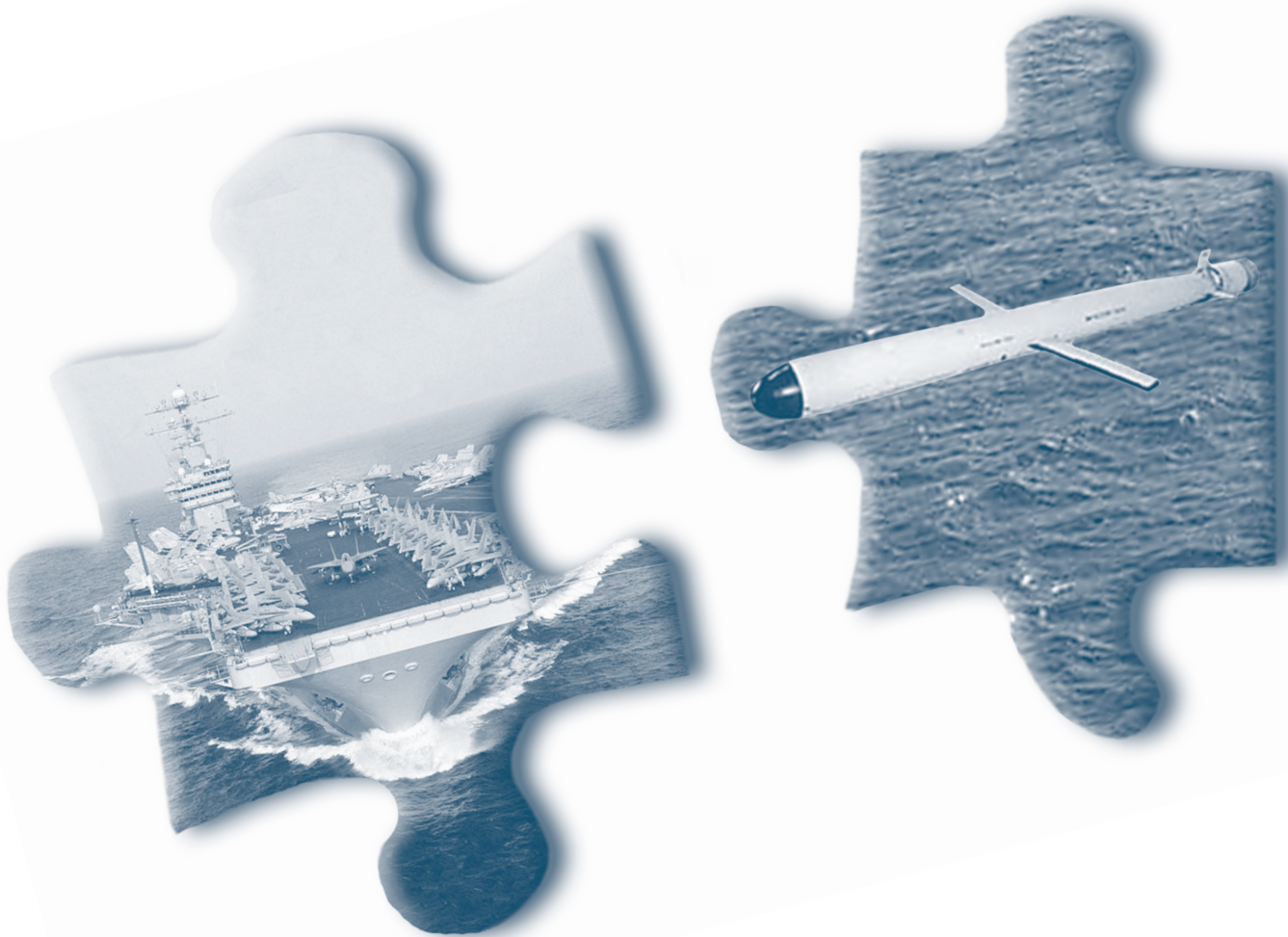


Assessing the Cruise Missile Puzzle:

How great a defense challenge?

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Introduction

In ancient times, armies would surround a city and demand its surrender. If the city resisted conquest, it would be brutally sacked if it fell to the invading army. The sacking of the city sent a strong message to other cities, making them afraid to resist unless they were confident they could withstand siege and assault. Nuclear strategists claim that nuclear weapons revolutionized warfare because they make it possible to threaten a city without ever having to lay siege to it.

In the aftermath of the 1991 Gulf War, Russian and Chinese strategic thinkers pointed out that the precision-strike systems demonstrated by the United States during *Desert Storm* were coming close to equaling nuclear weapons in strategic importance. They were obviously referring to the potential for using precision-strike systems to punish a country without having first to conquer it. In addition, some Russian and Chinese strategists have pointed out that long-range conventional precision strike systems could be used to preempt nuclear strike systems (e.g., see extract from Russian article, fig. 1, p. 2).¹ Such a strike could be conducted even though the striking state had pledged no first use of nuclear weapons.

The lessons of the *Gulf War* were further developed during the 1990s. The key military lesson learned by other states is that the United States is too powerful to be challenged by conventional military means alone. Advanced information-age weapon systems allow the United States to defeat industrial-age armies with little risk to forces or the U.S. homeland. The response of potential U.S. adversaries is to shift their focus to weapon systems that might enable them to hold the United States or its forces at risk during future crisis situations. Consequently, the most worrisome activities occurring deal with the development of weapons for which the United States possesses little or no defensive capability.



1 For a detailed example of this thinking see Anatoly D'Jakov and Eugeny Mjasnikov, "Precision Rockets Replace Nuclear," Moscow, *Independent Military Review*, No. 4, February 4-10, 2000.

RUSSIAN ILLUSTRATIONS ON U.S. CRUISE MISSILE POTENTIAL

Figure 1



These two Russian-produced charts reflect their perception of the potential for U.S. use of *Tomahawk* cruise missiles to preempt Russian nuclear systems.

Currently, the United States faces essentially four major emerging security challenges. Each has a tactical component that is applicable to military operations in support of friends, allies, and U.S. national interests abroad, as well as potential situations involving the strategic defense of the United States itself. The four challenges are:

- **Ballistic missiles.** Other than attack operations before missile launch and the threat of a retaliatory response to such an action, the United States has no national or theater-level defenses against ballistic missiles. Currently, the U.S. has only the *Patriot* system deployed to provide terminal defenses against tactical missile systems. A number of countries are working to take advantage of this vulnerability.
- **Terrorist attacks.** The United States faces the prospect that future terrorist attacks against its forces or a U.S.-located target could involve weapons of mass destruction. The United States needs to maintain sufficient freedom of action so as to be able to deter such an attack by hold-

ing sponsoring countries themselves at risk. It must also be prepared to deal with the consequences of such an incident if the terrorists are not deterred and counter-terrorism operations fail.

- **Information warfare (IW).** IW is becoming a major concern as the information age evolves and a number of states reportedly have begun to develop the means for disrupting information-based systems. Military operations, the U.S. economy, and many facets of modern civilization are becoming dependent on information technologies. The IW security challenge is the only non-lethal threat of the four cited above. Future U.S. vulnerability to IW threats is expected to include threats to communication satellites and other space-based assets as well as its domestic infrastructure such as air-traffic control and banking system.
- **Cruise missiles (and related systems).** The United States can destroy cruise missiles that have been detected, but it faces a significant

challenge detecting the missile early enough to mount an effective defense and target the missile over the horizon. Cruise missile development activity reportedly is occurring in a number of potentially hostile states, but analysts disagree on the speed with which such a threat is evolving. The key issue in this debate centers on land-attack cruise missiles, although anti-ship systems continue to be of concern. (See figure 2.)

Cruise missiles are an obvious system of choice for conducting precision strikes. They are difficult to detect and can deliver a payload with great accuracy. Currently, over 80,000 cruise missiles comprised of 75 differ-

ent systems are deployed in at least 81 countries.² The inventories of at least 20 of these countries include air-launched cruise missiles.³ As for the future, 42 new systems are reported to be in development.⁴ However, only the United States and Russia are known to have cruise missiles with ranges greater than 1000 kilometers; China, Israel, and perhaps India are likely to join this club during the upcoming decade.

It must be understood, however, that the vast majority of the cruise missiles currently deployed are anti-ship systems not configured to attack land-based targets. Roughly 90 percent of the existing missiles are short-range systems, having a range capability of about 100 kilometers or less. The limited nature of



2 Ibid., National Defense Industrial Association, "Feasibility of Third World Advance Ballistic & Cruise Missile Threat, Volume 2: Emerging Cruise Missile Threat," *Systems Assessment Group NDIA Strike, Land Attack and Air Defense Committee*, August 1999, p. 136; testimony of Lt. Gen. James R. Clapper, Jr., Director, Defense Intelligence Agency, "Hearing on Worldwide Threat to the United States," *Committee on Armed Services, United States Senate, January 17, 1995* (Washington, DC: U.S. Government Printing Office, 1995) S. Hrg. 104-236, p. 64; and U.S. General Accounting Office (GAO), *Defense Acquisitions: Comprehensive Strategy Needed to Improve Ship Cruise Missile Defense*, GAO/NSIAD-00-149, July 2000, p. 5.

3 GAO Report, *ibid.*

4 Gjermundsen, *op cit.*

the current cruise missile inventory is expected to begin changing in the near future. At least 9 or 10 states will soon be deploying land-attack cruise missiles with range capabilities spanning 100 to 1000 kilometers (medium range).⁵ Some of these new medium-range systems will be exported (e.g., France has already signed a deal with the U.A.E.).

It is uncertain how fast the more capable land-attack cruise missile systems will spread to other international actors or whether many of the existing short-range anti-ship cruise missiles will be modernized or converted to land-attack systems. Moreover, since the technology involved in these systems is widely available, it is possible that long-range land-attack cruise missiles could spread to new international actors undetected. It should be pointed out that it is extremely difficult to detect the development of cruise missile systems; the potential for surprise is very high. As Robert Walpole, the National Intelligence Officer for Strategic and Nuclear Programs, recently testified,

We ... judge that we may not be able to provide much, if any, warning of forward-based ballistic missile or land-attack cruise missile (LACM) threat to the United States. Moreover, LACM development can draw upon dual-use technologies. We expect to see acquisition of LACMs by many countries to meet regional military requirements.⁶

When Walpole's testimony is matched with the testimony of Vice Admiral Thomas Wilson, Director of the Defense Intelligence Agency, it is clear that the U.S. intelligence community has a high expectation that land-attack cruise missiles will proliferate and pose a future threat to high-value targets. He testified that,

... the potential for widespread proliferation of cruise missiles is high. While the type of missiles most likely to be proliferated will be a generation or two behind the global state of the art, states that acquire them will have new or enhanced capabilities for delivering WMD or conventional payloads inter-regionally against fixed targets. Major air and sea ports, logistics bases and facilities, troop concentrations, and fixed communication nodes will be increasingly at risk.⁷

It is also clear that the types of systems that will be included in the proliferated threat will challenge U.S. air defense capabilities. As was reported by the National Air Intelligence Center, defending against LACMs will stress air defense systems.

Cruise missiles can fly at low altitudes to stay below radar and, in some cases, hide behind terrain features. Newer missiles are incorporating stealth features to make them even less visible to radars and infrared detectors. Modern cruise missiles can also be programmed to approach and attack a target in the most efficient manner. For example, multiple missiles can attack instantaneously from different directions.... Furthermore, the LACMs may fly circuitous routes to get to the target, thereby avoiding radar and air defense installations.⁸

While it is generally agreed that LACM capabilities will proliferate and that the capabilities of these systems will improve in comparison to those deployed today, there is little agreement as to when LACMs will be capable of posing a significant threat to U.S. forces or the national homeland. Yet, the timing issue is important because it has serious implications for U.S. cruise missile defense

5 National Air Intelligence Center, *Ballistic and Cruise Missile Threat* (Wright Patterson Air Force Base, Ohio, NAIC-1031-0985-99, April 1999), p. 20.

6 Robert L. Walpole, "Prepared Testimony Before the Senate Governmental Affairs Committee Subcommittee on International Security, Proliferation, and Federal Services," February 9, 2000.

