Michel Assouline, secretary general of the Association Aéronautique et Astronautique de France (3AF), presents at the fifteenth 3AF Integrated Air and Missile Defense Conference held 13–15 June 2023 in Porto, Portugal. (Photo courtesy of 3AF)

A Collective Overview of IAMD through the Fifteenth 3AF International Conference on Integrated Air and Missile Defense

Lt. Col. Emmanuel Delorme, French Air Force, Retired
Yannick Devouassoux
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Every two years, the integrated air and missile defense (IAMD) community gathers for the Association Aéronautique et Astronautique de France (3AF) International Conference on IAMD (3AF IAMD Conference) to discuss the status of the air and missile defense field from a political, military, and industrial perspective. The latest conference was held 13–15 June 2023 in Porto, Portugal, with 250 participants from seventeen countries. It was a special occasion since the conference reached its twentieth anniversary, making it an excellent opportunity to reflect on IAMD evolution.

A Brief History of IAMD, Seen through the Various Conference Sessions

The first "International Conference on Missile Defense: Challenges in Europe," held in 2003 in Arcachon near Bordeaux, France, was based on a shared analysis that a nongovernmental forum to discuss technical aspects of ballistic missile defense (BMD) was missing in Europe. Participating in the analysis were the the French Armament Procurement Agency (DGA—Direction Générale pour l'Armement); 3AF, the French Aeronautics and Astronautics Association; and ArianeGroup (formerly EADS Launch Vehicles), the only European maker of ballistic missiles. At the time, BMD was mostly a matter for nuclear powers and NATO was just beginning to assess its feasibility of theater BMD, a technical feasibility supported by contracts with industry.

This first conference was successful with strong support from U.S. and Israeli industries. The first day was dedicated to speeches by high-level government representatives to set the political/military context. The following days were filled with technical sessions to discuss the key issues related to BMD feasibility, including threat analysis, detection, tracking and discrimination, interception, and command and control (C2). This agenda continues to be maintained over the years.

On the European side, support grew with the active participation of Thales (France, Netherlands), ThalesRaytheonSystems (a joint venture between the Thales Group and Raytheon), European missile systems leader MBDA, and other European companies, including Bae (United Kingdom) and IABG mbH (Germany). The joint venture extended

Lt. Col. Emmanuel Delorme, French Air Force, retired, was appointed missile defense advisor to the director of strategic affairs from 2010 to 2013. He holds an aeronautical engineer diploma from the French Air Force Academy, and a master's degree at Sciences Po. He was certified as a fighter pilot in 1999, became a transport pilot in 2000, and went through a scholarship at the War College in 2010. In 2020, he retired to join MBDA as business management manager. He is a cochair of the 3AF (Association Aéronautique et Astronautique de France) Integrated Air and Missile Defence Conference.

Yannick Devouassoux has cochaired the 3AF Integrated Air and Missile Defence Conference since 2011. He was ArianeGroup's director for missile defense and space security programs from 2011 to 2021. Prior to this position, he was involved in numerous missile defense and space projects as guidance and navigation engineer, system engineer, and project manager. He holds an MS in aerospace engineering from the Georgia Institute of Technology and from Institut Supérieur de l'Aéronautique et de l'Espace, Toulouse, France; and an MS in physics and electronics from the École Polytechnique, Paris.

Luc Dini graduated as an engineer in aeronautics, and he is skilled in radars, hyperfrequence, missiles, and space. He is the former auditor of the 44th Defense Economy National Session of French Institute for Defense and Security, and of the Economic Intelligence Session. He has been a member of the Multinational BMD Conference IPC since 2006. Dini is a former military engineer. He has been the manager of development R&T program for penaids and ballistic missiles phenomenology and testing. He has been the director of IAMD and Product Line of Theater Defense since 2016. He has been chairing a NATO NIAG study on standards of IAMD multisensors fire control clusters of systems networking since 2017.

