

# Achilles' Heel

## *Adding Resilience to NATO's Fragile Missile Shield*

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### THE ISSUE

- Missile defense is a major part of the U.S./NATO strategy to counter Iranian aggression and limit damage in the event of conflict.
- The missile defense architecture currently protecting NATO from Iranian missile attack is fragile due to its heavy reliance on a single ground-based radar to track missiles headed towards Europe. This single point of failure makes the entire system susceptible to technical malfunction or concerted enemy action.
- A more diverse and modernized set of sensors would improve reliability and resilience against an Iranian ballistic missile attack.

Tensions with Iran are once again increasing. The slow implosion of the nuclear accord, Iran's harassment of cargo ships, and the downing of a U.S. unmanned aircraft have made plain the risk of conflict between Iran and the United States. The dispute should also draw attention to the questionable preparedness of the United States and its allies to fight a war with Iran on short notice and deal with that war's blowback across the Middle East and Europe. Regional missile defense architectures are an important part of that preparedness. Iran has the largest and most diverse supply of ballistic missiles in the Middle East region, and Tehran has shown an ability and willingness to use them in combat operations.<sup>1</sup> Iran is also learning to employ other kinds of aerial threats, such as long-range cruise missiles and unmanned aerial vehicles (UAVs). In a conflict with Iran, U.S. and allied forces would likely face a wide spectrum of air and missile threats.

The biggest U.S. investment in Iran-centric missile defenses has been the European Phased Adaptive Approach (EPAA). EPAA is a phased buildup of U.S. missile defense assets in and around Europe to deter and, if necessary, limit damage from an Iranian missile attack on the North Atlantic Treaty Organization (NATO). Yet the EPAA architecture is heavily dependent on the nominal, unencumbered performance of a single radar deployed relatively close to Iran. This produces a single point of failure susceptible to malfunction or operator error. It also presents an Achilles' heel that a determined or imaginative adversary could exploit. Iran certainly fits both descriptors.

In 1958, strategist Albert Wohlstetter wrote that U.S. confidence in its nuclear second-strike ability was achieved only by "ignoring the full range of sensible enemy plans."<sup>2</sup> This same critical judgment should be applied to confidence in the EPAA as currently configured. Inasmuch as a sensible adversary such as Iran relies upon its missile forces to achieve its defense goals, it should be credited with the foresight to

target single points of failure that would preclude the effective application of that missile force. Fortunately, there are practical steps that NATO and the United States can take to further adapt EPAA for greater resiliency. Upgrades to existing radars, the integration of allied radars into the missile defense mission, and the addition of air and space-based sensors would do much to improve EPAA's capability and survivability, improving U.S. and NATO preparedness for an unexpected Middle East conflict.

## THE EPAA ARCHITECTURE

As the centerpiece effort of President Obama's 2010 Ballistic Missile Defense Review (BMDR), the EPAA has consisted of a three-phase deployment of Aegis ballistic missile defense assets to Europe.<sup>3</sup> In Phase 1, the United States permanently deployed four BMD-capable Arleigh Burke-class guided missile destroyers to Rota, Spain, for operations in the Mediterranean, including BMD patrols.

In Phase 2, the United States constructed a land-based variant of the Aegis BMD system called Aegis Ashore in Deveselu, Romania. The Deveselu Aegis Ashore site in Romania contains a deckhouse with all relevant command and control infrastructure and a SPY-1 radar. This structure is hardwired to three 8-cell Mk 41 Vertical Launching System (VLS) modules, holding up to 24 Standard Missile-3 (SM-3) interceptors. NATO declared the site operational in 2016.<sup>4</sup>

Phase 3, which is currently under construction, consists of an identical Aegis Ashore site further north in Redzikowa, Poland. MDA has delayed the completion of the site until 2020, citing military construction complications.<sup>5</sup> The United States also plans to eventually arm both the Romania and Poland sites with the new and faster SM-3 Block IIA interceptor, which will increase the systems' defended coverage area.

One especially critical element of the EPAA is a TPY-2 X-band radar deployed in eastern Turkey. This radar is oriented to track Iranian missiles bound for Europe. It is indeed the keystone of the whole architecture. Without it, the capability of the Aegis Ashore sites to defend Europe becomes crucially degraded.

The purpose of EPAA has been to counter a ballistic missile threat to NATO from the Middle East, such as Iran. The



*Aegis Ashore facility in Deveselu, Romania*

Source: U.S. Navy Photo by Mass Communication Specialist 1st Class Sean Spratt/Released

Trump administration's 2019 Missile Defense Review (MDR) reiterated this mission, saying the system "provides continuous defense of European NATO territory against Middle East missile threats."<sup>6</sup> The NATO alliance has also endorsed this focus, stating that its BMD architecture is only designed to defend NATO European territory from limited ballistic missile attacks originating from "outside the Euro-Atlantic area."<sup>7</sup>

## ENGAGE ON REMOTE

The success of Aegis Ashore in protecting NATO territory rests upon a particular type of missile defense tactic called "engage on remote" (EOR). In EOR, the BMD shooter does not require its own co-located "organic" radar to get fire control data for its interceptors, as is the case with a "standard" engagement (Figure 1). Rather, it gets its target information from a different sensor that is often closer to the enemy missile's launch point (Figure 2). In the EPAA, this remote sensor is the TPY-2 radar in Turkey. Due to its position, it would be very difficult for a Europe-bound ballistic missile fired from Iran to avoid the TPY-2's field of view.