7 VADM Thomas R. Wilson, *Prepared Testimony Before the Senate Intelligence Committee*, February 2, 2000.

8 National Air Intelligence Center, *Ballistic and Cruise Missile Threat*, p. 19.

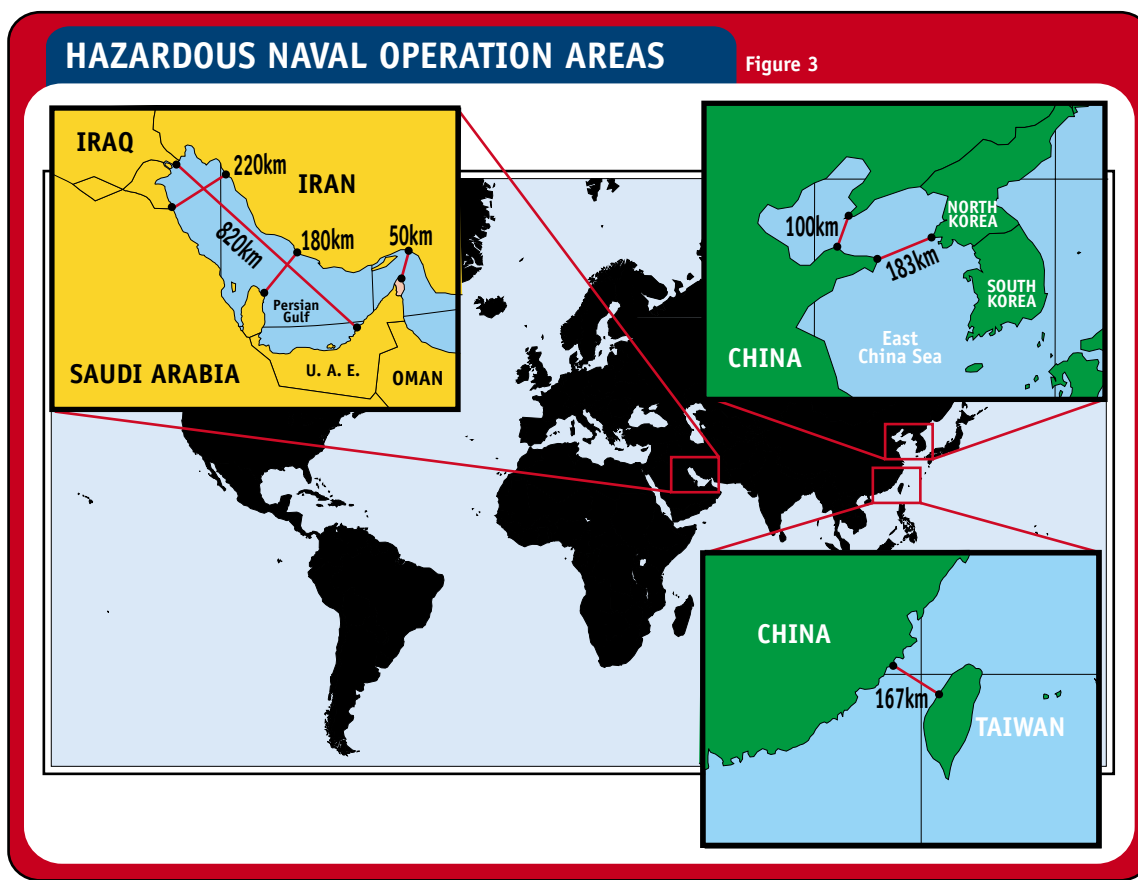
development efforts and the potential number of casualties the U.S. is likely to suffer in future conflict situations. It is too important an issue to ignore.

Although most of the foregoing overview focuses on land attack systems, anti-ship cruise missile systems are being improved. A July 2000 U.S. General Accounting Office (GAO) report states,

Current anti-ship cruise missiles are faster, stealthier, and can fly at lower altitudes than the missile that hit the U.S.S. *Stark* in 1987, killing 37 sailors... The next generation of anti-ship cruise missiles—most of which are now expected to be fielded by 2007—will be equipped with advanced target seekers and stealthy design. These features will make them even more difficult to detect and defeat.⁹

The growth in anti-ship cruise-missile capabilities has serious implications for U.S. power projection operations. Much of the recent U.S. military planning for naval use involves operations in coastal regions in support of U.S. objectives on land.

For example, the spread of advanced anti-ship cruise missiles would make it increasingly dangerous to operate U.S. warships in or near tense locations such as the Persian Gulf, the Taiwan Strait, or the Yellow Sea (west of North Korea—figure 3). The proliferation of advanced anti-ship cruise missile capabilities could pressure naval forces to operate further out at sea, thus limiting the distance ashore that naval aircraft could operate or the size of the ashore engagement zone that could be covered by the planned



⁹ GAO report, p. 6.

Naval Theater-Wide (NTW) ballistic missile defense system to be deployed on *Aegis* cruisers around 2007-2010. Unfortunately, the capabilities of ship-based defenses against projected cruise missile threats are not keeping pace with the anticipated deployment of new families of anti-ship cruise missiles.

To better understand the issues involved in the cruise missile challenge, this mini-study will examine the related cruise missile issues in some detail. The study will note the motives and technologies driving cruise missile proliferation, review proliferation indicators, then turn to the issue of defense options for dealing with cruise missile threats. Currently, the United States has very little capability to detect and track cruise missiles. When reduced-signature technologies are added to the mix, current defense capabilities would find the challenge “mission impossible.” Although the U.S. has some cruise missile defense programs on slow development paths, there is reason to question whether the current level of effort is adequate to deal with the evolving cruise missile challenge.

Assumptions

Obviously, when projecting the future, some assumptions must be used. It is assumed that:

- The international system will continue to be dominated by the United States, with other major powers or would be powers attempting to limit or circumvent U.S. capabilities. A number of major states, especially Russia, China, India, and France, have become very open in voicing dissatisfaction with what they call U.S. hegemony. Some of these states appear to be working to limit U.S. freedom to act by permitting

technologies required for the development of weapon systems to support asymmetrical defense strategies to flow to other states, especially those likely to oppose U.S. intervention in their regions. Although some of the technology exported is due to unsanctioned black-market activities, it is also clear that official acquiescence is involved in some known cases of sensitive technology transfers.¹⁰ It is assumed that this situation will not change significantly during the next decade.

- The Missile Technology Control Regime (MTCR) and other arms control agreements and measures will not have an appreciable effect on states determined to sell dual-use aircraft/cruise missile components to other states. Essentially, this study does not envision a new international arms control agreement on cruise missiles or a significant strengthening of current MTCR provisions to prevent such proliferation.
- That countries with cruise-missile aspirations will pursue cruise missile acquisition. In short, this study assumes that countries will carry out the programs that are under discussion or in development with regard to cruise missile systems.

¹⁰ The international flow of technology with an expected intent of weakening U.S. dominance of the international community is discussed in some detail in the study, Institute for Foreign Policy Analysis, *National Missile Defense* (Washington, D.C.: Conway Printing, July 2000), Chapter 1.

Section II: Cruise Missile Threat Development

Although ballistic missiles provide a country with a highly visible deterrent capability, cruise missiles are actually more versatile, accurate, and employable than are ballistic missiles. The extensive use of the *Tomahawk* cruise missile by the United States during the 1990s demonstrated to the world the value of being able to punish or retaliate for violations of international norms using a precision-strike conventional munition. The United States used cruise missiles in:

- *Desert Storm*, 1991 (Iraq)
- *Southern Watch*, 1993 (Iraq)
- *Deliberate Force*, 1995 (Bosnia)
- *Desert Strike*, 1996 (Iraq)
- Afghanistan/Sudan, 1998 (Afghanistan and Sudan)
- *Desert Fox*, 1998 (Iraq)
- *Allied Force*, 1999 (Serbia/Kosovo)

In most instances where U.S. cruise missiles were employed during the last decade, the use of ballistic missiles, even with conventional warheads, would have raised the profile of those actions and likely would have resulted in widespread international condemnation, but cruise missiles and other precision strike capabilities have coerced other international actors into complying with U.S. demands during the last decade without raising an international outcry. Other states, including the European Allies, have taken note of U.S. *Tomahawk* cruise-missile diplomacy and are interested in developing similar capabilities.¹¹

What Incentives are Driving Cruise Missile Proliferation?

For some countries, cruise missile technology offers the means for developing a precision strike capability much more cheaply than would be required to procure a modern air force. Once built, cruise missiles require little maintenance and fewer trained personnel to operate and deploy than does a fleet of jet aircraft. Moreover, unlike strikes from manned aircraft, cruise missile use does not carry the political risk of captured pilots. They are also suitable against both land- and sea-based targets. Furthermore, cruise missiles are better suited for the delivery of chemical or biological munitions than are ballistic missiles.

Perhaps most important to modern warfare, cruise missiles allow a state to destroy specific targets using conventional munitions without creating much collateral damage or inflicting many civilian casualties, a point that is particularly important in enforcement actions short of full-scale war.¹² Cruise missiles are also capable of reaching through U.S. defenses and inflicting a significant level of damage and casualties on U.S. forces, a key consideration for many states seeking the means to deter U.S. intervention in their region. Consequently, cruise missiles are the most likely weapon system to be actually employed against a wide-array of U.S. target sets. Thus, as states follow the U.S. example in cruise missile acquisition and use, these systems will become a major threat to U.S. forces and perhaps the U.S. homeland. The more puzzling questions are how quickly and how extensively?

¹¹ For example, see Bernard Bombeau, "The Navy Wants Cruise Missiles," *Paris Air & Cosmos/Aviation International*, March 31, 2000, p. 35, translated in FBIS.

¹² Robin Ranger, Humphry Crum Ewing, David Wiencek, and David Bosdet, "Cruise Missiles: New Threats, New Thinking," *Comparative Strategy*, vol. 14, 1995, p. 262.

Cruise Missile Acquisition Pathways

Early cruise missile designs were based on an aircraft frame that had been modified for self-guidance or remote control and loaded with explosives.¹³ Over time, the designs have evolved to resemble missiles more closely in appearance—primarily as a means of reducing their volume so as to allow them to be packaged in compact launch tubes for storage, transport, and employment.

The formal U.S. Department of Defense (DOD) definition states that a cruise missile is “a guided missile, the major portion of whose flight path to its target is conducted at approximately constant velocity; depends on the dynamic reaction of air for lift and upon propulsion forces to balance drag.”¹⁴ The key elements of this rather arcane depiction are 1) that cruise missiles are guided (i.e., they are not unguided rockets), 2) they are aerodynamic (i.e., they do not operate outside of the earth’s atmosphere) and, 3) they fly to their targets under power at nearly a constant velocity (i.e., they are not gliders or manned aircraft). In appearance, modern cruise missiles usually have short stubby wings attached to a body shaped more like a missile than an aircraft.

Unfortunately, the DOD definition is designed to specify the differences that distinguish a cruise missile from, for example, an unmanned aerial vehicle (UAV). In terms of mission assignment, most UAVs are used for reconnaissance and surveillance missions and are equipped to return to a home base. As Air Force Chief of Staff General Ryan has noted on more than one occasion, cruise mis-

siles and other stand-off munitions are merely UAVs on a one-way trip.¹⁵ Since there are 74 different UAV systems in service and more than 51 new models in development worldwide,¹⁶ they pose a significant potential for use as precision-strike weapon systems in future conflicts. UAVs and cruise missiles also share many common components, both with each other and with commercial aircraft.

If a country of concern (formerly called rogue states) wanted to acquire a cruise missile capability, it could: 1) obtain complete missile assemblies, 2) obtain, as a minimum, guidance systems, engines, and cruise missile design and guidance software packages from an outside supplier and assemble the system indigenously or, 3) modernize or convert an existing anti-ship cruise missile to a land-attack system.¹⁷

Option I: Procure complete systems from a producing state. Purchasing complete missile sets is an attractive option since it provides an immediate capability to field a proven system. However, this option has some hurdles in that most cruise missile producers adhere to the Missile Technology Control Regime (MTCR). For MTCR member states, the transfer of systems having a range of more than 300 kilometers carrying a 500-kilogram payload would be subject to challenge by other MTCR members as a Category 1 transfer.

Unfortunately, the MTCR has a loop-hole regarding cruise missile range classification, especially for air-launched systems that fly longer distances than a comparable surface-launched system due to the speed and altitude of the launch.

13 Systems Assessment Group NDIA Strike, Land Attack, and Air Defense Committee, “Briefing: Feasibility of Third World Advanced Ballistic & Cruise Missile Threat, Vol. 2: Cruise Missile Threat,” National Defense Industrial Association, August 1999, p. 65.

14 Joint Publication 1-02, *U.S. Department of Defense Dictionary of Military and Associated Terms*.

15 Kent Kresa, CEO Northrup Grumman, “For Unmanned Systems, the Time Has Come,” *National Defense*, July 2000, p. 8.

16 Ibid.

17 The three paths cited are extracted from a letter from Under Secretary of Defense Paul G. Kaminski to Congressman Floyd D. Spence, July 30, 1996.

Option II: Indigenous development using components procured on the world market.

If a state were to embark on development of an indigenous cruise missile capability, its primary challenge would be the acquisition of the major components needed to fabricate these systems. Since all of the technology used in cruise missile systems is dual use, having both a commercial and a military application, it is not difficult to obtain needed parts and components.

Cruise missiles are built around four key component groups:

- Airframe (same manufacturing skills as required for light aircraft)
- Propulsion system (e.g., a rocket, turbojet, turbofan, or ramjet and corresponding fuel supply)
- Guidance system (e.g., a INS, GPS, terrain matching, radar, IR, and/or video, and an electronic brain capable of interfacing with the airframe's flight controls)
- Payload (WMD or various conventional munitions)

Appendix A contains a complete discussion of the major components needed to build cruise missile systems.

Option III: Convert or modernize an existing unmanned aerial vehicle or anti-ship cruise missiles. Analysts are divided over the feasibility of this approach. Of the many thousands of anti-ship cruise missiles spread around the world, most are limited in capability. Because countries, to include the United States, have difficulty identifying and targeting ships over the horizon, there have been few incentives for developing anti-ship cruise missiles (ASCMs) with long-range capabilities.

Typically, older ASCMs have ranges of less than 120 kilometers carrying a 100 to 500 kilogram payload. Their high-explosive warheads are detonated by delayed fuses that allow the warheads to penetrate a ship's hull before exploding. Moreover, most ASCMs are equipped with simple navigation and flight control systems not suitable for land-attack missions.

ASCMs would need to be fitted with a new guidance system if converted to perform a land-attack mission. At a minimum, the INS/radar terminal guidance system used by the ASCM would have to be replaced with an INS/GPS satellite navigation system, and the flight control system would have to be modified to permit integration of GPS guidance.¹⁸ The degree of difficulty involved in this modification would vary from system to system. On the other hand, even after guidance modification, the resulting land-attack cruise missile would still have a limited range capability.