(*Left to right*) Emmanuel Delorme, Luc Dini, and Yannick Devouassoux, the three cochairs of the 3AF Integrated Air and Missile Defense Conference, preside at the fifteenth conference held in June 2023 in Porto, Portugal. (Photo courtesy of 3AF)

with companies from other nations like Aselsan, a Turkish defense corporation (as a participant in 2013 and sponsor in 2017); and laboratories from South Korea. This conference has always been chaired by industry—first by ArianeGroup, then cochaired with Thales in 2008, and then MBDA joined in 2017 as a third cochair—showing a turn in the emphasis on missile defense in Europe by main European industry groups and the convergence between the starting point of BMD to counter ballistic missiles and the air defense to counter air breathing threat including cruise missiles. It is to be noted that the coordination with the U.S. Missile Defense Agency-led BMD Multinational Conference is active as chairmen of the 3AF Conference sit at its International Program Committee.

With the involvement of NATO, the conference gained enough momentum to warrant its annual periodicity. The conference provided a modest contribution to the following turning points. In 2006, NATO developed an Active Layered Theatre Ballistic Missile Defence (ALTBMD) program to protect troops from ballistic missiles. In 2008, with the conference being held in Prague, there was an agreement between the United States and the Czech Republic to deploy a third ground-based interceptor site in Europe to better protect the United States against ballistic missile attacks from Iran. In 2009, the Obama administration changed course and decided that a European-phased adaptive approach, based on SM-3 interceptor sites in Poland and Romania and a forward-based radar in Türkiye, was a better solution given the technical and political situation at the time.[1] The European-phased adaptive approach was proposed as a U.S. contribution to NATO defense. After more feasibility studies of territorial missile defense, NATO decided to expand the ALTBMD program in 2010 to protect its territory and population.[2]

The first demonstration of ALTBMD intermediate capacity occurred in a 2010 test with NATO AirC2 and Air Command and Control System TMD prototypes. The program was renamed NATO

Ballistic Missile Defence. Of course, these evolutions in Europe met strong opposition from Russia from the very beginning. Official Russian representatives were invited to voice Russia's position on day one of each conference; however, Russia was no longer invited after the invasion of Crimea in 2014. Meanwhile, rockets rained on Israel, and Iran developed a ballistic arsenal, prompting the country's fast development of a layered missile defense.[3]

In addition, the 3AF IAMD Conference steering committee took several initiatives in the period of negotiations about cooperation on missile defense among NATO, the Russian council, and the United States:

- Russia was invited to participate in the 2008 3AF Missile Defense Conference in Prague when Lt. Gen. Trey Obering, then director of the U.S. Missile Defense Agency, signed the agreement regarding cooperation on BMD radar with the Czech prime minister. This participation showed an open mind from U.S. and European industries into possible cooperation under the umbrella of official discussions. Russia continued to be invited at the Lisbon (2010), San Sebastian (2011), Paris (2012), and finally Bucharest (2013) 3AF conferences, when Russian participation then stopped because of the situation in Crimea.
- Despite this history, this period was useful for analyzing and comparing the perception of missile defense roles on both sides.
- In parallel, 3AF sent European industry representatives to the NATO missile defense exhibition, which took place during the NATO summit in Chicago in 2012, to emphasize contributions of European Union industry to the missile defense effort and to complement the strong effort from the United States. Among the topics was multisensor networking, later discussed again among 3AF representatives who were, at that time, invited by the Atlantic Council in 2013 to an exchange of views in Washington, D.C. The topic was still on the agenda of the 2014 3AF Missile Defense Conference in Mainz, Germany, where members of U.S. and European industries drafted a white paper to propose a study to NATO NIAG.[4] This study started within the frame of a NATO Industry Advisory Group (NIAG) in 2017 on multisensor clusters; thirty-three companies and seventeen countries participated.

These are milestones of initiatives taken throughout the conference that take advantage of the presence of industry and government representatives to explore cooperation and solutions versus the history stream of missile defense and emerging threats.

Over two decades, conflicts emerged that either confirmed or reoriented the focus of the community. Short-range ballistic missiles were heavily used in Syria in 2014 and then by the Houthis against Saudi Arabia in 2015, with close to one thousand missiles fired.[5] Missile defenses proved efficient during these events twenty years after a sketchy record in the First Gulf War in 1991, strengthening the usefulness of BMD.

