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1946–1996

AIRBORNE INTERCEPT

BOOST- AND ASCENT-PHASE OPTIONS AND ISSUES

David R. Vaughan
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Joel S. Kaitky

RAND

The research reported here was sponsored by the United States Air Force under Contract F49642-96-C-0001. Further information may be obtained from the Strategic Planning Division, Directorate of Plans, Hq USAF.

Library of Congress Cataloging in Publication Data

Vaughan, David R., 1935–
Airborne intercept : boost- and ascent-phase options and issues / David R. Vaughan, Jeffrey A. Isaacson, Joel S. Kvitky.
p. cm.
"Project AIR FORCE."
"Prepared for the United States Air Force."
"May 1996."
"MR-772-AF."
Includes bibliographical references (p.).
ISBN 0-8330-2434-5 (alk. paper)
1. Ballistic missile defenses—United States—Research.
I. Isaacson, Jeffrey A. (Jeffrey Alan), 1960– . II. Kvitky, Joel S. III. Project AIR FORCE (U.S.) IV. United States. Air Force. V. Title.
UG743.V38 1996
623.4'5194—dc20 96-26419
CIP

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Published 1996 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
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Prepared for the United States Air Force
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PREFACE

This report was written to inform the decision process for development of airborne (i.e., aircraft-based) boost- and ascent-phase intercept of theater ballistic missiles. Several possible development paths are considered. For each, we discuss test and development, early contingency, and final objective capability (i.e., full capability). The paper is based on RAND's broader research on countering TBMs with active defense or ground-attack operations and on its participation on the boost-phase intercept panel of the 1993 USAF Scientific Advisory Board summer study on Theater Air Defense. In January 1994, a briefing on our research was presented to the Gold Panel, an independent panel formed at the request of Dr. John Deutch, then the Undersecretary of Defense for Acquisition and Technology.

The work was conducted for Air Combat Command under RAND's Project AIR FORCE, C^3I/Space project, which is part of Project AIR FORCE's Force Modernization and Employment Program and also sponsored, during its early phases, by OUSDA&T/Tactical Systems. The paper should be useful to U.S. Air Force, Department of Defense, and other decisionmakers and analysts concerned with theater missile defense architecture and cost and with operational effectiveness analysis.

PROJECT AIR FORCE

Project AIR FORCE, a division of RAND, is the Air Force federally funded research and development center (FFRDC) for studies and analyses. It provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat

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In 1996, Project AIR FORCE is celebrating 50 years of service to the United States Air Force. Project AIR FORCE began in March 1946 as Project RAND at Douglas Aircraft Company, under contract to the Army Air Forces. Two years later, the project became the foundation of a new, private nonprofit institution to improve public policy through research and analysis for the public welfare and security of the United States—what is known today as RAND.

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SUMMARY

This report documents an analysis of countering theater ballistic missiles (TBMs) by using manned aircraft with onboard radar sensors in an airborne intercept role. Although current defense planning does not anticipate such a role for manned aircraft, more-advanced airborne intercept options harbor significant uncertainties with respect to development, and it remains to be demonstrated that they will prove practicable in the decade ahead. Thus, the approaches we analyzed and similar ones may be revisited as nearer-term options in the future.

Moreover, although recent discussions have focused almost exclusively on boost-phase intercept (BPI), ascent-phase intercept (API) has significant operational merits that should not be dismissed wholesale. Indeed, our analysis suggests that the development of a dual BPI-API capability should be strongly considered for the reasons cited in this report.

Our approach consists of first describing the factors that bear on the decision to develop airborne interceptors, then assessing three nominal development paths, illustrated in Table S.1. Each path is characterized by the sequence of boosters used for development and for the final (objective) operational system. The paths differ in test and development, early contingency, and final objective capabilities.[1] The first two paths, which start with exoatmospheric API early

[1]Subsets and variants of these systems and development paths may also be of interest, but we believe these paths illustrate the range of possibilities for early contingency

Table S.1

Airborne Intercept Development Paths

Development Path	Test and Development	Early Contingency Capability	Final Objective Capability
Path 1: SRAM-ASAS (grow down)	Test and develop KKVs on SRAM-ASAS	API on SRAM-ASAS	BPI/API on SRAM-ASAS
Path 2: SRAM-ASAS/ Peregrine (grow down)	Test and develop KKVs on SRAM-ASAS	API on SRAM-ASAS	BPI/API on Peregrine
Path 3: AMRAAM-Hellfire/Peregrine (Direct)	Test and develop KKVs on AMRAAM-Hellfire	BPI/API on AMRAAM-Hellfire	BPI/API on Peregrine

NOTE: Short-Range Attack Missile (SRAM); Advanced Solid Axial Stage (ASAS); Advanced Medium-Range Air-to-Air Missile (AMRAAM).

contingency options and end with endoatmospheric BPI systems, are sometimes called "grow down" paths, implying that lower-altitude BPI may be pursued later through follow-on development. The final path, which starts with an early BPI capability, is called "direct."

The problem, simply stated, is to decide which capabilities to enable and to choose the most desirable development path. In what follows, the results of our analysis to inform this decision process are summarized briefly.

If the BPI requirement is limited to TBMs with ranges of 600 km or more, the desired capability can be most quickly and cheaply developed with a SRAM-ASAS system (Path 1, Table S.1). If desired, an API capability with an exoatmospheric kinetic kill vehicle (KKV) could be developed first as an early contingency capability. The endoatmospheric KKV for the BPI system would be designed for dual-mode operation, unless this is prohibited by technical barriers (e.g., size, weight, lethality). The SRAM-ASAS booster would be used for all developments and operational systems. Because of its weight and size, this booster could not be operated from carrier-based aircraft.

options (available in roughly 3 years) and final objective capability in the midterm (available in roughly 5 years).

If the BPI requirement is to include intercepts of TBMs with ranges as short as 300 km, a more capable endoatmospheric KKV and a shorter-burn (i.e., high-acceleration) booster are required. Two distinct paths—differing primarily in their early contingency capabilities—are attractive:

- In the first approach, the more capable endoatmospheric KKV would be developed on SRAM-ASAS. Assuming satisfactory progress, a shorter-burn, smaller Peregrine-type booster would be developed to be ready for the operational system. This booster would be compatible with joint (Air Force, Navy) operation, and an early contingency API capability with an exoatmospheric KKV could be developed first.
- In the second approach, the more capable endoatmospheric KKV would be developed on AMRAAM-Hellfire, a much shorter-burn, smaller, and somewhat lower-velocity booster than SRAM-ASAS. An early contingency capability for BPI of TBMs down to 300 km range would be possible with this booster coupled with an interim endoatmospheric KKV matched to AMRAAM-Hellfire's lower velocity. As in the first approach, this booster would be compatible with joint (Air Force, Navy) operation, and assuming satisfactory progress, the higher velocity, somewhat larger Peregrine-type booster would be developed to ensure a full-capability operational system.