A TPY-2 is a very high-resolution sensor, producing data that the command and control systems can use to determine the type, speed, course, and possible destination of the threat missile. This data is relayed to the Aegis Ashore sites, which use it to determine a predicted intercept point. The predicted intercept point is the spot in space along the threat's trajectory where an interceptor will meet and destroy it. After the Aegis Ashore site fires its interceptors, it continues to send information updates about the target to the interceptors using its SPY-1 radar.

Figure 1: Standard Engagement

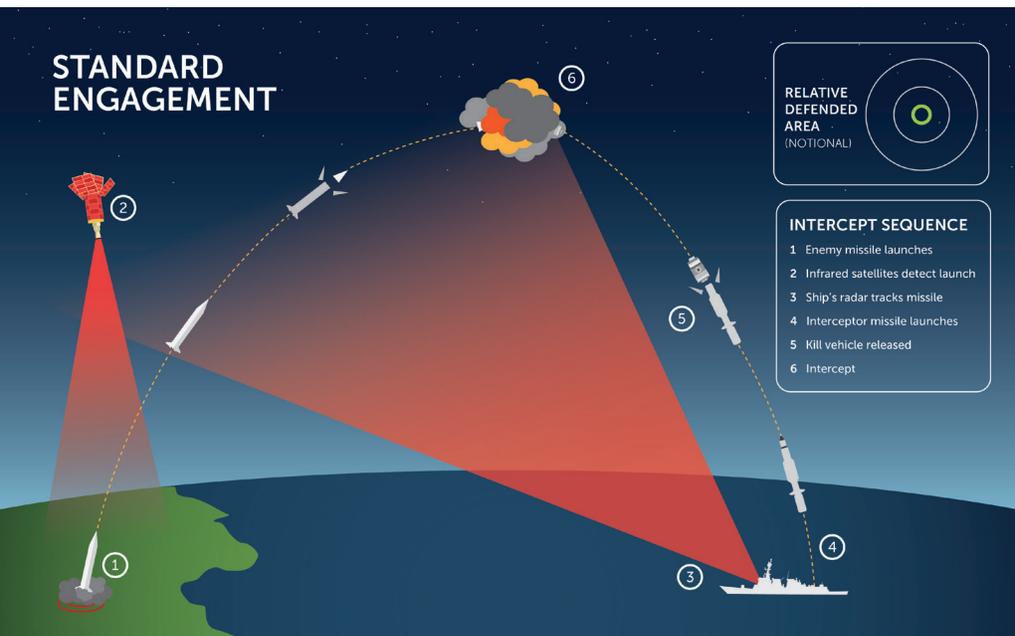
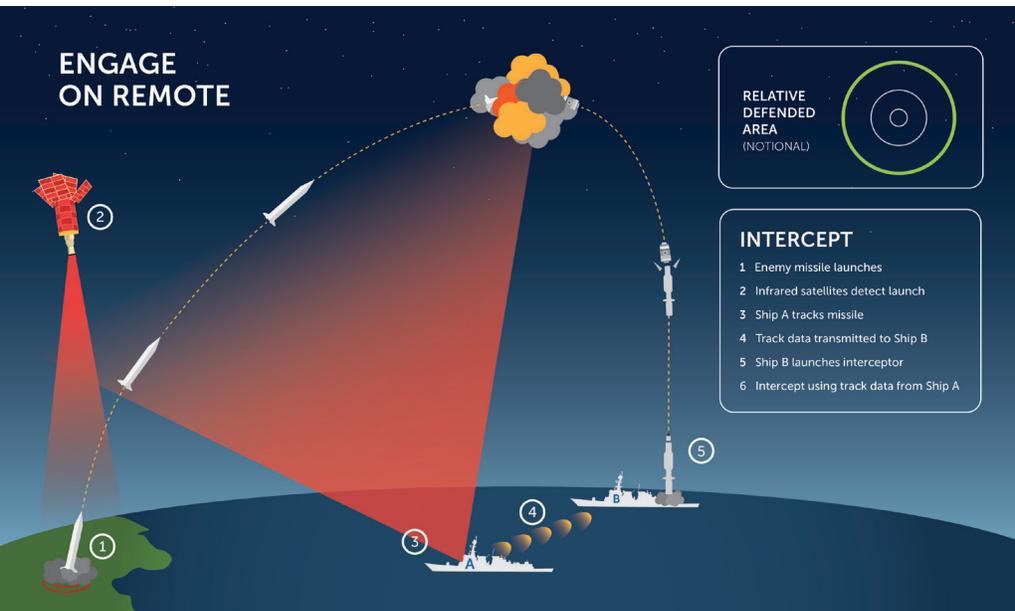


Figure 2: Engage on Remote



EOR is desirable because it enables a vastly greater defended area. It allows a shooter to launch an interceptor much earlier than if it had to wait for its own collocated radar to pick up the target. The sooner you launch, the earlier in an enemy missile's flight you can intercept it. The earlier you intercept, the more turf you can protect. Figure 3A and 3B depict the estimated defended area of both Aegis Ashore sites when integrated with the forward TPY-2, using a notional 3.0 and 4.0 km/sec interceptor, respectively.

