based on the burn times for existing US and Russian solid-propellant ICBMs, that solid-propellant ICBMs have a nominal burn time of 180 s; the APS study assumed a 170-s burn time based on US solid-propellant submarine-launched ballistic missile technology. Also, airborne missiles can accelerate faster; hence, they can have higher average flight speeds compared to surface-based interceptors (on which the APS study focused) because the drag force is lower at high altitudes.

Nevertheless, solid-propellant ICBMs are very difficult targets. Successful intercept will require sensor architectures that push the limits of target detection and tracking, and large (1500 kg), high-speed (6.0 km/s ideal velocity) two-stage airborne interceptors carrying lightweight KKVs. While 50-kg KKVs stretch the limits of what currently is possible, solid-propellant ICBMs stretch current offensive threat possibilities. Neither may be far-fetched 10 years from now.

ABIs do have drawbacks. However, none of them are so severe as to eliminate ABIs from consideration as a viable component of a future US missile defense architecture. In fact, airborne intercept is probably the most attractive boost-phase missile defense option.

Preferences regarding boost-phase ballistic missile defense often have more to do with different threat assessments, operational and political issues, and cost than with technical disagreements. I see no serious technical barrier to an effective ABI system. Nevertheless, the decision to proceed with any form of ballistic missile defense, ABIs included, should be based on an assessment of the system's priority relative to such other important US security concerns as countering terrorism and modernizing conventional forces. From this perspective, the US currently is spending too much on ballistic missile defense.

References

1. D. K. Barton et al., *Report of the APS Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues*, July 2003; available at http://www.aps.org/public_affairs/popa/reports/nmd03.cfm.
2. See D. A. Wilkening, *Science and Global Security*, (in press).

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Authors Kleppner, Lamb, and Mosher report on an excellent APS study that provides a wealth of data and analysis. Especially new are the array of possible maneuvers during the boost phase of intercontinental ballistic missiles (ICBMs) and the problems those maneuvers pose for a boost-phase intercept (BPI) system. My judgment from the report itself of the utility of BPI against North Korean ICBMs, however, is more positive than are the executive summary and press reports of the APS study.

For instance, according to an earlier PHYSICS TODAY story (September 2003, page 26), "Boost-phase missile defense . . . is virtually impossible in all but a few limited circumstances." But among those few is the most likely circumstance for ICBM attack: a liquid-fueled ICBM launched from North Korea against the continental US. I have long proposed using 14-ton interceptors based on ships or land near North Korea to defend against such an attack.[1] And I assumed the boost phase of such an ICBM to be 250 seconds, little different from the 240 s assumed by the APS study, and not the "300 s or more, as some earlier studies had [assumed]," as stated in the January 2004 PHYSICS TODAY article. The study's first conclusion, that the "interceptor rockets would have to be substantially faster (and therefore necessarily larger) than those usually proposed," refers to some people who have advocated much smaller interceptors than my 14-ton proposal.

If the US Department of Defense decided to deploy within four years a system using large surface-based interceptors against North Korean ICBMs, the US could likely expect at least several years of protection.

Necessary? Maybe not. Feasible? Yes. And that is not the end of the line for boost-phase intercept. Simple geometry shows that airborne radar at altitudes typical of modern airline jets (12 km) will see to the ground at a range of 400 km, adding important tens of seconds to the time available for intercept by a ground- or sea-based BPI system.

Reference

1. R. L. Garwin, http://fas.org/rlg/991117.htm; http://fas.org/rlg/031208-boost.pdf.

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The authors of the *Report of the APS Study Group on Boost-Phase Intercept Systems for National Missile Defense* are to be commended on the most in-depth public examination of boost-phase missile defense to date. However, their study and the PHYSICS TODAY article based on it are marred by overstatement. I particularly address the analysis of ground-based interceptors.

The study's crucial calculation of the earliest possible time to launch an interceptor appears to be flawed. The study authors claim that the defender must wait until a fairly precise track on the offensive missile has been established before launching an interceptor—that wait is a major factor in the firing delay. In a sense, that claim is true: If a defender fires its interceptor too far away from the threat missile's actual track, the interceptor will be unable to correct course and destroy the threat missile.

The defender can compensate, however, by firing multiple interceptors, each in a direction predicated on a different potential threat-missile trajectory; that option was not considered in the study. Using only a few interceptors, the defender can bracket the range of possible offensive trajectories thoroughly enough that at least one interceptor will always be able to correct course and intercept the threat missile—assuming, of course, that the threat missile can be reached in time. Thus, the defender could possibly shave 15–20 seconds off the launch delay by firing when the enemy missile is detected, rather than waiting to establish its trajectory.

The second problem with the study's launch-delay calculations, as reported in the PHYSICS TODAY article, concerns the assessment of cloud cover. The article authors, Daniel Kleppner, Frederick Lamb, and David Mosher, "assumed that a modern system would first see a bright spot when a missile reaches [7 km]." They noted that even "state-of-the-art sensors would not detect a rocket until it has risen above any dense clouds. But at midlatitudes, dense clouds are relatively rare above 7 km." Of course, that only shows that detectors would likely see a rocket when or before it reached 7 km; a more careful analysis would have to show that 7 km is both the lower and the upper bound on detection altitude. The study does not contain such an analysis. Because the expectation of lower cloud cover would imply a shorter launch-delay time, it is essential to tighten the 7-km estimate before making such certain conclusions. Estimates should also be made on a more careful regional basis—a general mid-latitudes average might differ significantly from a specific estimate for Iran or North Korea.

