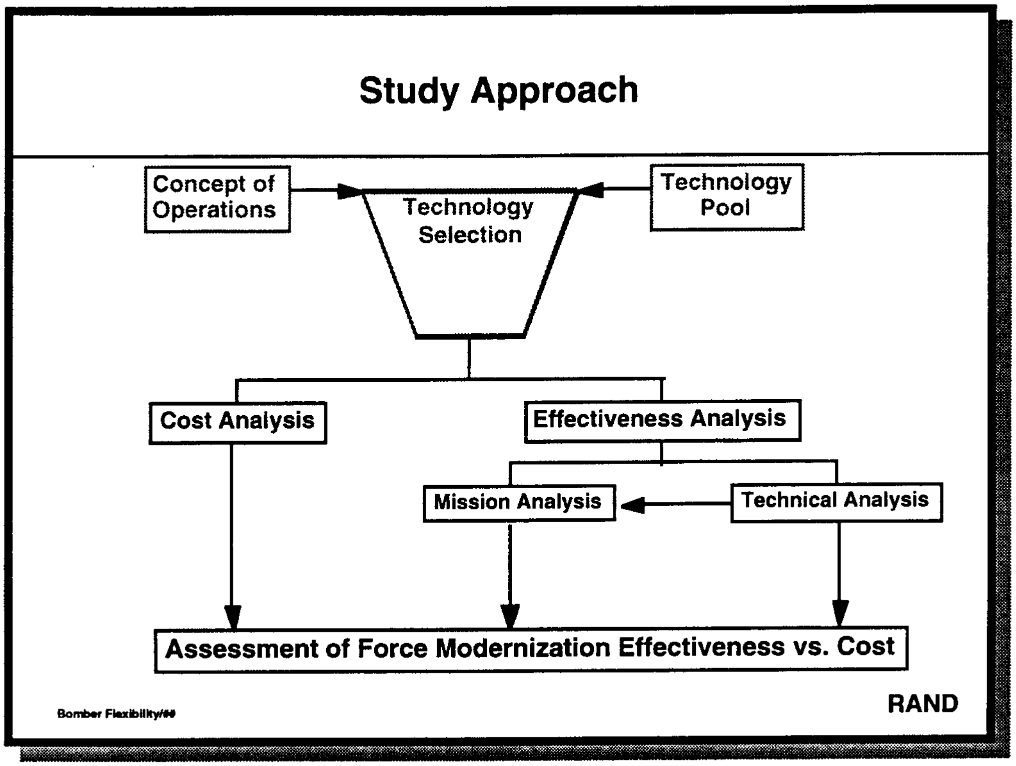
The objective of the RAND Bomber Flexibility Study is to provide the U.S. Air Force with guidance for the long-term improvement of the bomber force as an integral element of U.S. conventional military strategy. The analysis will

- focus on integrating the heavy bomber force within a consistent joint military doctrine that exploits the unique capabilities of the bomber force while capitalizing on the existence of other friendly forces
- examine promising candidate technologies that enable and/or significantly improve the bombers' performance of their assigned missions in a manner consistent with the desired employment doctrine and then select an appropriate critical set of these technologies for detailed assessment
- identify effective operational concepts for employing the bombers
- place bomber modernization plans within a realistic set of budgetary constraints.



In the Bomber Flexibility Study, we are performing a set of trade-off analyses with the assumption that money is fungible across the entire range of bomber modernization options, i.e., options related to survivability, avionics, information systems, weapon type, and integration, as well as carriage, repair, and maintenance. The two motivating factors are (1) relative performance of the offensive mission of the bomber and (2) maintenance of the heavy bomber forces over several major conflicts.

To perform this analysis, we adopted a generalized approach, illustrated above, that selects the appropriate sets of potential technologies based on their applicability to a variety of missions and then performs detailed effectiveness and cost analysis. Ultimately, we will produce a listing of assessments of the relative contributions of various technologies and operational concepts that will help decisionmakers to better understand the benefits and costs of different approaches.

We are conducting trade-off analyses within a range of scenarios that covers most of the potential employment regimes of the bomber force. We discuss the particulars of these scenarios and their motivation later. Because of the danger of focusing on specific regional scenarios for the

analysis, we are treating the missions as generic military functions applicable to any region.

The modernization options also will be investigated in terms of the possibility of employing other forces in lieu of bomber-specific options. Possibly, money tagged for bombers can be applied to other forces and thereby accomplish a military objective at a lower cost. This option could be important for both avionics and survivability improvements where the real possibility exists of capitalizing on offboard intelligence systems and/or the early use of small numbers of friendly fighters (either land-based or naval) to significantly alter the air defense environment.

Finally, we will be employing the current U.S. Air Force Bomber Roadmap as a point of departure for our analysis. We will evaluate the Bomber Roadmap options, as well as additional options we have generated, against a spectrum of bomber missions.

Outline

- Objectives and Approach
- **Background**
  - Changing attack force structure
  - Changing role of bombers
  - Bomber Roadmap
- Concept of Operations
- Selection of Technology Options
- Assessment of Modernization Options
- Remaining Tasks

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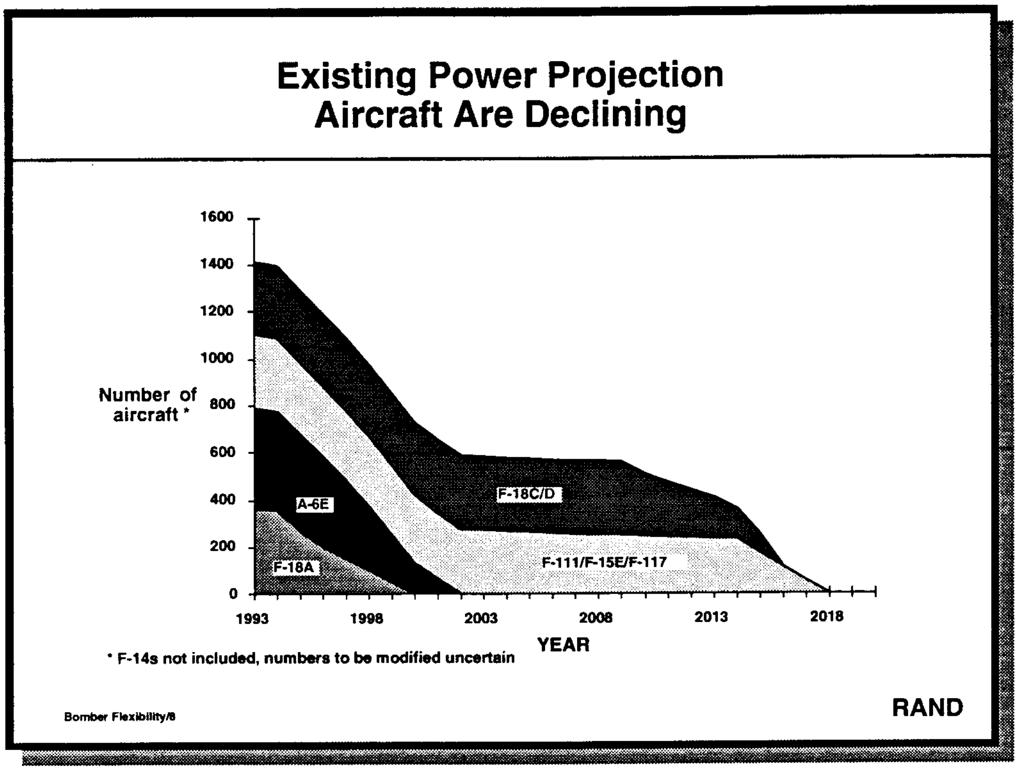
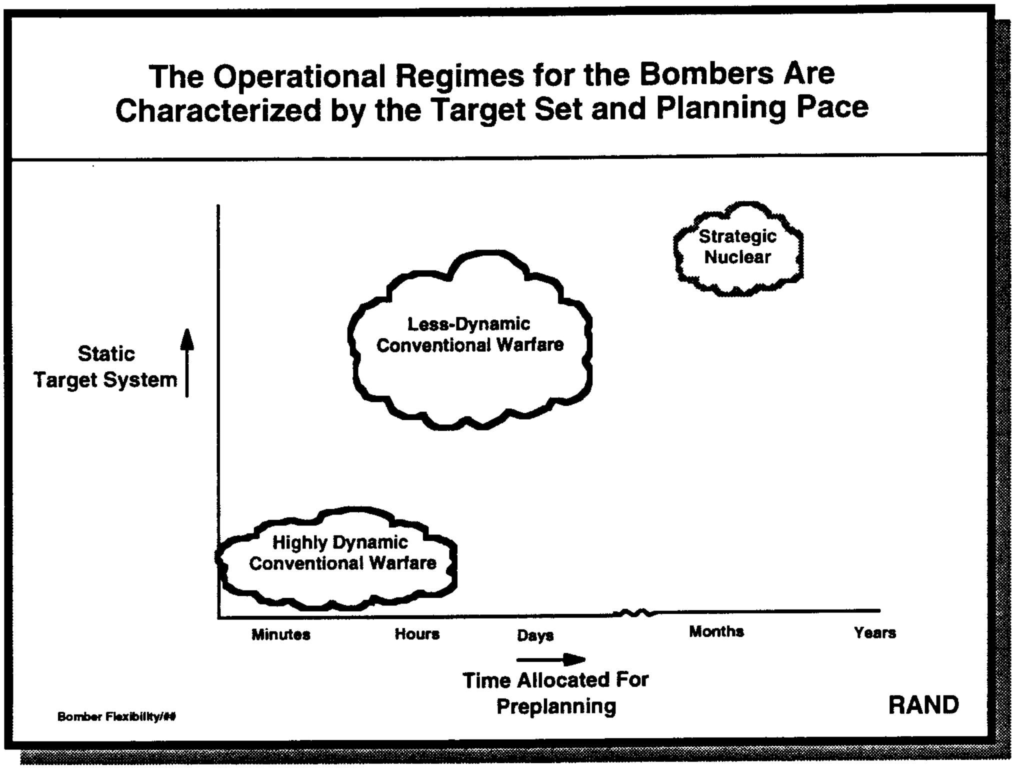
In this section, we present some of our thoughts on the background against which bomber modernization discussions will occur in the coming years. First, decreases in the number of aircraft available for the early power projection mission provide an incentive for shifting the bombers to missions previously associated with fighters. Second, the military role of bombers is changing, partially because of the drawdown of other forces. The bomber force, however, was mechanized to perform a very different kind of mission than is being envisioned for it today. Finally, we use the Bomber Roadmap as the departure point for our analysis. Some options under consideration will be additive to the existing roadmap, while others might be pursued in place of some existing Roadmap programs.



The chart above is an estimate of the number of available U.S. Navy strike aircraft and U.S. Air Force deep interdiction aircraft through the year 2020. With upgraded capabilities, the bomber force may be able to supplement these diminishing assets, potentially forgoing the need to invest the large sums necessary to develop a new long-range interdiction aircraft for the Navy and Air Force.

The chart includes aircraft delivered to inventory through 1993 and the effects of flying hours on airframe lifetimes and attrition. The number of A-6Es was reduced from the current total active inventory based on recent discussions about their early retirement. F-14s are not included since the number to be upgraded is uncertain, as are estimates of airframe life. Navy F/A-18s, although not dedicated strike aircraft and lacking the range of heavier aircraft, are included because the F/A-18 (in some form—C/D or E/F) will make up the bulk of the aircraft on an aircraft carrier—consequently, the bulk of the Navy's air-to-ground capability available in the early days of a conflict. Planned replacement aircraft include the F/A-18 E/F for the Navy, while the Air Force has not yet finalized plans for a future interdiction aircraft.



One problem we faced early in the analysis was the spectrum of future bomber missions. We approached this problem by examining the broad types of operations in which the bomber might be employed. This chart depicts the relative position of three notional groupings of military operations, based on the dynamism of the target set and the amount of time allotted for planning the operation. The Y-axis denotes the target's relative mobility and propensity of discovery during a conflict; the X-axis denotes the amount of time nominally associated with the planning of an attack.[1]

Strategic nuclear operations are classed separately to reflect the differences in destructiveness and the political sensitivities associated with nuclear operations. The major characteristic that they enjoy in this space, however, is long planning timelines and the relatively static nature of the vast majority of targets.