## SINGLE POINT OF FAILURE

If the forward TPY-2 radar failed to provide early tracking information for any reason, the defended area of the two Aegis Ashore sites would degrade significantly. Many military bases and major cities across Europe would become undefended. The SPY-1 radars installed at the Aegis Ashore sites are simply too limited in range to enable defensive coverage of Europe on their own. In some cases, the SPY-1s would detect Iranian ballistic missiles too late for the system to engage the target missile. Longer-range, higher-flying missiles headed for western Europe could overfly these radars altogether. Therefore, nominal operation of the forward deployed TPY-2 is essential for the Aegis Ashore sites to fulfill their mission of NATO territorial coverage. Absent the data provided by the Turkey TPY-2, the defended footprints of both Aegis Ashore sites shrink dramatically (Figures 2A and 2B). Prior studies and modeling of EPAA have presented similar findings as well.<sup>8</sup>

There are abundant ways that any one element of a missile defense architecture can fail. A 2012 National Academy of Sciences report pointed out that a "radar outage is a likely source of single-point failure in a missile defense system."<sup>9</sup> The EPAA's TPY-2 in Turkey represents just such a point of failure. The radar in Turkey could, for example, succumb to aerial attack. Iran has demonstrated some aptitude for more complex integrated attack, aiding Houthi fighters in Yemen with targeting Saudi Patriot radars with UAVs.<sup>10</sup> The Iranians have also shown some ability to use UAVs and ballistic missiles in concert and other kinds of combined arms operations.<sup>11</sup> The TPY-2 radar in Turkey is around 560 km (350 mi) from the Iranian border and just over 160 km (100 mi) from Syria. It is unclear if the site has any kind of lower tier air defense.

Figure 3A: Composite Notional Defended Area Footprint of Deveselu and Redzikowo – 3.0 km/sec Interceptor – EOR

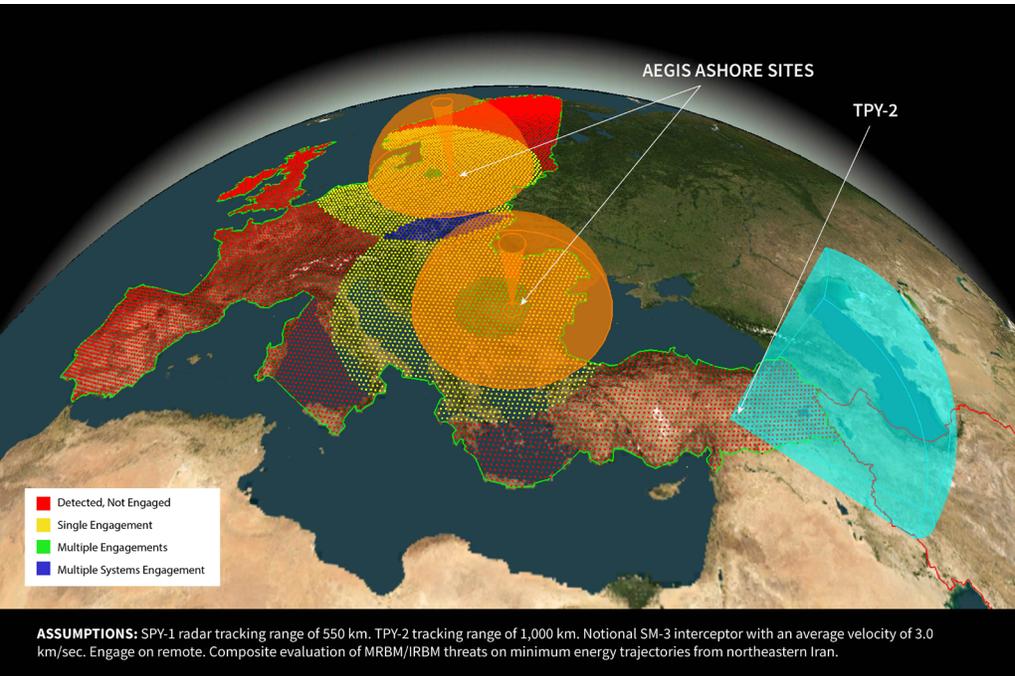
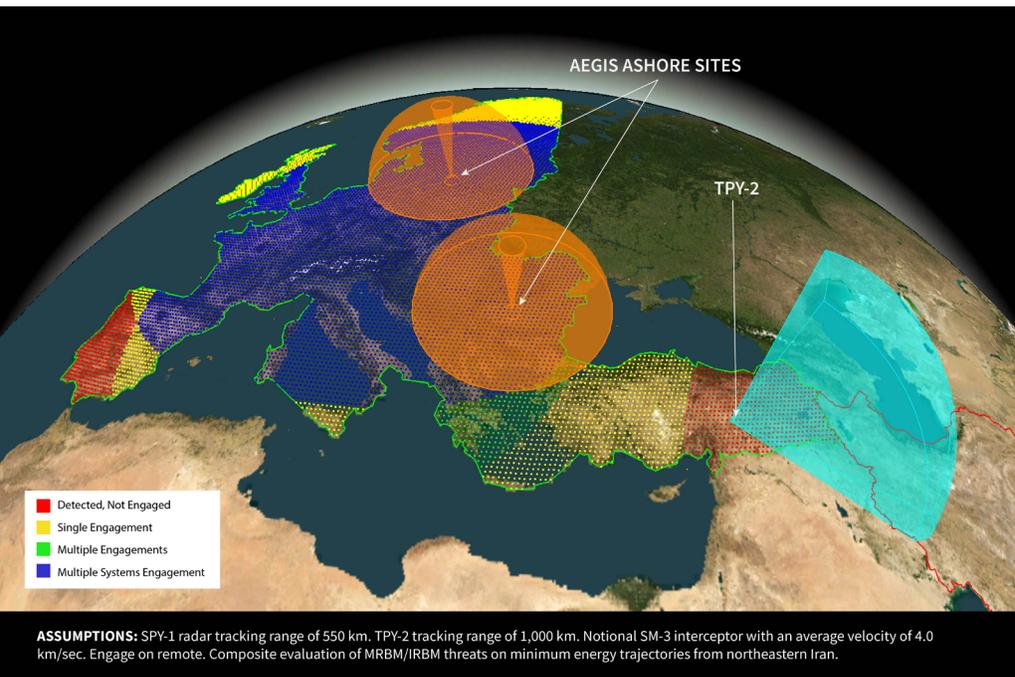


Figure 3B: National Defended Area Footprint of Deveselu and Redzikowo – 4.0 km/sec Interceptor – EOR



Beyond enemy activity, the radar could simply suffer a technical malfunction or operator error. There are also political pressures that could jeopardize the continued presence of the radar in Turkey, as most recently evidenced by the NATO-Turkey dispute over Turkey’s purchase of the

its trajectory, it seems sensible that Iran would pursue that capability.

