BASE CASE FOR DISRUPTING THE MISSILE DEFENSE INDUSTRY

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About Citadel Analytics (UK) Ltd.

At the Intersection of Missile Defense and Advanced Innovation

Citadel is a think tank co-founded by Dr. James Bosbotinis and Harris S. Fried, Esq. Colonel David Shank (US Army (ret.)) and an expert in Air and Missile Defense joined the board in 2021 as a key advisor. Citadel's mission is to engage with government, military and industry partners to create the best solutions to the increasingly vital job of improving our defensive capabilities and by utilizing our defensive capabilities and any appropriate advance in technology to maintain and/or achieve superiority across all domains and weapon systems providing the equipment that the warfighter needs in the most expedient and cost-effective manner possible. Citadel through its network of affiliates also serves as a consultant, advisor and partner to industry in its quest for supply chain solutions.

Our Vision

In 2016, Citadel Analytics (UK) Ltd. ("Citadel") first published its vision for the future of the Missile Defense industry, believing that key geopolitical, military and industrial trends pointed to a near-term future where missile-defense was paramount in the face of increasing threats, while new technologies would greatly enhance defensive efforts. Throughout the integrated air and missile defense (IAMD) industry supply chain, especially via the introduction of cutting-edge technologies, such as additive manufacturing, industry should have as a top priority the delivery of a qualitatively superior product to the warfighter in an expedited mode. This entails a new, more modernized look at supply chains and how the advent of advanced innovation can be and is being utilized to make sure that the US and its allies do not yield superiority to our adversaries across any weapons system and any domain.

What follows in this brief paper is a top-down analysis supporting Citadel's thesis, which is, that through the application of advanced technology the supply chains currently being utilized by major defense contractors can be enhanced in a careful yet precise manner to achieve cost savings, quicker delivery of critical components and in many cases a superior part or component.

The Geopolitical Overview[1]

The global strategic environment is in a period of flux encompassing shifts in the global balance of power, spheres of influence and serious challenges to the so-called "liberal world order' first propagated in 1941 by Winston Churchill and Franklin Roosevelt. The ongoing war in Ukraine, following Russia's unprovoked full-scale invasion on 24 February 2022, provides dramatic evidence of both the lethality of offensive missile systems and the critical importance of robust integrated air and missile defense (IAMD). Russia has employed a wide variety of ballistic (the SS-26/Iskander-M) and cruise missiles (namely the Kalibr, AS-15 Kent, and AS-23A Kodiak) in strikes against Ukrainian targets, and has employed the Kinzhal, an air-launched ballistic missile providing a hypersonic strike capability. Russia has also resorted to the use of anti-ship missiles, including the AS-4 Kitchen, and surface-to-air missiles, namely the S-300, in the land-attack role, due to dwindling numbers of ballistic and cruise missiles.[2] Through poor employment and gross misuse, in particular the targeting of civilian facilities and areas, Russia's investment in long-range precision strike systems has not produced the results that would have been expected. Conversely, Ukraine is demonstrating the effectiveness of uncrewed air systems on both the battlefield and in strategic strikes, including within Russia and against maritime targets, as well as the M142 High Mobility Artillery Rocket System (HIMARS). Ukraine has also husbanded its air and missile defense capabilities, surviving Russian attempts to suppress them and is integrating Western systems, in particular the National Advanced Surface-to-Air Missile System (NASAMS), a distributed, networked

[1] The analysis in this section draws on James Bosbotinis, Harris S. Fried, Colonel David Shank, USA (ret'd), 'Missile Defense in a Multipolar World', *Journal of Policy and Strategy*, Vol. 2, No. 1 (2022), pp. 41-55.