Another trend came under the spotlight with the attack on a Saudi refinery by drones in 2019 and with the Nagorno-Karabakh conflict. If ballistic missiles have become the "aviation of the poor," drones have become the "cruise missiles of the poor."[6]

This was well perceived by NATO, which moved from BMD to IAMD in 2014, and as a consequence led to the transformation of the 3AF Missile Defense conference from 2003 into the IAMD conference in 2017 (in Stockholm). This shift from BMD to IAMD has the command and control role at its core: essential for the Air Defense and Air Operations with the development of ACCS by NATO, it is paramount for the Theater Missile Defense and the territorial Missile Defense in Europe and therefore for the integration of these two capabilities.

After decades of development, hypersonic missiles are now coming of age and are employed in the war in Ukraine along with other air and missile threats. Defense is now faced with a vast spectrum of threats, from cheap, slow, low-flying, and low-radar-cross-section (RCS) drones to very hard-to-develop, ultrafast intercontinental ballistic missiles and hypersonic gliders. As the availability and efficiency of traditional air defenses increases, these two ends of the spectrum are initially favored by the offensive side to either saturate or penetrate defenses.

This is why the IAMD conference opened the themes of threat and defense to cover the entire spectrum from counter rocket artillery and mortar up to space, including space surveillance and antisatellite.

Current and Possible Future Trends

The fifteenth IAMD conference provided an invaluable insight into current political, military, and technical issues concerning participating countries through the numerous interventions from government officials, academics, and technical experts. A contextualized summary of the rich and diverse discussions held during the conference is provided.

Political and military context. Recent conflicts have confirmed the necessity of IAMD. Defense budgets are increasing worldwide, and IAMD is always in the portfolio of capabilities to procure and/or develop for reasons proper for each country. One or several of the following reasons apply:

- While nuclear deterrence remains at the core of nuclear countries and NATO defense, IAMD changes the calculus from an adversary, as it increases the required scale of attack to reach its objectives and therefore increases for the adversary the risk of reaching a possible nuclear threshold. As an example, the Russian aggression toward Ukraine shows once again that nuclear deterrence still holds: NATO countries are not targeted by Russia despite the tremendous help provided to Ukraine, and NATO weapons delivered to Ukraine are not to be used against Russian territory.
- IAMD provides antiaccess capability; while air defenses hold, airborne platforms necessary for heavy bombing campaigns are banned from the sky. They are, therefore, an attractive capability for countries faced by an extensive air force. Recent Russian air defense systems S-300 and S-400 export successes can be viewed in that light.[7]
- IAMD counters area denial weapons such as precision-strike missiles (cruise and maneuvering ballistic missiles), an imperative for anyone with an expeditionary force. Maritime missile defense proceeds from that logic.
- IAMD protects key economic infrastructures such as power plants, refineries, and decision centers, all necessary to pursue any war effort, and it protects population centers to preserve morale.
- IAMD is a facilitator of military integration; the more systems cooperate through exchange of information, the more capability they have and the more efficient they are. IAMD, therefore, helps cement alliances and is a tool of influence.
- IAMD is a very challenging mission that requires technological and operational innovation, pulling industry toward excellence. Excellence spreads in the industry and is key for export, which makes IAMD capabilities more affordable for its developers.