Even if one were to accept the article authors' basic technical analysis, there is still reason to question how they translate it into judgments about North Korea and Iran. Consider the authors' first conclusion on North Korea: "Using terrestrial-based interceptor rockets to defend the 50 states against liquid-propellant ICBMs [intercontinental ballistic missiles] launched from North Korea may be feasible, but that would push the limits of what is possible physically, technically, and operationally." Presumably, that statement refers to the 10-km/s I-5 interceptor, since only that interceptor is characterized in the article as "a surface-based interceptor with a performance at the limit of what might be practical." Yet the study refutes their conclusion—twice! In its executive summary, the study states that defending against North Korea "would require interceptors with speeds of 6.5 km/s"—those would be the less capable I-4, not the envelope-pushing I-5. And further on, in the detailed discussion of North Korea, the study says "To defend [the US], the 5-km/s interceptor would have to be fired with zero decision time." That the study authors offer no technical reason to reject the zero-decision-time option presumably implies that even the rudimentary 5-km/s I-2 interceptor could do the job.

The article authors assert, "Taking all relevant factors into account, . . . we reached the conclusion that defending the 50 states against solid-propellant ICBMs, from either North Korea or Iran, would not be feasible." But again, the study refutes this claim. Regarding North Korea, a statement on page 124 says, "Even the 6.5-km/s interceptor could be used to defend" the US. And farther down that same page, "The giant 10-km/s interceptor . . . could be used with about 30 s of decision time." Neither statement agrees with the article's conclusion that no defense is feasible.

The article's pessimism with respect to solid-propellant ICBMs isn't justified for Iran, either. According to the APS study, "It appears that by basing a 10-km/s interceptor in the Caspian Sea and a second one in Afghanistan or Turkmenistan, all 50 states could be defended" (page 94) against missiles launched from central Iran. However, the study further states, "If the launching site for solid-propellant missiles destined for [Washington, DC] . . . were moved about 200 km to the southeast, this defense would be precluded." That statement is transparently incorrect. If one extrapolates from the study's figure 5.17, the base in western Afghanistan would clearly be able to intercept effectively. Thus, the study should not be read as implying that defense against Iran is impossible.

These are technical, rather than political, reasons to question the study's overall pessimism. Still, because the study contains some optimistic assumptions that might yet be tightened, even a revised version would not necessarily conclude that boost-phase defense is possible. These persistent ambiguities warrant further study.

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The article about the APS study on boost-phase missile defense gave considerable information on the physical challenges of such defense. However, many more questions need to be asked and answered.

It may technically be possible to build a system to stop one missile, but how about 5, 10, or more? Where will those missiles be coming from? Who is going to have such missiles in quantity?

Can anyone guarantee that *all* incoming missiles will be stopped? What will such a total system cost? Are the potential lives and property saved worth that cost?

This and other space-based projects, many of which later turn out to be boondoggles, are supported by NASA, the military, and industries looking to generate job protection and company profits for years to come. The proposed manned trip to Mars, the permanent base on the Moon, the orbiting space lab now under construction, robots exploring the Mars surface, are or will be a waste of money. If water existed on Mars millions of years ago, what relevance has that to us on Earth today, or even in the distant future?

I think the excessive costs of space projects versus their minimal value gained needs a very careful reevaluation. I believe that very little has been gained from research in space; most of the benefits have been from research on the ground *for* the space program. Exceptions include satellites for weather, communication, Earth mapping, astronomy, and military information.

Congress will not stop spending on wasteful projects. The members get too much election campaign money from lobbyists. Citizens with some technical knowledge and common sense need to get together and demand a change in the funding of these projects, with members of the physics community taking a lead role. There are far better places than space to spend money for research, development, and education.

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Kleppner, Lamb, and Mosher reply: The APS study concluded that a boost-phase defense using airborne interceptors (ABIs) incorporating technology that would be available within the 10-year period considered could be useful in limited circumstances. Dean Wilkening's analysis agrees with the study's in most respects, but his assessment of the utility of ABIs is more positive.

One reason the assessments differ is that Wilkening assumes an airborne X-band radar system will be available. No such system yet exists. The study judged that the time required to field such a system would be greater than the 10-year period considered. A second reason is that his interceptor has a higher acceleration than the study's comparable interceptor I-2 and has a 20-second burn time compared to the 40-s burn time of I-2. Because Wilkening's interceptor has a higher average velocity, it can reach a greater distance, but there are penalties for such a high acceleration. Wilkening's analysis appears to neglect one of these: The interceptor's final stage (kill vehicle) must have more velocity change ("divert") capability because it is released after only 20 s, when it has less information about the intercontinental ballistic missile's flight and must maneuver for a longer time. Wilkening's kill vehicle has a total divert capability of 2 km/s, which is what the study estimated would be required for a kill vehicle released after 40 s. Additional divert capability increases the mass of the kill vehicle and its boosters and reduces the final speed of the intercep-