Less-dynamic conventional operations is the term we chose to encompass the class of operations associated with targets amenable to the normal air tasking order (ATO) cycle for fragging sorties. This is a description of the

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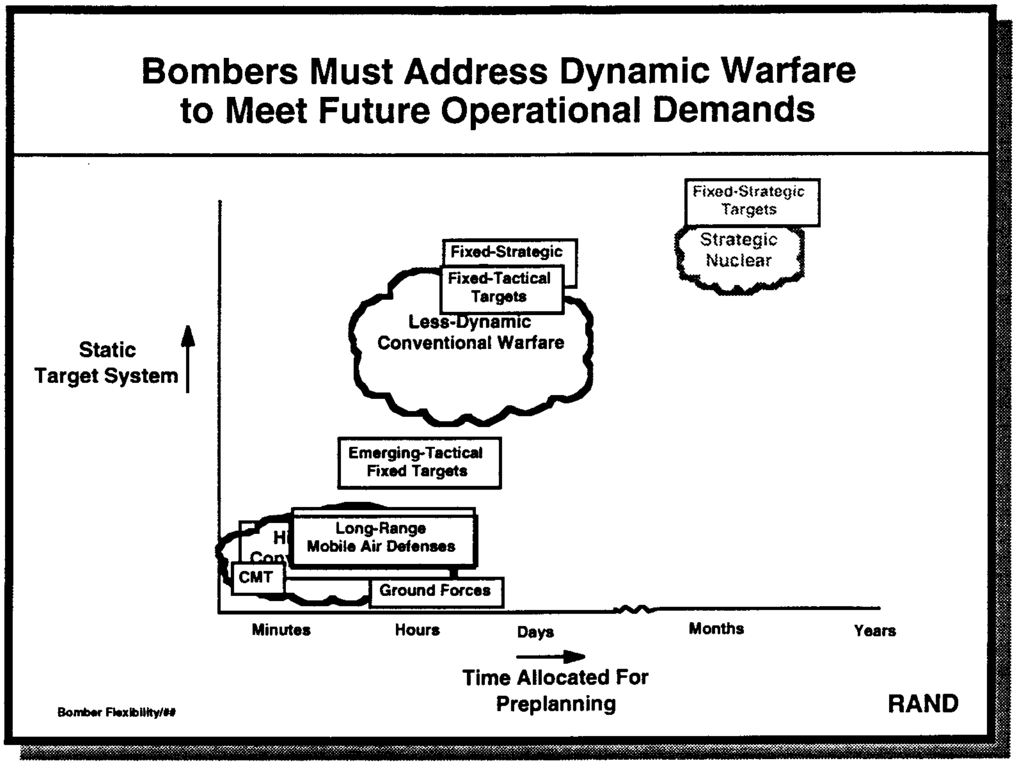
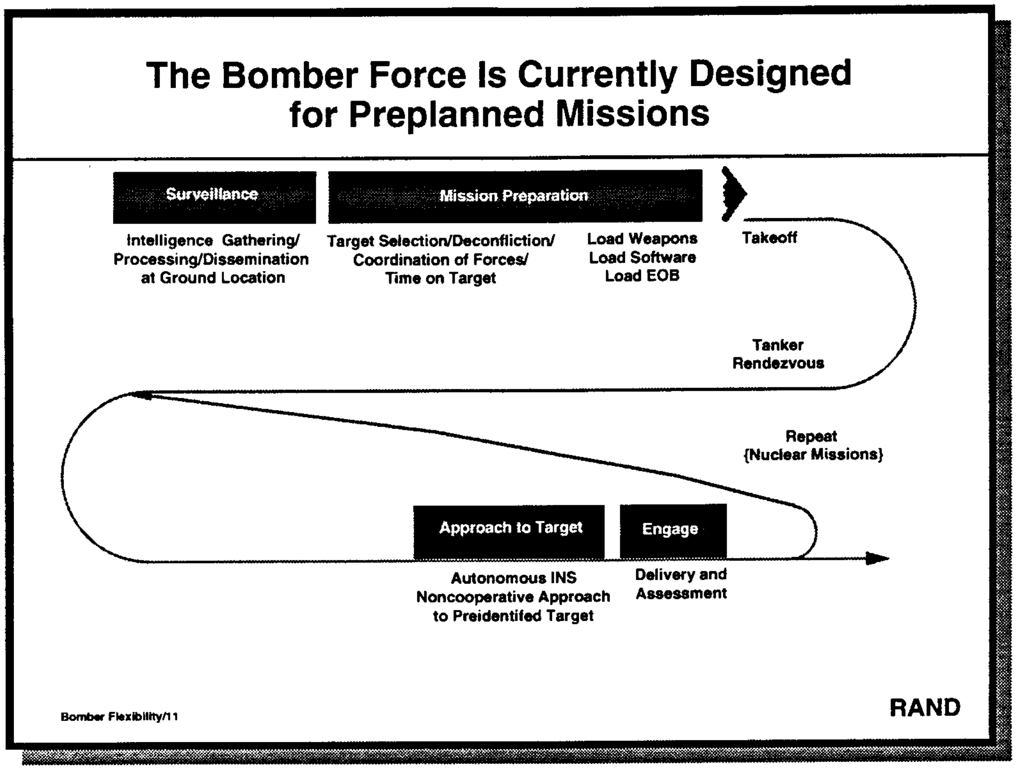
[1]This cut at the problem is greatly simplified, and it must be remembered that the terms are intended to be relative and that these operations lie along a continuum.

union of the target set, intelligence, planning, and execution cycle. Many of the targets normally associated with nondynamic operations (e.g., power plants, war-supporting industries, fixed communications nodes) are compatible with the use of unmanned systems, since little human judgment is necessary after mission planning. The fact that air crews are tasked to perform these operations reflects technical limits and costs associated with current autonomous systems and a frequent preference on the part of Air Force planners to use manned aircraft to accomplish these missions.

Highly dynamic operations are differentiated on the basis that they include targets that require *current* information to localize them, and that planning, in terms of tactical engagement, must be done very quickly to ensure target destruction.



In this chart, we map a set of representative target classes that might be attacked by a bomber during the war. Clearly, dynamic operations include some of the most important missions for the bomber force in the future.



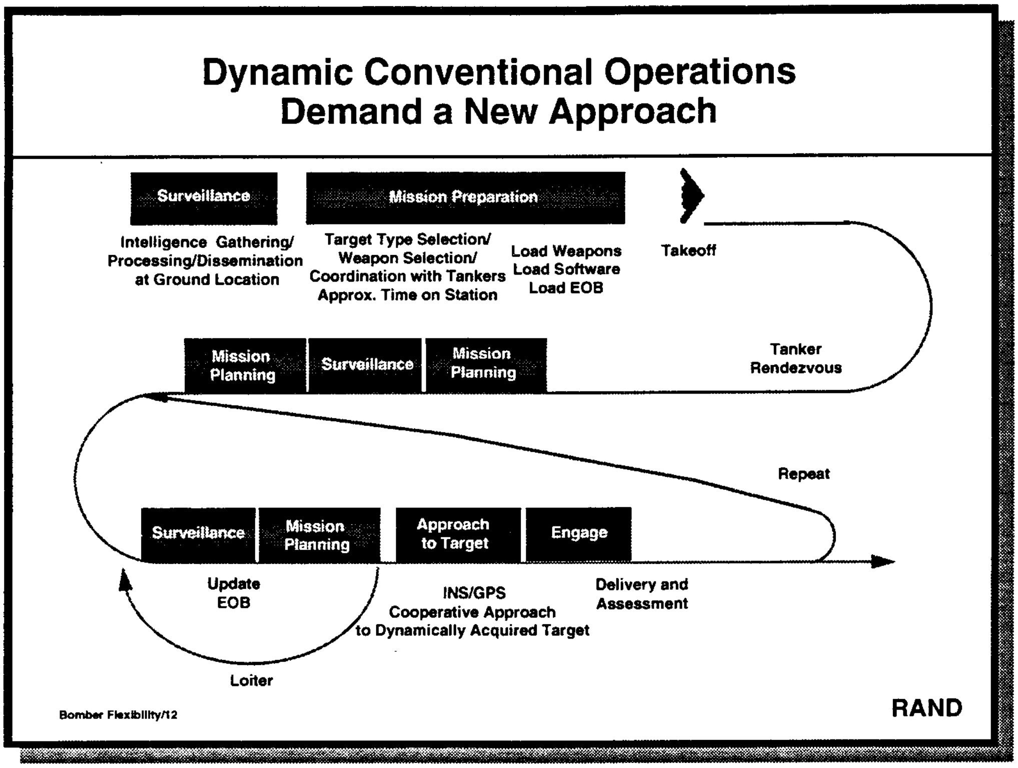
The current bomber force concept of operations assumes that bombers operate primarily in the strategic nuclear or less-dynamic conventional arenas of warfare in which the normal mode is a preplanned mission. The assumption of extensive preplanning time has significantly influenced the bomber's information systems design and its concept of operations.

For example, the bomber is mechanized and the crew trained to perform their mission under the assumption that all the relevant information about how the operation is to be conducted is loaded before takeoff during the mission-preparation phase. Thus, in-flight communications can be very limited, and the onboard bomber systems are not intended to assist the aircrew in mission planning. The bomber's crew is expected to execute the agreed mission with little, if any, modifications. After takeoff, bombers are expected to fly a largely autonomous role, with any coordination between aircraft already built into the mission plan. Each bomber would approach a target autonomously, usually acquiring a fixed installation with minimal use of sensors and then engage the target according to the mission plan.

This dependence on detailed mission planning is reasonable within the context of the bomber's original mission of attacking fixed installations during either conventional or nuclear operations. In conventional

operations, the bombers had to be coordinated carefully with other bombers to ensure that adequate numbers of weapons were delivered on target and to coordinate with supporting aircraft. Independent planning could hopelessly complicate an operation, endangering multiple air crews and decreasing the probability of mission success.

In nuclear operations, uncoordinated operations are anathema to the Single Integrated Operations Plan (SIOP), in which thousands of nuclear warheads on missiles and bombers are coordinated. Coordination of forces is absolutely essential to employ the force effectively and decrease fratricide. No way exists to rapidly and confidently recoordinate such large and intricate operations based on real-time information. The route selected is assumed to be the most survivable given the mission objective. Deviations are assumed to endanger both the individual aircraft and the mission's probability of success.



In contrast with the preplanned mission paradigm, conventional missions in highly dynamic operations impose a far different set of demands on the bomber force.[2] As in the previous chart, we see an early phase dedicated to mission planning and preparation. But unlike the earlier case, this mission plan might need to be extensively altered to meet the demands of a changing environment. The aircrew must be able to act on late-arriving information on target and threat locations based on onboard or offboard sensors or on information from control centers.[3] Dynamic operations require the crew to employ cooperative approaches and coordination to actively search for a target and enable successful attack employing only a fraction of the bomber's payload of accurate weapons.

[2]These operations have more of the character of interdiction missions where the air crews are expected to accommodate last minute target changes.

[3]The former requires more onboard processing, while the latter requires only the ability to use more-digested data.

Selected Missions for Analysis

- **Suppress infrastructure**
  - Attacks against high-value targets either early or late in a conflict
  - May or may not have support assets available
- **Halt invading armies**
  - Early force projection mission
  - Few support assets
- **Defeat Enemy Air Defenses**
  - Selective attack of high-quality, long-range SAMs
  - Performed when other defense suppression forces are unavailable
- **Critical mobile target**
  - Extensive search period
  - May or may not have support assets available

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To facilitate the analysis of the bombers, we identified four missions that cover much of the possible range of bomber operations, while at the same time simplifying the analytic process.

SUPPRESSION OF INFRASTRUCTURE

Missions to suppress infrastructure consist of attacks against deep fixed targets. The critical characteristics of such missions are penetration into an integrated air defense system (IADS) consisting of area and terminal defenses, target acquisition and identification for high-confidence attacks, and the ability to be retargeted based on late-arriving intelligence data.

HALTING INVADING ARMIES

Missions to halt invading armies focus on enemy maneuver forces as the target for attack. The use of bombers for such missions is a relatively new concept. Such missions stress target acquisition, dynamic planning, and cooperative tactics, as well as the ability of the bombers to operate largely independently from theater support assets. Such attacks are presumed to be conducted primarily early in a conflict when alternative forces are less

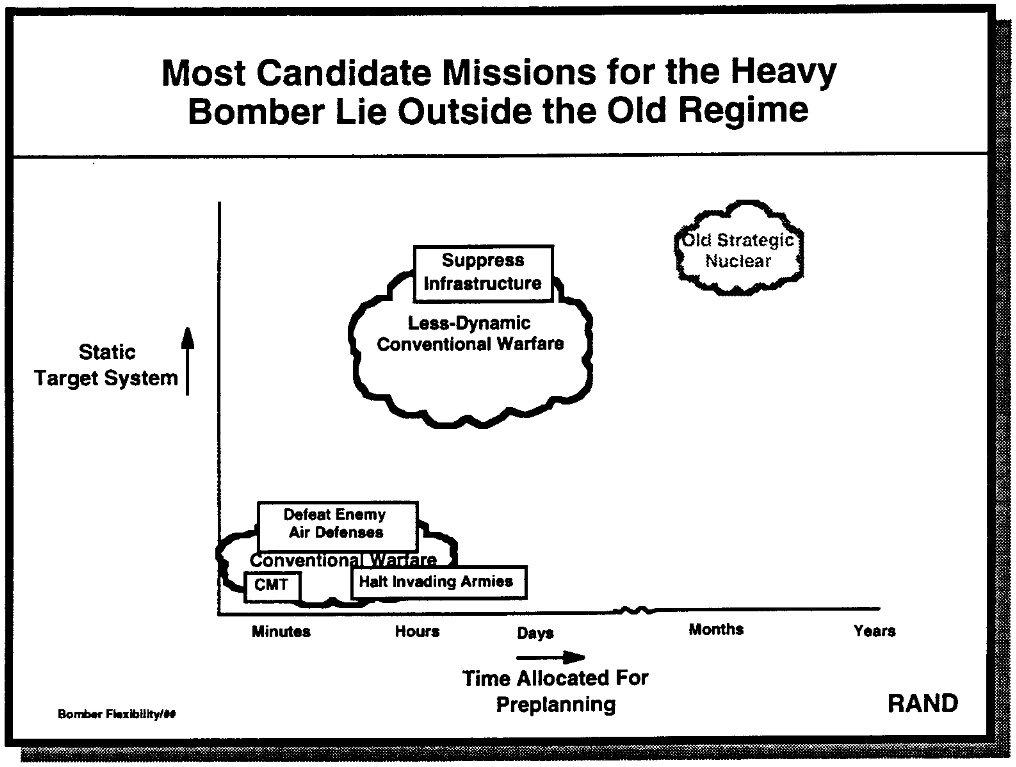
available. Such missions are expected to be conducted near national boundaries and to involve only limited penetration of a national IADS. The tactical air defenses of the maneuver forces, as well as fighter forces tasked for peripheral and point defenses, provide the basic threat defense environment.