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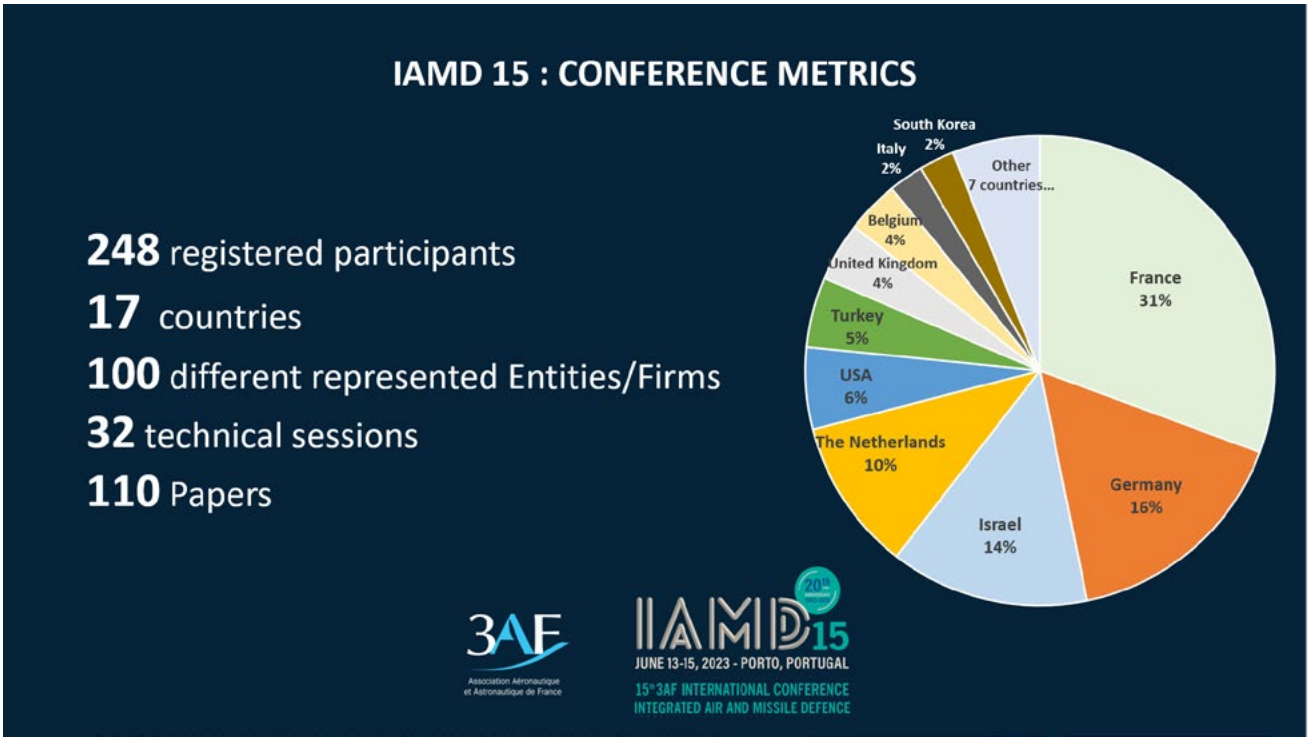
IAMD is one of the pillars of NATO defense strategy. The capability, based on the interoperability of national systems, is progressively deployed. Newcomers Sweden and Finland will provide additional capability to the alliance.

In the last three years, several European countries committed to expanding their existing capabilities through the development or the acquisition of new assets. Space-based early warning and interception systems able to detect or defend against hypersonic missiles are studied in the frame of the Permanent Structured Cooperation project called Timely Warning and Interception with Space-based TheatER (or TWISTER), which is coordinated by France with Finland, Germany, Italy, the Netherlands, and Spain.[8] This political will is supported by the European Defence Fund, which granted one project to study the feasibility of a space-based theater missile defense early warning system and two projects for the concept phase of an interceptor against high-end threats, including hypersonic



Conference metrics for the fifteenth 3AF Integrated Air and Missile Defense Conference. (Photo courtesy of 3AF)

ones.[9] Germany signed a nonbinding agreement with fourteen countries around the European Sky Shield Initiative, a missile defense architecture built around the American Patriot, the German Iris-T, and the Israeli Arrow 3 missile defense systems. The United Kingdom has planned the deployment of an enhanced missile defense radar system by the end of the decade. France and Italy launched the SAMP/T NG (surface-to-air medium-range/land-based new generation) program (development and production), which is an upgrade to the SAMP/T air defense system currently deployed in Ukraine. The SAMP/T NG program has notably new active electronically scanned array (AESA) radars (with same AESA technology used for French and Italian frigates), a new engagement module, and an enhanced Aster missile, thus providing not only an enhanced capacity but also a strong growth potential. In parallel, NL developed new AESA multimission SMART-L radars, deployed for the Air Force long-range capacity. For naval application, NL took part in Exercise Formidable Shield demonstration campaigns of naval IAMD, together with other navies' part of MTBM—Maritime Theater Ballistic Missile forum.[10] Finally, France, Germany, Italy, and the Netherlands are cofunding one of the European Defence Fund-granted projects, the Hypersonic Defense Interceptor Study (HYDIS), led by MBDA for the concept phase for a new interceptor against high-end threats.