Airframes are designed to lift specified loads based on their aerodynamic lifting surfaces and flight velocity. Any attempt to increase the range of an existing missile would require some possible modifications. These could include adding more fuel-carrying capacity (perhaps by trading-off payload), adjusting the balance point of the missile to prevent it from becoming nose or tail heavy as fuel is consumed, redesigning the wing elements to provide more lift, or possibly replacing the propulsion system with one that is more fuel efficient or provides more thrust. These modifications could involve a major engineering effort.

UAVs. UAVs have the same four component groups as cruise missiles—plus a vehicle recovery subsystem. Clearly, UAVs could be modified for use as cruise missiles (usually

¹⁸ For a critical assessment of the difficulty in converting an anti-ship cruise missile into a land attack system, see Steven J. Zaloga, "The Cruise Missile Threat: Exaggerated or Premature?" *Jane's Intelligence Review*, April 2000, pp. 47-51. It should be noted that a couple of cruise missile engineers who reviewed this article claimed that it was not quite as difficult to convert the guidance system as was depicted in the article. They did agree with the comments on propulsion systems.

with a light payload). However, if the landing gear or other hardware needed for vehicle recovery were removed, the UAV would be able to carry a larger payload. Thus, UAV development also provides a potential route for the development of cruise missile systems.

Of note, the most critical components for constructing either cruise missiles or UAVs are engines and guidance systems. Unfortunately, these systems are the staples of the commercial aviation world and could be obtained by a determined state. The MTCR specifically excludes manned aircraft, an exclusion that provides a ready-made means for obtaining aircraft parts that could be diverted to cruise missile production. In future years, it likely will become even easier to obtain these components as commercial aviation activity grows.

Cruise Missile Proliferation

Within the context of the preceding discussion, a brief country survey is warranted. This survey is not intended to be an exhaustive country-by-country review of cruise missile programs, rather it is designed to provide a flavor of known cruise-missile development activities.

In this case, the key word is “known.” The characteristics of cruise missiles make them difficult to detect; thus they are easily hidden from space assets. Moreover, most countries of concern have put their missile development facilities and production factories underground—preventing monitoring by overhead assets. As a result, no person or agency can report with total confidence the current status of international cruise missile proliferation.

YAKHONT 3M55 (SS-NX-26)



Russian air-launched version of new anti-ship missile.

- Ramjet engine, 300km-range
- Payload: 200kg
- Some of its technology is used in *Club* missile family. (*Club* is an export system)

Figure 4

Russia. Russian strategists claim that stand-off precision munitions, such as land-attack cruise missiles, are similar to nuclear weapons—because they allow a state to punish other international actors without sending troops or manned aircraft across a border. Russian planners seek the acquisition of these types of systems, especially in light of anticipated reductions in nuclear force levels resulting from a negotiated START III treaty or unilateral initiative.¹⁹ To the dismay of the Russian military, the dismal state of the Russian economy has stymied their efforts. There are, however, indications that the pace of development for next generation Russian cruise missile systems could soon increase.

For example, Russian military planners reportedly agreed to declassify the Kh-41 *Moskit* supersonic anti-ship cruise missile (a more capable version of the noted SS-N-22 *Sunburn*) in hopes that international sales of this system will generate the revenue needed to produce a next generation anti-ship system. The *Moskit*, with a range capability of up to 250-kilometers, attacks its target at speeds greater than mach 2 while making 10-g turns to evade ship defenses.²⁰ The *Moskit* has been

19 For examples, see Boris Tolav, “21st Century’s Super Arrows,” Moscow *Rossiyskaya Gazeta*, April 21st, 2000, p.3, translated in FBIS; and “Putin: Russia, U.S. Can Avoid Impasse in Tackling START III Problem,” Moscow *Interfax*, July 23, 2000, transcribed in FBIS.

20 Dmitriy Safonov, “Moskit Has Been Completely Declassified. The Chinese Navy Will Get A Unique Russian Missile,” Moscow *Kommersant-Daily*, April 14, 1998, p. 2, translated by FBIS.

exported to China.²¹ Press reports indicate that Iran may also have gained access to an earlier version of the *Sunburn* through a deal with Ukraine.²²

Russia is working to finish development of the 3M55 *Yakhont* (also called the *Oniks*—NATO designation SS-NX-26). (Figure 4) The missile could be launched from ground, ship, or submerged platforms. It will have a maximum range of 300 kilometers. The system is being developed as a follow-on to the *Moskit* cruise missile discussed above. Reports also indicate that Russia developed a land-attack version of this missile, one capable of delivering submunitions.²³ The *Yakhont* initially will be deployed on Russia's new strategic submarines of the Yuri Dolgoruky class as they become operational beginning in 2005.²⁴ Some components from the *Yakhont* have been incorporated into the *Club* (3M54E) (Figure 5) cruise missile system designed for export and recently sold to India. China is also interested in procuring the *Club*.

Russian military planners are not in agreement as to what type of future air-launched cruise missile development they should pursue. One faction advocates deployment of a mach-5 hypersonic cruise missile. The system would depend on speed rather than stealth for its survival. Other analysts are advocating production of subsonic cruise missiles that incorporate signature-reduction technology.²⁵

For the Russians, the problem is that U. S. development of anti-ballistic missile defenses and possibly tactical laser systems might lead to the emergence of technologies that would make hypersonic missiles more vulnerable to interception. In reality it is likely that Russia

THE CLUB MISSILE FAMILY

ANTI-SHIP SYSTEM WITH SOME SECONDARY CAPABILITY AGAINST FIXED LAND TARGETS



3M-54E

- Fired from surface ship vertical launch tubes or submarine torpedo tubes.
- Flies low subsonic cruise profile to 20km from target, then drops cruise-stage engine and flies supersonic to attack ships.



3M-54E1

- Subsonic cruise missile launched from vertical launch tubes or submarine torpedo tubes
- Larger warhead than 3M-54E



91RE2

- Anti-submarine missile with separable underwater rocket with homing sonar warhead
- Fired from surface ship vertical launch tubes



91RE1

- Anti-submarine missile with separable underwater rocket with homing sonar warhead
- Fired from submarine torpedo tubes

Source: Russian Military Parade magazine, 2000

Figure 5

21 Ibid.

22 Sergey Viktorov, "Al-Ahram Article Cites Ukrainian Missiles to Iran," *Moscow Radio*, May 12, 1993, translated in FBIS.

23 "Russian Federation, SS-NX-26," *Jane's Strategic Weapon Systems*, Issue 32, ed. Duncan Lennox (Coulson, Surrey: Jane's Information Group, 2000), p. 158.

24 "Russian Admiral Vaunts Naval Missile Systems," *Moscow Interfax*, January 4, 2000, transcribed in FBIS.

25 Conversation with Steve Zaloga, July 24, 2000.

would prefer to develop both subsonic reduced-signature and hypersonic cruise missiles. If a hypersonic system is produced, Russian cruise missile designers plan to follow that development with a generation after next anti-ship cruise missile envisioned to have a velocity as great as 14-times the speed of sound.²⁶

For the land attack mission, Russia is converting some of its 3000-kilometer-range Kh-55 air-launched nuclear cruise missiles to carry conventional payloads. This turbofan missile system with inertial and terrain matching guidance, known in the West as the AS-15 *Kent*, is a nuclear-capable system that may soon be replaced by a new conventionally armed system known as the Kh-101. The new system has only been depicted in simple drawings, but reportedly may have a range of 5000 kilometers carrying a 400-kilogram payload.²⁷

Russia's turbofan engine technology has been weaker than that of the United States. However, there are hints that Russia is making progress on improving its turbofan engine production technology. It should be expected that Russian access to advanced commercial aviation propulsion systems will gradually lead to an improved engine production capability in Russia. Thus, it must be anticipated that Russia's long-range cruise missile strike capabilities will improve in the future.

It also seems likely that some of Russia's cruise missiles or related components will be exported in light of the country's continued economic weakness and President Putin's stated objective of increasing Russia's defense exports. The key unknown is whether Russia can afford to produce these new systems while confronted by a mountain of pressing priorities and few resources.

China. The People's Liberation Army cloaks its military development in great secrecy, making it difficult to assess China's defense programs. It is known that China has a number of anti-ship cruise missiles, including the 120-kilometer C-802 (discussed earlier). China is also acquiring Russian *Moskit* cruise missiles as discussed in the Russian section. China is also in the process of trying to acquire 300-kilometer 3M54 *Club* anti-ship cruise missiles. What is less certain is the status of China's land-attack cruise missile programs.

China is working on at least two long-range land-attack cruise missiles. The first is an air-launched system projected to be operational by mid-decade.²⁸ It is likely that the missile being developed is based on the Russian Kh-65/SE (see figure 6), which is a 600-kilometer-range version of the Kh-55 strategic cruise missile (air-launched turbofan with a 3000-kilometers range).²⁹ Reports indicate that China is developing a 1500-2000 kilometer land-attack cruise missile that uses a turbofan engine and may include integrated inertial, GPS/GLONASS, and terrain matching navigation systems.³⁰

KH-65 (AS-15 KENT)



Russian air-launched land-attack cruise missile

- Turbofan engine, 600km-range
- Payload: 410kg
- China's program to build an air-launched cruise missile is believed to be based on this design

Figure 6

26 Safonov, op cit.

27 Roy Braybrook, "Air-Launched Cruise Missiles," *Air International*, July 2000, p. 50.

28 U.S. Department of Defense, *Annual Report to Congress on the Military Powers of the People's Republic of China*, June 2000, p.16.

29 "China is Expected to have its Own Cruise Missile Soon," PRC related web-site, www.chinaddict.com/military/cruise_missile, September 10, 1999.

30 Ibid.; and "China has Developed a Killer Land-Attack Cruise Missile," *Hong-Kong Sing Tao Jih Pao* (Internet version), August 14, 1999.

Unconfirmed reports claim that this missile may incorporate technologies taken from recovered *Tomahawk* systems and that Russian technicians are providing assistance.³¹

Although there is uncertainty as to how close these cruise-missile projects are to becoming operational,³² China clearly will have a much greater cruise-missile capability by 2010 than it has today. Based on China's past behavior in transferring ballistic missile technology to Pakistan, Iran, Libya, Syria, and other states, it is likely its cruise missile technology may also migrate abroad.

India. India has at least three reported cruise missile development programs: the *Lakshya*, the *Coral*, and the *Sagarika*.

- The *Lakshya* is based on the design for a pilotless target aircraft, which first flew in 1985. The cruise missile variant is believed to use INS and GPS mid-course guidance with radar or IR terminal seekers. The system is thought to have a 600-kilometer range carrying a 450-kilogram warhead. An Indian turbofan engine was flight tested on this vehicle in 1995 (figure 7). An unconfirmed report in 1997 suggested that this system could have a range objective of 2500 kilometers.³³
- The *Coral* program is designed to produce improved Russian *Moskit* (*Sunburn*) anti-ship cruise missiles for deployment on Indian destroyers. The existence of this program indicates that India likely has some *Sunburn* anti-ship cruise missiles.

LAKSHYA (UAV VARIANT)

Indian UAV upon which land-attack cruise missile is based



- Turbojet engine, 600km-range
- Payload: 450kg
- Guidance: INS, GPS, and radar or IR
- Turbofan in development (2500km range?)

Figure 7

- The *Sagarika* program is believed to cover the development of both a ballistic and a cruise missile for deployment on its nuclear submarine when it completes development around 2009.³⁴ The cruise missile part of this program reportedly is focused on providing a land-attack cruise missile system that uses a turbojet engine to provide the missile with a planned range of 300 kilometers. The system is expected to incorporate terrain contour matching, INS, and GPS guidance systems. It will be able to carry nuclear or conventional warheads. An unconfirmed 1999 report indicates that a follow-on version is planned that will have a 1000-kilometer range.³⁵

The *Club* cruise missiles India procured from Russia are being deployed on its *Kilo* (*Sindhurashtra* class) submarine fleet.³⁶ The *Club* missile is produced in four variants to

31 Ibid.; and *Jane's Strategic Weapon Systems*, Issue 32, "People's Republic of China," p. 3.

32 Ibid.

33 *Jane's Strategic Weapon System*, p. 5.

34 Andrew R. Koch, "Nuclear-Powered Submarines: India's Strategic Trump Card," *Jane's Intelligence Review*, June 1998, p. 30.

35 Ibid.

36 "India to Add Cruise Missile," *Aviation Week & Space Technology*, March 27, 2000, p. 38.

include land-attack and anti-ship/submarine versions (see figure 5, 3M54E). Currently, India has only purchased the anti-ship version; India's second *Kilo* submarine just departed a Russian shipyard in August 2000, modified to carry this missile system.³⁷ There are indications that India may be planning on fitting cruise missiles on other warships for land-attack missions.³⁸

Israel. Israel has developed anti-ship cruise missiles to include the MK4 LR *Gabriel*. This turbojet cruise missile has a range of 200 kilometers, carrying a 240-kilogram payload. There have also been unconfirmed reports that a cruise missile variant of the *Delilah* UAV is being developed for China. The basic *Delilah* is a 400-kilometer range drone that uses a small-US designed Williams turbofan engine.³⁹ Israel has denied this report. Also unconfirmed are reports that Israel may be developing a supersonic cruise missile using ramjet engines. This project may have links with South Africa.⁴⁰

In a recent development, the *London Sunday Times* reported that Israel launched a long-range cruise missile from a submarine in the Indian Ocean. The missile was reported to have a range of about 1500 kilometers (over 900 miles), be capable of carrying a nuclear warhead, and provide a retaliatory capability against countries such as Iran. The *Sunday Times* claimed that Israel plans to mount four nuclear-armed cruise missiles on each of the three German-built submarines it is in the process of acquiring.⁴¹ Israel has denied that it conducted the claimed test.⁴² Regardless of the validity of the reported missile test, the news account is likely to help spur long-range



Figure 8

cruise missile acquisition efforts in a number of Middle-Eastern states.