In conclusion, several operational considerations deserve some attention in sorting through development options for BPI/API. For example, a long-range API system carried in bombers could contribute in a standoff mode in the early phases of a conflict before air superiority has been achieved. Operating a BPI system with a small footprint could require a large number of aircraft to maintain combat air patrol, and puts a premium on positioning the interceptor platform properly. Finally, several potential synergies between API/BPI and ground-attack operations may be exploited, including post-launch ground attack of launchers and other assets fleeing to hide and resupply sites.

A detailed examination of these issues is clearly beyond the scope of the present work. Nonetheless, highlighting them underscores the need for a broader analytical context within which the operational viability of airborne intercept may be understood properly.

ACKNOWLEDGMENTS

The authors wish to thank Laura Zakaras for many helpful suggestions and Keith Henry and Ken Saunders for thoughtful reviews. We are also indebted to Emily Rogers for constructing tables and figures. Needless to say, responsibility for any errors or omissions is our own.

ACRONYMS

AMRAAM	Advanced Medium-Range Air-to-Air Missile
API	Ascent-phase intercept
ASAS	Advanced Solid Axial Stage
BPI	Boost-phase intercept
E^2I	Endo/Exoatmospheric Interceptor
GBI	Ground-Based Interceptor
HEDI	High Endoatmospheric Defense Interceptor
HVM	Hypervelocity Missile
IR	Infrared
IRST	Infrared search and track
KKV	Kinetic kill vehicle
LEAP	Lightweight Exoatmospheric Projectile
SRAM	Short-Range Attack Missile
TBM	Theater ballistic missile
THAAD	Theater High-Altitude Area Defense
TMD	Theater missile defense
UAV	Unmanned aerial vehicle

Chapter One

INTRODUCTION

BACKGROUND

At the time this work was performed and originally promulgated,[1] we primarily had manned aircraft in mind as the only near-term weapon platform and onboard radar sensors as the nearest-term all-weather target-acquisition system for countering theater ballistic missiles (TBMs) with ranges of 600 km or less. Raptor Talon, an unmanned aerial vehicle (UAV) platform with an infrared (IR) sensor system, was considered a longer-term possibility.

Currently, there is interest in the Tier II+ UAV as a platform for the boost-phase intercept (BPI) mission.[2] It is argued that the UAV has been developed and could be modified for this mission. Although recent discussions have focused almost exclusively on BPI, ascent-phase intercept (API) has significant operational merits that should not be dismissed wholesale. Indeed, our analysis suggests that the development of a dual BPI-API capability should be strongly considered for the reasons cited in this report.

Some of the near-term options that we analyzed, such as an API-only system based on the Short-Range Attack Missile (SRAM) with the Advanced Solid Axial Stage (ASAS) as a kick stage, are not likely candidates for a UAV platform. Also, other missiles, such as the High-

[1] Summer 1994.

[2] See, for example, Scott (1996).

Speed Anti-Radiation Missile (with modifications), have been considered since our initial work was performed.

The above comments notwithstanding, this report documents our analysis of the options that were being considered and contains useful results on the kinematics of engagements and other factors that are relatively independent of the weapon carrier platform. Moreover, the UAV and other advanced options for BPI harbor significant uncertainties with respect to development—that is, it remains to be demonstrated that they will prove practicable in the decade ahead. Thus, the approaches we analyzed and similar ones may be revisited as nearer-term options.

NOMINAL AIRBORNE INTERCEPTOR CONSTRUCTS

For theater scenarios, airborne BPI and API of TBMs are feasible intercept modes having unique advantages (particularly BPI) in a layered active defense.[3] Also, in many scenarios, airborne intercept could be inserted sooner than land- or sea-based systems, and in some cases, it might be the only active defense capability that could be inserted at all. Thus, options to develop an early contingency and more-robust airborne intercept capability are of interest.

Figure 1.1 illustrates typical potential capabilities of API and BPI systems against a 600-km TBM. The figure shows maximum range loci for interceptor and target-acquisition sensor platforms—referenced to the intercept and launch points. For the ascent phase, intercept at apogee is illustrated (for earlier API intercepts, the interceptor range would be less). For BPI, intercept is a few seconds before booster burnout. For API, a single platform carrying interceptors and a target-acquisition sensor can operate within the lightly shaded zone. A BPI platform must operate within its interceptor range locus, shown by the darker shaded circle. Overall, the much longer ranges for API functions allow much greater standoff.

[3]For API, we are thinking primarily of post-boost, prefractionation intercepts. For high payload fractionation levels, post-boost intercepts after fractionation are probably not feasible, unless the number of objects has been thinned by a BPI. The battle space for prefractionation intercept depends upon the interval between booster burnout and payload fractionation.

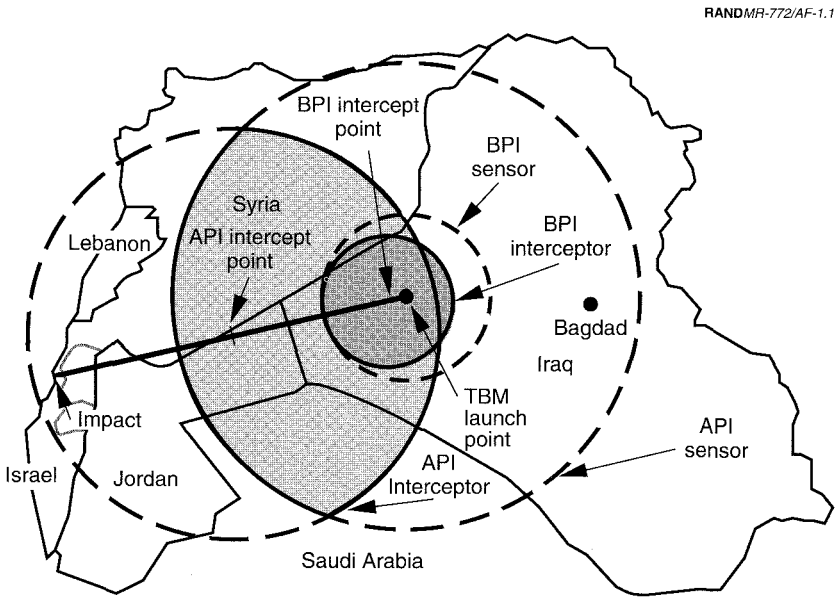

Figure 1.1—Maximum Range Locus of Interceptor and Target Acquisition Sensor for BPI and API of a 600-km TBM

API's potentially long engagement, compared to that of BPI, and the possibility of a relatively early limited operational capability have motivated the current debate on airborne intercept development options. We limit our discussion to the three development paths shown in Table 1.1. Each path is characterized by the sequence of boosters used for development and for the final (objective) operational system. The paths differ in test and development, early contingency, and final objective capabilities.[4] The first two paths, which start with exoatmospheric API early contingency options and end with endoatmospheric BPI systems, are sometimes called "grow down" paths, implying that lower-altitude BPIs may be pursued later

[4]Subsets and variants of these systems and development paths may also be of interest, but we believe these paths illustrate the range of possibilities for early contingency options (available in roughly 3 years) and final objective capability in the midterm (available in roughly 5 years).