[2] See respectively, Douglas Barrie and Joseph Dempsey, 'Russia's Missile Inventories: KITCHEN Use Points to Dwindling Stocks', IISS *Military Balance Blog*, 12 July 2022, https://www.iiss.org/blogs/military-balance/2022/07/russias-missile-inventories-kitchen-use-points-to-dwindling-stocks; and Thomas Newdick, 'Russia Now Firing S-300 Surface-to-Air Missiles at Land Targets in Ukraine: Official', *The War Zone*, 8 July 2022, https://www.thedrive.com/the-war-zone/russia-now-firing-s-300-surface-to-air-missiles-at-land-targets-in-ukraine-official.

medium-range air defense system developed by Kongsberg and Raytheon, which contributes to the air defense of the US National Capital Region.[3]

A resurgent Russia, deeply dissatisfied with the post-Cold War settlement, had been pursuing an increasingly assertive and muscular challenge to international order, in particular in Europe, prior to its invasion of Ukraine. The Russian Armed Forces were in the midst of a major rearmament program intended to replace, for the large part, its current Cold War-era order of battle. A significant element of this involved the development and deployment of an anti-access/area denial capability, including a significant long-range strike component, centered in Europe on the Kola Peninsula, the Kaliningrad exclave, occupied Crimean Peninsula, and in Asia, on the Kamchatka Peninsula. An anti-access/area denial zone had also been established in Syria. Russia's disastrous war in Ukraine and its impact, in particular via sanctions, will significantly restrict Moscow's ability to continue its rearmament efforts and is also forcing a scaling back of its military presence in Syria, and wider pressures on the Russian military. The collapse of the INF Treaty in 2019, following Russian violations including the covert deployment of a ground-launched cruise missile, will enable Russia to expand and enhance its ground-launched missile capabilities, including through the deployment of a ground-launched version of the Tsirkon hypersonic cruise missile and the development of an anti-ship ballistic missile, 'Zmeyevik', described as similar to the Chinese DF-21D and DF-26, have a range of 2,500 miles, and be equipped with an HGV.[4]

In the Indo-Pacific region, China continues to comprehensively modernize and develop its armed forces and challenge the US-led regional order, particularly in the East and South China Seas. Most recently China has taken a more aggressive posture toward Taiwan. The People's Liberation Army Rocket Force, responsible for China's ground-launched nuclear and conventionally armed ballistic and cruise missiles, possesses the largest and most-potent force of short, medium and intermediate range ballistic missiles in the world. China is deploying hypersonic weapons, including the medium-range DF-17, armed with a hypersonic glide vehicle (HGV), the ship-launched YJ-21, and is developing an expansive hypersonic technology base for civilian and military applications. It is also modernizing and expanding its strategic nuclear forces, centered on the DF-41 intercontinental ballistic missile, JL-3 submarine-launched ballistic missile, and H-20 stealth bomber.

In northeast Asia, despite an apparent commitment to diplomacy (including a self-imposed moratorium on long-range missile and nuclear testing) and "denuclearization", North Korea appears to remain committed to developing its ballistic missile and nuclear capabilities. Pyongyang possesses an extensive short and medium-range missile and long-range rocket capability that can hold at risk U.S. forces across South Korea and Japan, with a nascent ability to prosecute strikes against regional targets, in particular Guam.[5] Pyongyang has also successfully tested the Hwasong-14 and 15 ICBMs and unveiled in October 2020, the Hwasong-16 ICBM. In 2021, it also conducted the first test of the Hwasong-8 ballistic missile equipped with an HGV. North Korea is also developing submarine-launched ballistic missiles,

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[3] 'NASAMS: National Advanced Surface-to-Air Missile System', Raytheon Missiles & Defense, https://www.raytheonmissilesanddefense.com/what-we-do/missile-defense/air-and-missile-defense-systems/nasams.

[4] Thomas Newdick, 'Russia Developing Anti-Ship Ballistic Missile: Report', *The War Zone*, 13 July 2022, https://www.thedrive.com/the-war-zone/russia-is-working-on-a-new-anti-ship-ballistic-missile-report.

[5] James Bosbotinis, Harris S. Fried and David Shank, "Guam: A Critical Line of Defense – Threats and Means to Deter and Defend," National Institute for Public Policy *Information Series, Issue No. 498*, 4 August 2021, available at https://nipp.org/information_series/james-bosbotinis-harris-s-fried-david-shank-guam-a-critical-line-of-defense-threats-and-means-to-deter-and-defend-no-498-august-4-2021/.

namely the Pukguksong-3 and 5, and a conventionally-armed intermediate-range cruise missile. Moreover, North Korea is looking to develop tactical nuclear weapons, in part to offset US and South Korean conventional superiority.[6] Pyongyang has also enshrined its nuclear status into law, and set out provisions for nuclear use, including pre-emptive strikes.[7]