France, the U.K., Italy, Germany, and Sweden. During the 1991 Gulf War, French and British forces had few standoff weapon systems. Many news accounts of that era noted the need for *Tornado* aircraft and crews to over-fly Iraqi airfields to drop cratering charges. These European allies also noted the extensive U.S. use of *Tomahawks* and other standoff munitions, a use that reinforced their previously drawn conclusions that they needed similar systems.

During the last decade, two groupings of European countries have nearly completed the development of two very capable cruise-missile systems. The first is a stealthy French-U.K.-Italy turbojet powered cruise missile system, the *Apache* (Storm Shadow) (figure 8). Of the three modular-designed models now being completed, the Storm Shadow achieves the longest range. It is an

37 Nikolay Novikov, "Russian Shipyard Begins Refit of Indian Submarine," Moscow *ITAR-TASS*, August 7, 2000, translated in FBIS.

38 "Indian Navy to Induct Russian Cruise Missiles," New Delhi *The Hindustan Times* (Internet version), December 4, 1999.

39 "China is Expected to Have Its Own Cruise Missile Soon," op cit: and *Jane's Strategic Weapon Systems*, p. 8 & 9.

40 *Jane's Strategic Weapon Systems*, p. 9.

41 Uzi Mahnaimi and Matthew Campbell, "Israel Makes Nuclear Waves With Submarine Missile Test," and "Fears of New Arms Race as Israel Tests Cruise Missile," *London Sunday Times*, Internet Version, June 18, 2000.

42 Dani Shalom, "IDF Denies Testing Cruise Missile Launch From Submarine," *Tel Aviv Hatzofe*, June 19, 2000, p. 2.

air-launched land-attack missile that can fly up to 400 kilometers carrying a 400-kilogram payload.⁴³ There are indications that a number of additional variants of the *Apache* (above the three already in the works) may be developed in the future.⁴⁴

Of particular concern is the fact that France does not consider the *Apache* to be an MTCR Category I system and has contracted to export the Storm Shadow version of the *Apache* to the U.A.E. The U.S. objected to the sale, claiming the system is a Category I missile and that its export would violate MTCR standards. Nevertheless, France is proceeding with the export. Reportedly, Russia has taken particular note of this sale. Defense analysts worry that the export of the *Apache* sets a precedent for future cruise missile exports by other states.

The second standoff system is the German *Taurus* modular weapon system, which will have a range of 350 kilometers. Germany began the program in March 1998. It is being partnered in this effort by Sweden. The system will be very technologically advanced—adaptable to varying situations. It will utilize a smart warhead capable of point and area attack. It can also be launched from either ships or aircraft and employed against land or sea targets.⁴⁵

Although the ranges of the systems noted will be limited in comparison to long-range Russian and U.S. systems, the technology in these two families of missiles is very advanced. It seems likely that these systems will be exported to other states.

Other states. Many other states either have or are expressing interest in acquisition of cruise missile capabilities. There are numerous examples of this interest:

- North Korea reportedly is assisting Iran with guidance improvements on the Chinese C-802 anti-ship cruise missile (which begs the question, what are North Korea's cruise missile development capabilities?);⁴⁶
- China and Iran have agreed to cooperate on a new generation of missiles and Iran is building anti-ship cruise missile production facilities with help from China;⁴⁷
- Iran's defense minister claims that Iran is about to deploy an extraordinary shore-to-sea cruise missile and begin to manufacture its own laser gyros;⁴⁸
- Iran may be capable of manufacturing turbojet engines, such as those needed to propel the C-802 Chinese cruise missile that Iran is now producing;⁴⁹
- There is an unconfirmed report that Iran may be working on a 400-kilometer range cruise missile;⁵⁰
- Norway wants to acquire land-attack cruise missile systems as a means of offsetting anticipated reductions in its defense establishment;

43 *Jane's Strategic Weapon Systems*, Issue 32, "France: Apache," p. 69.

44 Bernard Bombeau, "The Navy Wants Its Cruise Missile," *Paris Air & Cosmos/Aviation International*, March 31, 2000, p. 35.

45 Nick Cook, "Europe's Cruise Missile Conundrum," *Interavia Business & Technology*, Vol. 53, Issue 621, June 1998, p.39.

46 Michael Evans, "Tehran Upgrades Chinese Missile," London *The Times* (Internet Version), January 11, 2000.

47 Bill Gertz, "Pakistan Gets More Chinese Weapons: Beijing Also Sells To N. Korea, Iran," *The Washington Times*, August 9, 2000, pp. A1, A8; and Bill Gertz, "Cohen Sees Iran Making Progress With Missiles," *The Washington Times*, July 18, 2000.

48 "Defense Minister Inaugurates Project To Manufacture Laser Gyroscope," *Tehran Vision of the Islamic Republic of Iran Network 1*, August 28, 2000, translated in FBIS.

49 John Mintz, "Tracking Arms: A Study in Smoke," *The Washington Post*, April 3, 1999, p. A3.

50 *Jane's Strategic Weapon Systems*, Issue 31, "Iran," p. 7.



- South Africa has developed an advanced cruise missile with a 150-kilometer range.⁵¹ (Figure 9)

It seems clear that momentum is building—cruise missiles are going to become a major missile challenge to U.S. security. Unfortunately, there is no way to know how quickly these programs will come to fruition. For the past ten years, warnings that “the cruise missiles are coming” have been sounded repeatedly. For some, the situation is beginning to resemble the traditional Jewish invocation at Passover celebrations during the Diaspora, “next year in Jerusalem.” As a result, policymakers are beginning to ask, where is the cruise missile threat? Yet a careful review of known information indicates that work is being undertaken on these systems and that a threat is certain to emerge. Unfortunately, it is difficult to determine accurately how close many of these systems are to being deployed. There is a clear possibility, and perhaps even a strong likelihood, that U.S. forces could be surprised by the use of these systems during a future crisis.

⁵¹ Ibid., p. 12.

Section III: Cruise Missile Detection and Defenses

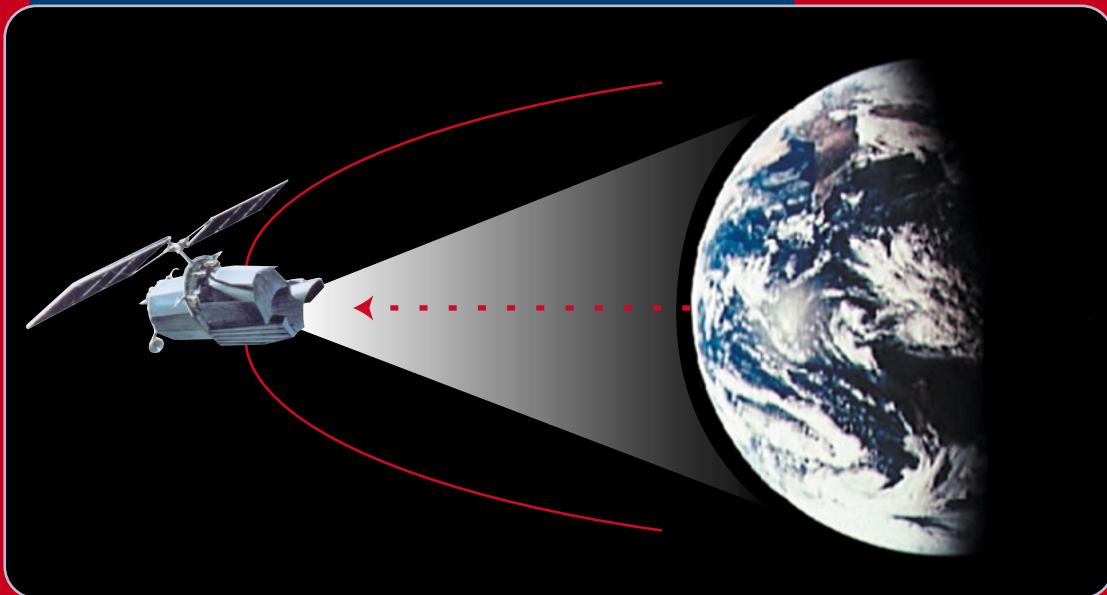
A typical modern cruise missile usually is about six meters in length (give or take one or two meters) by one-half to three-quarters of a meter in diameter. Most systems, especially those with longer-range capabilities, fly a high-low flight path to their target. Initially, the missile flies at a higher altitude to conserve fuel, then drops down as it nears its target to fly as close as possible to the earth's surface. In the case of more advanced land-attack systems, the flight paths used during the nap-of-the-earth portion of their flights are programmed to use valleys, terrain masking provided by hills and mountains, and to use the earth's curvature to avoid detection for as long as possible. Consequently, the greatest challenge facing cruise missile defense planners is to detect and track the

missiles early enough to engage them before they reach their target—and to do so using the most cost-effective methods possible.

The detection challenge. Space-based sensors cannot detect weak sources of infrared that are masked by a heavy cloud cover. Unfortunately, there are many parts of the world that are cloud-covered much of the time. For example, southern China and the equatorial regions of the globe located 10-degrees north and south of the equator (an area known as the cloud belt) are usually obscured by clouds; other regions experience similar cloud patterns and cannot be monitored routinely by space-based optical sensor systems (figure 10). In the case of satellites deployed in geostationary orbits to monitor missile launches, such as the Defense Support Program (DSP)

CLOUDS: A MAJOR IMPEDIMENT TO SPACE-BASED OPTICAL SENSING

Figure 10



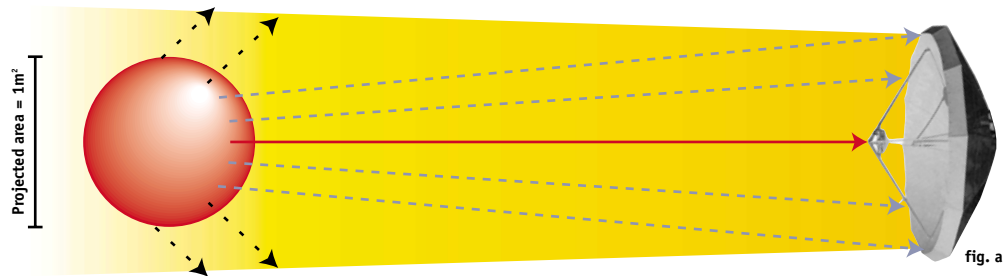
Visual and infrared sensors cannot “see” through cloud cover.
Cruise missiles can be tested below this cover.

RADAR DETECTION TUTORIAL

Figure 11

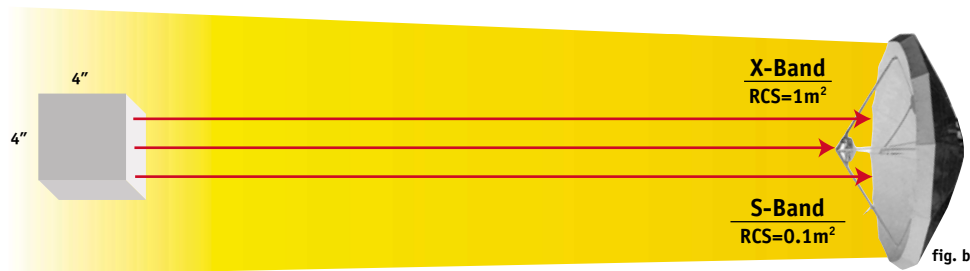
Radar Cross Section (RCS) measurement standard

The strength with which a radar signal will be reflected from an object is called the radar cross section (RCS). The RCS is recorded in square-meters. The amount of energy represented by a one-square-meter RCS is equal to the amount of energy reflected from a sphere having a projected area of a square meter (see figure a):



The Effect of Flat Surfaces and Angles on the RCS

With a high-frequency, short-wavelength radar, such as an X-band system, a 4-inch square flat surface directly facing the radar's beam will produce a RCS of 1m^2 . That same square will produce a RCS of only one-tenth of a square meter if illuminated by an S-band radar (due to the wavelength differences) (figure b).

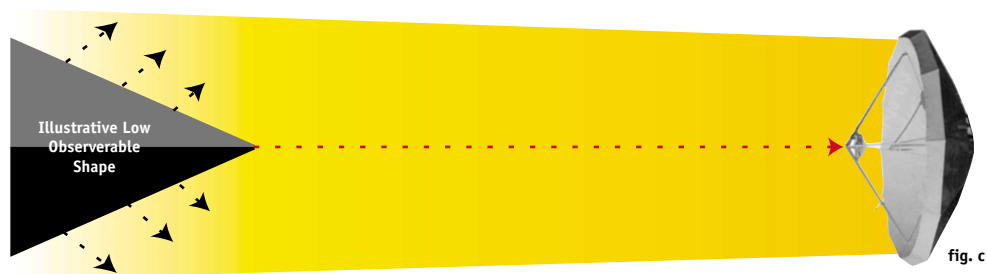


$$\text{The formula for this calculation is: } \text{RCS} = \frac{4\pi \times \text{Area}^2}{\text{wavelength}^2}$$

However, if the above shown cube begins to turn, an X-band will lose the reflected signal once the cube rotates 10 to 20 degrees. The S-band will not completely lose all signal returns until the cube rotates 30 to 50 degrees.