Table 1.1

Airborne Intercept Development Paths

Development Path	Test and Development	Early Contingency Capability	Final Objective Capability
Path 1: SRAM-ASAS (grow down)	Test and develop KKVs on SRAM-ASAS	API on SRAM-ASAS	BPI/API on SRAM-ASAS
Path 2: SRAM-ASAS/Peregrine (grow down)	Test and develop KKVs on SRAM-ASAS	API on SRAM-ASAS	BPI/API on Peregrine
Path 3: AMRAAM-Hellfire/ Peregrine (Direct)	Test and develop KKVs on AMRAAM-Hellfire	BPI/API on AMRAAM-Hellfire	BPI/API on Peregrine

through follow-on development. The final path, which starts with an early BPI capability, is called "direct."

The problem, simply stated, is to decide which capabilities to enable and to choose the most desirable development path. This report describes the results of our analysis to inform this decision process.

OVERVIEW

Our approach consists of first describing the factors that bear on the decision to develop airborne interceptors, then assessing the three development paths illustrated above.

In Chapter Two, we first analyze the value of API in the overall theater missile defense (TMD) context. We conclude that it is valuable both generally and as an early contingency capability. Thus, final objective systems that could be available in the midterm (5 years or earlier) should strive for dual-mode capability (BPI and API). We then describe the potential API and BPI kinematic range capabilities. The results show the long-range potential of API and the dependence of capabilities on TBM type. We illustrate the dependence of engagement range on three factors: interceptor kinematics, target-acquisition sensor range and overall launch delay, and TBM type. This leads to the conclusion that BPI ranges will be limited to about

150 km until the early 2000s. We next discuss the comparative difficulties of kinetic kill vehicle (KKV) sensor operation and lethality for API and BPI. The level of KKV seeker heating, the major issue for high-velocity BPI of shorter-range targets, is compared to the heating levels that the Theater High-Altitude Area Defense (THAAD) and the Endo Lightweight Exoatmospheric Projectile (LEAP) are striving to achieve. Even for the most stressing TBM engagement considered, the BPI engagement heating levels are shown to be lower.

Building on these results, Chapter Three illustrates the comparative difficulty of KKV engagement environments and the potential TBM engagement capability of various points on the candidate development paths. Thus, API and BPI engagement environments and potential capabilities for different TBMs are viewed in the same space. We used these considerations to select and assess three development sequences:

- A grow-down path to BPI of TBMs with ranges of 600 km or more.
- Two paths to BPI of TBMs with ranges down to 300 km—one grow-down and one direct.

Finally, in Chapter Four, we briefly compare operational considerations for API and BPI and several potential synergies between airborne intercept and air-to-ground counterforce operations.

Chapter Two

ANALYZING AIRBORNE INTERCEPT

In analyzing the viability of airborne intercept using manned aircraft, four issues appear to be the most pressing: (1) the intrinsic value of an API capability, (2) kinematic range capabilities, (3) interceptor and sensor issues, and (4) kinetic kill vehicle issues. This chapter focuses on each of these in turn.

THE VALUE OF AN ASCENT-PHASE INTERCEPT CAPABILITY

The value of intercept before booster burnout is widely accepted. If the missile's thrust is terminated just a few seconds early by the KKV impact, the debris and any surviving pieces, including the warhead, multiple warheads, or submunitions, will fall short of the target or even on enemy territory. Moreover, there are potential psychological benefits to be gained from thwarting a TBM offensive close to the launch point, where it can be witnessed by the adversary. Figure 2.1 illustrates the value of a BPI capability.

The value of post-boost (ascent-phase) intercept is of interest since it bears on (1) the early contingency value of having such a capability a few years prior to having a boost-phase capability and (2) the value of having such a capability in addition to a boost-phase capability.

The early contingency value and the basic value for various situations are shown in Table 2.1. In the first situation considered (first row), no other active defense systems are present, either because they cannot be inserted as soon or because they cannot be deployed in the scenario. Also, the payload is either not fractionated at all or not fractionated early enough to negate post-boost API effectiveness.

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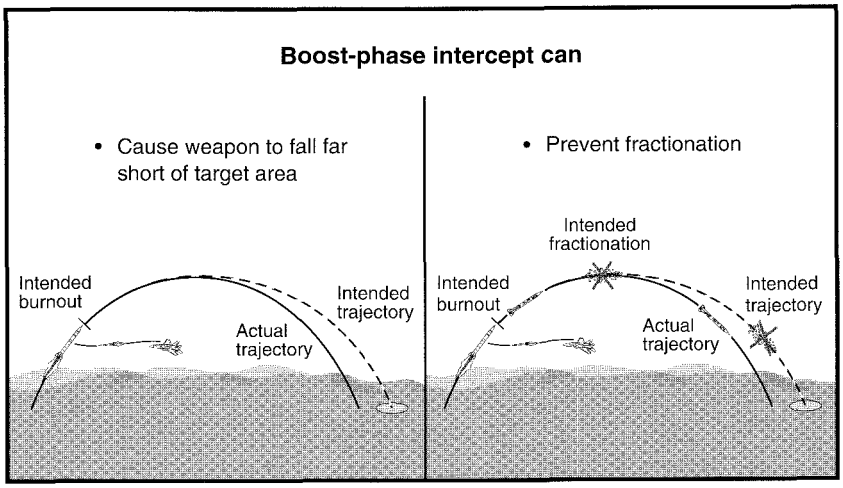


Figure 2.1—The Value of a BPI Capability

Table 2.1

The Value of an API Capability

Situation	Early Contingency Value (BPI not yet developed)	Basic Value (BPI is developed)
No other active defense is present, and API has a prefractionation window	Value is very high throughout the campaign	Value is very high early in the campaign
Other defenses are present, but are foiled by payload fractionation	Value is high throughout the campaign	Significant value persists (assuming API has an adequate prefractionation window)
Other defenses are present and functioning, but there is no payload fractionation	Value as an additional layer is marginal for areas defended by the other layers	
TBM payload is nuclear, and API has a prefractionation window	Value is very high throughout the campaign. Killing the nuclear warhead is paramount; dropping it short of the target is secondary	

If BPI is not yet developed, the early contingency value is obvious, and very high, since TBM attacks in the absence of other active defenses would have no opposition. Also, in this instance particularly, intercept at any feasible point along the TBM trajectory—ascent or descent—would be of value. (We use the API terminology in deference to the usage in the current debate but take it to mean any post-boost intercept that is sensible in each particular context.)