Iran has deployed a potent arsenal of short and medium-range rocket and ballistic missiles and is developing a burgeoning uncrewed air and cruise missile capability. The 14 September 2019 cruise missile and drone, and 8 January 2020 ballistic missile attacks on Saudi oil infrastructure and Iraqi bases hosting U.S. forces respectively, provide a tangible demonstration of Iran's growing air and missile threat. Moreover, Iran provides considerable material support, including the provision of rocket and missile technologies to militant proxies, most notably the Lebanon-based *Hezbollah*, Palestinian *Hamas* and the Yemen-based Houthi rebels. Tehran also provides significant support to the Bashar Al-Assad regime in Syria. Further, Iran and North Korea cooperate in the development of ballistic missile systems. Iran too is, whether surreptitiously or not, intent on developing a nuclear capability while developing sophisticated delivery systems. The Trump Administration's withdrawal from the JCPOA considerably undermined efforts to contain Iran's nuclear ambitions, and at the time of writing, a return to the JCPOA remains uncertain.

Notably, and in a vivid demonstration of the pressures on and weakness of the Russian military establishment, Moscow has had to acquire UAS from Iran, and importing military hardware, including artillery shells and rockets, from North Korea.[8]

Missile Contagion and the Threat Spectrum

The proliferation of increasingly sophisticated ballistic and cruise missiles, guided rocket artillery and other aerial threats including guided mortars and uncrewed aerial systems (UAS) poses a growing threat to both military forces, national security and economic infrastructure. It is extremely important to keep in mind the central theme common to the military strategies of Russia, China, North Korea and Iran which is the development of potent missile forces intended to counter the ability of the US and its allies to operate in Europe, the Asia-Pacific and the Middle East. It warrants emphasizing that Russia's conventional missile forces pose a significant threat despite operational performance in Ukraine. While Russia has employed its missile capabilities poorly in Ukraine, and has major weaknesses in intelligence, surveillance and reconnaissance, thus limiting its ability to prosecute mobile targets, it nonetheless could conduct effective strikes against critical NATO facilities in Europe. Moreover, its hypersonic missiles constitute a particularly challenging and potent threat.

Iran and North Korea also pose significant conventional threats with ballistic missiles, rocket artillery and UAS. At present, Iran and North Korea pose a primarily regional threat, although North Korea is making rapid progress in its development of intermediate-range and

[6] Ankit Panda, 'North Korea's Tactical Nuclear Plans Are a Dangerous Proposition', *Foreign Policy*, 28 April 2022, https://foreignpolicy.com/2022/04/28/north-korea-tactical-nuclear-plans-dangerous-proposition/.
[7] 'New North Korea Law Outlines Nuclear Arms Use, Including Pre-emptive Strikes', Channel News Asia, 9 September 2022, https://www.channelnewsasia.com/asia/north-korea-makes-nuclear-weapons-policies-enshrined-new-law-denuclearisation-2928686.
[8] See respectively, Ellen Nakashima and Joby Warwick, 'Iran Sends First Shipment of Drones to Russia for Use in Ukraine', *The Washington Post*, 29 August 2022, https://www.washingtonpost.com/national-security/2022/08/29/iran-drones-russia-ukraine-war/; and Matt Murphy, 'Ukraine: North Korea Supplying Russia with Weapons, Says US', BBC, 6 September 2022, https://www.bbc.co.uk/news/world-europe-62804825.

intercontinental ballistic missiles (the KN-17, KN-20 and KN-22 respectively). This was most vividly illustrated by its November 2017 test of a KN-22 (Hwasong-15) intercontinental ballistic missile capable of hitting targets across the United States. Pyongyang is also developing a submarine-launched ballistic missile, the KN-11. Iran is working on improving its arsenal of ballistic missiles and heavy caliber rockets, in particular through such measures as the incorporation of terminal guidance systems, maneuvering re-entry vehicles, improved rocket engines and solid-fuel propulsion for ballistic missiles. Moreover, Iran is a proliferator of rocket and missile systems, for example, supplying *Hezbollah* with the 300 km-range Fateh 110 ballistic missile and providing Hamas and Hezbollah with the Fajr-*5* 75 km-range rocket. However, effective missile defenses can counter the Iranian and poxy threat, as demonstrated by the Israeli Iron Dome, and in January 2022, the first successful combat engagement with THAAD. In this case, a UAE THAAD successfully intercepted a Houthi medium-range ballistic missile as part of a wider multi-axis attack against an oil facility in Abu Dhabi.[9]

The accuracy and effectiveness of the latest conventionally armed Russian and Chinese ballistic missiles fired in large salvos, and appropriately targeted, would be devastating; while the consequences of chemical, biological or nuclear ballistic missile strikes could be catastrophic. Even non-state actors such as Hezbollah could pose such a destructive threat through the targeting of civilian facilities: Hezbollah has, in this regard, threatened to launch missile strikes against a chemical storage plant in Haifa, Israel.