Given these challenges, achieving an effective defense of NATO will likely require a more layered and resilient sensor network than the current EPAA plan articulates.

S-400 and its subsequent expulsion from the F-35 program. Even with nominal performance, overreliance on a single, sectored radar limits the architecture’s flexibility, as it is only effective against threats emanating from a single general direction. The system could also be vulnerable to maneuvering ballistic missiles. The TPY-2 can only track an Iranian missile for a small portion of its flight. After the missile overflies the radar’s field of view, Aegis predicts where the missile will be by its trajectory. Interceptors are guided to a predetermined intercept point along that predicted path. This is a manageable challenge against a traditional ballistic missile since ballistic trajectories are by their nature predictable. Some more advanced missiles, however, can execute maneuvers during flight. Should an Iranian ballistic missile perform midcourse maneuvers after it overflies the TPY-2, the SM-3’s fire to intercept could very well miss.<sup>12</sup> Intercepting maneuvering threats requires more than an extrapolation from an early TPY-2 track. It requires continued observation to determine if it changes course.

It is unclear whether Iran currently possesses maneuvering ballistic missiles. Iran’s Emad missile, for example, is a version of its Shahab-3 medium-range ballistic missile (MRBM) which Iran claims is equipped with a terminal maneuvering reentry vehicle. While terminal maneuvers would most likely not affect an SM-3 intercept in midcourse, the Emad is also, according to analysts in the U.S. intelligence community, powered throughout its entire flight. While it is unclear whether the missile can execute midcourse maneuvers enough to change

Figure 4A: Notional Defended Area of Redzikowo and Deveselu – 3.0 km/sec Interceptor – Organic Tracking Only

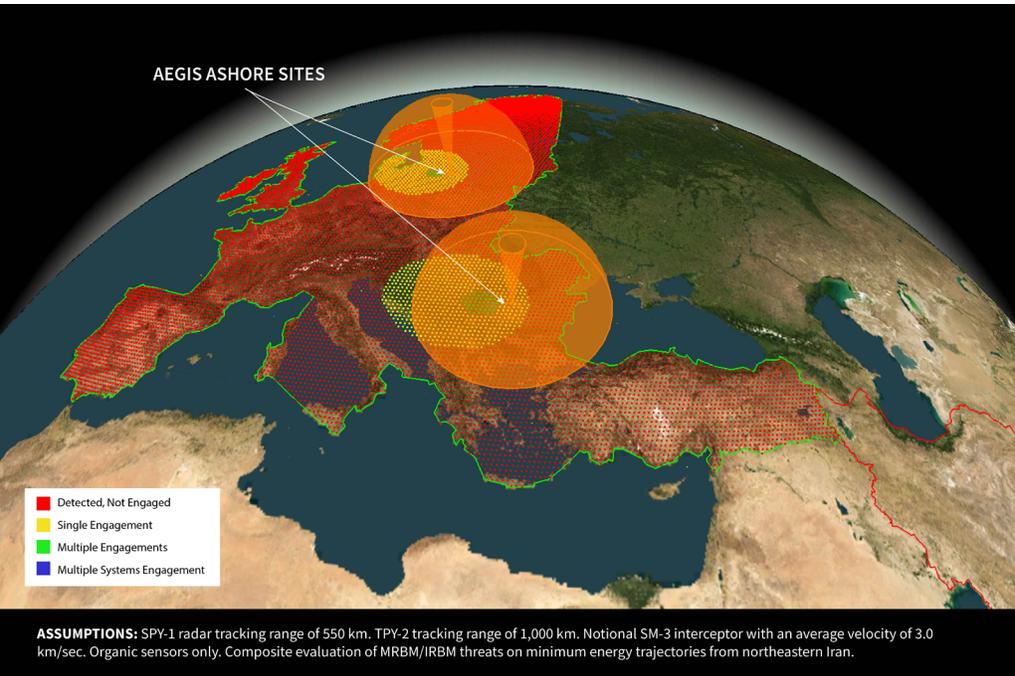
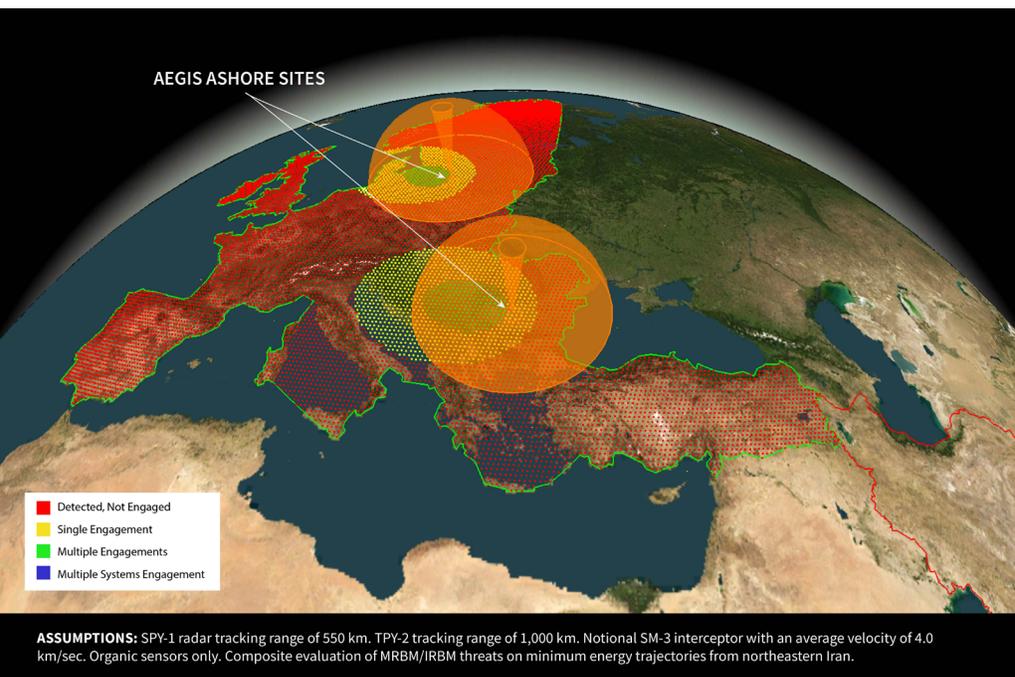