If a BPI capability has also been developed, the value of API is still high until the airborne BPI system can operate close enough to the TBM launch area to be within the range of the target. Since it is unlikely that a BPI range of more than about 150 km can be developed before the year 2000, penetration of enemy airspace would most likely be required.

For the second row, the situation is that other active defense systems are present, but TBM payload fractionation substantially reduces their effectiveness, since fractionation takes place before they can intercept. A significant API prefractionation intercept window remains. Here, the API is again of value throughout the campaign. Even if a BPI capability has been developed, the value of API persists. The API system is the second and final defense layer and could contribute strongly, since the difficulties of kill assessment and sorting the debris from the next layer's look-shoot are intrinsically easier for the BPI layer than for post-boost defense layers.

In the third case, other defense systems are present and functioning in certain areas, and there is no payload fractionation. For these areas, API has marginal value as an additional defense layer, which may compound the kill probability and reduce the load on the subsequent layers. Also, by intercepting earlier than the other layers, the TBM payload may be further diverted from the intended target area, since any momentum changes have a greater action time.

However, in the above case, the contribution of API as an additional defense layer to the calculus of overall system leakage and resource requirements is not a strong one. To gain these benefits, the difficulties of kill assessment and sorting the debris from the next layer's look-shoot would have to be solved, and even then the buy-in investment could be difficult to justify. Moreover, the potential for greater TBM payload diversion (than for later intercepts by other ac-

tive defenses) has not yet been adequately evaluated. With the maximum possible momentum exchange, the TBM payload could be diverted tens of kilometers, but the actual degree of exchange is uncertain and depends on the kill-vehicle design.

For the final row of the table, we assume the TBM payload is nuclear. In this case, for rest-of-world threats prior to 2000, the payload will probably not be fractionated at all and almost certainly not to the high degree feasible with chemical submunitions. Decoys are slightly more likely, but for early deployment, they would have to be so heavy they would cause a large virtual attrition of the nuclear payload. Thus, for nuclear payloads, API is very likely to have a pre-fractionation window. If only API (or API plus BPI) is operative, the value of the API system is very high because of the great need to keep out the first (and subsequent) nuclear warheads. Moreover, even though the payload is not dropped far short of the target area (as it could be with a BPI system), the value of killing the nuclear warhead is paramount.

To summarize, we conclude that an API capability has a basic value in addition to its importance as an early contingency. There are possible exceptions when BPI has a very long range or can be carried on effective penetrating systems, or when payload fractionation greatly diminishes API capability.

KINEMATIC RANGE CAPABILITIES

The capability to perform BPI or API of a particular type of missile depends on the minimum intercept altitude. For BPI, the minimum intercept altitude must be less than or equal to the maximum allowable intercept altitude required to drop the target TBM short of the target by the required amount. Generally, this is a few seconds before TBM burnout. For API, the minimum intercept altitude must be at least enough below apogee to prevent the TBM from underflying the interceptor and to allow a modicum of battle space. Minimum intercept altitude requirements are shown in Table 2.2 for generic targets with 150-, 300-, 600-, and 1,200-km ranges (target 150, target 300, etc.). The atmospheric density is about 10 times greater at 25 km than at 40 km—a fact that makes the BPI engagement environment against shorter-range TBMs particularly difficult.

Table 2.2

Minimum Intercept Altitude for BPI/API

	Target 150 (km)	Target 300 (km)	Target 600 (km)	Target 1,200 (km)
BPI	—	25	40	60
API	25	75	125	250

Our definitions for BPI and API engagement ranges are shown in Figure 2.2. For API, the engagement range corresponding to intercept at apogee is assumed (except when the interceptor has difficulty reaching that high, and a preapogee intercept produces the maximum possible range).

In our definitions, the engagement range is measured from the interceptor launch point to the intercept point (ground projection). Note that this range is less than the frequently quoted maximum range

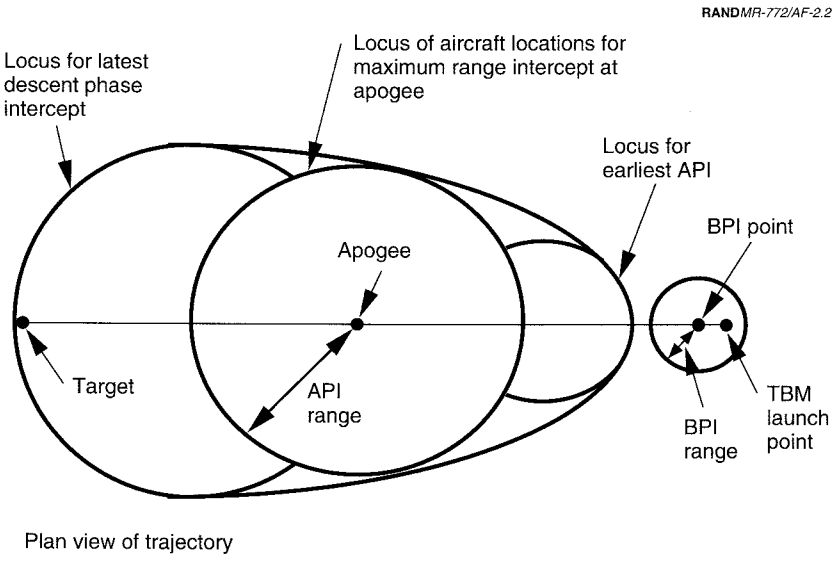


Figure 2.2—API and BPI Engagement Ranges

measured from the interceptor platform to the TBM launch point for an in-line engagement. Either definition scheme is valid, but the one we have chosen allows an easier interpretation for situations other than the in-line engagement.

Engagement ranges for the systems and TBMs considered are shown in Table 2.3. The first system is SRAM-ASAS with an exoatmospheric KKV. The second has an endoatmospheric KKV capable of intercept down to 40 km. Next is the Advanced Medium-Range Air-to-Air Missile (AMRAAM)–Hellfire, followed by Peregrine I—both with intercept down to 25 km. Last, for completeness, is Peregrine II with the entry-level KKV capable of intercept down to about 40 km. This capability could be extended down to 25 km with further development (P3I) of the KKV. A launch delay of 50 seconds for API and 15 seconds for BPI is assumed.[1]

These ranges illustrate the long API ranges possible with interceptors of modest velocity[2] and the difficulty of achieving a long BPI range.[3] As discussed below, target-acquisition sensor limitations will truncate these capabilities in some cases—certainly for the BPI, where all-weather acquisition of the TBM early in the boost-phase is required, and most likely for API, where the long acquisition ranges required to match kinematic ranges may not be possible for an early contingency system.