The development and application of Artificial Intelligence (AI), including via, for example, AI-enabled drone swarms, and to missile guidance systems, will likely significantly enhance the threat posed by those systems. Countering uncrewed aerial systems operated by both hostile states and terrorist groups is a key part of the integrated air and missile-defense mission.

Countering the Threat

Countering the threat posed by ballistic and cruise missiles and other threats such as guided rocket artillery and UAS is a major priority for the United States and its allies in Europe, the Middle East and Asia. The war in Ukraine is prompting significant interest in IAMD. In its Fiscal Year (FY) 2023 budget request, the Biden Administration has requested $24.7 billion for "missile defeat and defense", which includes "traditional missile defense programs funded in the Missile Defense Agency (MDA) and military services but also programs usually associated with strategic missile warning and certain programs to counter missile threats prior to launch, including hypersonic strike and cyberattack."[10]

The US is the current leader in missile defense ("MD") systems, deploying strategic, theater and tactical interceptors. This includes respectively the Ground-based Midcourse Defense (GMD – 44 Ground Based Interceptors (GBI), deployed in Alaska and California providing defense against intercontinental ballistic missiles), the Terminal High Altitude Area Defense (THAAD), the Aegis Ballistic Missile Defense (providing sea and land-based MD using SM-2 and SM-3 interceptors – see below), and the PATRIOT Advanced Capability (PAC)-3 providing the US Army with simultaneous air and missile defense, including against short-

[9] Jen Judson and Joe Gould, 'THAAD, in First Operational Use, Destroys Midrange Ballistic Missile in Houthi Attack', *Defense News*, 21 January 2022, https://www.defensenews.com/land/2022/01/21/thaad-in-first-operational-use-destroys-midrange-ballistic-missile-in-houthi-attack/.

[10] Wes Rumbaugh, "FY 2023 Missile Defense and Defeat Budget Tracker," Missile Threat, Center for Strategic and International Studies, June 17, 2022, last modified June 17, 2022, https://missilethreat.csis.org/fy-2023-missile-defense-and-defeat-budget-tracker/.

range ballistic missiles and heavy caliber rockets, and cruise missiles. The PAC-3 (and preceding PAC-2 variant), THAAD, SM-2 and SM-3 have, and continue to attract export customers: for example, the United Arab Emirates and Saudi Arabia have acquired THAAD, 18 countries have acquired PATRIOT variants (in excess of $500 million per year is invested in PATRIOT by international partners), while Japan has acquired the SM-3 for sea-based MD and is cooperatively developing with the US, the improved SM-3 Block IIA. Japan is also looking to build two 20,000-ton missile defense warships, replacing a previous plan to acquire Aegis Ashore.[11]

The US also cooperates closely with Israel in the development of MD systems. The Iron Dome, which counters rocket, artillery and mortar threats, is in operational service with Israel and is being marketed in the US by Raytheon, which manufactures components for the Iron Dome's Tamir interceptor. Two Iron Dome systems were ordered by the US Army in 2019, to provide an incremental cruise missile defense capability. Two systems have been acquired, one of which was deployed to Guam in 2021.[12] Raytheon also co-manufactures the Stunner interceptor for David's Sling, a mid-level system intended to defend against heavy-caliber rockets and ballistic missile threats such as the Scud operated by Hezbollah, and Syria. The US and Israel have also jointly developed the Arrow Weapon System (utilizing Arrow-2 and the latest Arrow-3 interceptors), which is intended to provide upper-tier defence against long-range ballistic missile threats. Boeing co- develops and manufactures the Arrow with Israel Aerospace Industries. The US and Israel have also commenced development of the Arrow-4, which will offer improved capabilities against threats both outside and within the atmosphere, that is, potentially offering a means to intercept hypersonic threats.[13] Rafael Advanced Defense Systems is also developing the Iron Beam laser system to counter rocket, artillery, mortar and UAS threats.[14]