The Effect of a Reduced-Signature Shape

If the planes of the object are angled such that the signal is reflected in directions other than back toward the radar's receiver (figure c), the radar may not detect enough of a signal to allow the object to be discriminated from the electronic noise created within the system.



Under these conditions, the object may not be detected until it gets very close to the radar's location.

constellation, they are too far from earth to detect cruise-missile flights.

Even the Space-Based Infrared System-Low (SBIRS-Low) satellite constellation, planned for deployment around 2010 to support ballistic missile defense efforts, will be unable to detect the signatures of low-flying cruise-missiles routinely, especially when rain or heavy cloud cover is present to obscure the IR signature.⁵² It could be, however, that in cases involving hot missiles, such as those powered by ramjet engines or rockets, or when cruise missiles are flying at high altitudes or under a cloudless sky, that the SBIRS-Low constellation might be able to detect and track those systems if it is given the mission to do so and programmed accordingly. At the current time, cruise missile detection is not a SBIRS-Low requirement and it is not yet clear how much potential that system might have against cruise missiles. The key point is that for the foreseeable future, space assets cannot perform the cruise missile detection and tracking mission reliably.

Unfortunately, the difficult cruise missile detection challenge is expected to become even more difficult. As signature reduction technology gradually becomes embedded in new cruise missile systems, the difficulty detecting these threat systems will increase. Based on current projections, technical personnel working cruise missile detection issues postulate that it will be at least another three decades before space-based sensors might become capable of detecting and tracking low-flying cruise missiles reliably. Consequently, cruise missile target acquisition will remain a mission dependant upon terrestrial-based assets for the foreseeable future.

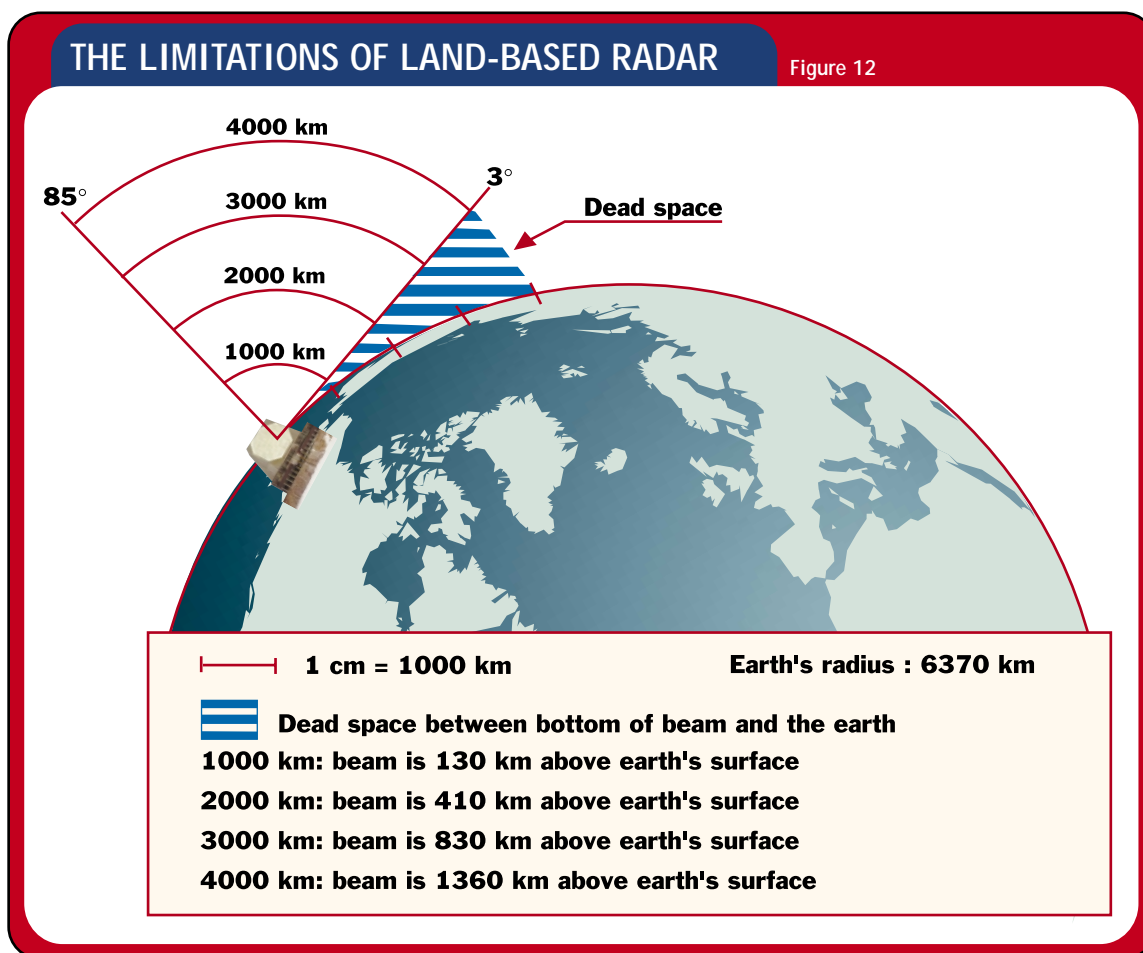
With but a few exceptions, radar is the primary asset used for cruise missile detection

and tracking. Unfortunately, radar detection of cruise missiles is difficult.

- **First, a cruise missile, even one of standard design, presents a very small radar cross-section** (see figure 11 for insights into the radar detection process).⁵³ If a cruise missile is flying directly toward the searching radar, a spherically shaped nose on the missile will present a very small radar cross-section, thus reflecting only a very faint signal back toward the direction from which the signal originated. On the other hand, if the nose of the missile is shaped to reduce the missile's radar signature, the RCS will be even smaller. The smaller the signature of an object, the closer that object must be to the radar's location before it can be detected.
- **Second, low flying objects are difficult for radar to detect against ground clutter** (trees, birds, insects, moving water, people, vehicles, etc. all generate signal returns that must be processed by the radar). It is very challenging for the radar's computer to process the hundreds of thousands of echoed returns from signals created by ground clutter and identify the faint signature associated with a cruise missile. The task is similar to trying to hear a pin drop in the middle of an artillery barrage. To minimize the amount of ground clutter included in a radar's search area, ground-based anti-aircraft radar is tilted back about three degrees to lift the bottom of the search beam above the ground. However, this operational

52 For a detailed explanation of the SBIRS-Low program, see National Missile Defense, *op cit*, pp. 3.18-3.20.

53 For those interested in gaining a more detailed understanding of radar functioning and methods for decreasing radar signatures, see J. C. Toomey, *Radar Principles For the Non-specialist*, 2nd ed. (Park Ridge, New Jersey: Scitech Publishing, Inc., 1998); the small RCSs for cruise missiles and reduced-signature technologies is discussed in Humphry Crum Ewing, Robin Ranger, David Bosdet, and David Wiencek, "Cruise Missiles: Precision and Countermeasures," *Baillrigg Memorandum 10*, Centre for Defence and International Studies, Lancaster University, 1995, p. 50.



requirement makes it even more difficult for ground-based radar to detect low-flying aircraft or cruise missiles.

- **Third, the earth's curvature severely limits the distance at which a ground-based radar can detect objects near the surface.** As shown in figure 12, missiles or aircraft flying near the earth's surface cannot be detected by ground- or ship-based radar until they near the radar's location.

Complicating the radar detection challenge is the trend toward incorporating signature reduction technology into cruise missile designs. It was discovered during the 1970s that by forming

the sides of an object in flat planes (called facets) set at carefully calculated angles to the anticipated direction of likely radar search beams, the echoed energy would be reflected in a different direction. Since very little of the signal is reflected back to the point of transmission, the radar cannot discriminate the faint echo buried in the electronic noise of the returns until the object of interest gets close enough to the radar for the echoed signal to become stronger and more distinct. Moreover, to further complicate the radar challenge, an advanced reduced-signature airframe design might use special radar absorbing material on surfaces such as the wing edges and other joints in an attempt to further reduce the RCS.⁵⁴

⁵⁴ The techniques used to produce reduced-signature aircraft were discussed in some detail on The History Channel, *Stealth Technology: Modern Marvels*, July 5, 2000, 10:00 p.m. The program included interviews with Denys Overholser, a key stealth design engineer for the F-117 Stealth Fighter in support of Lockheed's Skunk Works during the 1970s, and Pyotr Ufimtsev, the Russian mathematician who developed the formula for predicting the scatter of electromagnetic energy.

In addition, to mask engine signatures, the engine might be located behind and under the body of the missile. This placement hides the engine's fan blades from radar observation (the blades create a large radar signature). The missile's body would also mask the IR signature produced by the engine.

As was noted in the Introduction, it is not expected that other states will produce cruise missiles with the same degree of sophistication the U.S. is capable of producing. However, it is clear that future systems will pose a greater challenge than has been the case heretofore. The evolving cruise-missile threat will require a new approach to target detection and tracking.

Since the curvature of the earth prevents low-flying cruise missiles or aircraft from being detected by a surface-based radar until it closes on the radar's location, any system designed to counter a cruise missile threat must use elevated sensors capable of seeing beyond the earth's local horizon. The systems must also incorporate advanced radar detection technologies capable of processing and interpreting very faint signal returns.

Theoretical approaches to reduced-signature object detection. No object can become entirely invisible to detection. The simple passage of an object through the atmosphere displaces air molecules and disturbs the electromagnetic spectrum. The key to detecting reduced-signature objects is to focus collection efforts against those disturbances that cannot be shielded. While it is much more difficult to detect objects that incorporate signature reduction technologies, it is not impossible.

Bistatic radar provides a potential means for detecting objects with a very small RCS. Bistatic means that the radar's transmitter is separate from the receiver. To put the system in perspective, all early radar sets were bistatic since the switching between transmit and receive in the same antenna was not fast

enough—the pulse got back to the antenna before the radar could switch to the receive mode. By necessity, the radio signal had to be broadcasted by a stand-alone transmitter; the return pulse was recorded and processed by a separate receiver. As technology advanced the two functions were combined into a single equipment set that used a common antenna.

Almost all modern radar sets combine the transmit/receive functions in a single equipment set. However, the need to detect reduced-signature objects is creating renewed interest in the development of networked radar sets that can receive and process the echoes of signals transmitted by other radio sources. In essence, the situation resembles a baseball game. Until now, all of the individual games being played involved only a pitcher and a batter. The batter always bunted the ball back to the pitcher. (See figure 13, p. 22)

The emergence of aircraft and cruise missiles with smaller RCSs are creating a requirement to field more players on the team, all of whom can be kept aware of the common situation and all of whom are capable of catching a ball regardless of where it is hit (the echoed signal). Likewise, it is clear that future detection challenges will require the use of bistatic radar techniques, networked into a system of systems to detect targets that are difficult to sense naturally or that incorporate signature reduction technologies. (Figure 14, p. 23) (Note: technically, situations involving multiple receivers and a common transmission source are called multistatic.)

The source of the radar signal transmitted for bistatic detection can originate from a source other than a radar set. After all, the acronym RADAR stands of **R**adio **D**etection and **R**anging. Consequently, a radio signal transmitted from any source could be incorporated into a bistatic radar detection system. In fact, China may be working on such a system to detect reduced signature

BASEBALL/RADAR ANALOGY

Figure 13



Current radar systems, each acting independently throw their balls (signals) to batters, who always punt it back to the pitchers (radar transmitters/receivers).

What is needed is a team of fielders, who are all aware of the situation on the playing field, and can catch the "signal," wherever it is hit.



aircraft.⁵⁵ The key to such a system is an ability to network various radar receivers so as to be able to detect and measure the outgoing signal and the echoed returns, some of which might be reflected from an object in directions other than back toward the radio source (e.g., a baseball hit to right field rather than back to the pitcher).

Computer-processing advances are also opening the door to the development of more advanced radar processing capabilities, processes that can extract more information out of the echoed returns. Moreover, new algorithms, such as those used in high-resolution radar (HRR) could be discovered that will increase radar efficiency. For example, some

⁵⁵ Mai Shilong, "Window to China: New Radar Makes It Impossible for Stealth Fighters to Remain Undetected," Hong Kong, *Sing Tao Jih Pao*, August 16, 2000, p. A15, translated in FBIS. The Hong Kong article was based on an article published in a semi-open Chinese military monthly run by China North Industries.

new discoveries, such as may evolve out of ultra-wide-band (UWB) technology, could provide the means for future radar advancements.