Figure 4B: Notional Defended Area of Redzikowo and Deveselu – 4.0 km/sec Interceptor – Organic Tracking Only



## SHORING UP THE EPAA

The fragility and inflexibility of the EPAA’s sensor network were not caused by a lack of foresight by its original planners. Rather, it stems from a failure to fully implement all the elements of EPAA as originally planned. When first

announced, the EPAA included two additional sensor systems that would have provided other means to track ballistic missiles threatening NATO. One of these systems was the 12-satellite Precision Tracking and Surveillance System (PTSS) constellation for space-based tracking.<sup>13</sup> The U.S. government canceled PTSS in 2013, citing budgetary pressures brought on by sequestration.<sup>14</sup> Another sensor system articulated as part of the EPAA was the Airborne Infrared (ABIR) program, which sought to deploy sensors onboard high-altitude UAVs. The ABIR program was defunded in the FY 2013 defense budget.<sup>15</sup> Research and development on airborne sensors has, however, continued under other auspices. The Missile Defense Agency has included airborne sensors in Aegis intercept tests, although the actual operational status of these platforms is unclear.<sup>16</sup>

A space-based or air-based sensor layer would do much to alleviate the weaknesses outlined above. A space-based layer would, in theory, be able to track a missile throughout most or all of its entire flight. It would also be more difficult for Iran to attack compared to forward-based radars. An air-based tracking system would be the next best thing, providing tracking capability over a much larger area than a sectored, ground-based radar could. Either system would add redundancy but also flexibility, as they could also provide EOR cuing for missiles from unexpected directions that do not happen to pass through the TPY-2’s field of view.

Actualizing a space-based sensor layer has proved elusive. Indeed, every presidential administration since Ronald Reagan has included a space-based sensor layer for long range missile

defense—yet none have ever become operational. Despite the 2019 MDR’s endorsement of space sensors that would break the logjam, the subsequent defense budget has thus far failed to adequately fund the effort.<sup>17</sup>

Figure 5A: Notional Defended Area of Redzikowo and Deveselu with 1,000 km Radar – 3.0 km/sec Interceptor – Organic Tracking Only