Israel, under the constant threat of rockets and missiles, is thickening its layered defense architecture with the addition of the David's Sling defense system and is developing the Arrow 4 to succeed to the Arrow 2. Rafael has partnered with Raytheon to produce the combat-proven Iron Dome in the United States.[11]

South Korea is developing indigenous systems to protect itself against North Korea, which is regularly increasing and testing its missile arsenal.[12] Japan continues its long-standing cooperation with the United States to do the same.

The United States is improving the full spectrum of its capabilities, developing new systems to deal with hypersonic threats, and reinforcing alliances to keep its two strategic competitors, Russia and China, in check. Of note are the developments of its next-generation interceptor to replace the ground-based interceptor and of the glide phase interceptor to deal with hypersonic gliders. The national defense architecture extends into space to allow 24/7 global detection and tracking of missile threats, including hypersonic missiles. To do this, constellations of satellites are launched in low earth orbit to detect

launchers (custody layer), detect launches (early warning), track missiles during their flight (tracking layer), and exchange data with low latency (transport layer).

In reaction to the increasing value of space functions, space warfighting means are under development, testing, and fielding, including spy satellites, kinetic and nonkinetic antisatellite weapons, electronic warfare, and cyber capabilities to jam, incapacitate, or even take control of space assets.

The lower end of the threat spectrum is an increasing concern, as drones are now not only the missiles of the poor but also the new improvised explosive devices. In that respect, security issues join military issues and cheaper and effective solutions against these threats are under development.

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Fifteenth IAMD Conference

The technical aspects of the previously mentioned threats and defense means were discussed during the conference and are further developed hereinafter.

Threat evolution. As new missile systems appear on the world stage, they are analyzed by the intelligence community and retro-engineered by technical experts to estimate their performances, assess the involved technologies and their limitations, position the country on the scale of missile expertise, and estimate operational constraints and concepts of operations. The conference dedicates a half day to such analyses by prominent experts in the field. On the menu this year, a Russian ICBM, a North Korean ballistic missile with a hypersonic glider, air-launched ballistic missiles (ALBMs), antiship threats, and the use of cruise missiles in conflicts.

The Russian and North Korean cases were retro-engineered in an effort to confirm official statements and performances of missiles after recent tests. The ALBMs presentation was a retrospective on the developments of such systems, back under the spotlight with the use of an air-launched Iskander by Russia in Ukraine. There were many developments in the past, but the concept fell out of fashion when they were replaced by cheaper and more compact cruise missiles. The improvement of missile defenses is the reason why ALBMs are now more relevant as they are harder to intercept than subsonic missiles. Since the Falklands War, the antiship missiles are recognized by a wide audience as a key element of maritime supremacy.[13] A presentation provided an overview of such systems. Finally, a synthesis on the use of cruise missiles in recent conflicts was made—a family that includes drones (unmanned, self-propelled, self-guided)—to conclude that their threat was until recently underestimated compared to the ballistic missiles.

Defense architectures. Defense architectures need to adapt to the threat evolution in performance, volume, and concepts of use. As new offensive systems emerge, they do not necessarily replace the old ones, so the threat spectrum to handle at the same time is widening. As with everything else in society, the pace of fight is increasing. This is a real challenge for defense architectures. Under a well-coordinated attack, multiple defense systems need to cooperate seamlessly and in real time in order to be efficient. Defense architectures are textbook system of systems, a collection of independently developed weapon systems coordinated by C2 functions designed for “countering advanced threats with advanced integration,” as one of the presenters said. So concepts of networking, interoperability, modularity, open architectures, layered architectures, and scalability were discussed at length. To keep costs down, adaptation of existing defense systems and of concepts of operation should be considered as well. Each conflict provides lessons to be learned in that area; the war in Ukraine is no exception and was discussed in many speeches.