DEFEATING ENEMY AIR DEFENSES

Missions to defeat enemy air defenses are the third type of mission we are considering. While these missions originally arose in the context of missions directed at supporting bombers halting enemy armor, they are beginning to emerge as a promising way to exploit the capabilities of the bomber force both to support autonomous bomber operations and to help fill an increasing need in the overall force structure. Part of such missions may be performed by B-52s armed with standoff weapons against fixed installations, while less vulnerable B-2s attack mobile long-range surface-to-air missiles (SAMs). This mission is emerging as an important driver of a number of qualities of corresponding onboard sensors. We also are investigating several associated novel techniques for suppressing enemy air defenses.

CRITICAL MOBILE TARGETS

Missions to attack critical mobile targets (CMT) such as theater ballistic missile (TBM) launchers, high-value command assets, and other similar entities are also being considered. Such missions could use bombers for prelaunch-phase destruction of missiles and launchers, and for boost and prefractionation interception of a TBM with an air-launched interceptor. Prelaunch counter-CMT missions are characterized by a penetration of an IADS, with or without support, and an extensive period of time devoted to searching for the target. Such missions stress the ability to search for targets, target acquisition, identification, and the ability to operate with and communicate with other forces and intelligence gathering assets. Boost and post-boost prefractionation CMT missions are characterized by a rapid reaction time, long loiter periods, and the ability to communicate and operate with the targeting assets actually directing the weapon firing by the bombers.



When these missions are mapped onto the chart, it is clear that dynamic operations encompass many of the most interesting and potentially most important operations for the future bomber force. These highly dynamic operations impose a different set of demands on the aircrew that will require changes both to aircraft mechanization and crew training.

Bomber Roadmap as Constituted Today Adds Significantly to Bomber Conventional Capability

	Avionics Enhancements	Added Weapons	Other
B-52H	Stores management 1760/hvy stores Baseline GPS Have Quick II	Harpoon Have Nap TSSAM JDAM I/II	Internal bomb racks
B-1B	Stores management 1760 Baseline GPS Have Quick II 1122 antenna fix ECM upgrades	TSSAM JSOW JDAM I/III	Deferred logisitics ECM Test equipment End contractor support WRSK
B-2A	Stores management Baseline GPS	JDAM I/III TSSAM GAM	Deployable planning system

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The Bomber Roadmap, as articulated early in 1993, will significantly enhance the conventional military potential of the heavy bomber force by adding modern high-quality weapons. New store management software, 1760 bus connections, and the addition of a global positioning system (GPS) for precision navigation will facilitate the addition of these weapons. Secure/interoperable antijam voice communication will allow more robust tactical voice communication, thereby improving the ability to employ the bombers tactically. The baseline roadmap also provides for B-1B survivability improvements associated with filling out the force with defensive avionics suites and rectifying shortfalls of the current ALQ-161 countermeasure system.

The Bomber Roadmap also specified improvements to the supportability and deployability of the force. These include war readiness spares kits (WRSK) for the B-1B and deferred spares not procured earlier in the B-1B program.

Strengths of the Bomber Roadmap

- **Adds effective weapons to the bombers**
- **Adds weapon control to the bombers**
- **Adds improved control elements to the bomber force (secure voice communications)**
- **Addresses long-standing logistics support issues**
- **Upgrades defensive systems**

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As it is constituted, the current Bomber Roadmap contributes significantly to the conventional warfighting capability of the bomber force. It adds the ability to carry and control a number of effective weapons on the bombers, improves tactical voice communications, addresses long-standing supportability issues that have kept the B-1B mission-capable rate low, and attempts to correct defensive system deficiencies on the B-1B to allow the aircraft to survive close approach to enemy defenses.

In many ways, however, the current roadmap attacks the problem of conventional employment of the bombers in a different manner than we might suggest. It focuses heavily on defensive improvements, whereas we believe the basic offensive capability of the bomber needs to be addressed first. Also, existing operational and weapons-related approaches could minimize the problem of close approach to defenses.

Limitations of the Bomber Roadmap

- **Computer system upgrades**
  - Extends the current control architecture
  - Limited extendibility to information processing
- **Communications**
  - No data links to theater or national assets
  - No data links to other bombers or weapons
- **Sensor upgrades**
  - Plans do not reflect needs of dynamic employment
  - No GMTI mode for mobile target tracking planned
  - No situational awareness enhancements
- **Weapons carriage**
  - Rotary launchers can decrease survivability and campaign effectiveness
  - No economy of scale in software or hardware

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The current Bomber Roadmap does not address some of the areas that we have determined to be potentially critical to the dynamic and flexible use of heavy bombers. While addressing some important areas of deficiency, the current roadmap focuses on improvements to weapon delivery and carriage. It does not significantly improve the ability of the bombers to find and attack targets on demand or to exploit the intrinsic capabilities of bombers such as the B-1B and B-2 to use their sensors and aircrew to adapt to tactical needs. Why these areas are important is detailed later in conjunction with the four canonical missions.

Computer system upgrades are needed to extend the current control-oriented architecture of the bombers' computers (e.g., systems designed to support control of avionics devices and sensors) to better meet information processing demands (e.g., in-flight manipulation of data and information flows) posed by highly dynamic operations. Information can be both the sword and shield of the bomber force, allowing bombers to choose the time and place of engagement most favorable to the attacking force and to react to enemy actions. In this approach to information systems, the aircrew and their computers form the heart of the force. Humans act as decisionmakers and the computer systems as facilitators by converting the myriad of data into information digestible by the aircrew. The longer time-lines associated with bomber operations, plus the

concentration of the computer systems on planning many minutes down line, allow for a degree of human intervention in the decisionmaking process not typically associated with airborne information processing. One possible approach includes building a dedicated information processing system that would exist in parallel with the existing computer and bus system, and that would use the existing system to interact with avionics whenever possible.

Communications and sensor improvements fit hand-in-glove with the computer system upgrades. Whereas the computer helped extend the crew's ability to process data, the communications and sensory improvements extend their information-gathering sphere. Communications improvements allow for the sharing of data between bombers, and between the bombers and other offboard systems. Thus, significant capability is added to the bombers without the proliferation of expensive sensory apparatus. The sensory improvements extend only to those areas where the basic capabilities are already present on the bomber and the capability is vital to successful completion of the mission.

The roadmap's plans for weapons carriage improvements consist of adding the ability to carry a variety of new weapons (e.g., Joint Direction Attack Munition [JDAM], Joint Standoff Weapon [JSOW], and Tri-Service Standoff Attack Missile [TSSAM]) on bombers. However, untouched in the current roadmap are concerns focusing on sustainability, decreasing exposure to enemy defenses, and providing a common set of software and hardware that would allow for at least some economy of scale among the bombers.

Outline

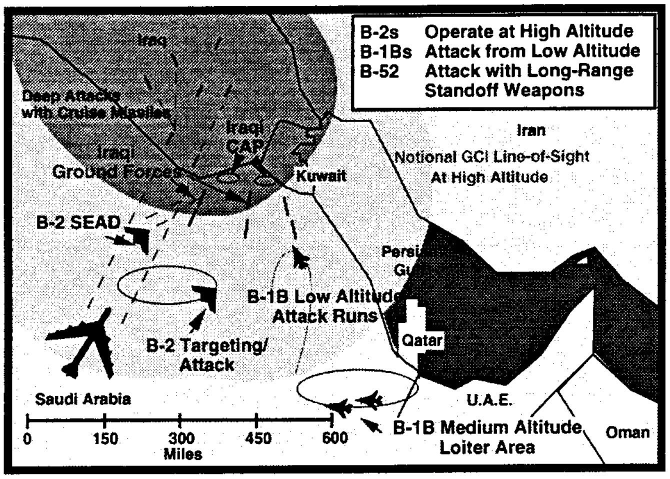
- Objectives and Approach
- Background
- **Concept of Operations**
- Selection of Technology Options
- Assessment of Modernization Options
- Remaining Tasks

Bomber Flexibility/##

RAND

In the first two sections of the briefing, we provided an overview of the objectives of the study, as well as some background on how we are thinking about the bomber force in general. Next, we examine in more detail one of the concepts of operations for employing the bomber forces. In this particular concept, we focus on bomber-only operations. In later analyses we will explore employing other forces such as naval fighters and cruise missiles in support of the military objective.

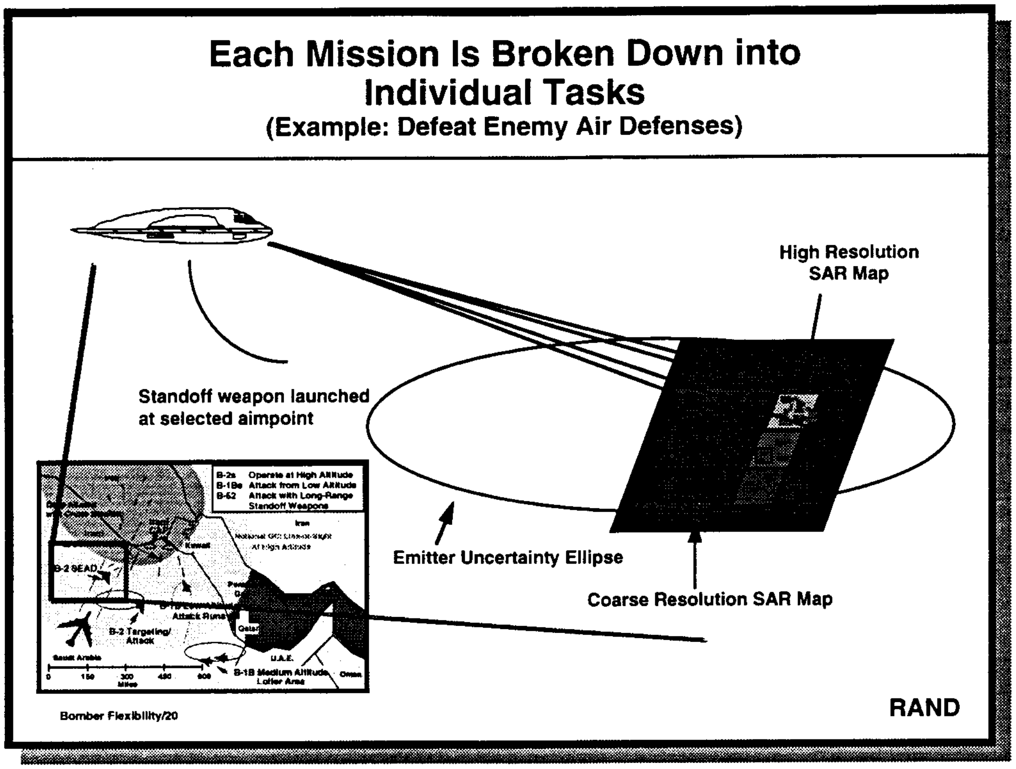
Example of Combined Bomber Operations Early in a Conflict Emphasizing Dynamic Operations



Bomber Flexibility/19

RAND

We are planning to evaluate the bomber modernization options within the context of the four canonical missions discussed earlier. In the example shown here, the focus is on a high-leverage force projection mission early in a conflict. As illustrated, the mission consists of many different elements, with B-2s and B-1Bs operating together to counter the invading army, while B-52s launch deep attacks using cruise missiles. The following charts illustrate how we are decomposing this rather broad-brush description of the operation into the individual tasks to be performed by each bomber and then the respective subsystems of the bombers.