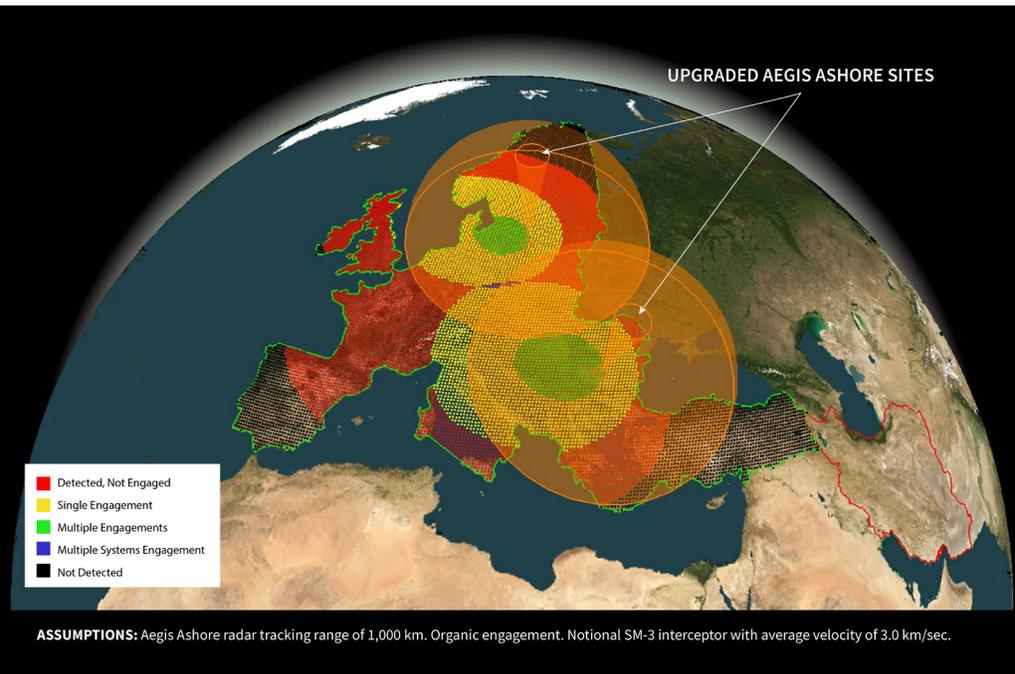
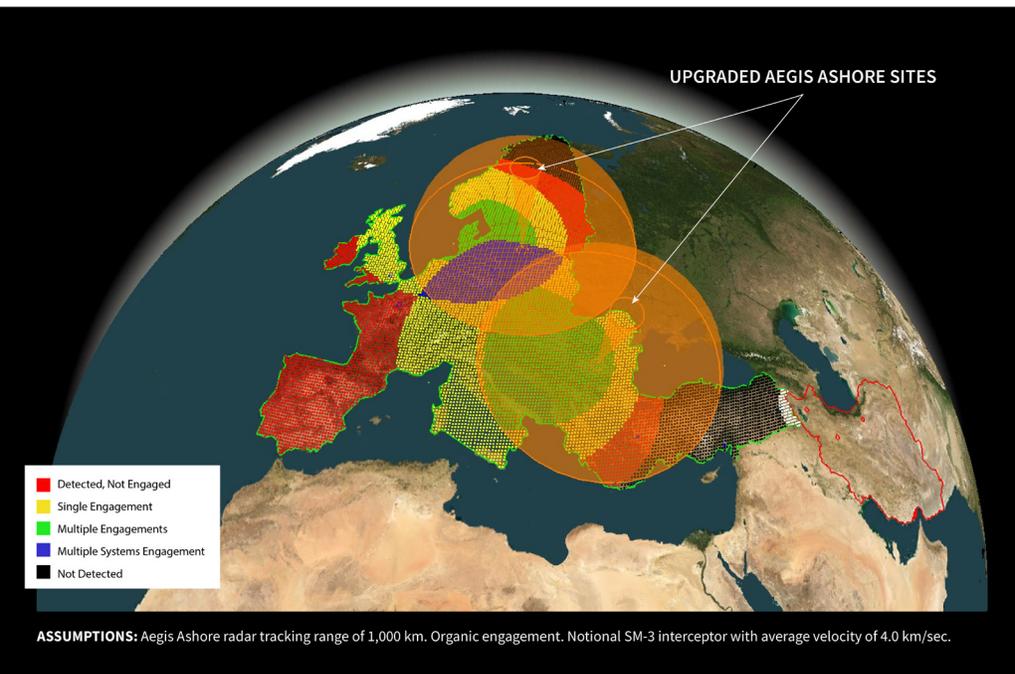


Figure 5B: Notional Defended Area of Redzikowo and Deveselu with 1,000 km Radar – 4.0 km/sec Interceptor – Organic Tracking Only



In the nearer term, there are several options that could improve the sensor architecture supporting the EPAA. One course of action would be to upgrade the Aegis Ashore sites with more advanced and longer-range radars. SPY-1 radars, although much evolved, are still based on 1980s hardware. Integrating newer technologies, such as solid-state radars that use gallium nitride, could improve range and sensitivity

at lower power levels. Next generation digital radars capable of operating in different bandwidths may offer further capability. Installing more powerful radars at these sites could enable them to still provide significant territorial coverage even in the event of EOR failure (See Figures 6A and 6B). It could also improve midcourse discrimination and counter maneuvering reentry vehicles.

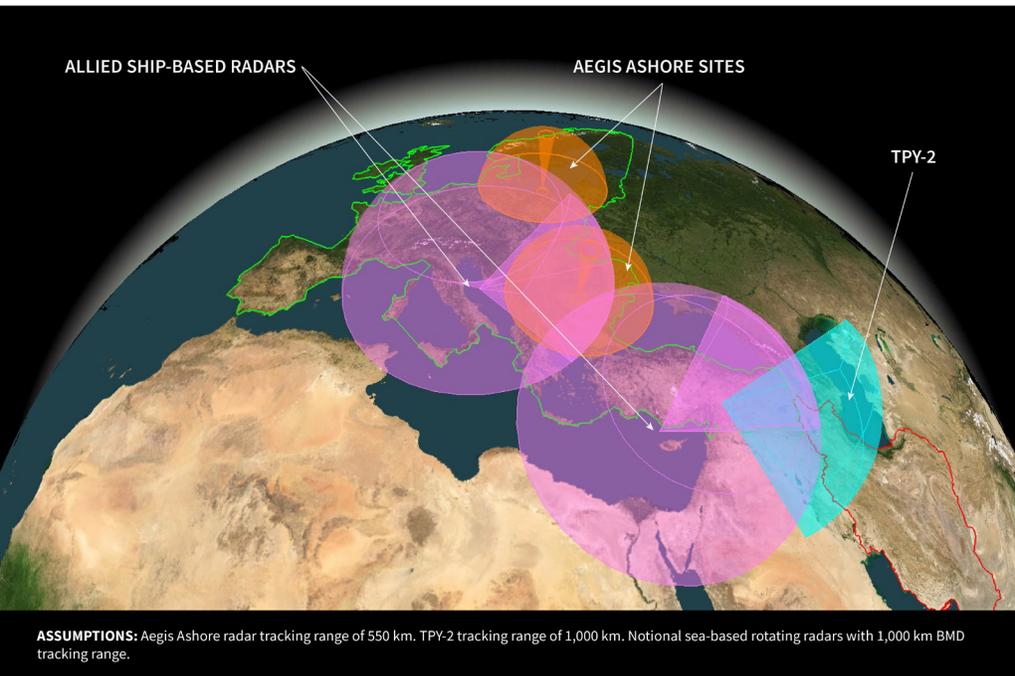
Another option could be the construction of additional ground-based radars around the Mediterranean for persistent, redundant sensor coverage.