The Aegis Ballistic Missile Defense ("BMD") system warrants particular highlighting. Using the SM-2 Block IV and SM-6 for terminal and SM-3 for mid-course interceptions, the Aegis Ballistic Missile Defense system is the only operational MD capability deployed both at sea and on land: 47 US Navy destroyers and cruisers are Aegis BMD-capable.[15] Eight Japanese destroyers are also operational with Aegis BMD. The first Aegis Ashore installation in Romania was declared operational with the SM-3 Block 1B in 2016; the second Aegis Ashore installation in Poland is due to become operational no earlier than 2022 with the improved SM-3 Block IIA. The SM-6 provides a nascent counter-hypersonic threat capability, while the US is also developing a Glide Phase Interceptor to defend against hypersonic missiles. It is also developing a Next Generation Interceptor for the Ground-based Midcourse Defense system.

The development of MD capabilities is a growing area of international interest and cooperation. The MDA lists the following countries as engaged in cooperation, to varying extents, with the

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[11] Dzirhan Mahadzir, 'Japan to Build Two 20,000-ton Missile Defense Warships, Indian Carrier Commissions', *USNI News*, 6 September 2022, https://news.usni.org/2022/09/06/japan-to-build-two-massive-20000-ton-missile-defense-warships-indian-carrier-commissions.

[12] Andrew Eversden, 'US Army Successfully Tests Iron Dome at White Sands Missile Range', *Breaking Defense*, 2 August 2022, https://breakingdefense.com/2022/08/us-army-successfully-tests-iron-dome-at-white-sands-missile-range/.

[13] Seth J. Frantzman, 'Israel and US Begin Arrow-4 Development', *Defense News*, 18 February 2021, https://www.defensenews.com/industry/techwatch/2021/02/18/israel-and-us-begin-arrow-4-development/.

[14] Laurie Kellman, 'Israel Successfully Tests New Laser Missile Defense System', *Defense News*, 15 April 2022, https://www.defensenews.com/training-sim/2022/04/15/israel-successfully-tests-new-laser-missile-defense-system/

[15] Missile Defense Project, "Aegis Ballistic Missile Defense," *Missile Threat*, Center for Strategic and International Studies, last modified August 4, 2021, https://missilethreat.csis.org/system/aegis/.

US: Czech Republic, Denmark, France, Germany, Italy, Netherlands, Poland, Romania, Spain. Turkey, the UK, Israel, Kuwait, Qatar, Saudi Arabia, the UAE, Australia, South Korea and Japan; NATO is also a partner, ~~while~~ India and the Philippines are developing partnerships with the US. India has an indigenous BMD program; France and Italy operate the SAMP/T, a ground-based variant of the ASTER-30, providing air and missile defense. The UK, Australia and US have also announced plans to cooperate on hypersonic defense as part of the trilateral AUKUS pact. Japan is looking to develop an electromagnetic railgun capability as part of a hypersonic defense system. Under the auspices of the European Union's Permanent Structured Cooperation (PESCO) initiative, five European countries (France, Italy, the Netherlands, Spain and Finland) are collaborating on 'Timely Warning and Interception with Space-based Theater surveillance', or Twister, which will include an endoatmospheric interceptor to counter hypersonic and other advanced threats.

The Importance of Space

In light of the growing threat posed by hypersonic weapon systems, in particular the different flight profiles that such systems fly in comparison to ballistic missiles, the US is developing a Space Sensor Layer. This will be a constellation of satellites to provide enhanced missile warning and tracking capabilities. However, space is becoming an increasingly contested environment, with Russia, China and others developing anti-satellite capabilities, both kinetic (e.g. killer satellites or anti-satellite missiles) and non-kinetic (such as, lasers, electronic warfare systems). In the event of conflict, providing operationally responsive space capabilities, such as low-cost access to space, to replace degraded sensor networks will be critical.