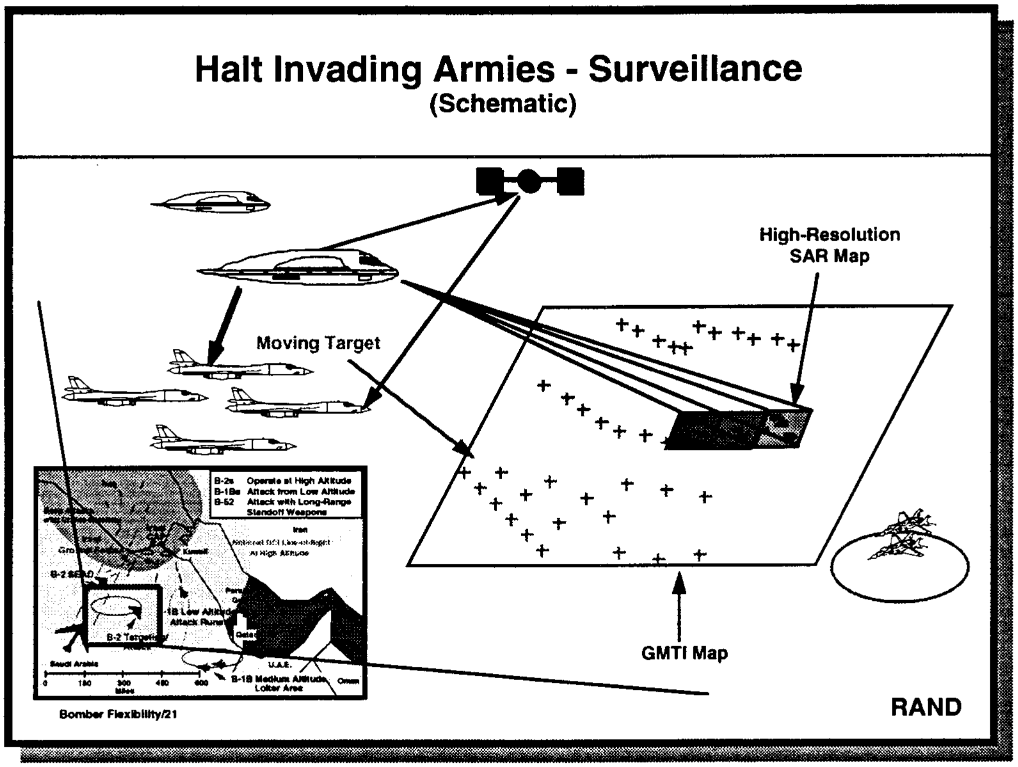


A main task of the B-2 being considered is to ensure that the operating environment is relatively safe for the B-1B attack force. In this role, the B-2 is responsible for eliminating the high-quality SAM threats that endanger the B-1B attack force and also have some significant capability against even low-observable aircraft. Fixed targets are amenable to suppression by cruise missiles that could be launched by any bomber. Also, the B-2 radar could provide a means of occupancy checking of possible SAM locations before missile launch. The major problem, however, is a mobile SAM unit moving within the intelligence cycle time, such as with a SAM accompanying an army in the field.

We are investigating the possibility of using the B-2 as a defense suppression asset to suppress and destroy these threats. In this role the B-2 would, as shown, obtain an estimated target position and uncertainty ellipse from either an onboard or offboard sensor. Once this information had been obtained, the bomber would use its onboard synthetic aperture radar (SAR) to actively search the ellipse for the threat SAM and then would dispatch a standoff weapon against that location.

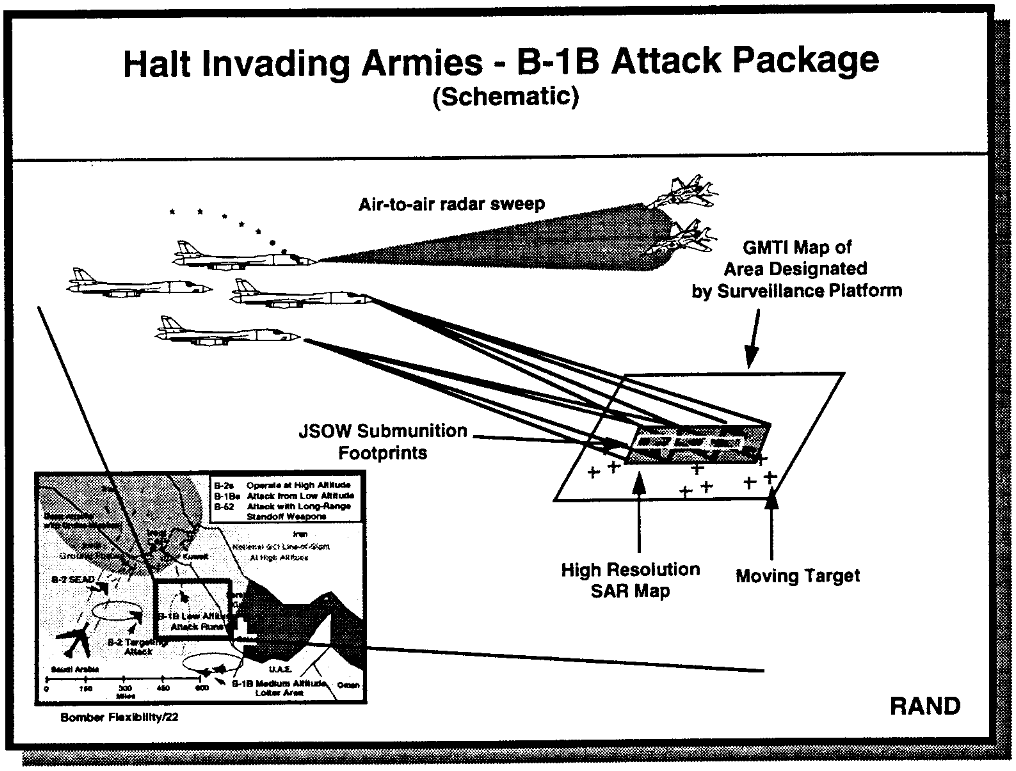
We are looking at several possibilities for managing the search strategy against the SAM site. These include a multistage SAR area search with medium-resolution SAR imagery. The high-resolution search is cued by

the medium resolution search; so the high-resolution search occurs only following a detection from the medium-resolution sensor. We are also looking at the possibility of processing the entire area at high resolution. Variations of these two approaches include the possibility of processing the entire SAR footprint to decrease our active emission time, assuming we can solve the increased processing problem.



To attack an invading force effectively, the maneuver elements must be located, and the attack called in when the enemy force is in a formation vulnerable to an attack. Determining when assets should and should not be called in is important in ensuring the maximum effectiveness of the attacking force. In this surveillance role, the B-2's basic capabilities would be exploited to allow it to perform a small subset of the capabilities of the E-8 Joint Surveillance Target Attack Radar System (JSTARS), for use when the JSTARS has not been deployed into the theater or when it would not yet be possible to protect a large non-low-observable aircraft that must operate near the forward edge of the battle area (FEBA).

The B-2 would provide key situational awareness data and corresponding airborne command/control inputs to the B-1B force. This capability could eliminate having to integrate a wide variety of systems into the B-1B or to operate the B-1B in a profile inconsistent with its basic survivability characteristics.



The final stage of the engagement would occur when the group of B-1Bs deliver their Skeet-equipped JSOWs against the invading force.

In the chart, the B-1Bs are shown approaching the target area designated by the B-2. In doing so, they would have taken into account the threat location data passed from offboard systems to avoid as many surface and air threats as possible. The B-1Bs would use their ground-moving target indication (GMTI) radar to locate the invading force, which could have changed position by up to perhaps 20 km from the location identified by the B-2.[4] The B-1Bs would then precisely aim their JSOWs, programming the missiles to orient their submunition footprints against the target and flying to set way points that would allow the missiles to converge on targets so as to increase their probability of penetration in the face of determined terminal defenses. This relatively simple mission planning sequence would occur in a secondary processor that, in turn, would communicate to the existing weapon control systems. This chart also shows B-1Bs cooperatively and actively searching their immediate

[4]The B-1B is slated to lose its GMTI capability with the next release of software because of memory limitations in the current computer system.

environment with their radar in an air-to-air mode so as to keep aware of any silent fighter threat. Currently, such detection might trigger the release of an effective countermeasure or could be used as a mission-abort criterion.

New Elements of the Operations Concepts

- **Bombers are used dynamically**
- **Cooperative tactics**
- **Attacking moving and mobile targets**

Bomber Flexibility/##

RAND

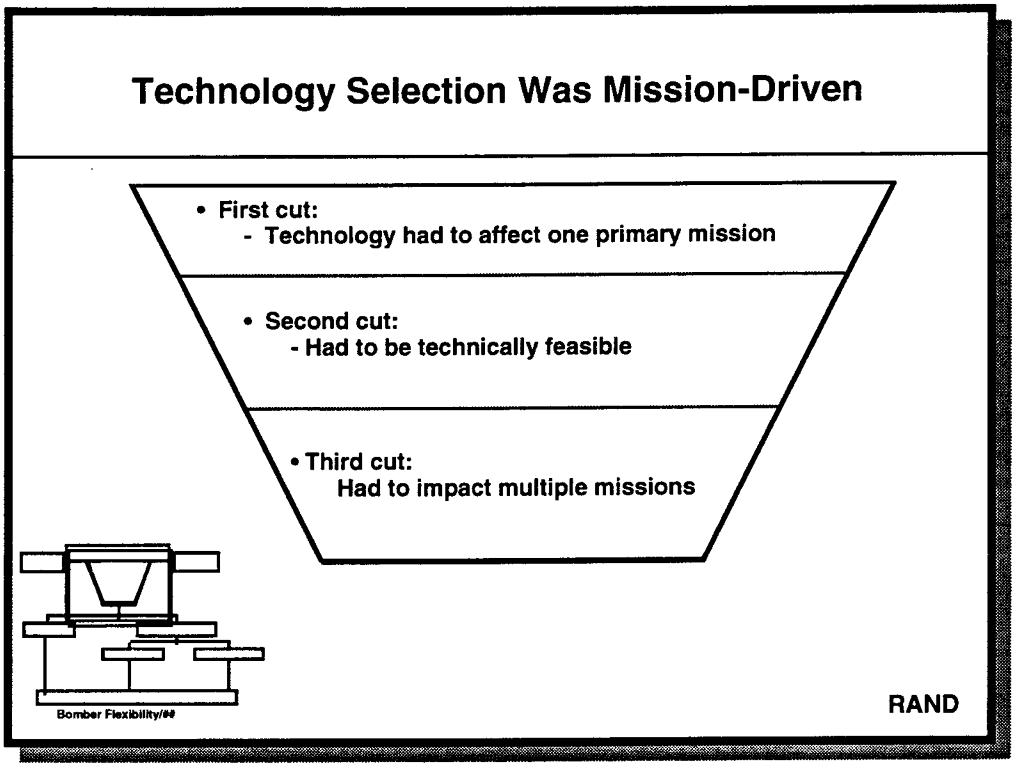
The concept of the operations just discussed differs from those normally associated with heavy bomber operations by employing bombers in a highly dynamic operation that requires timely use of targeting information, employment of cooperative tactics in an unscripted manner, and attack of targets that are changing position.

Outline

- Objectives and Approach
- Background
- Concept of Operations
- **Selection of Technology Options**
- Assessment of Modernization Options
- Remaining Tasks

Bomber Flexibility/## RAND

We now discuss the process of selecting technological options for improving the bomber force.



Recalling the general analytic approach, we use the concepts of operations to generate the demands for technological responses and then draw from a broad pool of possible approaches to develop candidate solutions to the problem. We use a three-stage filter to select appropriate technologies from a wide variety of possible technologies that might be applicable to the problems generated by our basic set of missions. The first two filters, to ensure completeness, designate the technologies of interest for the bombers in any of the missions. The first ensures that a technology affects one primary mission area for a bomber. The second ensures that the technology is technically feasible within the time-frame of interest and that it can be integrated onto the bombers. The final filter selects a high-priority set of technology bundles (e.g., combinations of capabilities such as a GMTI mode, computer system and communications upgrades, and an advanced countermeasure that would support B-1Bs) for use early in the analysis and provides some insights into whether a particular mission generates a disproportionate number of options. These initial bundles are used for preliminary cost and mission analysis.

Approach to Assessing Technical Feasibility

- **Discussions with technical and operational community**
  - B-2 SPO
  - Boeing
  - Rockwell
  - ACC
  - Northrop
  - IDA
  - Hughes
  - ARPA
  - Grumman
  - Lincoln Lab
  - Westinghouse
- **Quantitative analysis at RAND**
- **Technical assessment of current bomber system capabilities**
  - Raw data from ACC, contractors
  - Past contractor analysis done for Air Force (SPO, SAC)
  - Past analysis conducted on bomber missions at RAND
  - Initial quantitative analysis

Bomber Flexibility/##

RAND

In evaluating the feasibility of options, we built on the expertise of the broader analytic, operational, and laboratory communities. We held extensive discussions with a large number of organizations to obtain the latest and most complete information available on technologies, as well as to understand the technical capabilities of the bombers. We also performed quantitative analysis in selected areas to assure ourselves that the information we were recovering was sound.