U.S. Programs for Countering Cruise Missiles

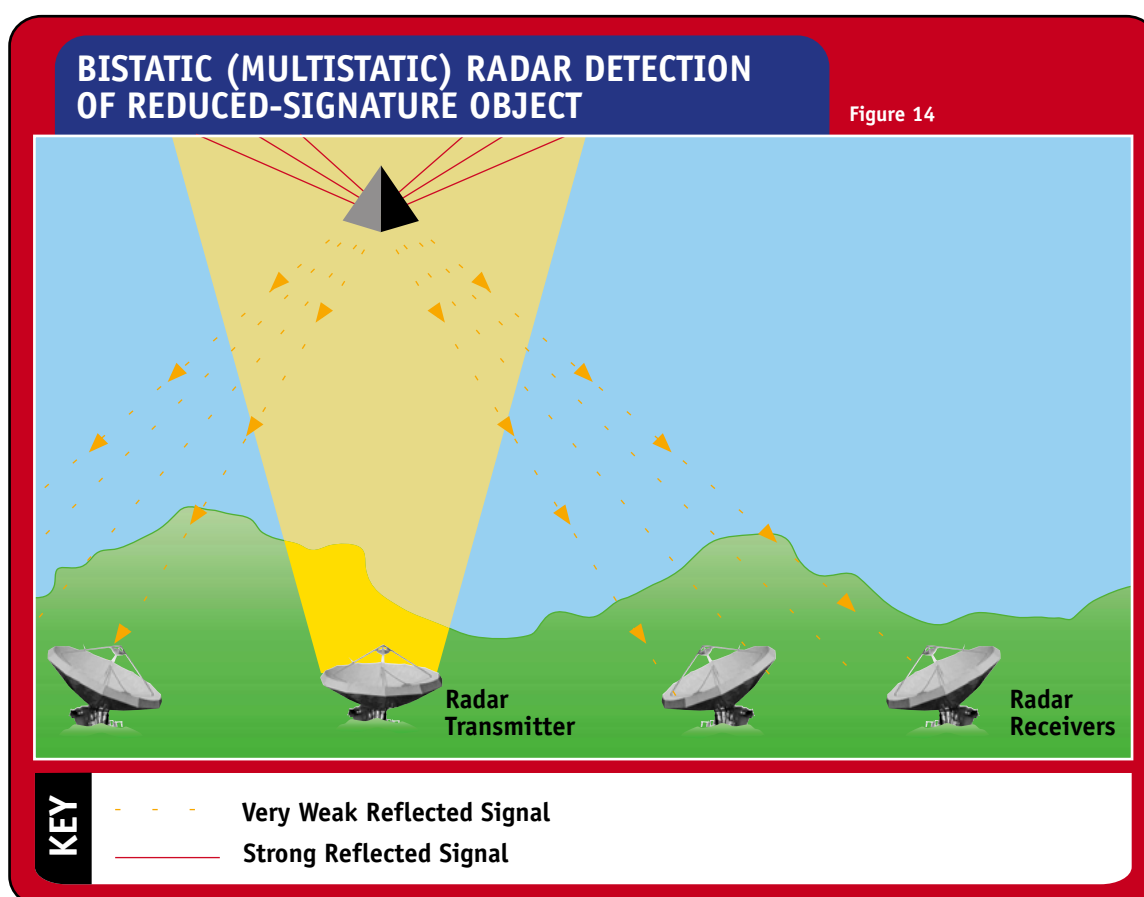
The key issue is whether or not the counter-cruise missile programs are evolving quickly enough to protect against the emergence of more robust cruise missile threats. The cruise missile defense programs being pursued or contemplated are focused on three general areas of endeavor:

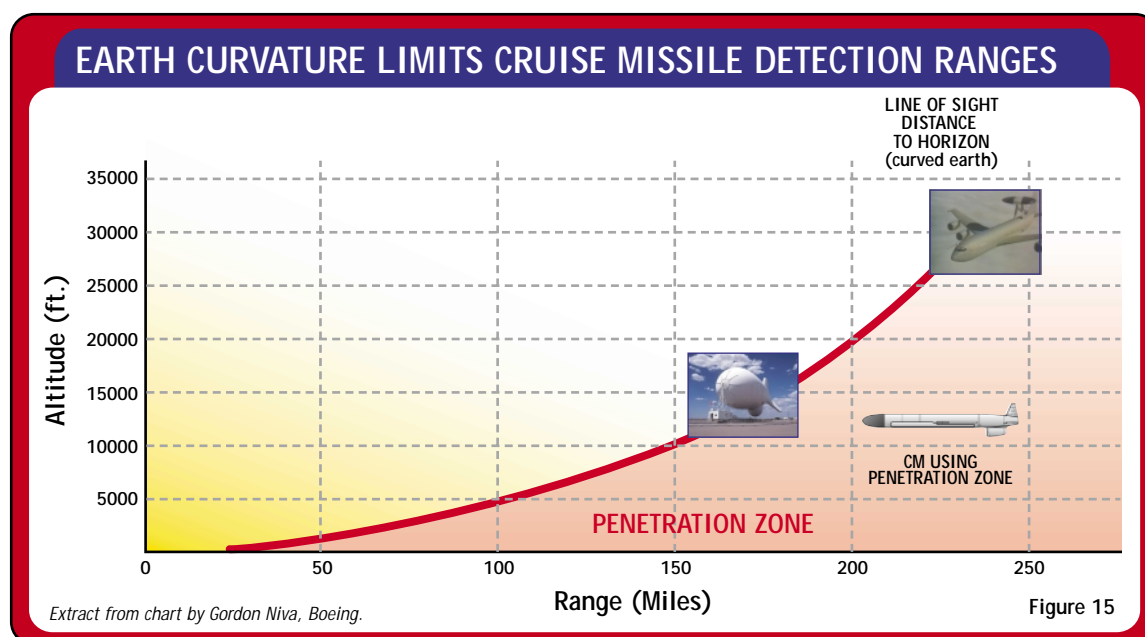
- Advanced sensors for use on elevated or airborne platforms
- Netted sensor capabilities (i.e., the full baseball team)

- Low-cost interceptors/kill mechanisms

As was described in the foregoing section, curvature of the earth and terrain masking are huge obstacles to early detection of cruise missile attacks (see figure 15, p. 24). It is clear that any effective defense against cruise missiles must be based on elevated sensors operating within a common network. Once the cruise missiles are detected and tracked, they must be destroyed, preferably using low-cost interceptors launched from firing locations beyond the horizon of their intended targets.

There are a number of programs being worked with varying degrees of intensity and with differing levels of inter-service coordination to try to improve the United States' capability to counter the evolving cruise missile threats. Although there are few open-source details available on some of





these programs, there is enough information to make some judgments on the general direction of U.S. cruise missile defense efforts.

Airborne Warning and Control System (AWACS). The Navy's E-2 and the Air Forces E-3 AWACS aircraft monitor air traffic operating in their sectors, provide military air traffic control, and vector friendly aircraft against hostile air threats (among other missions). These aircraft are large platforms operated by large crews; AWACS aircraft are unquestionably superb assets, but they are also expensive to operate over prolonged periods of time.

As cruise missiles and other air threats with reduced signature technology evolve, the capabilities of the AWACS aircraft must grow in concert with those threats. Currently, the Radar System Improvement Program (RSIP) is being incorporated into the E-3, adding advanced radar and sensor fusion capabilities to the aircraft to "capitalize on the newest technologies for cruise missile defense....

RSIP provides increased detection range for low radar cross section targets."⁵⁶

Although there are few details available, the Air Force reportedly is examining ways of linking the search capabilities of AWACS with other platforms such as JSTARS. This type of linkage would facilitate usage of more advanced radar detection techniques. However, this possible course of action is still in the conceptual stage of consideration.⁵⁷

F-15 upgrade program. By the end of 2000, an active electronically scanned array (AESA) will be installed on a small number of APG-63 radar systems used by F-15C interceptors. The upgrade will allow the aircraft to control a large number of advanced medium-range, air-to-air missiles (AMRAAM), which are intended to intercept a swarm of cruise missiles scattered over a wide area (i.e., provide mission control similar to that of the AWACS).⁵⁸ It is interesting to note that the first F-15C unit to be equipped with this upgrade is located in Alaska.

⁵⁶ General Michael E. Ryan, *Testimony on the Air Forces Budget Request*, House Armed Services Committee, February 10, 2000.

⁵⁷ David Mulholland, "Joint STARS to Get Upgrades to Fly New Missions," *Aviation Week & Space Technology*, August 9, 2000, p. 8.

⁵⁸ Robert Wall, "F-15 Radar Upgrade Expands Target Set," *Aviation Week & Space Technology*, December 13, 1999, p.40.

Expansion of the Navy's Cooperative Engagement Capability (CEC) system. The CEC development program is designed to provide all ships in a battle group with the same situational information. The ships will be able to use data from other radar systems to engage targets outside the range of their own sensor systems. To begin to examine the hurdles to this concept, the Ballistic Missile Defense Organization (BMDO) is planning to test the concept in Fall 2000. As a preliminary exercise, a small-scale test of a CEC network was conducted August 7-17, 2000 to determine how much information the elements could exchange. The elements involved included a Wallops Island radar, a P-3 aircraft, two *Patriot* battery command posts and radar,

and an *Aegis* cruiser.⁵⁹ There is also interest in expanding this network capability to include land-based air and other missile defense assets. However, this program is a long-term evolutionary effort that is still in its infancy. It will require years to perfect.

Single Integrated Air Picture (SIAP). The SIAP is a joint program to develop the capability of a shared common depiction of all airborne objects, both friend and foe for all relative assets in a theater of operation. This program would incrementally develop the software and assets needed to integrate and display information from the CEC, the Joint Tactical Information Data System (JTIDS), and Identification Friend or Foe (IFF) signals from



Figure 16

59 "BMDO Successfully Completes Cooperative Engagement Capability Test," *Defense Daily*, August 24, 2000, p. 7.

friendly air vehicles operating in the region. By creating a common picture of the operational airspace, and therefore reducing the uncertainty of whether an object is hostile or friendly, the various military forces in theater will have more freedom to act quickly in fluid situations. (Figure 16, p. 25) The development of the SIAP program promises significant increases in combat effectiveness. The SIAP effort is being organized in late 2000.

The Joint Land-attack Cruise Missile Defense Elevated, Netted Sensor System (JLENS). The primary focus of JLENS is to develop the advanced radar capabilities and communication systems necessary to network the sensing capabilities of the various systems in a theater of operations. The JLENS program also includes the acquisition of aerostat balloons to provide a low-cost platform to elevate the advanced sensor systems needed for long-term observation of potential attacks.

The system will also control and guide interceptors, such as Army *Patriots* and HUMRAAMs, Air Force AMRAAMs, and Navy *Standard* missiles that could be launched blindly from beyond the horizon and guided to intercept hostile targets by JLENS. This capability was demonstrated on April 4, 2000 when, for the first time ever, the control of a missile in flight was handed over to another radar (JLENS surrogate system); the missile achieved a direct hit on its target (*Forward Pass* demonstration). Since the JLENS program is a primary element of the cruise missile defense strategy being pursued by the U.S. Department of Defense, a little time needs to be spent examining this program.

In a number of regions threat levels remain high on a continual basis. Places like the Korean DMZ, the Taiwan Strait, the Persian Gulf, and Iraqi border areas all represent regions that could require long-term counter-cruise-missile surveillance. As the future unfolds, this type of mission could include

the Mediterranean and Black Sea regions if hostile powers in the Middle East and North Africa should acquire long-range land-attack cruise missile systems and threaten NATO.

To keep AWACS aircraft constantly aloft in these potential trouble spots would be a very expensive proposition that would entail the deployment of an extensive support base. In addition, the constant use of these platforms would prematurely wear out these valuable assets.

In response to these emerging requirements, the Department of Defense established the Joint Land-Attack Cruise Missile Defense Elevated, Netted Sensor (JLENS) program to develop advanced sensor and netted communication systems that can be deployed for prolonged periods of time at reasonable costs. The system is not a replacement for AWACS, but rather designed to complement fixed-wing collection capabilities. Most importantly, the JLENS program is designed to provide advanced netted sensor capabilities that act as a gateway for linkage of all of the various service capabilities that could contribute to an effective defense.

At first glance, the JLENS program seems comical in that the sensor suites being developed will be deployed on large tethered aerostats. Program personnel refer to the standard reaction to the aerostats as the "giggle factor." The aerostat, when inflated, is two-thirds the length of a football field and would be flown at the end of a slender 75,000-pound tensile strength power/data/anchor cable at altitudes between 10,000 and 15,000 feet. The balloons are envisioned to be employed in pairs, anchored by mooring trucks positioned about five kilometers apart (see figure 17). In most cases, the five-person crews will be collocated with a *Patriot* battery; if they are supporting naval forces operating in littoral waters, they may be located on off-shore barges or cargo ships to provide over-the-hori-

JLENS CONCEPT OF OPERATION

Figure 17



zon fire control against anti-ship cruise missiles or other air or surface threats.

The radar mounted under one of the aerostats will search a 360-degree area out to a range greater than 250 kilometers and illuminate objects of interest. The radar on the other aerostat will provide precision tracking of objects of interest to a range of 150 kilometers. Operating power will be sent up a power cable inside the tether, and data will be transferred to and from the aerostat via a fiber-optic cable. The data will be processed on the ground to minimize the size and value of the 6000-pound sensor package hung under the balloon.

Unfortunately, there are several misconceptions about the aerostat that contribute to the giggle factor. The myths that plague the program include:

- **Myth 1: The aerostat is a big fat target that would be easy to destroy.** It is true that the balloon is big and ungainly; few will get excited about such a monstrosity. However, it is much more survivable than generally understood. Sensor systems on air-to-air missiles are not programmed to lock onto this type of object. Radar beams receive little reflection from the round shape, with most passing through the balloon; it has little IR radiance as well. In addition, the JLENS system is capable of shooting down aircraft and missiles by controlling the fires of any defensive asset in the area.

The more likely problem is that the balloon might be punctured by Cal .50 machinegun fire (if hostile forces got

within about a mile of the balloon. Since the internal helium pressure is only slightly higher than the external air pressure, any holes in the balloon would not cause a massive venting of gases, but would result in a gradual loss of helium as the gases slowly began to establish equilibrium with the outside air. The balloon would stay up anywhere from a few hours to several days, slowly losing altitude. If this occurred, an AWACS or other similar sensor system would have to be moved on station to assume the mission until the aerostat could be repaired.