INTERCEPTOR AND SENSOR ISSUES

Two points emerge from the discussion in this section. First, sensor acquisition range and the time required to detect the target may be

[1]Launch delay is measured from the time of TBM launch to the time of interceptor launch. Because the boost phase of a missile is typically much shorter in duration than the ascent phase, BPI generally requires a shorter launch delay than API.

[2]Ideal velocities are calculated at burnout from the rocket equation without regard to gravity and atmospheric effects or trajectory shaping.

[3]The kinematic reach of boost-phase interceptors can be constrained as much by acceleration as by velocity. Thus, AMRAAM-Hellfire—with a smaller ideal velocity but a faster burn rate than SRAM-ASAS—achieves longer BPI ranges than does SRAM-ASAS.

Table 2.3

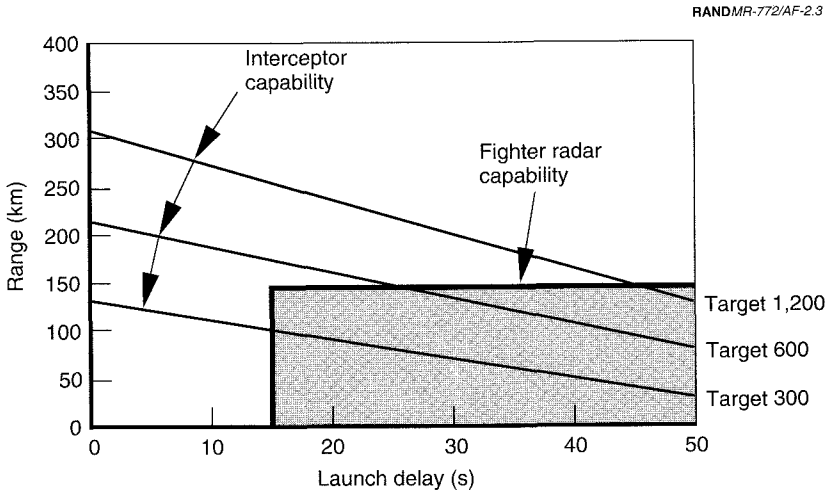
Maximum Kinematic Range Capabilities of BPI/API Options

Interceptor, KKV, Ideal Velocity	Limited Operational Capability (years)	Minimum Intercept Altitude (km)	150-km Class Target	300-km Class Target	600-km Class Target	1,200-km Class Target
SRAM-ASAS, exo KKV, ~3 km/s	~3	~90	N/A	N/A	API at 385 km	API at 540 km
SRAM-ASAS, endo KKV, ~3 km/s	~4	40	API at 45 km	API at 220 km	BPI at 80 km API at 385 km	BPI at 120 km API at 540 km
AMRAAM-Hellfire, endo KKV, 2.1 km/s	~4	25	API at 65 km	BPI at 70 km API at 165 km	BPI at 95 km API at 155km	BPI at 125 km API at 45 km
Peregrine I, entry-level KKV, 3.0 km/s	~5	25	API at 95km	BPI at 95 km API at 220 km	BPI at 135 km API at 320 km	BPI at 180 km API at 255 km
Peregrine II, entry-level KKV, 5.6 km/s	>5	~40	N/A	API at 515 km[a]	BPI at 240 km API at 750 km	BPI at 325 km API at 1,020 km

NOTES: Ranges are referenced to the ground projection of the intercept point. Launch delays are 15 and 50 seconds for BPI and API, respectively. Target-acquisition sensor range or limitations in interceptor functions may reduce some of these ranges.
[a]171-km BPI range with preplanned product improvement KKV.

the limiting factors in determining engagement range capability—both for BPI and for API. Second, these will limit BPI to ranges of no more than about 150 km until a new, large-aperture radar is developed.

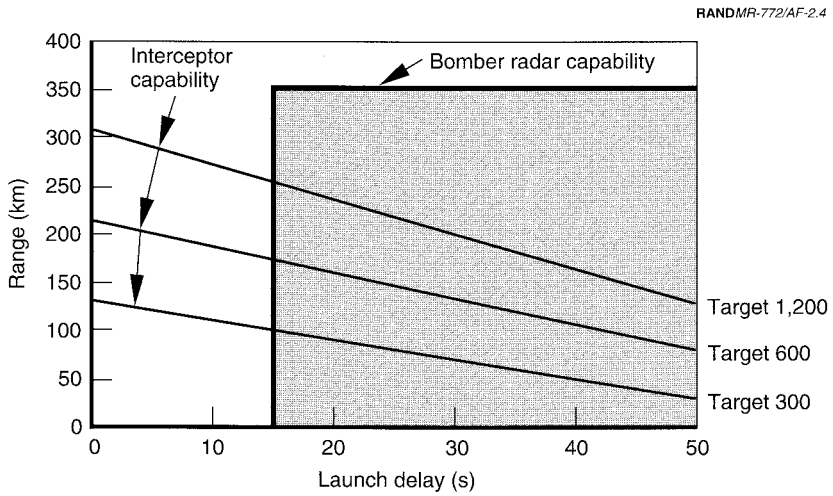
For any particular TBM, overall system engagement range capability is not determined from kinematics alone. It is determined jointly by sensor detection range, the fire-control solution and interceptor launch timeliness, and interceptor kinematic capability. The limiting factor varies from case to case, as illustrated in Figures 2.3 and 2.4. Figure 2.3 illustrates the situation for BPI with a medium-velocity interceptor[4] carried in a fighter with an upgraded radar with a 150-km acquisition range. It is engaging 300-, 600-, or 1,200-km TBMs



NOTE: All ranges are referenced to the TBM launch point.

Figure 2.3—BPI Medium-Velocity Interceptor and Fighter Radar Capabilities

[4]The medium-velocity interceptor is assumed to have an ideal velocity comparable to Peregrine I (see Table 2.3).



NOTE: All ranges are referenced to the TBM launch point.

Figure 2.4—BPI Medium-Velocity Interceptor and Bomber Radar Capabilities

(designated targets 300, 600, and 1,200, respectively). Here, the engagement range is determined by kinematics for target 300 and the radar acquisition range for targets 600 and 1,200—assuming a 15-second launch delay.

Figure 2.4 illustrates the situation for BPI with the same interceptor carried in a bomber with a new, larger-aperture radar (350 km detection range). Here, the engagement ranges for all targets are determined by kinematics (and the launch delay).