Maintaining the Edge Through Advanced Innovation: The Case for Disruption

Missile threats do not stand still: improved propulsion, guidance, maneuvering re-entry vehicles, penetration aids and decoys and advanced technologies such as hypersonic glide vehicles are being developed and deployed to enhance the survivability of ballistic missiles in the face of existing missile defense systems. Likewise, cruise missiles are being improved with the incorporation of low observable technologies, while rocket artillery, and other aerial threats such as UAS also continue to be developed and improved. As the war in Ukraine, and other conflicts (for example, against the Houthis in Yemen) demonstrates, air and missile defense is critical, and for maximum effectiveness, needs to be fully integrated. While the concept of an integrated air defense system is not new, the evolving nature of the air and missile threat requires a genuinely integrated approach to defeat it: "cruise missile defense", "ballistic missile defense", "air defense" should not be stovepiped. For example, an adversary may employ low-observable cruise missiles to target critical air/missile defense nodes, while ballistic missiles prosecute targets with battle damage assessment, or targeting updates provided by tactical uncrewed air systems.

Existing systems such as THAAD, PATRIOT and SM-3 are receiving incremental updates, including improved propulsion technologies, sensors and kinematic performance enhancements. Such efforts are underway to both improve operational capability and reduce the cost of the interceptors themselves: for example, an SM-3 Block IIA missile costs $20-24 million, while a THAAD interceptor costs $15 million.

Research into, and development of advanced technologies, especially directed energy weapons, electronic warfare systems and hyper velocity projectiles is a particular priority in order to realize significantly reduced engagement costs compared to current hit-to-kill interceptors and larger magazine capabilities. Moreover, again as the war in Ukraine dramatically highlights, modern high-end warfighting will very quickly deplete stockpiles, particularly of precision weapons and missiles. Ensuring that industry can scale-up production in response to operational contingencies will be of significant importance.[16] In this regard, advanced manufacturing technologies, including additive manufacturing ("AM") will be key. In May 2022, President Biden unveiled a voluntary program – Additive Manufacturing Forward, which Boeing and Northrop Grumman have joined, promoting the use of AM and other advanced technologies, to enhance US supply chain competitiveness and resilience.[17]

Citadel's thesis draws on key trends and developments (and the empirical data that generates) already influencing the aerospace and defense industry. In particular, the adoption of AM technologies and processes is yielding significant benefits to those companies that have invested in it. Also of importance are the significant breakthroughs in the material sciences yielding new metals and alloys, and when combined with AM, a broad range of advantages can be achieved such as minimizing the impact of supply chain disruptions, etc.

Raytheon, for example, in research and development, has printed 80 percent of the components that would go into a missile, including the rocket motor, fins, guidance and control systems: the use of AM is enabling the development of new components in days rather than weeks, and major reductions in cost and production time.

Leveraging the public-private partnership concept the NDIA can play a leading role in expanding this idea. Utilizing its extensive network of defense contractors more can be done to integrate industry and the Pentagon. Increasing communication is an important place to start by aligning what our warfighter's need with industries ability to deliver in a timely, efficient and cost-effective manner

Airbus Defense and Space have highlighted the significant benefits of AM, citing the example of a four-part structural bracket for use in a satellite: the bracket was redesigned, and produced as a one-piece aluminum component resulting in a 35 percent weight reduction, 40 percent increase in stiffness and 40 percent reduction in manufacturing time.

Paula Hartley, MFC Vice President of Enterprise Performance at Lockheed Martin has stated that, "Technology is transforming the way we do business by optimizing the processes required to support and produce critical capabilities like a PAC-3 missiles."[18]

Even though Phillip Burton and Samantha McBirney at *National Defense* have highlighted a number of challenges, such as a cumbersome qualification process, as well as IP issues to name a few, when it comes to introducing new and innovative technologies like additive

[16] David Vergun, 'Defense Official Speaks on Supply Chain Investments', *DOD News*, 7 September 2022, https://www.defense.gov/News/News-Stories/Article/Article/3151356/defense-official-speaks-on-supply-chain-investments/.
[17] David Shepardson, 'Boeing, Northrop to Join White House-Backed Advanced Manufacturing Program', *Reuters*, 17 August 2022, https://www.reuters.com/technology/boeing-northrop-join-white-house-backed-advanced-manufacturing-program-2022-08-17/
[18] Lockheed Martin, 'Successful Missile Defense Requires Disruption', 2021, https://www.lockheedmartin.com/en-us/news/features/2021/successful-missile-defense-requires-disruption.html.