- **Myth 2: The U.S. has AWACS, therefore JLENS is an unnecessary expense.** This statement is partially true in that netted AWACS systems would be capable of performing the JLENS mission. The issue is cost, plus the loss of some other capabilities that JLENS will bring to the fight. JLENS will cost much less to procure than does AWACS platforms and its operating costs will be less than one-tenth that of an AWACS. JLENS is designed to supplement AWACS capabilities so as to free up those assets for missions that require the mobility that AWACS brings to the battlefield. In essence, JLENS will provide sentry duty while AWACS gallops off to lead cavalry charges.

It is also envisioned that JLENS will be capable of providing information on ground movements, a task also performed by JSTARS. Thus, the sensor systems could provide both air and ground surveillance so that more of the mobile assets can be deployed in areas with fluid situations while JLENS guards fixed facilities or assets that are less mobile.

- **Myth 3: A UAV could do the mission so JLENS is unnecessary.** It is true that the UAVs are extremely valuable machines and have fantastic optical capabilities. However, large radar systems are heavy and use large quantities of power. For continuous coverage of an area, regardless of cloud conditions, the U.S. needs radar systems. As noted earlier, the JLENS sensor package weighs 6000 pounds and uses a fiber optic cable to down-link the massive data stream. UAVs cannot handle this requirement on a routine basis.

- **Myth 4: Aerostats are fair weather assets that will be down more than up.** It is true that severe weather will require that the system be grounded. However, aerostats can fly in winds up to 60 knots. Consequently, the system is projected to remain on station for prolonged periods, only being reeled in for monthly maintenance or extremely severe weather, especially so during high-threat conditions.

The development of the JLENS has been slowed in recent years as tight budgets have squeezed defense programs. As currently structured, the JLENS system is unlikely to be deployed until 2010 or later.

Low-cost interceptors. The Defense Advanced Research Projects Agency (DARPA) is working to develop low-cost missile systems that could be employed against cruise missiles. The objective of this program is to avoid using too many multi-million-dollar assets to destroy missiles costing less than one-fourth as much. Therefore, DARPA is searching for low-cost kill systems that can be used to engage the cruise missiles once detected. (This initiative also has a sensor-related program that spawned the JLENS program discussed above.)

Findings and Recommendations

The speed at which highly capable cruise missiles are likely to become a serious threat to U.S. forces, and perhaps even to the homeland, cannot be pinpointed. However, the information needed for U.S. policy development can be determined.

Finding 1: Countries should be expected to seek advanced cruise missile capabilities because the benefits and motivations for doing so are too persuasive for them to ignore. They include:

- The success of U.S. *Tomahawk* diplomacy. (Precision strike systems are seen as the military means that will be used most often to resolve early 21st Century conflicts.)
- Ballistic missile defenses will increase the value of cruise missiles. (As ballistic missiles become vulnerable to counter measures, less expensive, but more versatile, cruise missile systems are likely to become the system of choice.)
- Cruise missiles are highly useful for situations requiring the use of coercive diplomacy. They also can be employed against major powers without risking nuclear war. (The use of cruise missiles for coercive diplomacy is politically more acceptable than is the use of ballistic missiles.)
- The precision with which cruise missiles can be delivered increases their value. (Cruise missiles are much more accurate than are ballistic missiles, making them cost effective platforms for the delivery of conventional payloads.)

- The limited amount of skilled manpower that is required to maintain and deploy cruise missiles is an attractive benefit for many states. (Many countries are finding it difficult to train and maintain skilled military manpower. Cruise missiles can reduce the size of this burden.)
- The survivability of cruise missiles. (Cruise missiles are difficult to detect and track in time to take effective counter-measure action.)

Finding 2: There are numerous indications that interest in cruise missile development is gaining momentum. Some examples include:

- Russia is developing long-range, land-attack cruise missiles, while selling highly capable anti-ship systems in an attempt to fund procurement of next-generation cruise-missile systems.
- China is developing long-range, land-attack cruise missiles, while purchasing Russian *Sunburn* supersonic, anti-ship cruise missiles. News reports indicate China may also be interested in procuring Russian *Club* cruise missiles.
- India is purchasing Russian anti-ship cruise missiles, while developing at least three cruise missile systems indigenously. Its 600-kilometer land-attack cruise missile may be fielded.
- Iran is building a cruise missile production factory and is upgrading its Chinese *Silkworm* anti-ship missiles. It is also working on building a UAV.

- North Korea and Iran are cooperating on cruise missile guidance systems. This cooperation indicates that North Korea may have an active cruise missile development program.
- Several European countries are developing advanced cruise missile systems that include reduced signature technologies. France is selling one of these systems to the U.A.E. (supply and demand indicator).
- South Africa unveiled a high-capable 300-kilometer, 500-kilogram land-attack cruise missile in November 1999. The missile has a very advanced guidance system. The manufacturer claimed it has a CEP of 2 meters.
- Since cruise missiles usually fly the terminal leg of their flights close to the earth, elevated sensors are required to detect these systems while they are still behind the local horizon.
- The networked sensor system used to detect and track cruise missiles must also be able to control interceptor missiles launched blindly toward targets that cannot yet be viewed by the firing unit.
- The netted system must be able to connect and operate across military service lines (connect together assets from the Army, Navy, Air Force, and Marines).

Since cruise missiles are built almost entirely with dual-use technologies, it is nearly impossible to monitor the international flow of parts and components used in these systems. As a result, it is impossible to predict cruise missile proliferation rates.

Finding 3: Standard cruise missiles have very low radar cross sections. A cruise missile's radar cross section becomes minute when signature reduction technologies are applied. The United States requires advanced radar capabilities and sensor employment approaches to deal with advanced cruise missile and aircraft threats.

- Reduced signature objects require that radar detection systems become more capable, able to identify much weaker radar returns than has been the case heretofore.
- Signature reduction technologies will demand that sensor suites be networked together so as to allow use of bistatic and multistatic radar employment techniques.
- AWACS aircraft from both the Air Force and the Navy must be optimized to detect low RCS cruise missile threats.
- JSTARS aircraft should also be studied to determine whether it can be modified to detect small RCS low-flying air threats.
- The JLENS program promises to provide detection and tracking of advanced cruise missile threats at a reasonable cost. JLENS is likely to be most useful in areas of tension or under conditions of limited conflict over prolonged spans of time. The Korean DMZ, the Taiwan Strait, the Persian Gulf, the Iraqi border, and perhaps even some NATO border areas are examples of potential locations for possible JLENS deployment.
- The above programs also need the Single Integrated Air Picture (SIAP) program to be successfully developed so that all service capabilities oper-

Finding 4: The U.S. needs multiple capabilities that can link together to defeat advanced air threats.

ate within a common situational framework (i.e., all the ball players can see the entire playing field).

sile defense ball team needs a full complement of players, not just an adjacent series of pitchers and batters.

Recommendation 1: Since estimates of cruise missile proliferation rates are uncertain, the U.S. should move smartly to develop anti-cruise missile capabilities.

- The lack of anti-cruise missile capabilities is likely to encourage cruise missile proliferation.
- Since the amount of work required to develop the netted system of systems needed to detect and destroy cruise missiles over the horizon is extensive, the United States cannot afford to delay this development until after the anticipated cruise missile threats are already deployed.

Recommendation 2: The cruise missile defense puzzle is very complex and not easily solved. Consequently, the Administration and Congress should ensure that stove-piped service programs designed to counter cruise missile threats are properly coordinated to operate within a common network of sensors and interceptors needed to defeat the types of systems described in this study.

- It is not enough that a couple of sensor-platforms can coordinate together to detect cruise missiles over the horizon. U.S. security requires that a system of systems be developed to counter the evolving cruise missile threat.
- JLENS, AWACS, JSTARS, the Army's *Patriot* and HUMRAAM interceptors, the Air Force's AMRAAMs, and the Navy's *Aegis* capabilities must all operate as part of a cohesive and coordinated force based on a common situational awareness. The cruise mis-

APPENDIX A

Cruise Missile Building Blocks and Modification Challenges

Defense analysts disagree on the speed with which the cruise missile threat is likely to develop (to include suggestions that anti-ship systems might be converted to land-attack systems). To appreciate the basis for this lack of unity, it is necessary to briefly survey some cruise-missile-related technology issues. To produce an indigenously assembled land-attack cruise missile or to convert an anti-ship missile to a land-attack system involves building a new missile or replacing at least one or more components of an anti-ship cruise missile. This appendix will provide a layman's overview of the issues involved.

The airframe. Since cruise missile designers want to make their systems difficult to detect (and thus more capable of penetrating defenses), it is desirable (but not required) to keep the airframe as small as possible to minimize its detectable signatures. The airframe need only be constructed out of light aluminum or even wood and canvas. Advanced technology airframes may include or be built entirely of composite materials, especially if the missile incorporates signature reduction technologies.

Since many of the underlying principles for reducing the radar cross-section of objects are common knowledge (an effort traceable to 1944),¹ it is clear that many of the recently unveiled cruise missile airframes have been developed with the intent of reducing the missile's detectable signatures. The airframe has been shaped to reflect radar echoes away from the transmission source while the thermal infrared (IR) produced by the propulsion system is often masked. However, building an

airframe that incorporates highly advanced signature reduction technologies is complex—the design must still be capable of aerodynamic flight.

Engineers develop airframe designs based on a set of calculations that consider the inter-relationship between the planned weight of the missile, the velocity that its propulsion system can provide, and the amount of aerodynamic lift that will be generated by the vehicle's airframe, wings, and velocity. In packaging the missile's components, the engineers also calculate fuel consumption and its effect on the vehicle's center of gravity as the fuel tanks or rocket motors lighten during flight. The missile designers do not want the system to become too nose- or tail-heavy as fuel is consumed.

Many of the emerging cruise missile airframes are incorporating composite materials to reduce the weight of the missile and, in some cases, to reduce the radar reflectivity and the infrared signature of the system. Welds and rivets on aluminum airframes increase the radar reflectivity of the body; however, in those instances where composite materials are used, the airframe usually is smooth and shaped so that the radar cross section and infrared signature are minimized.

In terms of cost and complexity, fabrication of the airframe (especially one of traditional design) is fairly straightforward and is a minor portion of the cost of building such systems. If a country has a manufacturing base for light aircraft, or some related industry, it could fabricate cruise-missile airframes. The major variable is the amount of signature reduction technology that is incorporated.

¹ Systems Assessment Group NDIA Strike, Land Attack, and Air Defense Committee, pp. 44 and 120.

V-1: CRUISE MISSILE OF THE THIRD REICH

Figure 1



Propulsion systems. Although there are a number of potential propulsion systems that can be used (even a piston-engine driven propeller), most cruise missiles are propelled by one of four types of engines: solid-fueled rockets, turbojets, turbofans, or ramjets. It should be noted that surface-launched turbofan, turbojet, and ramjet engines require a booster system to accelerate the missile to the velocity required by that particular airframe and main engine to sustain cruise flight. For example, the World War II era German V-1 missiles used inclined ramps and catapults to launch the missile (figure 1). Modern cruise missiles equipped with air-breathing engines usually use a small solid-fueled booster rocket to blast the missile out of its launch tube and provide the acceleration needed for cruise flight. In the case of aircraft-launched cruise missiles, some designs use the speed of the aircraft to attain the required cruise velocities. Each of the four propulsion systems cited below has advantages and disadvantages:

- **Solid-fueled rockets** are fast but tend to have a short range. Since the oxidizer required to burn solid fuel is part of the fuel mix, cruise missiles using this type of propulsion system are relatively heavy and carry small payloads for a given airframe size. It should also be noted that the faster a cruise missile travels through the atmosphere, the more intense its IR signature will be due to atmospheric

heating of the airframe. Add to this signature the heat of a burning rocket engine, and it is easy to understand why rocket-propelled cruise missiles are easily detected by IR sensors and destroyed by IR-homing warheads. At the same time, solid-fueled cruise missiles are simple to design since the propulsion system also provides the boost needed to launch the missile. The French *Exocet* is an example of a solid-fueled anti-ship cruise missile. The longest-range *Exocet* variant can fly 70-kilometers carrying a 165-kilogram payload. (Note: some old cruise missiles held in national inventories use liquid-fueled rockets with similar characteristics, but greater handling difficulties.)

- **Turbojet engines** produce high thrust levels, can obtain supersonic velocities if so desired, and use atmospheric oxygen to oxidize fuel. However, these engines are not as fuel efficient as turbofan systems. Turbojets use a turbine-driven compressor to pack air into the combustion chamber as needed to obtain the air-volume required for efficient combustion of the fuel being burned. Between the combustion chamber and the exhaust nozzle is a turbine that is turned by the exhaust gases to produce power to

turn the air-compressor blades. The exhaust gases from the jet engine propel the missile forward. Many of the cruise missiles currently deployed are equipped with turbojet engines. Since turbojets consume a lot of fuel, turbojet-powered cruise missiles have limited range capabilities. The Chinese C-802 anti-ship cruise missile, for example, uses turbojet propulsion. It has a range of 120-kilometers carrying a 165-kilogram payload. Some emerging turbojet-powered cruise missiles have ranges of 350-400 kilometers. (Of course, a passenger aircraft using this type of engine could be loaded with explosives and used as a long-range cruise missile if cost factors and radar-signature considerations were ignored.)