In the midterm (within 5 years), all-weather TBM acquisition ranges are unlikely to exceed 150 km with radar. Longer, all-weather ranges are possible with an infrared search and track (IRST) detection after high cloud breakout (at approximately 10 km altitude), but the launch will be delayed to the extent that engagement range still will not exceed 150 km—except possibly for long-burn TBMs, such as

target 1,200. A higher-velocity, high-acceleration interceptor will not help much except for the short-burn target 300.

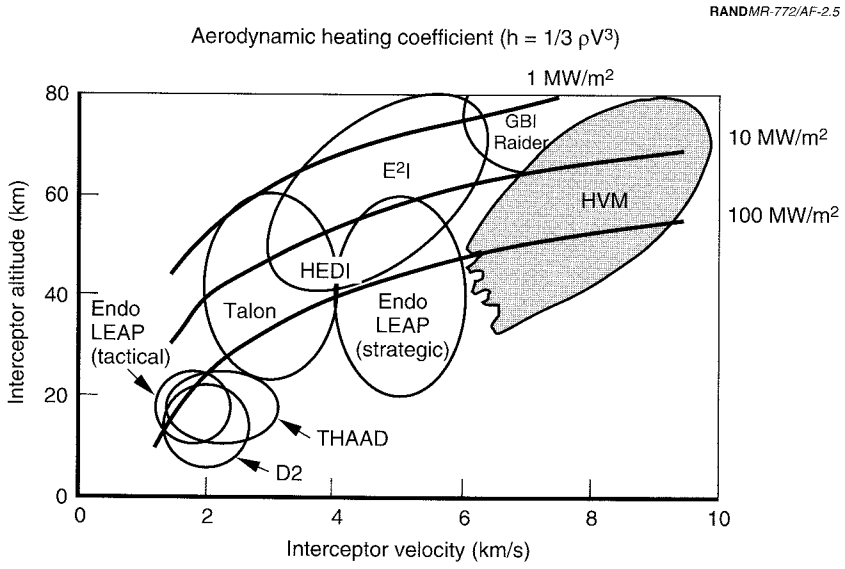
Similar considerations apply to API. Now, however, the detection and engagement timelines can be significantly relaxed, and much longer ranges are possible, since intercept can occur much later. Thus, sensor acquisition of the TBM after high cloud breakout is acceptable, and long-range IR detection augmented with triangulation, ladar, or cued radar ranging is acceptable as a baseline all-weather solution. Assessment of the API sensor alternatives for early contingency and midterm systems is less developed than for BPI. Although the API sensor problem is technically easier, the analysis required to give a clear picture of the situation has not yet been assembled.

KINETIC KILL VEHICLE ISSUES

For both BPI and API, issues associated with end-game TBM engagement using a KKV are the most challenging and limit the pace of development. In particular, operation of the onboard seeker and the guidance and control of the KKV at high velocity in the atmosphere pose formidable challenges for BPI, and lethality poses a formidable challenge for API. In what follows, we discuss each of these KKV issues in turn.

For BPI, high levels of aerodynamic heating of the lightweight KKV—particularly its seeker window—are the main problem. This heating can cause excessive window radiation to the detectors and window material failure due to excessive temperatures and thermal stress. The severity of the problem is a function of the interceptor's altitude and speed, as depicted in Figure 2.5. This figure shows the lines of constant aerodynamic heating coefficient ($h = 1/3\ \rho V^3$). While this parameter does not capture every aspect of the heating problem, it is a reasonable first-order measure of the severity of KKV seeker window heating. In addition, the various ovals depicted in the figure represent the domains in which high-speed endoatmospheric systems are attempting to operate.[5] Among the most ambitious pro-

[5]These systems include endoatmospheric versions of the Lightweight Exoatmospheric Projectile (LEAP) designed for strategic and tactical applications, Theater High Altitude Area Defense (THAAD), Talon, High Endoatmospheric Defense Interceptor



SOURCE: Schoenberg and Mamon (1994).

Figure 2.5—KKV Aerothermal Issues

grams, THAAD and Endo LEAP are striving to achieve operation below 20 km at 2 km/s and below 40 km at 5 km/s, respectively.

High dynamic pressure and the resultant high force level on the KKV are also important. Operation at high dynamic pressure requires high control-authority levels and increases stability and control requirements. This measure of difficulty, the dynamic pressure, is proportional to $1/2\ \rho V^2$. Again, this is a function of interceptor altitude and speed, and here, too, ambitious systems, such as THAAD and Endo LEAP, are striving to achieve operation below 20 km at 2 km/s and below 40 km at 5 km/s, respectively.

Lethality is another stressing issue, particularly for API, for which killing the unitary warhead or submunitions is desired. Here, hit-to-kill may not be adequate, and some kind of lethality enhancer may

(HEDI), Endo/Exoatmospheric Interceptor (E^2I), Ground-Based Interceptor (GBI) Raider, and the Hypervelocity Missile (HVM).

be required. Lethality for BPI is generally thought to be easier, since rapid venting of the propulsion system should achieve the desired result of dropping the payload short of the target area.[6]

Dual-mode capability, whatever the development path, introduces problems of integrating disparate capabilities into the KKV. For example, payload kill (API) is likely more demanding than booster kill (BPI). This may lead to additional weight or volume requirements in the kill vehicle. Lower-altitude, endoatmospheric operation (BPI) tends to drive KKV design toward the use of aerodynamic control surfaces, whereas higher-altitude, exoatmospheric operation (API) tends to drive the design toward the use of divert thrusters. Thus, because of conflicting requirements, a dual-mode system will undoubtedly be more complicated and will probably take longer to develop than a single-mode API or BPI system.

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[6]Note, however, that very little direct experimental evidence to date supports the assessment that a KKV hit will result in rapid venting.

Chapter Three

NOTIONAL TEST AND DEVELOPMENT PATHS FOR AIRBORNE INTERCEPT

We frame our discussion of alternative development paths in terms of intercept speed and altitude and depict likely candidate paths graphically in Figures 3.1 and 3.2. Increasing interceptor velocity and reducing intercept altitudes—i.e., moving down and to the right in the figures—increases capability by increasing the engagement range and enabling engagement of shorter-range TBMs, respectively. Lines of constant aerodynamic heating coefficient, as shown in Figure 2.5, are presented as a measure of the KKV seeker development difficulty.