Modeling and simulation. The complexity of modern IAMD cannot be handled without appropriate tools. Modeling and simulation are key components of the toolbox. Through the simulation of defense architectures, we can do the following:

- Progressively refine concepts of operations by playing them out, observing the outcomes, and looping back to adapt the concepts.
- Predict and evaluate performances.
- Define requirements for future systems.
- Communicate effectively with stakeholders and in particular decision-makers.
- Train military personnel.

Architecture simulation capabilities expand to integrate new threats, especially hypersonic systems, new defense systems, and the space battlefield. Even if computing power is largely available, questions of model fidelity are always present; the level of detail required depends on users' needs.

As threats evolve, so does the way we need to evaluate architecture performance. For example, while the concept of defended area is relatively straightforward to understand and implement when considering attacks by purely ballistic missiles, the concept is much more complex to implement in the case of attacks by ballistic missiles with hypersonic gliders. One of the presentations included definition and visualization of a defended area in that case.

Of course, the traditional role of simulation in assessing and verifying a defense design remains and was discussed at the conference, mainly around the simulation of hypersonic gliders and hypersonic cruise missiles. The physics involved in flight are complex and depend on atmospheric conditions and material properties, so model validation is key. As all engineers well know, the quality of simulation depends on input data. Having validated data on materials, and models validated through flight tests, is mandatory to predict trajectories with accuracy.

Another area where simulation is heavily used is the prediction of threat signatures, radar or infrared, in all phases of flight. This is the major input to assess the detection and discrimination functions, and good fidelity is needed to evaluate architecture performance with confidence. Here again the physics are complex, the input data is hard to obtain, and real measurements are required to validate models. There are very few people able to discuss this secretive topic closely linked to intelligence.

Interceptors and weapon systems. As we previously discussed, there are now several weapon systems and interceptors on the market, some of which were presented in greater detail at the conference, including SAMP/T (current and NG versions), Principal Anti-Air Missile System and Sea Viper with the Aster missile developed by MBDA, and the Iris-T.

New concepts were discussed as well, such as concepts to intercept hypersonic weapons. This is a difficult problem, because the interceptor is the last element of a chain that needs to work perfectly in hopes of neutralizing such a fast and maneuverable threat.

Finally, exchanges about detailed technical issues such as control algorithms and propulsion systems were held. These topics are closely linked; an interceptor needs to outmaneuver its target. It requires a very reactive and flexible control system to do so. As the intercept altitude gets higher, aerodynamic control surfaces become inefficient and a specific propulsive system is required. Solid propellant is usually (but not always) used, as it is easier to store and to handle. Various concepts of such systems were presented.

Directed energy weapons. For decades, lasers have been researched as potential game changers because in theory, they provide a low cost, unlimited magazine solution with the speed of light effect. Lasers were supposed to reverse the cost equation in favor of the defender; the munitions of traditional kinetic missile defense systems are much more expensive than their targets. But real life is tough for lasers. Their range and power on a target depend greatly on weather conditions. Their effect on a target strongly depends on target material, which can potentially lead to huge power requirements and technical hurdles, and they need to stay on target for some time before the target is neutralized—no fire and forget here. The potential for collateral damage is high with high-powered lasers as well, because the eye-blinding threshold is low and therefore the hazardous range is well beyond the target.

However, technical progress has allowed the development of systems or concepts that are operationally relevant. Short-range lasers have demonstrated their usefulness in dry areas against "soft targets" such as unmanned aerial vehicles (UAVs) and rockets, artillery,

and mortars. Laser systems to neutralize earth observation satellites are fielded.

The conference addressed the antidrone and more futuristic antihypersonic missiles applications, as well as the impact of atmospheric turbulence on laser performance.

Sensors and sensor networks. Sensors allow detection, discrimination, and tracking of missiles. In rough terms, the earlier the detection, the better; and the more sensors in different wavelengths, the better for discrimination. Of course, there is a cost consideration.