- **Turbofan engines** are highly fuel efficient and quiet. They are the propulsion system used to power long-range, subsonic cruise missile systems. The turbofan engine works by using a large fan to force air into the engine's combustion chamber at the same time some of the air drawn into the engine is routed around the outside of the combustion chamber and vented into the exhaust stream creating added propulsion (figure 2). The air bypassing the engine also acts to cool the exhaust gases, reducing the engine's infrared signature. Since the engine is highly fuel efficient, it creates less exhaust than other types of engines further lowering the missile's IR profile. The U.S.

Tomahawk is the best example of a turbofan-equipped land-attack cruise missile. The most recent Block III model has a reported maximum range in the vicinity of 1700 kilometers carrying a 700-kilogram improved-explosive payload.² An improved missile called Tactical *Tomahawk* is being developed and is expected to have a range of 2800 kilometers.³

- **Ramjet engines** require a supersonic air flow to operate. They are also heavier-built engines than those needed for subsonic flight. These engines are simple in that compressed air is provided by scooping it into the air passage at speeds of mach 1 or greater. The air is compressed into the combustion chamber by the shock wave of supersonic flight.⁴ Thus, ramjets eliminate the need for the compressors and turbines used by other jet engines to get high volumes of air into the combustion chamber, but ramjets also require the use of a rocket booster or aircraft to accelerate the missile to the speed of sound. Once the sound barrier is broken, or at least the air entering the engine achieves the

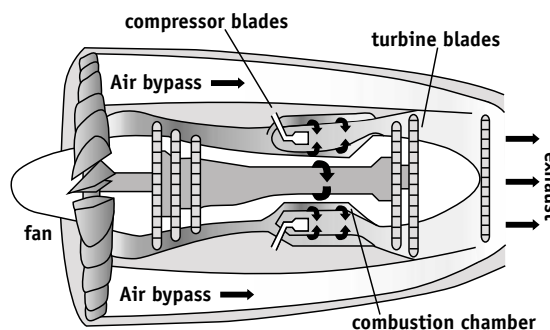


Figure 2: Turbofan engine

2 "World Missile Briefing, Missile Market Overview-Surface to Surface: BGM-109 *Tomahawk*," *The Teal Group*, March 2000, p. 4. The range of the *Tomahawk* is classified. The 1500 to 2000 kilometer figures are open source estimates.

3 *Jane's Strategic Weapon Systems*, Issue 32, "USA (*Tomahawk*)," ed. Duncan Lennox (Coulson, Surrey: Jane's Information Group, 2000), p. 194.

4 Some ramjets operate at high subsonic speeds by routing the air intake in such a way as to create a supersonic airflow even if the aircraft itself has not broken the sound barrier.

speed of sound, the ramjet can take over the task of propelling the missile using normal jet-engine principles. However, supersonic cruise missiles are more easily detectable by defensive systems than are subsonic systems. After all, it is hard to hide a very hot missile that is breaking the sound barrier. Thus, they depend on speed rather than stealth for survival. It should be noted that the feared Russian SS-N-22 *Sunburn (Moskit)* supersonic anti-ship cruise missile is an example of a ramjet propulsion system.

Guidance systems. As discussed earlier, the guidance system for an anti-ship cruise missile can be very simple. A commercial inertial navigation system (INS—measures movement rates and direction—provided by an integrated gyroscope), an altimeter, a simple autopilot, and a terminal radar-guidance system are all that is required. These systems are readily available commercially.

Conversely, the land-attack systems require a complex guidance system because land-attack cruise missiles usually are designed to survive by flying close to the earth. Thus, the missile must navigate around mountains, over or under tall power lines, and bypass other natural or manmade objects if it is to arrive at its intended destination.

The initial U.S. land-attack cruise missiles relied on INS and a terrain contour matching (TERCOM) guidance system to navigate to the target area. TERCOM uses digitized terrain-information maps that are stored in the missile's memory banks. The cruise missile uses radar to scan the terrain it is passing over; it then compares the contour elevation information obtained to that stored in its memory. The guidance system requires

sophisticated programming. However, the United Kingdom has developed a similar system called TERPROM.⁵ Russia, China, and a number of other countries have or are developing their own terrain matching systems.

TERCOM/TERPROM navigation systems are very work intensive in that they require that the regions where the missile will be used be mapped by radar or that high-quality maps be manually transformed into digital elevation readings and the resulting data used to create a digital map. The commercialization of space is making radar map data more accessible for purchase on the open market thus reducing a major obstacle to the development of a terrain-following navigation system.

The advent of the global positioning satellite (GPS) and its Russian counterpart, *GLONASS*, allows cruise missile designers to navigate using commercial aircraft INS with integrated GPS/*GLONASS* update capability. Both China and Europe have expressed intent to establish similar satellite navigation capabilities in the future to ensure that they are not dependent on the United States for navigation data. Although the use of satellite navigation requires detailed information about the terrain along the missile's flight path, it is a much less demanding challenge to use GPS/*GLONASS* than a TERCOM navigation system. Consequently, satellite navigation provides a means for developing states to become cruise missile powers.

Cruise missile developers could also incorporate a navigation system that uses a camera. If a video camera is mounted in the nose of the missile and used to fly the system by remote control via a television data link, the missile could be steered to a specific target by a human operator. This guidance system also allows the user to record reconnaissance information gathered along the flight path,

5 Jane's Strategic Weapon Systems, Issue 32, "France: Apache (Storm Shadow)," p. 69.

to take evasive action in the event the missile is engaged by air defenses and to loiter in the target area and await the optimal time to strike. These types of sensors and navigation systems require communication relays if the flight path is long or the terrain is such that the missile's data-link antenna could be masked, interrupting the data flow. To the dismay of many engineers, maintaining the data link for systems that operate over fairly long distances has proven difficult. It can also prove challenging integrating an acceptable antenna system into the missile's airframe. Consequently, video navigation technology on medium or long-range cruise missiles seems likely to proliferate more slowly than some of the other navigation systems.

It should be noted that a number of reports of cruise missiles now in development in the major states indicate that many of them will incorporate three guidance systems: INS, GPS, and terrain matching. This amount of navigation redundancy will make it difficult to defeat these missiles using jamming or signal denial tactics.

In the case of less advanced states contemplating converting anti-ship cruise missiles to land attack systems, the key component that must be replaced is the guidance system. For example, putting a GPS receiver in the airframe only provides coordinates of the missiles current location. Therefore, a modification of this type would also require that a system be added to the missile that could calculate the flight path that must be flown and interface with the existing flight control system to correct the direction and altitude of the missile. While this is not an impossible task, it does require some skill.

The payload. A wide variety of munitions can be carried on cruise missiles to include weapons of mass destruction (nuclear, biological, and chemical) as well as a variety of conventional options. Unlike ballistic mis-

siles, the accuracy of cruise missiles makes them cost effective when used to deliver conventional warheads. Most cruise missiles in service today have relatively small warheads designed for anti-ship targets while land-attack systems generally carry larger payloads. The known conventional payloads currently carried by various cruise missile systems in support of land-attack missions include high-explosive fragmentation, submunitions, runway cratering munitions, and carbon filament warheads for neutralization of electrical power grids. There are also unconfirmed reports that some countries may be developing or already have radio-frequency warheads designed to overload and fry electronic circuits.

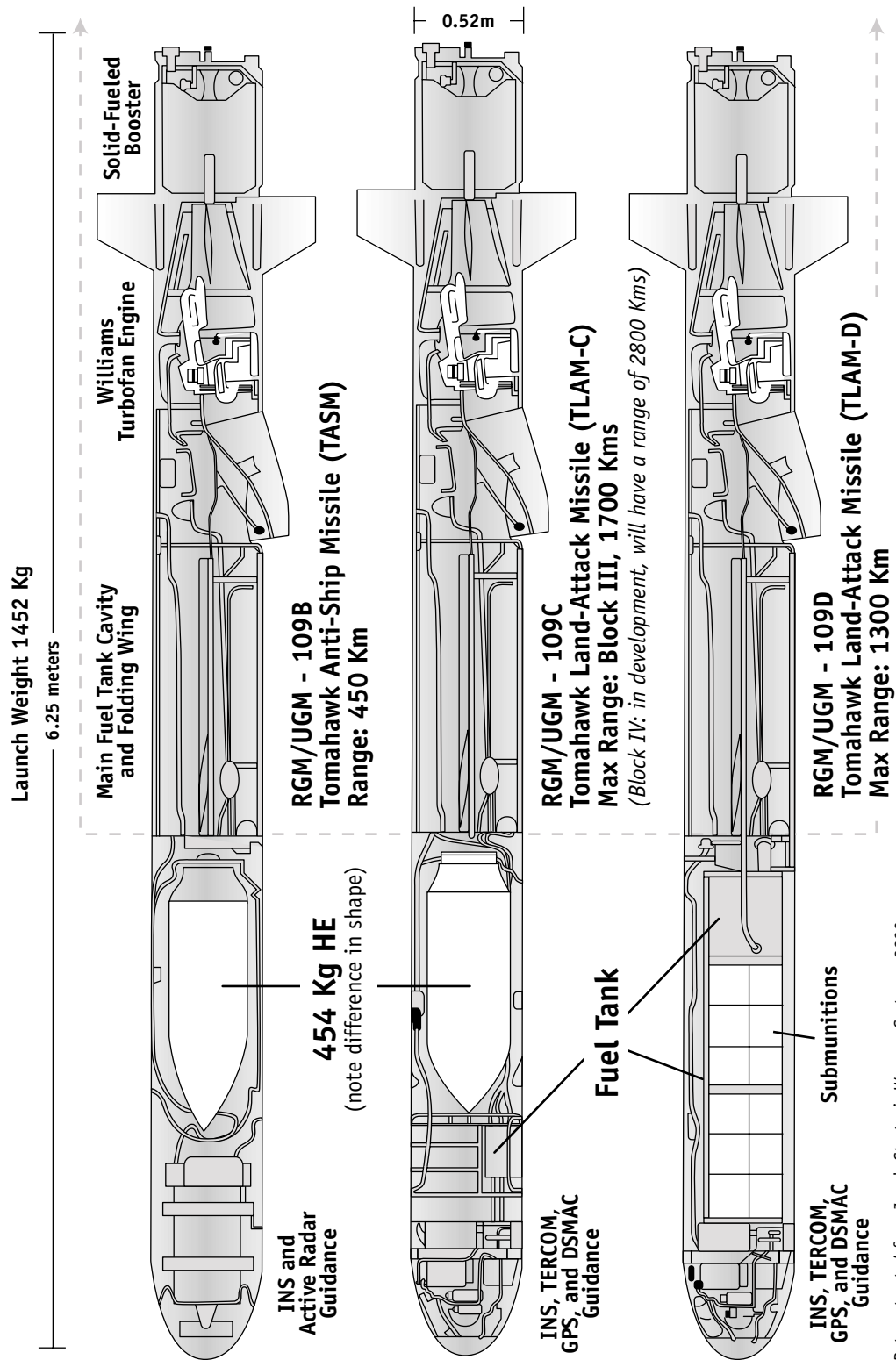
Since the payload mass of these various munitions can differ, missile engineers must modify the airframe's design, shift the internal placement of its components, or adjust fuel or payload weight to handle the various payload options. As noted in the discussion on airframes, the components must be positioned so that when coupled with the aerodynamic characteristics of the missile, the airframe remains stable during its flight.

Modifying Existing Anti-Ship Cruise Missiles

The degree of modification required to convert an anti-ship cruise missile into a land-attack system is dependent on the original design of the system in question. If the designer envisioned that the missile might someday be converted into a land-attack system or had built the missile as part of a family of missiles, the missile could have been designed to accommodate future modification requirements. Although modern cruise missiles often are designed to accommodate future modification, older anti-ship cruise missiles were built as specialized one-mission systems. Consequently, the degree of difficul-

U.S. TOMAHAWK CRUISE MISSILE - 3 VERSIONS

Figure 3



Data extracted from Jane's Strategic Weapon Systems, 2000

ty that might be encountered converting these systems to perform a land-attack role will vary from missile to missile.

Figure 3 shows the line drawings of three different models of U.S. *Tomahawk* cruise missiles. All three models are packaged in the same airframe dimensions, have the same weight, and use the same engine and wing section configuration for the rear two-thirds of the missile. Although the *Tomahawk* was designed for production in several variants and thus is more easily modified than are older systems, it still lends itself as a convenient model for discussing modification challenges.

In figure 3, one can see that the TASM-B (top drawing) incorporates a radar (heavy in weight) in the guidance section and that the missile has a shorter range than the TLAM-C (middle drawing) due to less fuel capacity. Both models carry the same size payload. Consequently, the primary tasks involved in converting the TASM-B into a TLAM-C are to change out the guidance system and add more fuel carrying capacity to the forward section. The *Tomahawk* maintains a balanced center of gravity over the wings by managing fuel draw down in the various fuel tanks. Consequently, converting this type of cruise missile into a land-attack system is not very difficult.

On the other hand, if the airframe required modification to accommodate a larger fuel supply or payload, or if the engine had to be changed out to obtain one that was more fuel efficient (increasing the missile's range), one can easily see that such a conversion could become very complex. Many anti-ship cruise missiles would require too much work to make it cost effective to convert them to land-attack systems. It would be more effective to obtain the needed components and assemble new systems in country.

It is the issue of feasibility and cost effectiveness that drives the debate among cruise missile analysts. Yes, old anti-ship cruise mis-

siles could be converted to land-attack systems. However, if only the guidance system were changed, the capabilities of these systems would be very limited. Yet, if many of the other components were changed, the work effort and expense would climb rapidly. It may be more cost effective to build new, more capable systems. The disagreement pivots on how each group assesses this question.