API TRANSITION TO BPI PATHS

For API transition to BPI, shown in Figure 3.1, we start at the top with a SRAM-ASAS booster and a LEAP-derived exoatmospheric KKV. With an intercept velocity and minimum intercept altitude of about 2.5 km/s and 90 km, respectively, this system has API capability against targets 600 and 1,200. Further development of the KKV could enable API for target 300 if the KKV minimum intercept altitude can be reduced to about 75 km and could enable BPI for target 1,200 at about 60 km. For the first step down the path (A), evolutionary development of the KKV might be possible. For the second step to 60 km (B), however, evolutionary development is far less likely. For the next step to 40 km (C), required for BPI of target 600, the KKV is

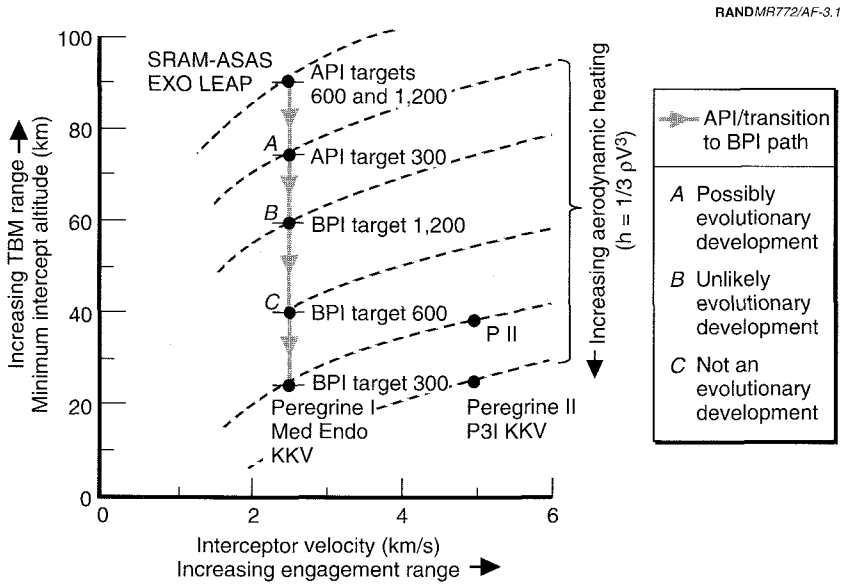

Figure 3.1—Test and Development Paths: API Transition to BPI

assuredly not a simple evolution from the 90 km starting point.[1] Any development down this path (Path 1, Table 1.1) to this point, however, could use the SRAM-ASAS booster—both for testing and for an operational system. Given the relatively large payload weight and volume capability, the BPI-capable system could likely have a dual-mode capability.

For even greater capability, we consider a KKV for operation at 25 km at the SRAM-ASAS velocity. The SRAM-ASAS booster could be used for test and development of the KKV, but its long burn time would not be acceptable for BPI of target 300. A new interceptor, along the lines of the proposed Peregrine I or the USAF/SAB medium-velocity interceptor, would be required (Path 2, Table 1.1).

[1]Since the atmospheric density increases by nearly a factor of 10 for every 15-km decrease in altitude, the transition from API at 90 km to BPI at 40 km involves over three orders of magnitude increase in the heating coefficient.

In summary, these development paths can be pushed deep into the atmosphere, but they are evolutionary only down to about 60 km insofar as operational capability is concerned. Further development down to 40 km is feasible (but not evolutionary), and stopping there would give considerable capability if the shorter-range TBMs are not emphasized. Testing and development for further grow-down to 25 km could be carried out on the SRAM-ASAS, which might be the earliest available vehicle for this purpose.

DIRECT BPI PATH

For direct BPI development (Path 3, Table 1.1), shown in Figure 3.2, we start with the AMRAAM-Hellfire booster stack.[2] Working immediately for intercept at a 25-km altitude could enable a modest BPI

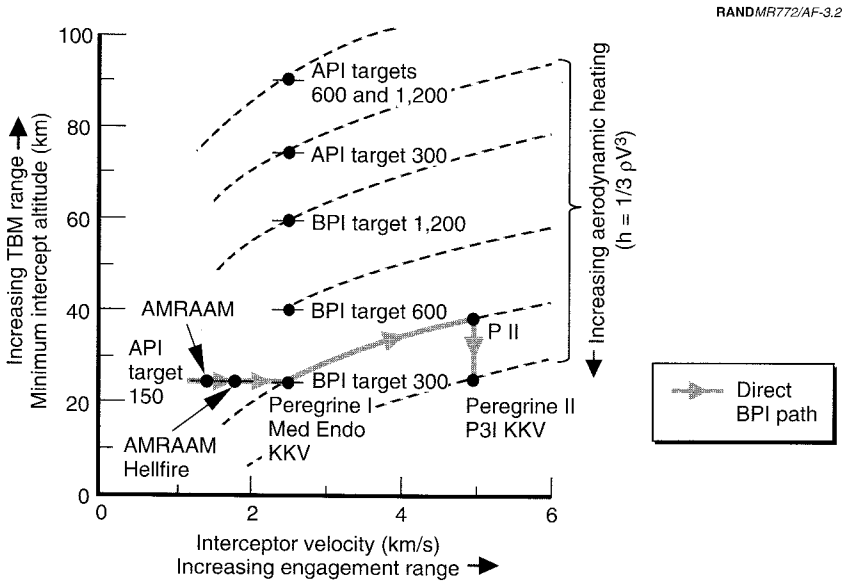

Figure 3.2—Test and Development Paths: Direct BPI Path

[2]Of course, it is also possible to start with AMRAAM alone and improve BPI capability by marrying it with the Hellfire booster. Although we illustrate this possibility in Figures 3.1 and 3.2, the analysis that follows focuses generally on the higher-velocity AMRAAM-Hellfire stack.

capability against targets 300, 600, and 1,200 and possibly an API capability against target 150. Since these systems have relatively smaller payload weight and volume capabilities, accommodating a dual-mode capability could be problematic. But given their short-range boost-phase capability, they would operate in positions that could not take much advantage of the greater API range, so a single mode (BPI) might be operationally sensible anyway. On the other hand, developing the KKV further could be accomplished on the AMRAAM-Hellfire (at lower altitude, in the domain of increased heating and dynamic pressure) and then could be transitioned to a Peregrine I medium-velocity interceptor that could accommodate a dual-mode capability more easily than could AMRAAM-Hellfire.

This KKV would also be capable of intercept at about 40 km on a 2-stage Peregrine II high-velocity interceptor, allowing BPI of target 600 at significantly greater range than Peregrine I, SRAM-ASAS, and AMRAAM-Hellfire, assuming a longer-range, timely target-acquisition sensor is also developed (see Table 2.3). Finally, developing this KKV further could potentially enable operation down to 25 km on the Peregrine II high-velocity interceptor. Once again, the potential benefits of increased engagement range from such a development could not be obtained without concurrent development of a long-range BPI-compatible target-acquisition system.