Mission Focus for Each Bomber Reflects Each Bomber's Characteristics

	B-52	B-1B	B-2
Suppress Infrastructure	√	√	√
Halt Invading Armies		√	√
Defeat Enemy Air Defenses			√
CMT			√

- B-52
  - Large RCS, and low speed during low-altitude penetration
  - Large payload of long-range standoff weapons
  - Space for cruise- missile mission planning systems
- B-1B
  - High-quality radar
  - Moderate RCS and high speed allow peripheral attacks using JSOW
  - Most numerous bomber in planned force
- B-2
  - High-quality sensor suite
  - Low signature confers many operational advantages both on peripheral and deep attack
  - Small number necessitates force multiplier role when mass required

Bomber Flexibility/##

RAND

As shown, each bomber type is associated with a mission that is based on the unique qualities of the aircraft. Thus, the United States can capitalize on the intrinsic strengths of each bomber design and can avoid assigning a bomber to a mission for which it is ill suited.

B-52

Suppression of Infrastructure

We have associated the B-52 with the suppression of infrastructure targets using long-range, standoff weapons based on the B-52's survivability, sensor characteristics, and ability to integrate standoff weapons. In terms of the B-52's survival characteristics, the B-52 cannot be expected to survive early in a conflict without fighter support or defense suppression assets. The B-52 has a demonstrated ability to carry and employ a formidable payload of long-range, standoff weapons that may be deployed under relatively benign operating conditions. This unique capability allows the B-52 to suppress enemy infrastructure targets throughout the duration of a war. The B-52's primary target sensor is its

radar (known as the *Strategic Radar*), which does not have the necessary modes and resolution to support relative GPS targeting.[5]

B-1B

Suppression of Infrastructure

The B-1B, when appropriately armed, could also support traditional bomber operations against infrastructure targets, either against lightly defended targets early in a conflict or in conjunction with escort aircraft later in a conflict. The B-1B can be modified to employ JDAM, or a possible unitary warhead variant of JSOW using relative GPS targeting, that will allow the B-1B to effectively exploit its large payload by attacking multiple aimpoints per sortie and will allow the B-1B to attack targets requiring low collateral damage.

Halt Invading Armies

The B-1B's moderate radar cross section (RCS), along with high-speed at low altitudes makes it attractive for a variety of operations where the B-1B can perform shallow penetrations into enemy air defense nets. The B-1B's radar, the APQ-164, is a high quality SAR that either has or could be made to have radar modes to support the precision targeting and localization of ground forces. The combination of survivability, sensors, and large payload makes the B-1B appear attractive as a platform to attack invading ground forces.

B-2A

Suppression of Infrastructure

The B-2's survivability characteristics make it a prime candidate for attacking some of the most highly defended targets by using accurate/low-cost weapons like JDAM that can effectively exploit the payload capability of the bomber.

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[5]The B-52 also has a combination of a forward-looking infrared system and a low-light television camera to support targeting. These systems, while useful, are not normally considered the primary targeting methods for the bomber.

Halt Invading Armies

By virtue of its survivability characteristics and combination of active radar and other sensors, the B-2 could be adapted to either act in the role of a direct attack platform against the ground forces or serve as an ad hoc surveillance and control platform to support attacks by the more numerous B-1Bs. In the former role, the B-2 could use weapons like guided tactical munitions dispensers (TMD) to attack the ground forces themselves. In the latter case, the B-2 could act as a force multiplier and allow the United States to capitalize on capability of the B-1B force early in a conflict.

Suppression of Enemy Air Defenses

The B-2's survivability and sensor characteristics make it a good candidate to conduct suppression of enemy air defenses (SEAD) operations against selected, high-value defense sites. In highly dynamic operations, the B-2 would exploit its low signature, sensor suite, and a possible onboard planning capability to conduct SEAD operations.

Destruction of Critical Mobile Targets

In this very difficult type of mission, such as destruction of tactical ballistic missile sites, the B-2's sensors and survivability offer the prospect of conducting attacks against enemy transporter erector launchers (TELs) by allowing the bomber to search in otherwise denied areas.

Rating Scorecard for Selected Technologies

Offensive

GMTI
UHR SAR
AA Mode
SAR Footprint Extension
LPI-TF/TA
Low-Frequency SAR
MTI Imaging
IFSAR
FLIR
Laser-Designator

Defensive

Advanced Countermeasure
1122 Antenna
ALQ-161 (Core)
Improved SA (ESM)
COM
Bistatic
IRCM
Missile Approach Warning
Missile Launch Warning
IRST
HPCM (Jammer)

Information Systems

Medium Data Rate (sat comm)
High Data Rate (sat comm)
Terrestrial Data Link
Mission Planning
ATR
Sensor Fusion
Display Enhancements
GPS
GPS++ (AJ/Relative)
Change Detection

Weapon Suspension

Rotary Modification
1760 Bomb-Rack

Munitions

JDAM 1/II
JSOW
TSSAM
ALCM-C
TLAM
HAVE NAP
Harpoon
SLAM
HARM
SRAM/LEAP
AMRAAM
Improved SEAD Weapon
GP Bombs

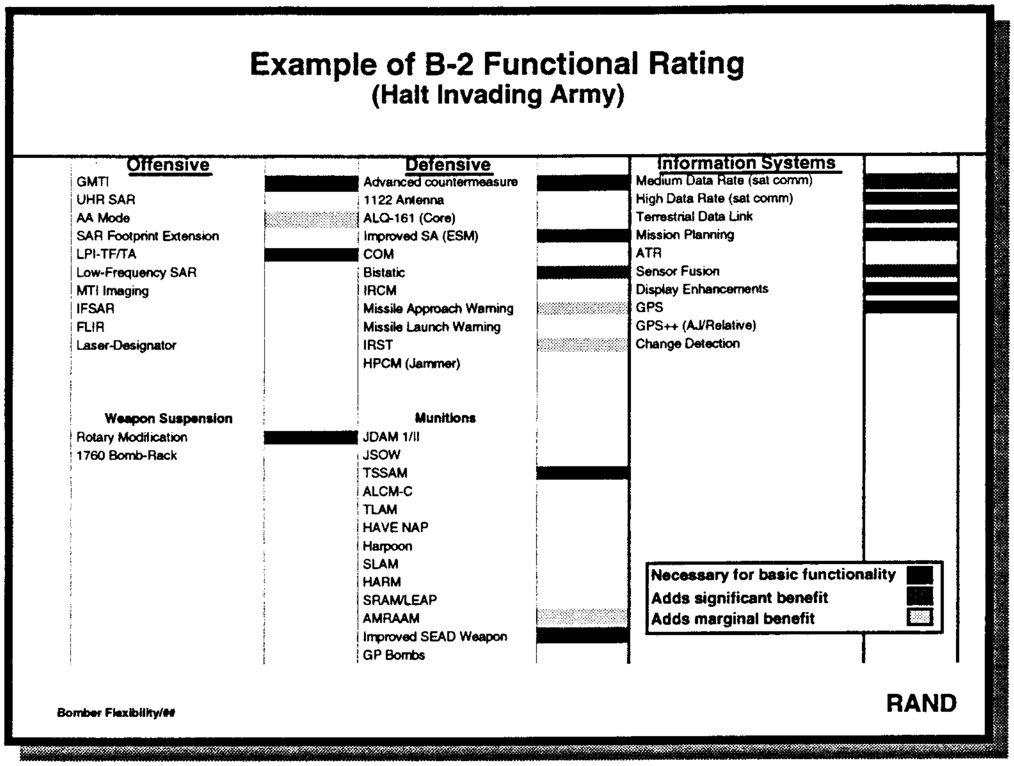
Necessary for basic functionality
Adds significant benefit
Adds marginal benefit

Bomber Flexibility/##

RAND

This chart depicts the scoring scheme used to rank systems for future examination in the study. These rankings were predicated on using the bombers in a highly flexible manner to meet the demands of a dynamic environment, where we believe that they could have the greatest influence on the battle in the theater. We attempted to group technologies into those necessary for performance of the mission, those with significant benefits, those with marginal benefits, and those (left uncoded) deemed of little interest for the bomber/mission combination. This prioritization reflects the desired functionality on the bomber and is not itself indicative of systems lacking on a particular bomber. We chose this approach to avoid trying to build either missions or capabilities around the baseline system's detailed performance characteristics.

Finally, a reminder is in order concerning the next few charts. The inclusion of a technology on this list with an associated aircraft does not imply that the aircraft does or does not have the enabling technology under consideration. The inclusion of a technology indicates only that a capability for that class of improvement appears attractive to the study team.



In this example, we looked at the B-2 providing both defense suppression and targeting support to the B-1Bs in the mission to halt an invading army. Items identified as most important are shown in black, those in the next group are shown in dark gray, and the next group in light gray. Systems left unmarked are not considered of sufficient significance in this context to be examined during the next round of analysis. As mentioned earlier, this list does not indicate that the B-2 either possesses or does not possess any particular technology. Detailed discussions of the B-2 are available in classified documents.

Highest Rated B-2 Modernization Options

- New weapons suspension/ 1760
- LPI GMTI mode in the radar
- Medium data-rate sat comm
- Terrestrial data link
- Improved situational awareness (onboard EOB with ability to update from external sources)
- Relative GPS (possibly with antijam capability)
- UHR SAR
- Addition of system operator with display enhancements
- Substantial information systems improvements
- Automatic target recognition
- SAR footprint extension

Bomber Flexibility/##

RAND

After looking at the cross section of missions the B-2 might perform, we selected a set of high-interest technologies based on their applicability in at least three of four mission areas.[6] We found that improvements to weapon suspension, communications, computing, and other informational systems would enhance the B-2's effectiveness across the variety of missions that the B-2 might perform.

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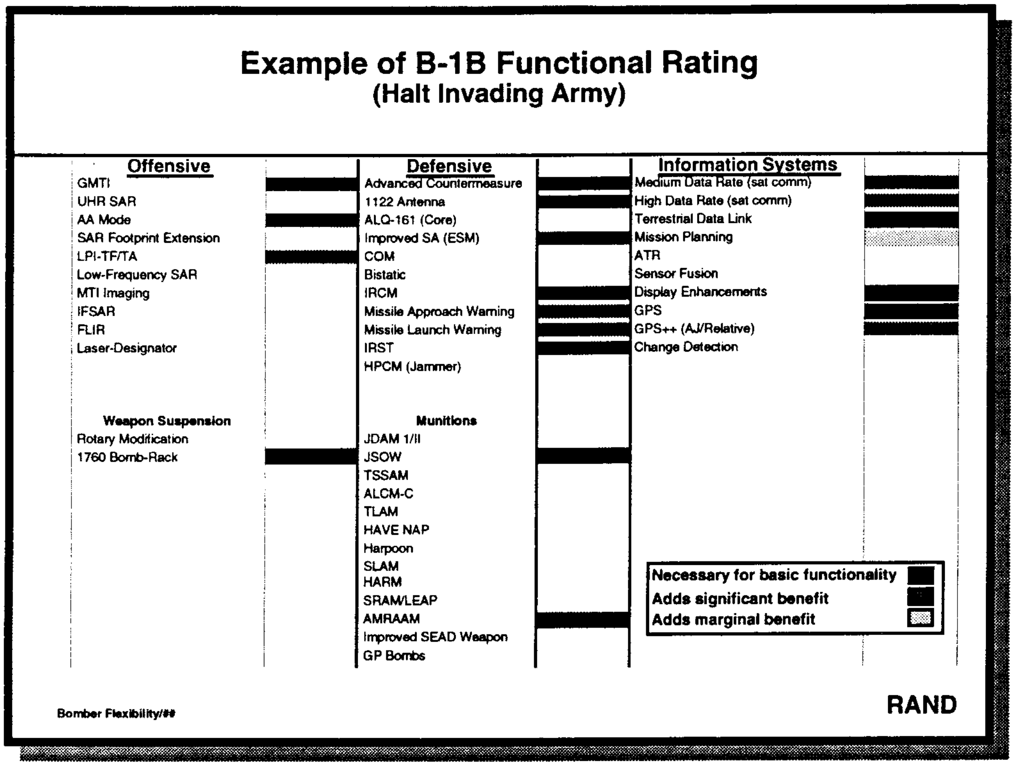
[6]This list does not constitute an output of our study, but rather an input to the initial cost and effectiveness analysis. Furthermore, the large list does not indicate that all these technologies will necessarily have to be integrated into the bomber.



As with the case of the B-2, here we highlight the applicability of some interesting technologies to the B-1B role of halting invading armies. The modest number of technologies marked as necessary highlights our approach of being very conservative in pursuing the addition of new technologies.