Also, beneficial would be to integrate the sensors onboard other NATO air defense ships to support Aegis Ashore. Denmark, Germany, and the Netherlands together have 10 ships with radars that could be modified for long-range BMD tracking.<sup>18</sup> Some of this modification has already begun. In 2012, the Netherlands began enhancing its four De Zeven Provinciën-class air defense frigates for BMD surveillance.<sup>19</sup> The first of these ships received this radar upgrade in March 2019. Some sources suggest that this upgrade increases the ships' radar detection and tracking range to between 1,000-2,000 km.<sup>20</sup> Denmark has also expressed its desire to modify its Iver Huitfeldt-class frigate to contribute to NATO missile defense. To be certain, integrating these systems may not provide a direct replacement to the high-resolution imagery or geographic advantages provided by the X-band TPY-2's, but it could nevertheless add redundancy and could help shore up gaps in EPAA's active tracking (Figure 6).

## CONCLUSION

As Wohlstetter warned 50 years ago, an opponent is not likely to pursue strategies and tactics that suit our strengths. They are going to seek out and attack our vulnerabilities. The current EPAA's sensor architecture may prove such a liability, lacking adequate resilience to overcome either technical malfunction or concerted enemy action.

Figure 6: Notional Fields of View of Two Allied Ships



Improvements to the sensor architecture would help insulate the system from disruption and make it more adaptable to complex and integrated attack. Radar upgrades and the integration of additional sensors could help alleviate some of these issues. Replacing the SPY-1 radars at Deveselu and Redzikowo with larger, more advanced radars would further improve capability and somewhat reduce reliance on the TPY-2 in Turkey. A more robust sensor architecture for birth to death tracking would both improve capability and allow the more graceful degradation of NATO missile defense capability should EOR fail. In the longer term, following through on elevated sensors would not only benefit EPAA in powerful ways, but would also enhance missile defenses globally. ■

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## METHODOLOGY

Figures 1-5 were produced using SMARTset, a modeling and simulations tool for air and missile defense analysis. All system performance parameters are derived from open source estimates.

The assumed interceptor parameters used here are notional only and do not represent any particular SM-3 variant. The precise burnout velocities of SM-3s are classified; most open source studies of Standard Missile 3 present speeds of between 3.0-4.5 km/sec. See for example: Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, Division on Engineering and Physical Science, National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other*

*Alternatives* (Washington, DC: National Academies Press, 2012); The assumption of a 550 tracking range for SPY-1 is drawn from estimates by George Lewis and Theodore Postol, “Ballistic Missile Defense: Estimating the Range of an Aegis Radar against a Missile Warhead Target,” *mostlymissiledefense* (blog), October 23, 2012, <https://mostlymissiledefense.com/2012/10/23/438/>.

The assumed 1,000 km tracking range is drawn from Michael Elleman and Michael J. Zagurek, Jr., *THAAD: What It Can and Can't Do* (Washington, D.C.: 38 North, 2016), 2, [https://www.38north.org/wp-content/uploads/pdf/2016-03-10\\_THAAD-What-It-Can-and-Cant-Do.pdf](https://www.38north.org/wp-content/uploads/pdf/2016-03-10_THAAD-What-It-Can-and-Cant-Do.pdf). The assumed electronic field of view for the TPY-2 radar is a 90-degree azimuth and 45-degree elevation. This estimate is based on numbers for the notional TPY-2 based GBX radar in National Research Council, *Making Sense of Ballistic Missile Defense*, 153. This is a conservative estimate; other open sources have assessed TPY-2's elevation as high as 60 degrees, and detection range of up to 2,000 km. See: Laura Grego, George N. Lewis, and David Wright, “Appendix 10: Sensors” in *Shielded from Oversight: The Disastrous U.S. Approach to Strategic Missile Defense* (Cambridge, MA: Union of Concerned Scientists, 2016), 9-10. Inputting these higher numbers for TPY-2, however, did not change the analytical conclusions presented here.