manufacturing the challenges are not insurmountable.[19] In fact it was in January of 2021 that the Department of Defense announced an additive manufacturing strategy under the auspices of the Under Secretary of Defense for Research and Engineering. In the July 29th, 2021 issue of DOD News it was announced that, "Through new strategies, policies and inter-departmental collaboration, the Defense Department is harnessing the potential of additive manufacturing to help warfighters maintain technological overmatch against our strategic competitors." [20]

A particularly interesting development recently announced is the Neighborhood 91 concept, essentially a public-private partnership. The premise as stated is by connecting the various technologies that enable scaled industrial AM, along with the suppliers, makers and customers of AM parts provide a microgrid for competitively priced products which could be utilized across all domains and services.[21]

Leveraging the public-private partnership concept the NDIA can play a leading role in expanding this idea. Utilizing its extensive network of defense contractors more can be done to integrate industry and the Pentagon. Increasing communication is an important place to start by aligning what our warfighter's need with industries ability to deliver in a timely, efficient and cost-effective manner.

Moreover, AM can be utilized to significantly improve the development of prototypes and tooling, compressing development cycles and reducing costs. Other advantages that have been highlighted (by Markforged, a leader in manufacturing 3D printing equipment) include speedy production. They have stated that, "the time it takes 3D printing to go from art to part is a fraction of what it takes through subtractive manufacturing".[22] Adopting AM also engenders a culture of innovation.

Will Roper, then-assistant secretary of the USAF for acquisition, technology and logistics, at the 2020 Air Force Association Air Warfare Symposium, highlighted the importance of AM within the context of an agile, responsive supply chain: "We're really looking at suppliers who can 3-D print components, like leading edges that we think we'll need to iterate on, so that we've got an adaptable agile industry base where we don't have single points of failure…"[23] This reinforces then Secretary of Defense Mattis' 2018 National Defense Strategy that "modernization is not solely defined by hardware; it requires change in the ways we organize and employ forces. We must anticipate the implications of new technologies on the battlefield,

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[19] Phillip Burton and Samantha McBirney, 'Military Yet to Fully Leverage Additive Manufacturing', *National Defense*, 16 February 2022, https://www.nationaldefensemagazine.org/articles/2022/2/16/military-yet-to-fully-leverage-additive-manufacturing.

[20] 'DOD Promotes Additive Manufacturing Expansion, Standardization, Training Through New Policies, Collaboration', *DOD News*, 29 July 2021, https://www.defense.gov/News/News-Stories/Article/Article/2712969/dod-promotes-additive-manufacturing-expansion-standardization-training-through/source/dod-promotes-additive-manufacturing-expansion-standardization-training-through/.

[21] Laura L Ely and John E Barnes, 'Neighborhood 91: The Bridge to Additive Manufacturing Production', *Metal AM*, Vol. 6, No. 3, Autumn/Fall 2020, pp. 195-204, also available at: https://www.metal-am.com/articles/neighborhood-91-the-bridge-to-additive-manufacturing-production/.

[22] 'Additive Manufacturing 101 Guide: The Basics', https://markforged.com/resources/blog/additive-manufacturing-101-guide-the-basics.

[23] Garrett Reim, 'Why the US Air Force Chose Hypersonic ARRW Over HCSW', *Flight Global*, 28 February 2022, https://www.flightglobal.com/fixed-wing/why-the-us-air-force-chose-hypersonic-arrw-over-hcsw/137018.article.

rigorously define the military problems anticipated in future conflict, and foster a culture of experimentation and calculated risk taking."[24]

In view of the rapidly expanding threat spectrum as indicated above, the US and our key allies around the world must leverage the technological advances we have developed, such as AM, to gain the tactical and strategic advantages that these remarkable scientific breakthroughs can deliver. It is imperative that industry and the military cooperate to the fullest extent possible to achieve our global objectives.

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FOR FURTHER INFORMATION ON ADVANCED INNOVATION AND ITS APPLICATION TO MISSILE DEFENSE PLEASE CONTACT THE COMPANY CHAIRMAN AT:

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[24] US Department of Defense (DoD), *Summary of the 2018 National Defense Strategy of The United States of America: Sharpening the American Military's Competitive Edge*, 2018, p. 7. https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf(link is external).