Highest Rated B-1B Modernization Options

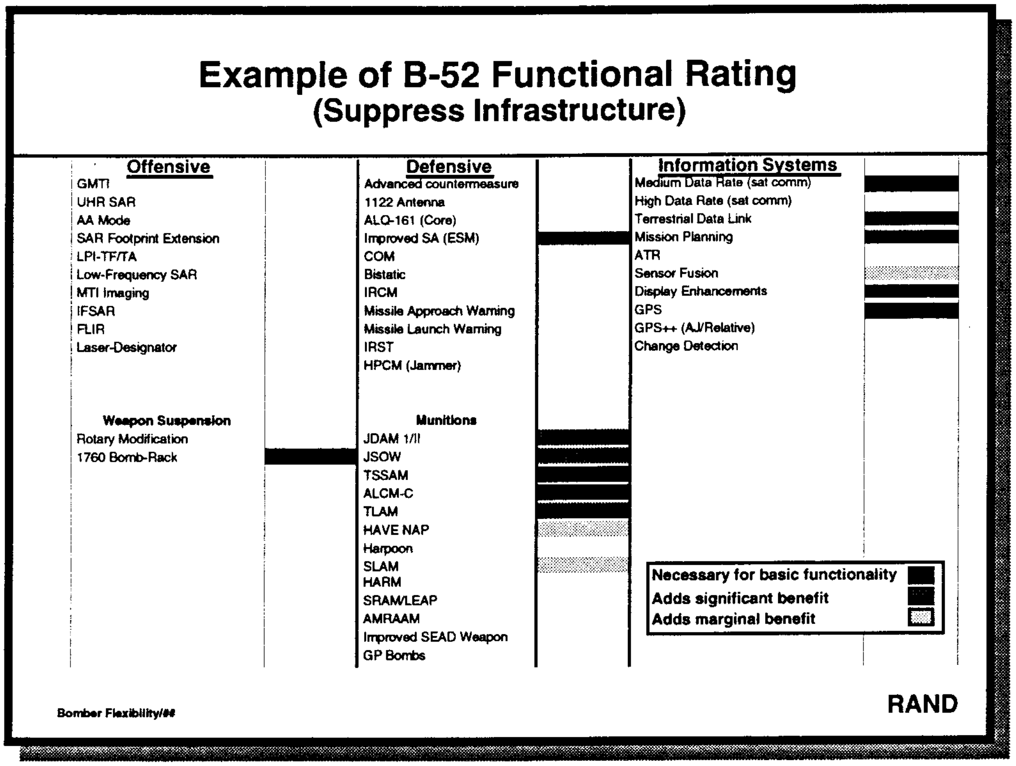
- New weapons suspension/1760
- GMTI mode in the radar
- Terrestrial data link
- Substantial information systems improvements
- Advanced countermeasure/1122 antenna fix
- Relative GPS (possibly with antijam capability)
- UHR SAR
- Display enhancements

Bomber Flexibility/##

RAND

The most interesting technologies that are applicable in both B-1B missions are weapon suspension, sensor improvements, and communications and computing upgrades to support information-intensive operations.[7]

[7]This list does not constitute an output of our study, but rather an input to the initial cost and effectiveness analysis. Furthermore, the large list does not indicate that all these technologies will necessarily have to be integrated into the bomber.



The applicability of various technologies to the B-52 in its mission of suppressing infrastructure is highlighted here.

Highest Rated B-52 Modernization Options

- Terrestrial data link
- Medium data rate satcom
- Substantial information systems improvements
- Onboard planning system for the missiles
- New weapons suspension/1760
- Display enhancements

Bomber Flexibility/##

RAND

As with both the B-1B and B-2, the most interesting technologies for modification of the B-52 lie in the areas of communications and computing to support dynamic employment, as well as some possibility of improving weapon suspension to allow for effective employment of accurate weapons.[8]

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[8]This list does not constitute an output of our study but rather an input to the initial cost and effectiveness analysis. Furthermore, the large list does not indicate that all these technologies will necessarily have to be integrated into the bomber.

Heavy Bombers Modernization Options of Interest

	B-52	B-1B	B-2
Advanced countermeasures/1122 antenna fix		*•	
Addition of system operator			•
Automatic target recognition			•
Relative GPS with antijam capability		•	•
Display enhancements		•	•
GMTI mode in the radar		•	
Improved situational awareness (onboard EOB with ability to update from external sources)			•
LPI GMTI mode in the radar			•
Medium data-rate sat. comm.	•		•
New weapons suspension/1760/Weapon Integration	*•	*•	*•
Onboard planning system for the missiles	•	•	•
SAR footprint extension			•
Substantial information systems improvements	•	•	•
Terrestrial data link	•	•	•
UHR SAR		•	•

• = Addition * = Partially Addressed in Bomber Roadmap

Bomber Flexibility/35 RAND

This chart illustrates the union of all the high-interest technologies identified as necessary for each bomber. The technology is cross-plotted against bomber type. We also illustrate where the current Bomber Roadmap is making contributions to improving the bomber force's operational capability in these areas. The roadmap makes significant contributions by pursuing the integration of new accurate weapons and by addressing supportability issues. However, since it was created within the paradigm of the preplanned mission, it does not reflect the demands of dynamic warfare operations.

The number of options associated with each bomber reflects differences in the mission areas. For instance, the B-52 is associated with relatively few modifications because its primary mission of suppressing infrastructure most closely resembles its original mission. The B-2 lies at the other extreme. Here, we have a highly capable aircraft that might be adapted to a variety of very different mission areas; therefore, we flag a number of applicable technologies.[9]

[9]The technical options associated with an aircraft type are based on mission demands. As before, the association of an area for technical enhancement of the B-2 should not be assumed to indicate that the actual aircraft has or lacks a given capability.

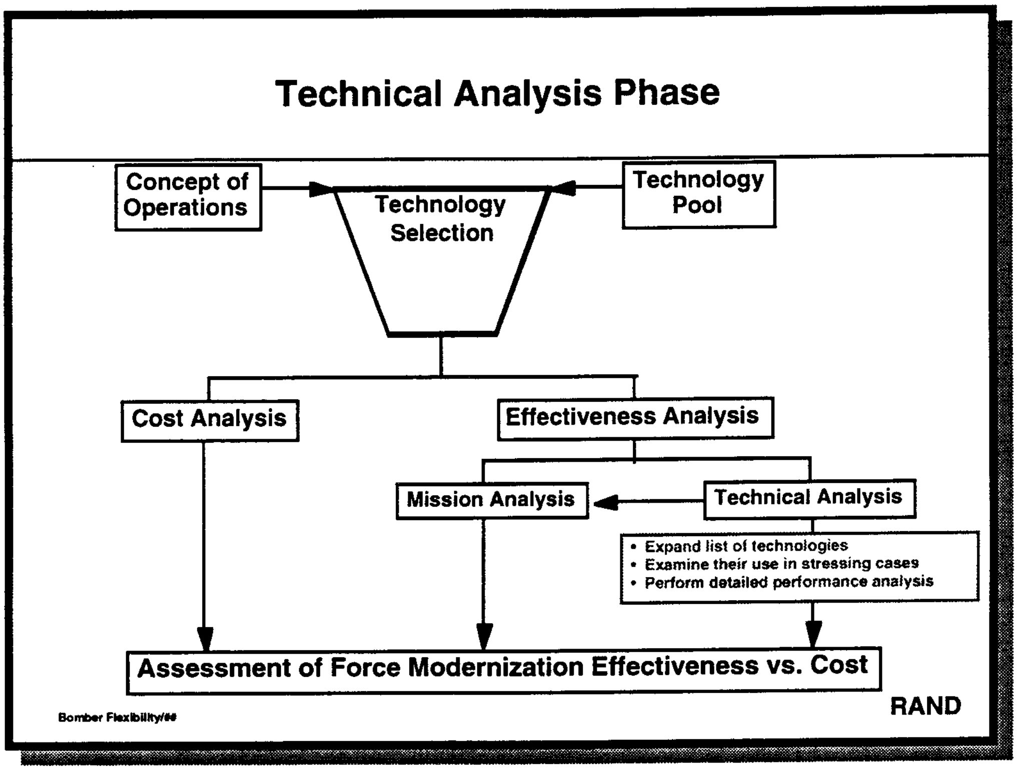
It is important to recall that this list is an input to our main analysis and represents a first cut at identifying technologies with applications across multiple bomber missions. We expect to trade these options off against one another, as well as against operational responses that exploit forces. During the analysis we fully expect this list to change, but this basic set of technologies was carried forward for our initial efforts at cost and effectiveness analysis.

Outline

- Objectives and Approach
- Background
- Concept of Operations
- Selection of Technology Options
- **Assessment of Modernization Options**
- Remaining Tasks

Bomber Flexibility/## RAND

Having discussed how we approach the problem of selecting technologies, we now discuss how we are actually doing the detailed analysis necessary to evaluate those technological options.



In the technical analysis phase of the study, we examine the full list of technologies that might be appropriate for each mission, examine their performance on stressing operational cases, and perform detailed performance analysis. This technical analysis will directly influence the mission analysis efforts by providing detailed performance estimates and also will contribute directly to the overall benefit/cost analysis.

Classification of Technologies

- **Radar and navigation**
- Communications
- Information systems
- Weapons carriage/integration

Bomber Flexibility/##

RAND

The modernization options fall naturally into four main areas: radar and navigation, communications, information systems, and weapons carriage/integration. In the next few charts we detail one particular area of improvement, radar systems, to demonstrate the approach we are taking for detailed performance analysis.

Radar Is the Primary Sensor for the Heavy Bombers

- **Appropriate radar modes significantly increase bomber flexibility**
  - Basic radars on the B-1B and B-2 have a great deal of inherent capability but lack some important modes
  - Existing radars can compromise survivability in certain modes
    - » B-1B terrain following
    - » Non-LPI GMTI modes
- **Some modes can be added with moderate hardware and software upgrades**
  - SGMTI
  - UHR SAR
  - LPI terrain following
  - Air-to-air detection
  - SAR footprint extension

Bomber Flexibility/## RAND

Radar is the primary sensor for the heavy bomber because of its long range, relative insensitivity to weather and atmospheric conditions, ability to support both air-to-ground and air-to-air modes, capability to detect moving targets in high clutter, and (in the case of SAR) good resolution independent of range. Some radar modes that could contribute to the performance of key missions are not available (including slow ground-moving target indication (SGMTI), ultra-high resolution synthetic array radar (UHR SAR), low probability of intercept terrain following/terrain avoidance (LPI TF/TA), air-to-air modes, and SAR footprint extension), but these could be added with moderate hardware and software changes. Moderate does not mean free, and an important goal of this study is to identify the high-leverage options.

Currently, slow ground-moving target indication is not implemented in the B-1B radar. Two proven ways exist for mechanizing SGMTI. The displaced phase center antenna (DPCA), used on the E-2C and JSTARS, requires that the antenna correct for phase changes caused by platform motion. This task is accomplished either by modifying the antenna pattern between transmission and reception or by switching between matched, horizontally displaced subapertures to move the antenna phase center forward at the platform speed.

Multiple monopulse nulling (used in Hughes Pave Mover and Enhanced ASARS-2) combines monopulse channels with adjustable weights that vary in each Doppler filter. The monopulse null in each filter is pointed toward the ground clutter having the same Doppler as targets appearing in the filter. As a result, the clutter relative to the target is suppressed. The signal-to-clutter enhancement increases with the distance between the target cell and the competing clutter cell, i.e., the faster the ground speed of the target.

Multiple monopulse nulling (MMN) is inferior to DPCA but is probably adequate and much less costly. It would extend radial velocity coverage down to 2 to 12 kts, depending on scan angle. Preliminary work on MMN was completed under Air Force Wright Aeronautical Laboratories (AFWAL/AA) sponsorship in the URR program. In the B-1B, MMN would require some software development and a new hardware pulse compressor. Currently, pulse compression is implemented in software that is adequate for the SAR mode, but too slow for moving target indication (MTI).

UHR SAR (having resolution of 1 to 2 feet) was developed for the B-1B radar under Air Force sponsorship in 1987-1989. The prototype, which resides on a Westinghouse BAC-111 aircraft, has been demonstrated out to a 60-nmi range at 2-foot resolution. Based on this work, one has reasonable confidence what modifications are required to the baseline radar. These include both software and hardware changes, the latter including a new signal processor, a direct digital-synthesis waveform generator, minor transmitter changes, and receiver changes to accommodate increased bandwidth.

UHR SAR's primary utility lies in the area of target recognition and bomb damage assessment; its potential contribution is targeting accuracy improvement (in the context of GPS-aided targeting). An important issue we will be addressing for the B1-B is whether these capabilities, to the extent they need to be exercised specifically on the B1-B, provide a sufficient rationale for implementing the upgrade.

In general, high-resolution SAR stresses the capability of the aircraft's inertial navigation system (INS), particularly if the mode will be used at long range. Very careful analysis, looking at the aircraft vibration spectrum, the coupling between the INS and the antenna, the INS characteristics, and the capability of autofocus algorithms is required to sort out future actions. Changes to INS would be very expensive if required and would probably make this option unacceptable. Strapdown motion sensors on the antenna could obviate INS changes, although this option is not available in some situations.

The increased bandwidth associated with UHR may exceed the bandwidth of the antenna or transmitter/exciter. In the case of the exciter, potential options exist for digital signal synthesis that would solve the problem. Digital synthesis, however, might compromise the capability of any MTI modes in the radar. If the instantaneous bandwidth is exceeded for the transmitter, probably a wideband chirp with the required bandwidth could still be generated, although at some price in terms of the low probability of intercept characteristics of the signal. Moreover, the need to "synthesize" bandwidth in the receiver/processor would still exist.