Different radar technologies and sensors and their capabilities were presented by Thales, Hensoldt, Weibel, Elta, the Naval Group, Aselsan, DRS Rada Technologies, and Leonardo. The main results of studies by the NIAG to multiply sensor effectiveness by high-rate information exchange and coordination were shown, including a presentation from the NATO Allied Command Transformation sponsor of NIAG SG217, then 260. Space-based infrared sensors were discussed as well by Airbus and OHB (a German company specializing in space systems). Such sensors can provide early detection and tracking of high-energy/high-velocity missiles. Very few countries have such a capability, and there is currently a European project called Odin's Eye, funded by the European defense fund, designed to assess feasibility under the TWISTER umbrella.

The use of AI in sensor processing is also undergoing study, in particular for classification. But as we saw before, signatures are hard to obtain, whereas a large dataset is available in most civil applications. There are therefore pitfalls to avoid that were pointed out in this technical session.

Command and control. C2 is the glue that makes the architecture work. The C2 provides planning services supported by simulation capabilities, builds the operational picture, and leads execution. It assigns tasks to sensors and weapon systems and ensures that rules of engagement are respected. It provides communication between all entities. It has to be resilient against attacks, both kinetic and nonkinetic, such as cyberattacks.

The C2 has to handle the complexity of IAMD and help decision-making by providing relevant data at the right time. This is an area where artificial intelligence could be used in the future. Human interface is key to achieve performance objectives. Notions and solutions for collaborative and netcentric engagement, mission optimization, and dynamic target weapon assignment were addressed.

C-RAM, C-UAS. As low-tech threats are proliferating, low-cost answers need to be found. Besides directed energy solutions presented before, other solutions based on mature technologies were presented, such as radar detection, jamming (UAV), and/or interception by kinetic means. For UAVs in civilian areas, other technologies are studied; where a swarm of drones is very unlikely, a capture can be envisioned and detection can be done by LiDAR with no impact on the electromagnetic environment.

Testing and demonstration. Testing is the truth of the field and is mandatory to update simulation models, qualify systems, train operators, and verify operational capability. It was addressed at different levels at the conference:

- at the subsystem level, with the proposal of a hypersonic glider test-bed to evaluate sensors, materials, and algorithms in relevant conditions;
- at the weapon-system level, with the presentation of the NATO missile firing installation in Greece; and
- at the architecture level using the NATO integrated test-bed that is able to connect the NATO C2 and the various national contributions.

Demonstrations have a larger scale and are used to evaluate interoperability, to rehearse coordination, and to send messages to potential adversaries. Exercise Formidable Shield at sea was described, involving more than twenty ships of thirteen countries and with multiple live fires to intercept missiles.[14]

Conclusion

IAMD is a dynamic field. Missiles (here in the generic sense, including drones) are under development and acquired globally at both ends of the technology spectrum because they provide high operational benefits for low risk of loss of human life for the attacker. Missile varieties complicate the calculus of the defender and generate high defensive costs. Conflicts in the last two decades demonstrated the usefulness of missiles but also the efficiency of air and missile defenses that have become mandatory to preserve operational capability before a counterattack.

IAMD is one of the most technically challenging tasks in defense. It needs to be supported by a highly trained workforce in industry, in

procurement agencies, and in the armed forces. The 3AF International Conference on Integrated Air and Missile Defense provides a unique forum to gather this community, discusses the many IAMD challenges, and embarks the future generation in this field. The fifteenth conference was a great success, with more than 110 papers submitted, around 250 participants from seventeen countries, and more than one hundred companies represented. This article provided a quick summary of the discussions held during the conference and covered all technical fields of IAMD. We hope it will raise interest in the discourse on IAMD and encourage participation in the next conference in two years. ■

Notes

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Glossary

3AF: Association Aéronautique et Astronautique de France (French Association for Aeronautic and Space)
AESA: Active electronically scanned array
ALBM: Air-launched ballistic missiles
ALTBMD: Active Layered Theatre Ballistic Missile Defence
BMD: Ballistic missile defense
C2: Command and control
C-RAM: Counter rocket, artillery, and mortar
C-UAS: Counter unmanned aircraft system
IAMD: Integrated air and missile defense
NIAG: NATO Industry Advisory Group
TWISTER: Timely Warning and Interception with Space-based TheatER
UAV: Unmanned aerial vehicle