Chapter Four

CONCLUSIONS

TBMs WITH RANGES OF 600 KM OR MORE

If the BPI requirement is limited to TBMs with ranges of 600 km or more, the desired capability can be most quickly and cheaply developed with a SRAM-ASAS system (Path 1, Table 1.1). If desired, an API capability with an exoatmospheric KKV could be developed first as an early contingency capability. The endoatmospheric KKV for the BPI system would be designed for dual-mode operation, unless that is prohibited by technical barriers (e.g., size, weight, lethality). The SRAM-ASAS booster would be used for all developments and operational systems. Because of its weight and size, it could not be operated from carrier-based aircraft.

TBMs WITH RANGES DOWN TO 300 KM

If the BPI requirement is to include intercepts of TBMs with ranges as short as 300 km, a more-capable endoatmospheric KKV and a shorter-burn (i.e., high-acceleration) booster are required. Two distinct paths are attractive. Although the desired end points are identical, the potentials for early capability and fallback options (in case technical problems arise) are different. Barring unforeseen complications, the following options should not differ greatly in overall development time and cost. The important difference is in their early contingency capabilities:

- In the first approach, the more-capable endoatmospheric KKV would be developed on SRAM-ASAS. Assuming satisfactory

progress, a shorter-burn, smaller Peregrine-type booster would be developed to be ready for the operational system. This booster would be compatible with joint (Air Force, Navy) operation. Again, an early contingency API capability with an exoatmospheric KKV could be developed first. If the desired KKV capability proved to be too difficult in the desired time frame, a less-capable SRAM-ASAS operational system, such as in the first approach, would be a reasonable fallback position. Also, if a dual mode for the more-capable endoatmospheric KKV proved to be too difficult, the SRAM-ASAS exoatmospheric KKV option would be a reasonable fallback for a separate API capability.

- In the second approach, the more-capable endoatmospheric KKV would be developed on AMRAAM-Hellfire, a much shorter-burn, smaller, and somewhat lower-velocity booster than SRAM-ASAS. An early contingency capability for BPI of TBMs down to 300-km range would be possible with this booster coupled with an interim endoatmospheric KKV matched to AMRAAM-Hellfire's lower velocity. As in the first approach, this booster would be compatible with joint (Air Force, Navy) operation, and assuming satisfactory progress, the higher-velocity, somewhat larger Peregrine-type booster would be developed to ensure a full-capability operational system. Here, if the desired KKV capability could not be achieved, a reasonable fallback position would be to settle for the lower-velocity AMRAAM-Hellfire system and a compatible KKV. The goal would be a dual-mode KKV capability; however, this might not be possible on AMRAAM-Hellfire, given its relatively low payload weight and diameter. If it is not, the final development of a dual-mode system for Peregrine would be complicated somewhat, and the early contingency AMRAAM-Hellfire system option would be a BPI-only system.

Some Operational Considerations

In sorting through development options for BPI/API, several operational considerations deserve some attention.

It is clear that a long-range API system carried in bombers could contribute in a standoff mode in the early phases of a conflict. Shorter-range BPI capability, most likely fighter-based, could be

brought to bear as air superiority is achieved. Also, the airborne API could be phased out, if appropriate, as sea- and ground-based API and upper-tier terminal defenses become available.

Because of the short range of potential BPI capability until after 2000, the number of aircraft required to maintain combat air patrol could be very large if the TBMs operated out of large areas or more than a very few distinct areas that are known a priori. Indeed, operating a BPI system with a small footprint puts a premium on positioning the interceptor platform properly.[1] It might be reasonable, therefore, to gear up for a modest BPI capability that would suffice in some but not the most demanding scenarios. More-robust capability would have to wait for development of a long-range BPI capability—including the target-acquisition required to support it. Depending on the progress of various developments, this could be a high-velocity interceptor, possibly with a preplanned product improvement KKV, or an aircraft-based laser.

There are several potential synergies between API/BPI and ground-attack operations. The most likely is post-launch ground attack of mobile launchers and other assets fleeing to hide and resupply sites. Target acquisition solutions for API and BPI could provide accurate backtrack for localization of the launch point. Within the current decade, however, rapid weapon delivery and tracking the launcher for kill on the run or in the hide will be limited to ranges of less than 100 km in most circumstances. Thus, weapons and sensors on BPI combat air patrol aircraft operating in a dual BPI and post-launch counterforce mode would be most attractive.

As a further development for ground-attack operations, long-range high-velocity standoff weapons could be developed as derivatives of the API/BPI interceptors. Here, the SRAM-ASAS burn time, excessive for BPI intercept of short-range TBMs, would be no disadvantage. Finally, if capabilities for detecting and identifying launchers and

[1]But even with proper positioning, saturating the BPI/API system by launching TBMs at close time and/or space intervals is a potentially worrisome issue. In the extreme, one can imagine countering a TBM salvo that utilizes all launchers in one area at one time.

TBM infrastructure over broad areas in the prelaunch phase improve to the point where they are operationally useful, the BPI platforms could perform search operations while on combat air patrol.

BIBLIOGRAPHY

Ballistic Missile Defense Organization, *Ballistic Missile Proliferation: An Emerging Threat,* Arlington, Virginia: System Planning Corporation, 1992.

Ballistic Missile Defense Organization, *1995 Report to Congress on Ballistic Missile Defense,* Washington, D.C.: Ballistic Missile Defense Organization, September 1995.

Buchanan, L. F., M. Fossier, and T. Wong, "USAF-SAB Review of ABI Status," unpublished ms., 10 March 1995.

Congressional Budget Office, *The Future of Theater Missile Defense,* Washington, D.C.: U.S. Government Printing Office, June 1994.

Gordon, G., B. Patz, and M. Summers, *Boost Phase Intercept Probabilistic Denied Launch Region Study,* Washington, D.C.: Ballistic Missile Defense Organization, PR-003-95, April 1995.

Johannsen, D. C., *Report on the Peregrine Concept Study Performed for the BMDO Boost Phase Intercept Study,* El Segundo, Calif.: The Aerospace Corporation, TOR-96(1019)-1, April 1996.

Scott, W. B., "Kinetic Kill Boost Phase Intercept Regains Favor," *Aviation Week & Space Technology,* 4 March 1996, pp. 22–23.

Schoenberg, K. F., and J. Mamon, eds., *Hypervelocity Missile Concept Definition Report,* Los Alamos, N.M.: Los Alamos National Laboratory, Report CA-CP-9422, 1994.

Weiner, S., "Systems and Technology," in A. B. Carter and D. N. Schwartz, eds., *Ballistic Missile Defense,* Washington, D.C.: The Brookings Institution, 1984, pp. 49–97.

ISBN 0-8330-2434-5

MR-772-AF