LPI terrain following is intended to prevent sidelobe tracking of the terrain-following radar at extended range by netted enemy electronic support measures (ESM) receivers. LPI TF/TA technology was developed by Westinghouse under Wright Labs/AAAS sponsorship. A prototype system consisting of modified B-1B radar hardware was flight-tested on the BAC-111. The modifications included a new high-power attenuator (HPA) to reduce the peak power and software changes affecting power management, digital pulse compression, pulse integration, adaptive scanning, variable range resolution, frequency agility, and profile storing and updating.

Air-to-air modes, which may be useful in supporting threat detection and tracking, do not exist on the B-1B; however, there is a good deal of overlap between the APQ-164 and APG-68 radar hardware and processor (also manufactured by Westinghouse).[10] The APG-68 radar, which appears on the F-16 fighter, has an extensive repertory of air-to-air modes that might be installed, with modifications, on the B-1B radar. The extent of the modifications needs to be established. Other issues for air-to-air modes include detection range, LPI characteristics, and trade-offs against potential passive modes.

SAR footprint extension is primarily a processor upgrade issue, although other modifications may be required because of the need for the antenna to be steered during the coherent dwell (to support the spotlight mode). One option to avoid steering during a dwell is to spoil or widen the beam by quadratic weighting across the aperture; however, the price is reduced gain that might degrade range performance. Some of the ramifications are discussed in more detail later in this briefing.

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[10]There is significant distinction between air-to-air radar modes for situational awareness and those required for supporting the lethal self-defense option. We are focusing on the former application.

Radar and Navigation Capabilities Selected for Further Analysis

	B-52	B1-B	B-2
Radar Modes			
TF/TA	■	●	▲
Real beam map	■	●	▲
Synthetic aperture radar (SAR)		●	▲
Ultra-high resolution SAR		▲	▲
GMTI search & track		●	▲
LPI TF/TA		▲	▲
LPI GMTI			▲
Air-to-air search & track		▲	▲
Interferometric SAR			▲
Navigation			
INS	●	●	●
GPS	●	●	●
GPS with antijamming		▲	▲
Relative GPS		▲	▲

▲ Mode desired   ● Bomber has desired mode   ■ Has mode, but not central to bomber's role

Bomber Flexibility/40

RAND

This chart summarizes the radar and navigation capabilities selected for further analysis, based on the criteria developed in the preceding charts. Since the radar and navigation modes of the B-2 are classified (except the basic GPS/INS), the indication that a mode is "desired" is not intended to signify whether or not the mode is currently implemented.

For clarification, we briefly touch on each mode. Terrain following and terrain avoidance are used to obtain the ground profile and salient features in support of low-altitude flight. Since the B-1B's TF/TA mode emits much higher power than required, it is of concern from a threat intercept viewpoint. For this reason, we have selected an LPI version of TF/TA.

Real beam mapping (RBM), a standard mode for airborne radars, obtains low-resolution "images" of the ground that typically are used for navigational purposes or to cue the SAR mode. The azimuthal resolution is just the physical antenna beamwidth (in some systems, this is sharpened by monopulse processing); in this respect, it differs from the SAR mode.

The SAR mode uses Doppler processing (exploiting the velocity gradient across the radar beam in the azimuthal direction) to obtain medium-to high-resolution along track and wideband pulse compression to obtain

similar resolution in range. This mode can be used to detect and classify targets, for navigation updates, to geolocate targets in concert with the onboard GPS/INS, and for bomb damage assessment (BDA). Ultra-high resolution refers to resolution of 1 to 2 feet, which clearly benefits target identification and BDA and may have some utility for precise geolocation.

GMTI is ground moving-target indication, which has search and track variants. The B-1B radar originally had a "fast" GMTI mode, which denotes the capability to detect vehicles having Doppler shifts outside the mainbeam clutter spectrum. This mode was cited for lack of utility in the strategic bomber context and will be phased out in the next software block version. A "slow" GMTI mode would require additional processing to suppress clutter but would ensure a high-detection probability against armored vehicles with low-radial velocity (either because of slow speed or nonideal aspect). Employment of GMTI for wide-area search raises concerns about signal interception resulting from the large area illuminated and the long duration of the scan. Therefore, an LPI version is of interest.

Air-to-air search and track modes are of interest to improve situational awareness, particularly as an option to detect the presence of silent fighters on combat air patrol (CAP). The B-1B hardware (apart from the antenna) is highly derivative of the APG-68, which should simplify the mechanization of the fighter air-to-air modes on the B-1B. If inserted on a low-RCS aircraft, probably these modes should be LPI to avoid defeating their purpose.

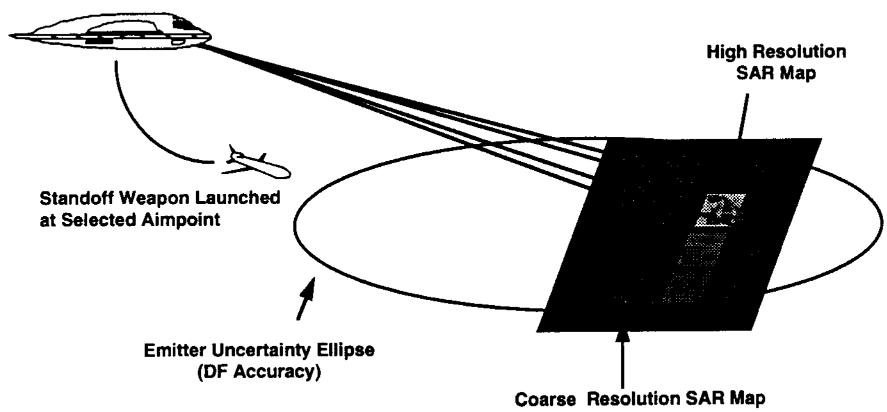
An interferometric SAR (IFSAR) processes the phase differences between SAR images collected by vertically offset antennas to obtain very accurate height measurements. This capability is one option to aid very precise geolocation, since the lack of height information with conventional SAR translates into slant range uncertainty. It is also potentially useful for target identification and discrimination. The concept has been validated by JPL/NASA using multipass shuttle imaging radar data. If multipass imagery is used, a high degree of temporal correlation is required to retain phase coherence between images. High correlation does exist over most terrain types, except over water, wind-blown foliage, and in geologically active regions. The technique could be also mechanized with vertically separated antennas on a single platform or with two platforms operating simultaneously and pooling their data.

Relative SAR targeting is a technique for geolocating and precisely attacking targets using a bomber equipped with GPS/INS and a weapon equipped with GPS and a low-cost INS. The bomber measures the target position with its onboard SAR (hence in coordinates relative to the

bomber) and inserts the coordinates into a weapon. The weapon is then GPS-guided using the same satellites that the bomber used, which has the effect of canceling out the bias errors that usually dominate the GPS error budget. Wright Labs is planning a demonstration of this concept.

GPS depends on receiving very faint signals from distant satellites, which makes the GPS receiver susceptible to jamming. The Air Force has long recognized this problem and has antijam (AJ) receivers and adaptive antennas in development. The AJ receivers typically employ adaptive notch filters to reject narrow-band jammers. Broad-band jammers are not amenable to this approach, but adaptive antennas can be used to null a small number of these jammers. Some issues need to be resolved that pertain to pulsed jamming, low-observable versions of the adaptive antenna, electronic interfaces, and reduced performance compared with the nonadaptive antenna. Also, the adaptive antenna solution is sensitive to the threat, particularly the number of broad-band jammers operating at once.

Example Operational Concept: Defeat Enemy Air Defenses



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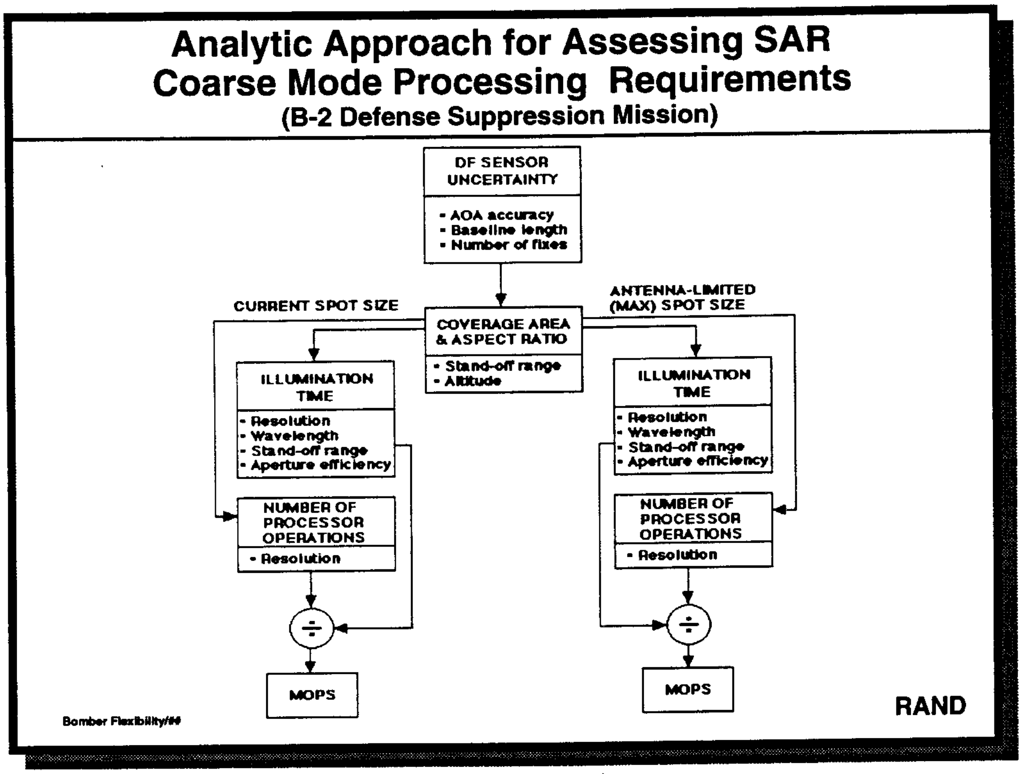
The concept for conducting SEAD missions using the bomber differs from the more traditional approach employed by Wild Weasel in that the focus for the bomber is on nonradiation homing precision standoff weapons. Here the bomber can either attack active radars, which may be direction finding (DF) using onboard ESM, or attack silent radars based on localization from national assets. Data links would also allow the near-real-time handover of emitter data from electronic intelligence (ELINT) platforms in the theater such as RIVET JOINT or U-2/SENIOR RUBY.

The operational concept calls for imaging the DF uncertainty ellipse using the bomber's coarse-resolution SAR mode, then identifying and locating the air defense components using a higher-resolution SAR mode. Damage assessment also might be performed in the higher-resolution SAR mode.

Whatever the ELINT data source, the data transfer procedure may have to be modified to define the ellipse size and orientation on the ground. These data are not routinely distributed in intelligence reporting media such as CONSTANT SOURCE, and at present do not flow automatically from the defensive to the offensive avionics computers on board the bombers.

Other issues that arise in connection with this approach to the SEAD mission are controlling the intercept probability for the SAR's emissions, providing adequate throughput for the SAR processor and adequate bus capacity to support the imaging data flow, managing crew workload associating with target identification, and meeting accuracy requirements to destroy the emitters.

Several of these issues are coupled, as we detail later in the briefing. The emerging trade-offs involve upgrade options for advanced processors, busses, SAR footprint extension, automatic target recognition, improved SAR resolution, low-probability-of-intercept modes, types of standoff weapons, and implementations of relative GPS.



Intercept of the SAR's emissions is a concern during the coarse resolution search of the DF uncertainty ellipse. The emission time can be reduced if the SAR footprint is extended, resulting in fewer illumination periods to cover the specified area. The consequences for the processor throughput are analyzed, however, as shown in this chart.

The starting point for the analysis is to look across the spectrum of ELINT sources to determine size and shape (or aspect ratio) of the uncertainty area. Sometimes emission control will deny radar intercepts to the bomber's onboard systems, so the spectrum should include national overhead and theater ELINT assets that can provide spatial and temporal diversity.