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## ENDNOTES

1. See: "Iranian Missile Launches: 1988-Present," Missile Threat, Center for Strategic and International Studies, July 27, 2017, last modified February 25, 2019, <https://missilethreat.csis.org/iranian-missile-launches-1988-present/>; "Iran Fires Missiles at Militants in Syria Over Parade Attack," Reuters, October 1, 2018, <https://www.reuters.com/article/us-iran-syria-missile-attack/iran-fires-missiles-at-militants-in-syria-over-parade-attack-idUSKCN1MB1ET>; "Iranian Guards, Claims Missile Attack on Iraq-based Kurd Dissidents," Reuters, September 9, 2018, <https://www.reuters.com/article/us-mideast-crisis-iraq-iran/iranian-guards-claims-missile-attack-on-iraq-based-kurd-dissidents-idUSKCN1LP08Q>.
2. Albert Wohlstetter, *The Delicate Balance of Terror*, (Santa Monica, CA: The Rand Corporation, 1958), 7.
3. In its original manifestation, the EPAA had a fourth phase that consisted of the development and deployment of a new type of Standard Missile-3, the Block IIB, that would have been capable of defending the U.S. homeland. This phase was canceled in 2013.
4. "Key Missile Defense Site Declared Operational," NATO, May 12, 2016, [https://www.nato.int/cps/en/natohq/news\\_130721.htm](https://www.nato.int/cps/en/natohq/news_130721.htm).
5. Jen Judson, "Construction Issues Still Plague Polish Aegis Ashore Site," *Defense News*, August 14, 2018. <https://www.defensenews.com/land/2018/08/14/construction-issues-still-plague-polish-aegis-ashore-site/>.
6. Department of Defense, *Missile Defense Review* (Washington, DC: Department of Defense, 2019), p. XII, [https://www.defense.gov/Portals/1/Interactive/2018/11-2019-Missile-Defense-Review/The%202019%20MDR\\_Executive%20Summary.pdf](https://www.defense.gov/Portals/1/Interactive/2018/11-2019-Missile-Defense-Review/The%202019%20MDR_Executive%20Summary.pdf).
7. NATO Public Diplomacy Division, *NATO Ballistic Missile Defense*, (Brussels, Belgium: NATO, 2016), [https://www.nato.int/nato\\_static\\_fl2014/assets/pdf/pdf\\_2016\\_07/20160630\\_1607-factsheet-bmd-en.pdf](https://www.nato.int/nato_static_fl2014/assets/pdf/pdf_2016_07/20160630_1607-factsheet-bmd-en.pdf).
8. See: Defense Science Board, *Defense Science Board Task Force Report on Science and Technology Issues of Early Intercept Ballistic Missile Defense Feasibility* (Washington, DC: Department of Defense, 2011), 26, <https://www.acq.osd.mil/dsb/reports/2010s/ADA552472.pdf>; Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, Division on Engineering and Physical Science, National Research Council, *Making Sense of Ballistic Missile Defense*; "The National Research Council Holds a Teleconference on Missile Defense Report," CQ Transcriptions, September 11, 2012.
9. National Research Council, *Making Sense of Ballistic Missile Defense*, 5-27.
10. Conflict Armament Research, *Iranian Technology Transfers to Yemen* (London, U.K.: Conflict Armament Research, 2017), 2, <http://www.conflic-tarm.com/perspectives/iranian-technology-transfers-to-yemen/>.
11. Babak Deghanpishes and Phil Stewart, "From Iraq to Yemen, drones raise U.S. alarm over Iranian plans," Reuters, July 17, 2019, <https://www.reuters.com/article/us-mideast-iran-drones/from-iraq-to-yemen-drones-raise-u-s-alarm-over-iranian-plans-idUSKCN1UC1X4>.
12. Mike Corbett, "A New Approach To Ballistic Missile Defense For Countering Antiaccess/Area-Denial Threats From Precision-Guided Weapons," *Air and Space Power Journal* 27, no. 2 (March/April 2013): 85-90, [https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-27\\_Issue-2/F-Corbett.pdf](https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-27_Issue-2/F-Corbett.pdf).
13. Gen. Patrick J. O'Reilly, "The European Phased Adaptive Approach (EPAA)" (statement before the House Armed Services Committee Subcommittee on Strategic Forces, 111th Cong. December 1, 2010), [https://www.mda.mil/global/documents/pdf/ps\\_oreilly\\_120110\\_HASC.pdf](https://www.mda.mil/global/documents/pdf/ps_oreilly_120110_HASC.pdf).
14. Missile Defense Agency, *Precision Tracking Space System* (Fort Belvoir, VA: Missile Defense Agency, 2013), <https://www.mda.mil/global/documents/pdf/ptss.pdf>.
15. "Fiscal Year (FY) 2013 President's Budget Submission: Missile Defense Agency, Justification Book Volume 2a, Research Development, Test & Evaluations - Defense Wide," Office of the Under Secretary of Defense (Comptroller), February 2012, p. 871, [https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2013/budget\\_justification/pdfs/03\\_RDT\\_and\\_E/Missile\\_Defense\\_Agency\\_PB\\_2013\\_1.pdf](https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2013/budget_justification/pdfs/03_RDT_and_E/Missile_Defense_Agency_PB_2013_1.pdf).
16. "SM-3 Block IIA Launched From Aegis Ashore Successfully Intercepts Intermediate Range Ballistic Missile Target During Operational Test," Missile Defense Agency Public Affairs, December 12, 2018, [https://www.navy.mil/submit/display.asp?story\\_id=108086](https://www.navy.mil/submit/display.asp?story_id=108086).
17. Thomas Karako, "Beyond the Radar Archipelago: A New Roadmap For Missile Defense Sensors," *War on the Rocks*, November 28, 2018, <https://warontherocks.com/2018/11/beyond-the-radar-archipelago-a-new-roadmap-for-missile-defense-sensors/>; Thomas Karako and Wes Rumbaugh, "Masterpiece Theater: Missed Opportunities for Missile Defense in the 2020 Budget," Center for Strategic and International Studies, March 29, 2019, <https://missilethreat.csis.org/masterpiece-theater-missed-opportunities-for-missile-defense-in-the-2020-budget/>.
18. NATO ships are equipped with the SMART-L/APAR sensor suite. These include Denmark's three *Iver Huitfeldt*-class frigates, Germany's three *Sachsen*-class frigates, and the Netherlands' four *De Zeven Provinciën*-class frigates.
19. Nicholas Fiorenza, "SMART-L for Smart Defense?" *Aviation Week*, June 27, 2012, <http://aviationweek.com/blog/smart-l-smart-defense>.
20. Richard Scott, "SMART-L MM/N BMD Radar Installed on First LCF Frigate," *Jane's 360*, March 26, 2019, <https://www.janes.com/article/87470/smart-l-mm-n-bmd-radar-installed-on-first-lcf-frigate>.