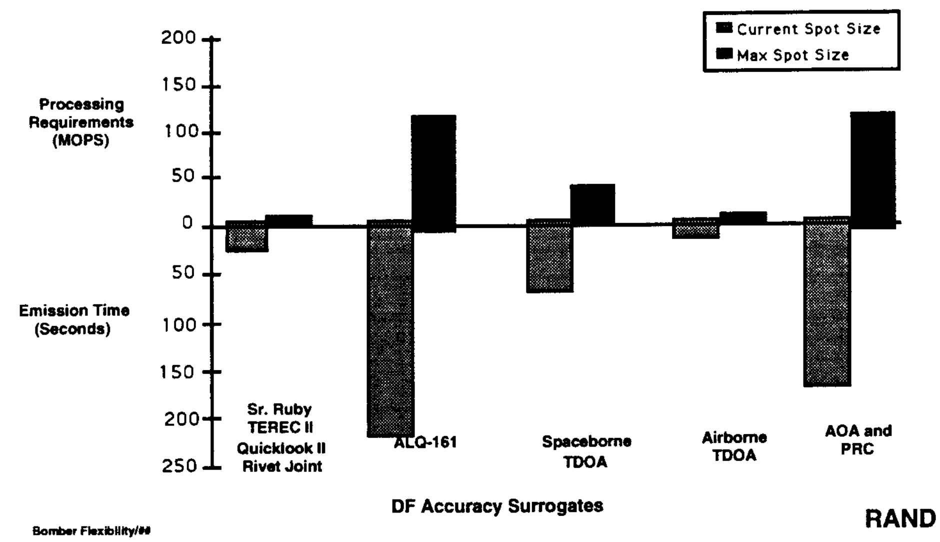
Typically, airborne systems obtain multiple angle-of-arrival (AOA) fixes over a line of bases to estimate range to the emitter. AOA is measured interferometrically or using monopulse. A more accurate and technologically advanced method (used in the COMMON GUARDRAIL's SIGINT DFing equipment) is time difference of arrival (TDOA), which involves cross-correlating signals received at two or more locations. Other new techniques having various proprietary implementations such as phase rate of change (PRC) use Doppler measurements to supplement AOA and thereby to converge more rapidly on a range estimate.

Generally, the uncertainty area and aspect ratio obtained from these methods depends on the range and altitude of the collection platform.

Currently, the maximum SAR image size or "spot" is constrained by the processor architecture and is but a fraction of the area on the ground within the antenna's footprint. Although the imaging time is fixed for a given slant range and resolution, the total illumination time is the product of the imaging time and the number of spots—potentially a large number with the current spot size. Another consequence of having the spot size smaller than the antenna footprint is that if a large contiguous region is imaged, the mainbeam illuminates each point several times. The analysis of current capability is represented by the left branch in the chart.

Alternatively, an upgraded processor would allow the full antenna footprint on the ground to be processed at a rate commensurate with the imaging time. In this case, far fewer spots and less total illumination time are required—but a much higher throughput. The output of the analysis is the required throughput associated with the two processor architectures.

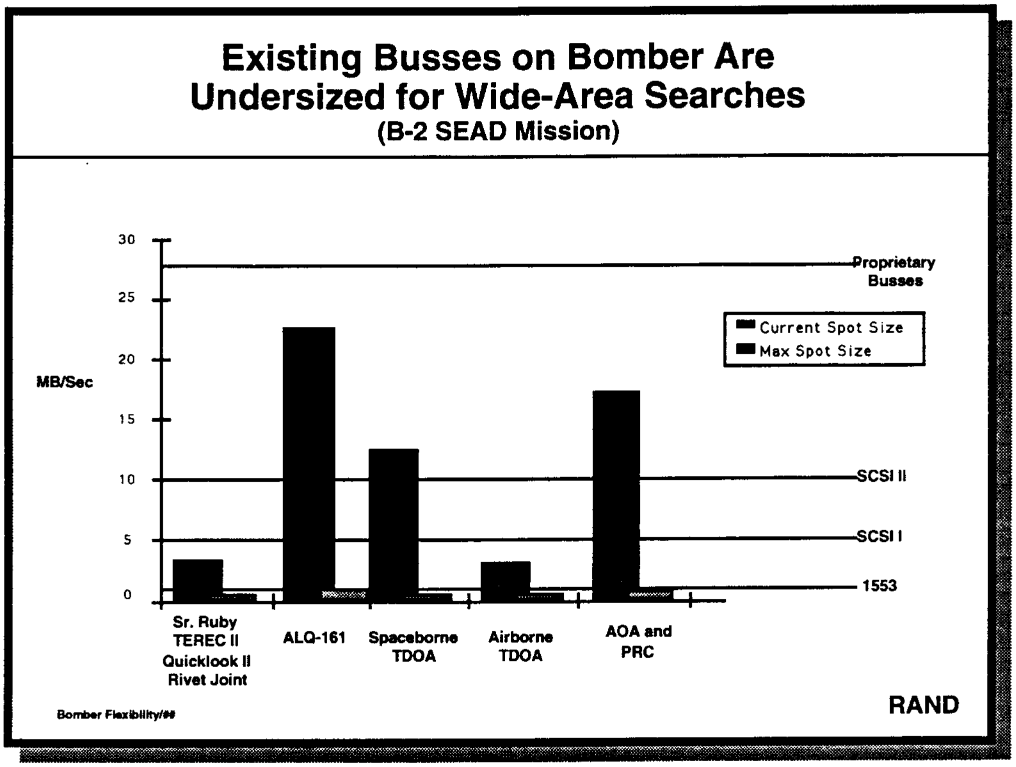
Improved Mission Performance and Survivability Drive Information System Improvements



As mentioned earlier, we are examining various methods of performing a wide-area search using SAR imagery. We focus on balancing emission time with processing requirements, which effectively trades survivability against onboard technology and cost.

Keeping a goal of real-time processing in mind, the analysis concerning a fixed (current) spot size presents no surprises. Identical data are processed over varying periods of time, and hence the longer the time period, the less the processing requirement. At the maximum spot size, and equivalently the minimum emission time, processing becomes an issue because of the inherent uncertainties in the direction finding system.

All the methods of direction finding yield requirements that fall well within the performance of current technology, with systems like Pave Pillar benchmarking at more than 10 billion operations per second and technologies involved in digital signal processing chips growing exponentially. The deciding factor will more than likely be related to survivability impacts of excessive emission times because of marginal direction finding of targets of interest.

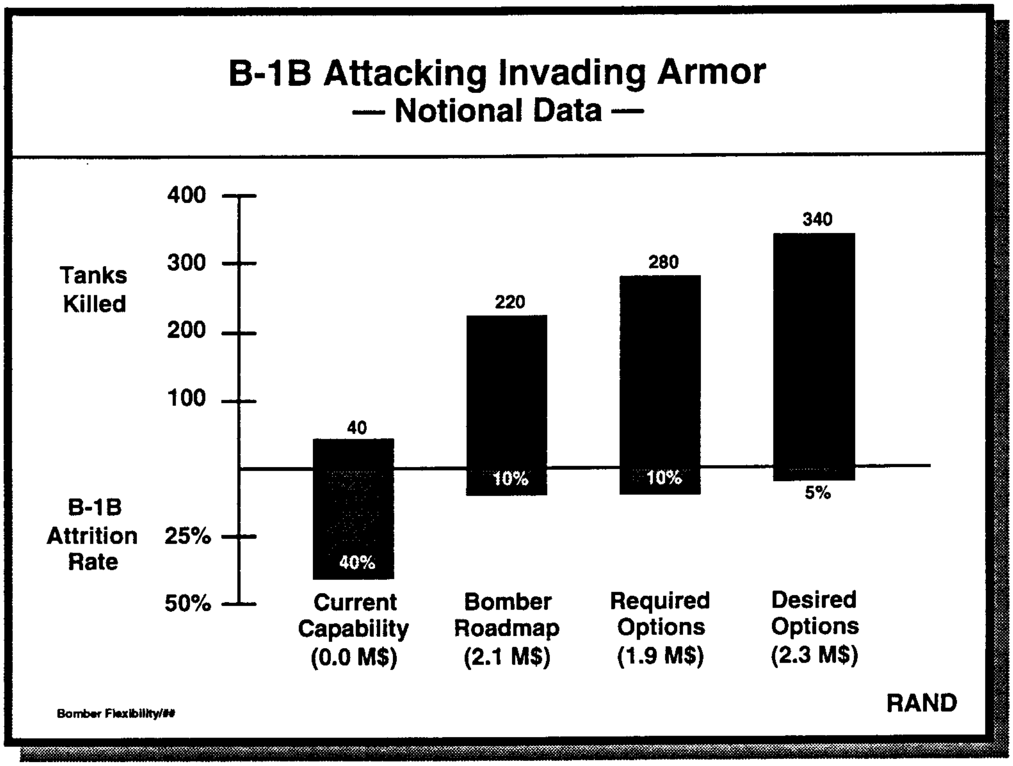


The current 1553 bus architecture, already operating at more than 75 percent capacity on all systems examined, quickly becomes inundated by the massive amounts of imagery generated by SAR. Since only a portion of these data are traveling across the bus, the problem is quite large. The options include providing hardware at the site of the image-gathering system and passing only minimal target information to other systems or incorporating a secondary bus designed to handle image processing data.

Inclusion of a secondary bus sounds prohibitive in terms of cost, but initial research shows it may provide a novel solution to the problem. After all, the 1553 is a control bus—not an information bus—and as such is overly conservative for information passing. Control busses focus on exceptionally stringent message accuracy, while information busses push for maximum flow rate with reasonable accuracy. A secondary bus could be included with only a minimal set of well-defined changes to the existing architecture, thereby providing a cost-effective solution.

Even though the requirements rate well above the current bus throughput, they are acceptable with commercially available technology. Three of the options may even be feasible over a present-day SCSI II bus, which the Navy recently adopted for several shipboard systems. Also, options such

as real-time data compression could be exploited to further reduce the amount of data, though it is unlikely that the 1553 could handle this reduced throughput.



Because technical analysis does not always translate straightforwardly into military effectiveness, our research must be extended to convert the technical analysis into a framework that can provide measures of effectiveness relevant to senior decisionmakers. This chart illustrates such an approach with an example comparing a number of improvement packages on a cost and effectiveness trade-off. While this chart is only notional, it illustrates how we hope to present our ultimate results for different modernization options. This method will ensure that our technical analysis will be presented in a framework useful to decisionmakers. This chart shows a notional example of such a final briefing slide highlighting the impact of different technical options.

Outline

- Objectives and Approach
- Background
- Concept of Operations
- Selection of Technology Options
- Assessment of Modernization Options
- **Remaining Tasks**

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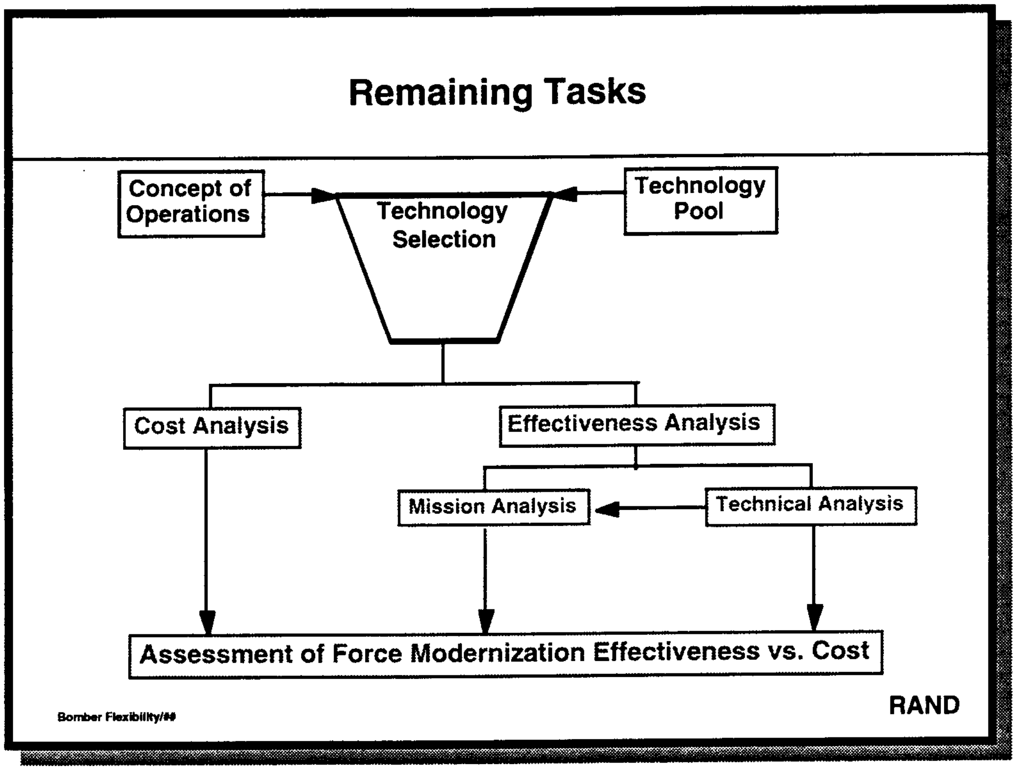
We can now move on to the remaining tasks for this analysis.



We are now in the heart of the analysis. We are examining these bomber modernization options in three major steps that are all built on our initial attempts at identifying high-leverage technologies to support each of the four mission areas identified for the bombers. First, the cost analysis work, including both initial and lifetime costs for modernization options, is beginning in earnest.

Second, we are beginning the overall effectiveness analysis, examining both the technical and operational implications of improvement to the bomber force. The technical analysis portion will focus on the identification of system breakpoints and will be conducted at a level of detail that will allow the Air Force to understand if a particular technology meets the requirements of being effective and feasible to integrate into the force. The mission analysis will examine the tactical utility of the technologies, as well as corresponding operational responses such as operating with friendly forces, to assess the impact of these systems in militarily significant terms.

Finally, we will combine the effectiveness and cost analyses into an assessment of the effectiveness of force modernization versus cost that will allow decisionmakers to make more informed decisions regarding bomber force modernization.

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